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Discovering Thoughts, Inventing Future

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Hydraulic Engineering in Dam-Type Tidal Power Plant Designs

By Alexander Yerkhov
Russian State Geological Exploration University

Abstract- During the years of Soviet power, several tidal power plants were procured on the territory of the RSFSR, but only one was built - experimental, despite several promising projects - interest in TPP fell. Economic and demographic trends suggest an impending shortage of energy resources in the world, and now in the foreign press they are increasingly discussing the results of the work of existing TPP, studying the options for the layout of stations, the advantages and disadvantages of various types of hydraulic turbines; the development of the theory of tidal power plants is a problem of energy, construction science (and construction sciences), as well as engineering: hydrology, geology, geodesy, geotechnics, ecology, hydraulics, etc., at each stage of the life cycle of significant in different ways - before the commissioning of the structure in the priority of engineering and construction sciences, and the emphasis in this work is on the main aspect of the life cycle of the design stage, while the scientific novelty is to designate the engineering hydraulics of TPP as a complex problem of system analysis.

Keywords: *tide, pool, dam, hydraulic turbine, impeller, blade, power, energy, pressure, operation.*

GJRE-E Classification: *JEL Code: Q25*

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Hydraulic Engineering in Dam-Type Tidal Power Plant Designs

ИНЖЕНЕРНАЯ ГИДРАВЛИКА В ПРОЕКТАХ ПРИЛИВНЫХ ЭЛЕКТРОСТАНЦИЙ ПЛОТИННОГО ТИПА

Alexander Yerkhov

Abstract- During the years of Soviet power, several tidal power plants were procured on the territory of the RSFSR, but only one was built - experimental, despite several promising projects - interest in TPP fell. Economic and demographic trends suggest an impending shortage of energy resources in the world, and now in the foreign press they are increasingly discussing the results of the work of existing TPP, studying the options for the layout of stations, the advantages and disadvantages of various types of hydraulic turbines; the development of the theory of tidal power plants is a problem of energy, construction science (and construction sciences), as well as engineering: hydrology, geology, geodesy, geotechnics, ecology, hydraulics, etc., at each stage of the life cycle of significant in different ways - before the commissioning of the structure in the priority of engineering and construction sciences, and the emphasis in this work is on the main aspect of the life cycle of the design stage, while the scientific novelty is to designate the engineering hydraulics of TPP as a complex problem of system analysis.

Keywords: tide, pool, dam, hydraulic turbine, impeller, blade, power, energy, pressure, operation.

Аннотация- **В годы советской власти на территории РСФСР было запроектировано несколько приливных электростанций, но построена только одна – опытная, несмотря на несколько перспективных проектов, – интерес к ПЭС упал. Экономико-демографические тенденции наводят на мысль о предстоящем дефиците энергоресурсов в мире, и уже сейчас в зарубежной печати всё больше обсуждают результаты работы действующих ПЭС, изучают варианты компоновок станций, достоинства и недостатки разных типов гидротурбин; развитие теории приливных электростанций – проблема энергетики, строительной науки (и строительных наук), а также инженерных: гидрологии, геологии, геодезии, геотехники, экологии, гидравлики и т.д., на каждом этапе жизненного цикла значимых по-разному, – до ввода сооружения в эксплуатацию в приоритете инженерные и строительные науки, и акцент в данной работе делается на основном аспекте жизненного цикла этапа проектирования, научная же новизна – обозначить инженерную гидравлику ПЭС как комплексную проблему системного анализа.**

Ключевые слова: прилив, бассейн, плотина, гидротурбина, рабочее колесо, лопасть, мощность, энергия, напор, эксплуатация.

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I. Введение

Ограничение ресурсов по ископаемому топливу и глобальное потепление, вызванное эмиссией парниковых газов [1], заставляют бедные ресурсами и социально ответственные страны обращаться к альтернативным природным энергетическим источникам: солнечной радиации, ветровым потокам, морским волнам, однако сила их действия носит вероятностный характер, поскольку определяется погодными условиями, – морской прилив предсказуем относительно – наступает периодически два раза в сутки в большинстве регионов и один – в некоторых, при этом суммарная энергия приливов составляет 3 ТВт[2] при КПД преобразования 35 %, что способно удовлетворить часть мирового спроса на электричество, однако, хотя глобальный приливной потенциал значителен, лишь в нескольких районах задействован [1]. Морская энергия заключена не только в приливах в виде потенциальной энергии разных уровней воды, но и в поверхностных волнах ветрового воздействия, а также включает термальную энергию температурных полей различных глубинных зон, – отраслевое значение имеют приливы. Энергию приливам даёт асимметрия гравитационных возмущений и океанические течения: 1) согласно модели Ньютона-Лапласа, лунная гравитация из-за значительного диаметра Земли не одинакова в ближних и дальних точках и неравномерно воздействует на её поверхность, и такое притяжение образует перемещающиеся за движущейся Луной (и Солнцем) горбы и спады поверхности водных масс, которые у материковых берегов создают приливы и отливы; 2) по динамической модели вращение планеты создаёт в океанах обратно-встречные течения из-за возникающего в результате действия силы Кориолиса инерционного движения водных масс, образуя водоворотные зоны

[1] Увеличение выработки электроэнергии в мире более чем в два раза за последние 30 лет с преобладанием доли горючих ископаемых связано исключительно со странами Азии, где наиболее ощутим и ожидаемо прогнозируем рост численность населения; за тот же период концентрация диоксида углерода в атмосфере воздухавозросла на 25%.

[2] Европа: 12 ГВт – от Норвежского и Северного до Средиземного и Эгейского морей, Китай: 13,9 – от Жёлтого до Восточно- и Южно-Китайского морей, Индия: 8 – от Аравийского моря до Бенгальского залива, РФ: 90 – Баренцево и 20 – Белое моря и т.д.

размером, определяемым орографией – береговым и донным рельефом, и поскольку морские берега России воспринимают приливную волну в двух точках – географических регионах: на побережье Баренцева и Белого морей, куда волна доходит от вихря северной части Атлантики, и на протяжённой береговой линии от Берингова до Охотского морей – от двух совместно действующих вихрей Тихого океана, есть только два экономических района РФ – Северный и Дальневосточный, где проектирование ПЭС целесообразно (при условии, что здесь сохранится дефицит электроэнергии при вы соком экономическом

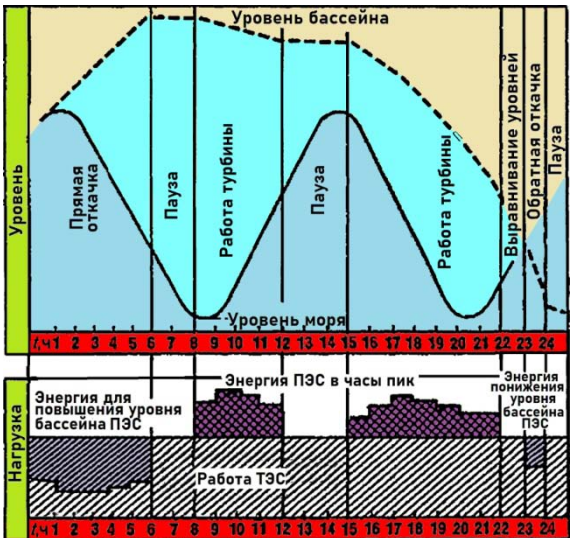


Рис. 1: Энергетические диаграммы ПЭС

уровне, и они будут работать в составе единой энергосистемы (рис. 1)). При приливно-отливном движении воды образуется солитон с амплитудой прилива до 6 м на Севере и 13 на Дальнем Востоке, что соответствует низконапорным ГЭС, однако, поскольку сейчас в приоритете атомные проекты, даже низкая себестоимость производства энергии и безопасность для окружающей среды, в сравнении с углеродной энергетикой, не стали аргументом для разработки новых проектов строительства приливных станций. И, казалось бы, в таком контексте, актуальность темы должна определяться выявлением преимуществ сравнения с АЭС (плавучего или иного типа), но важно заглянуть и в будущее, поскольку ископаемое топливо небезгранично, и кризис природных ресурсов станет отправной точкой возврата интереса к ПЭС; мировой нефтяной кризис 1970-х гг. открыл эпоху приливной энергетики, но только сейчас гидротурбины с горизонтальной осью диаметром 5-8 м стали настолько совершенны, что наряду с ветроэнергетическими появились в многочисленных зарубежных проектах ПЭС – ни что так не способствует научному обоснованию, как коммерциализация ВИЭ.

Главными достоинствами ПЭС являются низкая стоимость обслуживания – <0,5%, высокая эксплуатационная готовность – >95%; основные недостатки: очень высокая стоимость установленной мощности – в десять-сто раз выше других источников, долгий срок строительства – 5-15 лет, низкий коэффициент нагрузки – 22-35% [2], – проблемы инженерно-технического и проектно-технологического характера рассматриваются ниже.

II. Материалы и Методы

Приливная энергия используется по всему миру, но неравномерно: в Австралии, Великобритании, Канаде, Китае, США, Франции. В РФ проекты экспериментальных ПЭС рассматривали с 1930-х гг., причём Кислогубская опытная малая мощностью 1,7 МВт была построена (в 1968 г. первоначальной мощностью 0,4 МВт); другие проекты не были реализованы [3]: Северная в Баренцевом море, Лумбовская и Мезенская в Белом, Пенжинская и Тугурская в Охотском (таблица 1), – на исходе СССР в 1990 г. автор данной статьи в составе солнечногорской изыскательской экспедиции Гидропроекта проводил сейсморазведочные работы по исследованию скального основания под плотину проектируемой ПЭС Северная и геофизические исследования на Шантарских островах под проект Тугурской станции, но случившиеся за этим в стране социально-экономические неурядицы прервали ход работ[3]; для реализации проектов, помимо главных экономических, должны быть решены частные инженерные задачи.

Таблица 1: Проекты ПЭС РСФСР

Станция	Прилив ср. (м)	Площадьбассейна ($км^2$)	Установленная мощность (МВт)	Годовойобъем электроэнергии (ТВтч/г)	Годовой Коэффициент загрузки(%)
Северная	4,2	5,6	12	0,024	24
Лумбовская	4,2	70	320	0,7	24
Тугурская	4,7	1800	8000	27,6	24
Мезенская*	10	2640	11400	39	34
Пенжинская**	11 и 13,4	20530	108500	250	25

**В том же заливе проектировались Кулойская и Беломорская станции.*

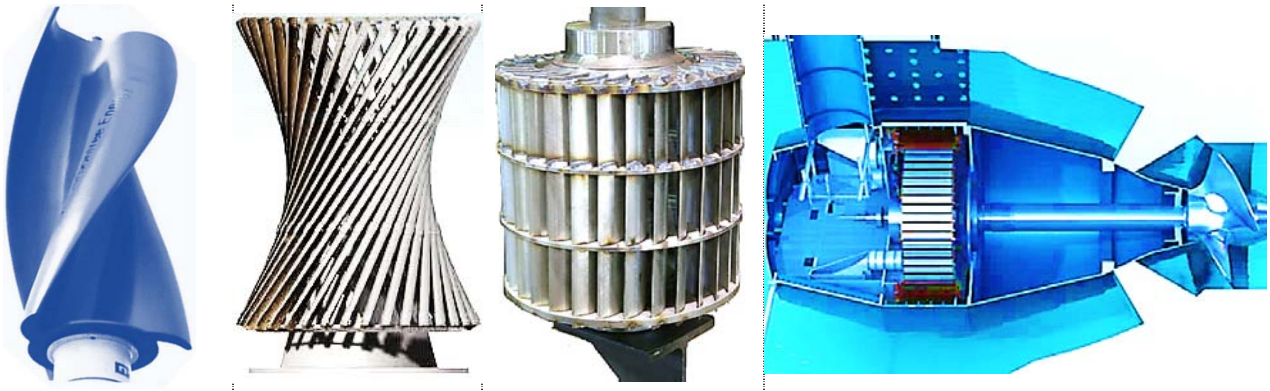
***Суммарно два бассейна.*

[3] И сохранились ли отчёты о результатах изысканий доподлинно не известно: государственные проектные институты распадались или перепрофилировались, их имущество по большей части ликвидировалось.

Проблема 1 – устойчивость плотины

Безотказность конструкции плотины при постоянных и временных нагрузках определяется силами сопротивления материалов и конструкций, не допускающими предельных состояний: 1) разрушения, потерю устойчивости формы, 2) предельных деформаций, колебаний, трещин и их раскрытия в конструкциях. Расчёт напряжённо-деформированного состояния (НДС) тела плотины при воздействии на неё внешних нагрузок, а также температурных волн и солнечной радиации, химических веществ и соединений в виде действия реакций, определяемых составом внешней среды и изменением свойств частиц конструкций при старении материалов, биологических процессов в виде биодеградации из-за действия грибов, водорослей, микроорганизмов, определяется совокупностью напряжений и деформаций, целиком характеризующих напряжённое состояние частиц тела плотины, – эту совокупность записывают в виде тензоров напряжений и деформаций конкретной конструкции и решают с применением средств вычислительной техники. Инженерная гидравлика напрямую не связана с методами компьютерного 3-D моделирования НДС численными методами, но ассоциируется с гидростатическими задачами ГТС, при этом в составе расчёта могут использовать отдельные решения: на сдвиг, напряжений по горизонтальному сечению и т.д.; методику гидростатических расчётов можно применять и для других элементов ГТС ПЭС: подпорных стенок, устоев... Наиболее актуальны и имеют принципиальное значение расчёты по определению устойчивости плотины на сдвиг и напряжения в основании. Исходные данные в расчёте: высота плотины $H_{пл}$ [м], глубина H, плотность бетона γ [кг/м^3], предел прочности грунта основания [Мпа], коэффициент трения бетона о грунт f, удельное сцепление грунта c [кПа], заложение откосов m, класс сооружения [КС]; искомая характеристика – ширина плотины B [м]. Расчёт сил и их плеч ведут относительно середины основания на основе действия группы сил: *вертикальных*: *а*) собственный вес плотины, определяемый по площадям плоских геометрических фигур, получаемым разбивкой её поперечного профиля, умноженным на плотность бетона, *б*) составляющие сил гидростатического давления воды, действующий на подводные грани плотины (с обратной стороны на подошву плотины действует сила фильтрационного противодавления – площадь эпюры, умноженная на объёмную массу воды), и *горизонтальных*: суммарное гидростатическое давление со стороны моря и бассейна (особым вопросом является расчёт флютбета проточной части ПЭС для защиты основания от размыва под действием скоростного напора и предупреждения фильтрационных деформаций, а также наличия и глубины противофильтрационной и дренажной завесы $h_{зав}$). В решении составленного уравнения необходимо учитывать нормативные показатели коэффициентов устойчивости и минимальные значения главных напряжений у верха плотины.

Особенности конструкции плотин ПЭС раскрыты в следующем разделе.



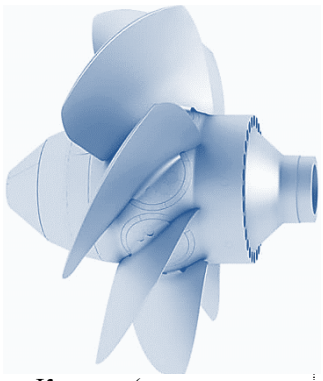
Савониуса(ортогональная)–от1,2м–от15кВт	Горлова (геликоидная) – эффективность 35 %	Банки(ортогональная)–от 2 м–1кВт-15кВт	Колбовая(капсульная, грушеобразная, трубчатая)– от 3 до 10м

Рис. 2: Низконапорные гидротурбины

Проблема 2 – необходимость эффективного управления скоростным напором

Рабочие скорости приливного течения – 2-3 м/с (дают 4-13 кВт/м^2), бо́льшие (>3,0) оказывают чрезмерную нагрузку на оборудование – на рабочее колесо, меньший напор – экономически неэффективен, – напор определяет тип роторной турбины с характерным рисунком гидродинамического профиля лопатки; применение средне и высоконапорных требует конструкторских доработок, экономических обоснований. Таким образом, первую проблему можно интерпретировать как создание эффективных, надёжных приливных агрегатов и их совершенствование: 1) турбина Савониуса (рис. 2) с рабочим колесом обычно 2-4 лопасти отличается от колбовой ротором двигателя на внешнем контуре рабочего колеса и статором в

центре, что имеет преимущества при переменном напоре, дешевле и проще в монтаже и обслуживании[4], – теоретически имеет бóльшую инерцию , и, значит, более устойчива, но может работать только в отлив, и не может применяться для накачки[5]; 2) в турбине Банки вода ударяет в лопасти, поступая поперечно оси, поворачивает относительно её и выходит, то есть лопасть воспринимает воздействие дважды, – эффективность невысока, подходят для небольших станций до 300 кВт, и имеют проблемы с вибрацией; 3) колбовую турбину, названную из-за формы гидроагрегата, на ПЭС применяют чаще из-за высокого КПД при низком напоре (до 90%), малого размера, низкой стоимости и реверсивности, позволяющей вырабатывать энергию как в прилив,



Каплана(радиально-аксиальная)– от 3 м–600кВт-2МВт

Томсона(радиально-аксиальная)– от 6 м–15кВт-4МВт

Фре(э)нсиса(радиально-аксиальная)–от7м–250кВт-2,5МВт

Дериаз(ис)а(диагональная)– от 4 м–до215МВт

Рис. 3: Среднескоростные типы рабочих колёс

так и в отлив, они отличаются надёжностью и высокими рабочими характеристиками, имеют низкие эксплуатационные затраты, – технология колбовых турбин хорошо отработана; 4) турбины средней скорости вращения[6] (рис. 3) можно адаптировать под различные гидравлические характеристики, однако они малопроизводительны в режиме насоса, потому что относительно короткие лопасти, расположенные под большим углом, создают нестабильное течение и приводят к чрезмерному замедлению потока (что видно по несовпадению рабочих точек режимов турбина/насос), однако конструкция турбины Дериаза, как разновидность Каплана с лопастями не перпендикулярно направленными к оси, а под углом, направляет поток диагонально – по образующей к вершине конуса, и несоответствие между прокачкой и генерацией решает , поскольку не возникают пульсации давления и кавитация [4]; турбина/насос Дериаза способна работать также при переменных скоростях вращения, что позволяет иметь в 1,5 раза бóльшую входную мощность, чем у турбин Френсиса; пропеллерная турбина Каплана с возможностью поворота лопасти относительно своей оси ранее (в СССР) называли по конструкции «поворотно-лопастной»; 5) высоконапорные (рис. 4) отличаются высокой скоростью при низком расходе: если удельная скорость выходит за критический диапазон, вращение замедляется и мощность падает [5].

Пел(ь)тона (ковшовая) – от 40 м – 30 кВт-4 МВт;

Тюрго – от 35 м – 30 кВт-2 МВт.

Рис. 4: Типы высоконапорныхгидротурбин

[4] Первоначально Кислогубская ПЭС работала на колбовой турбине мощностью 400 кВт, но в 2006 г. была модернизирована до экспериментальной ортогональной Савониуса 1,7 МВт (два агрегата), причём эффективность турбины Савониуса признаётся ниже колбовой.

[5] Самая большая диаметром 8,2 м и мощностью 17,8 МВт при КПД 89% работает на канадской ПЭС Аннаполис (зал. Фанди).

[6] Скорость вращения зависит от удельной скорости гидротурбины, частоты и числа пар полюсов генератора, при этом удельная скорость должна обеспечивать такую же скорость генератора.

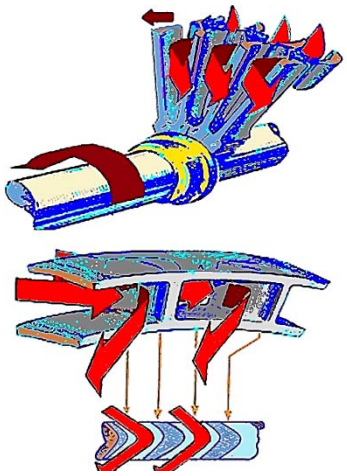


Рис. 5: Реактивный и импульсный потоки

Проблема 3 – необходимость выверенной ориентации рабочего колеса турбины в водоводе

Общее наблюдение – вертикальная ориентация вала гидротурбины большого диаметра лучше подходит для реактивных – Каплана, Дериаза, горизонтальное – импульсных – Пелтона (рис. 5); впрочем, изменение формы лопасти по длине – от центра к переферии – способно обеспечивать в одном колесе оба режима, что для требующих повышенных технических характеристик турбин, работающих в составе современного технологичного оборудования необходимо. *а*) Турбины с горизонтальной осью ориентированы валом ротора параллельно потоку, и поскольку, коэффициент их мощности достигает 40%, на большинстве ПЭС установлены именно они, что не означает отсутствия недостатков: стоимость турбины и конструкции выше, ортогональных, генерация энергии возможна только в одном направлении, что требует двух турбинных групп – на прилив и отлив. *б*) Турбины ортогональные с поперечно ориентированной осью: Банки-Митчелла или Особергера – при простоте конструкции, сказывающейся на стоимости, имеют высокий КПД – 80%, надёжны и просты в эксплуатации; КПД важнейший показатель турбины, в том числе, по признаку ориентации, – турбины с вертикальной осью и, например, пассивным переменным углом наклона лопасти для лучшего угла атаки (турбина Кобольда – рис. 6 – может иметь номинальную мощность >150 кВт), удерживающим аэродинамический профиль в положении наибольшей подъёмной силы, обеспечивая максимальную касательную силу для наибольшей мощности, – переменный угол добавляет 3% мощности.

Проблема 4 – неравномерность выработки электроэнергии из-за нерегулярности потока, вызванной длительными паузами прилив/отлив.

Оптимизации путём равномерного распределения выходной мощности (рис. 1) с повышением коэффициента нагрузки турбин выше 60% некоторым образом могут способствовать многоячеистые бассейны, более гибко реагирующие на изменение напора – отбор мощности должен осуществляться от отдельных турбин или их групп, и, таким образом, турбины нижних и верхних бассейнов работают синхронно-циклично по напору – море-бассейн$_1$-бассейн$_2$-море, как одна электростанция; и также станция может дооснащаться гидроаккумуляторами.

Рис. 6: Турбина Кобольда

Проблема 5 – недостаточная эффективность преобразования энергии.

Связана со второй проблемой, и решается усложнением конструкции гидротурбин – важно для оптимизации работы станции. Эффективность ПЭС определяется технико-экономическими показателями, то есть минимальными затратами на производство электроэнергии, тогда как КПД турбин – эффективностью в отношении преобразования энергии – зависит от условий работы турбин, и максимальна, если турбина работает с расчётной нагрузкой (рис. 7), – при неполной или перегрузке КПД падает, и рекомендуют турбины Дериаза или Каплана.

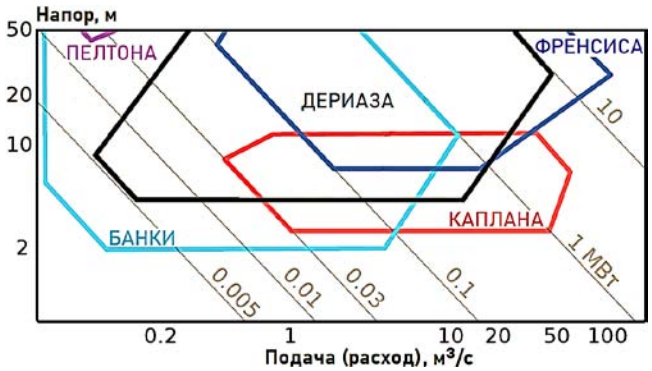


Рис. 7: Сравнение некоторых типов турбин. Эффективность

Проблема 6 – тяжёлые условия эксплуатации гидротурбин по ряду показателей, например, наличию шуги, активно идущих биологических/химических процессов.

Требует изменения свойств материалов или характера процессов путём особых технологических

мероприятий – для повышения надёжности оборудования. Большинство ПЭС имеют напорные плотины для накопления и эффективной выработки энергии турбинами, работающими в одну или обе стороны, – их конструкция должна обеспечивать КПД турбин 80-90% и бесперебойную работу в течение десятилетий, для чего поверхности конструктивных элементов, соприкасающиеся с внешней средой, покрываются защитными лаками от биообрастаний, подключаются к системе катодной защиты от коррозии и т.д. [6].

Проблема 7 – изменение экологического равновесия.

Плотина ПЭС, перекрывая вход в естественную бухту/залив/фьорд/губу/лиман/эстуарий и даже лагуну, но не пролив, образует бассейн, отделённый от моря, и имеющий различный с ним гидрологический режим (рис. 1), нарушая сложившуюся экосистему и в определённых случаях вызывая социальные проблемы, поскольку ограничивается доступ к лежбищам и ареалам обитания держащихся у берега морских животных – млекопитающих, моллюсков и др., изолируются места нереста и пути миграции ихтиофауны, а также сужаются возможности судоходства, – и тем не менее, последствия преодолимы, что должно отражаться в проектах, при этом учитывать надо то, что воздействия на дикую природу могут быть прямыми и косвенными.

Проблема 8 – влияние на прибрежно-морской наносный режим и переформирование дна за счёт отложений твёрдого стока рек.

Седиментация уменьшает приливную зону (площадь и объём) бассейна; в зависимости от источника аккумуляция донных отложений и эрозия способны оказать негативное воздействие как на работу сооружений ПЭС, так и на окружающую среду.

Эти проблемы с разной степенью важности определяются потоками отно сительно плотины и в рабочей зоне гидротурбин, – в проектах ПЭС гидравлика сооружений (плотины (потенциальная энергия прилива/отлива), турбинного водовода (кинетическая энергия скоростного напора), а также механических машин (механическая работа гидротурбин)) с вопросами электроэнергетики взаимосвязана: плотина – главное сооружение ПЭС с решающей долей инвестиционных затрат – имеет в теле на турбинном водоводе работающую на перепаде давлений горизонтально или вертикально ориентированную турбину, соединённую посредством вала с коротким и большим в диаметре электрогенератором (рис. 8 [7]), индуцирующим ЭДС, и имеющим, ввиду низкой частоты вращения, несколько пар полюсов, соединённых через трансформатор с сетью. И, следовательно, концепция с анализом и техническое обслуживание с эксплуатацией в жизненном цикле станции имеют приоритетное научно-теоретическое и утилитарно-прикладное значение.

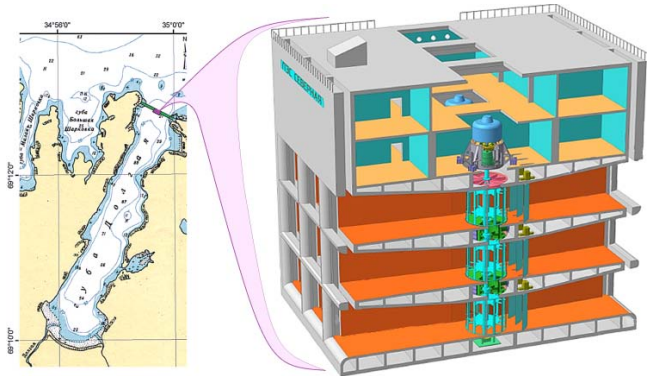


Рис. 8: Многоярусный ортогональный гидроагрегат диаметром рабочих колёс 5 м на примере проекта ПЭС Северная

Для каждого сооружения ПЭС важны, но рутинны конкретные технические параметры: размеры, тип грунта, используемый строительный материал, особенности конструкции, – они общедоступны и не обсуждаются.

III. Результаты

a) Решение проблемы 1 – расчёт конструкции плотины

В зарубежной литературе плотину ПЭС чаще называю «заграждением», вкладывая в это понятие значение несущественности сил давления воды со стороны «бьефов» – гидростатический напор воды настолько мал и одинаков в противофазе с обеих сторон, что в максимуме Δh составляет считанные метры, поэтому от речных плотин их отличает кубоидная форма (рис. 9), а по конструктивному исполнению – это ячеистые плотины с плоскими перекрытиями, в гидротехнике обычно называемые «облегчёнными»; по материалу – бетонные/железобетонные сооружения.

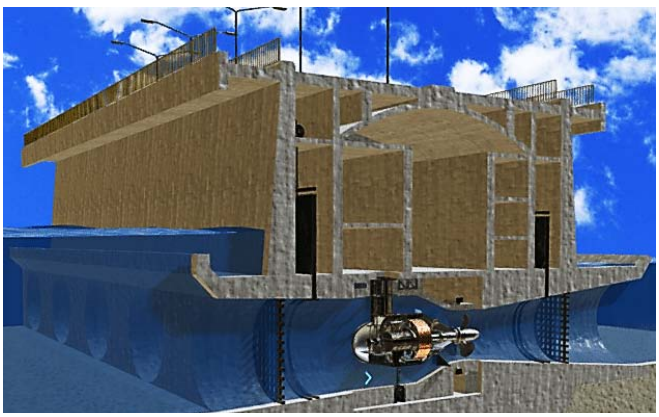


Рис. 9: 3-Dмодель saVRee обычного заграждения ПЭС с в ряд расположенными турбинами

Ячеистые низконапорные плотины стали разрабатывать в СССР с середины 30-х годов; размеры ячеек – 1,5×1,5-6×6 м, толщина стенок – 0,1...0,6 м, способ монтажа – монолитный или сборно-монолитный железобетон (с расходом арматуры – 20...30 кг на м^3

бетона) с соединением элементов сваркой и бетонированием. Положение и форма ячеек сказывается на напряженном состоянии конструкции плотины, что позволяет корректировать напряжения в теле и основании, методом предварительного напряжения повышать сжимающие напряжения у напорных граней. Верхнюю часть такой плотины рассчитывают, как гравитационную, нижнюю – как массивную раму с жёсткими узлами и заделкой в основании[7].

Помимо экономии бетона, ячеистая плотина имеет ряд других достоинств: удобные цементация швов, сбор и отвод инфильтрационной воды, управление температурным режимом, возможность коммуникации.

b) Решение проблемы 2 – расчёт турбинных агрегатов

1. *Энергетический потенциал прилива в исходных данных расчёта водовода гидротурбин.*

Разница уровней закладывает в приливную волну потенциальную энергию, которая в прилив выше, чем в отлив, поэтому в оценке приливной энергии следует рассматривать два случая: вращение турбины за счёт падающей воды, и поднимающейся. Энергию приливного цикла в работе ПЭС определяет инженерное решение по размещению плотины; приняв амплитуду – напор на плотину – как разницу уровней Δh ($-\Delta h$), а площадь бассейна обозначив как A [м^2], потенциальную энергию прилива выражают в виде $E=mg\Delta h2=A\rho\Delta hg\Delta h2=A\rho g\Delta h22$ [Дж], и мощность приливной энергии – $N=E\Delta t=12A\rho g\Delta h2\Delta t$ [Вт], а если предположить полный переход потенциальной энергии в кинетическую, скорость приливного течения из $N=12mu2=12\rho Hlu3$ равна $u=32NHl$, где H – глубина прилива, l – пройденное приливной волной расстояние в пределах ПЭС,Δ t – продолжительность падения или подъёма уровня, то есть половина приливной фазы. Вес поднятой и опущенной приливом воды составляет $G=\gamma HA$, где γ – удельный вес морской воды, равный 1025 [кг/м^3], и максимальная расчётная мощность ПЭС $P=280AH2$ [кВт], то есть накопленная энергия пропорциональна квадрату глубины прилива, высоты плотины.

Пример расчёта бассейна Пенжинской ПЭС:

определить теоретическую запасённую энергию и среднюю мощность при средней высоте прилива по северному и южному бассейнам 12,2 м, площади бассейнов 20 530 000 000 м^2 и времени прилива 6 ч, – $E = 0{,}5A\rho gh^2$ = 0,5·20 530 000 000 [м^2]·1025 [кг/м^3]·9,8 [м/с^2]·12,2^2 [м] = 1,53472·10^{16} [Дж], $P = E/t$ = 1,53472·10^{16} [Дж]/6 [ч]/3,6·10^6 [кВт·ч/Дж] ≈ 710 517 [МВт], при том что плотинные гидроагрегаты по проекту должны производить 108 500 МВт.

Турбина с генератором – наиболее чувствительная критически значимая составляющая ПЭС.

2. *Кинетическая энергия турбинного водовода в энергии осевых турбин.*

В водоводе, соединяющем море и бассейн, устанавливают турбину, мощность потока в которой $N\text{п}=gQH\text{т}$ [кВт], где $H\text{т}=C1ucos1g\eta$ – рабочий напор турбины, позволяет турбине развить мощность $N\text{т}=M\omega$, где $M=\rho QC1cos1R1\text{-}C2cos2R2$ – момент количества движения и ω – угловая скорость рабочего колеса, C_1, C_2 – абсолютные скорости на входе и выходе [м/с], u – окружная скорость на внутренней окружности рабочего колеса, R_1, R_2 – размеры окружностей рабочего колеса (рис. 10),α_1, α_2 – углы между касательными и кривой лопасти к наружной окружности на входе и выходе [°], $\eta=N\text{т}N\text{п}$ – гидравлический КПД, – и при низком напоре турбины с пропеллерными лопастями, как, например, Каплана, не могут обеспечить высокую мощность, Q – расход через гидротехническое сооружение: $Q = C_dA2gH\text{т}$, где C_d – коэффициент расхода, A – площадь проходного сечения через сооружение.

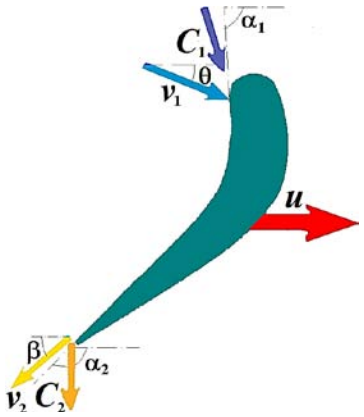


Рис. 10: Схема к расчёту скорости лопатки

3. *Гидравлические характеристики осевой гидротурбины в конструктивных параметрах мощности.*

Сегодня «испытания» концепта начинают с компьютерной модели, выполняя структурный анализ (ставшим ведущим методом конечных элементов – FEA, широко применяющимся в расчёте плотин) весовых характеристик конструкции, отдельных деталей и элементов, например, лопастей, и применяя вычислительную гидродинамику (CFD) для оценки набегания и взаимодействия потока с граничными поверхностями. Кинематическая характеристика движения потока и рабочего колеса описывается производными физическими величинами передачи скорости потока – скорости на входе лопатки – скорости на выходе – скорости самой лопатки, – лопатка, таким образом, определяет диаметр колеса и размер турбины вне зависимости импульсная/реактивная, – лопасти колеса неподвижные, то есть угол их наклона не может изменяться (на рис. 10 показана изогнутая лопасть с входом и выходом струйного потока под заданными

[7] Методика расчёта изложена в Рекомендациях по конструированию сборно-монолитных ячеистых конструкций и организации изготовления их элементов. М.: Союзгипроводхоз, 1983. – С. 36.

углами, векторно представляющего треугольники скоростей). Чтобы рассчитать крутящий момент, действующий на водяную турбину, необходимо оценить обмен импульсом, то есть обмен импульсом происходит за счёт изменения направления вектора скорости. Мощность турбины определяется силой на входе, скоростью вращения лопастей, выходной мощностью и скоростью потока на выходе. Сила, по второму закону Ньютона – это изменение количества движения F=dm,vdt [Н], то есть определив его получают силы на лопатках, – методика расчёта представляет алгоритм: 1) для расчёта эффективной силы, действующей на лопатки, необходимо рассчитать величину и направление относительной скорости набегающей струи; определение компонент *x* и *y* вектора относительной скорости на входе: vx1=v₁cos, vy1=v₁sin и на выходе: vx2=-v₂cos , vy2=v₂·sinβ, где v_1 и v_2 – относительные скорости входящего и выходящего потока струи, представляющие сумму векторов скоростей лопасти *u* (окружная составляющая скорости $u = \pi \cdot d \cdot n$, где *d* – диаметр [м], *n* – частота вращения [$с^{-1}$]) и абсолютной на входе C_1 и выходе C_2 [м/с], *θ, β* – углы между соответственно v_1, v_2 и *u* [°]; 2) сила, передаваемая реактивным потоком лопатке в направлении *x*, равна массовому расходу *Q* [кг/с], который равен плотности жидкости *ρ* [кг/$м^3$] на площадь поперечного сечения струи A_c [$м^2$] и на скалярное значение скорости набегания v: Q=ρAcv; сила, передаваемая реактивным потоком лопатке в направлении оси *Y*: Fy=ρAcvvy2-vy1=ρAcvv₂sin +v₁cos; полная сила, приложенная к лопатке, равна результирующей: F=Fx2+Fy2, а угол равнодействующей силы – =FyF; выходная мощность: движущая сила турбины равна Fx=ρAcvvx2-vx1=ρAcv-v₂cos -v₁cos; 3) КПД водяной турбины – отношение выходной мощности к кинетической энергии движения: *η*=Acvvx2cos +vx1cos ·uAcv·v·a·i22.

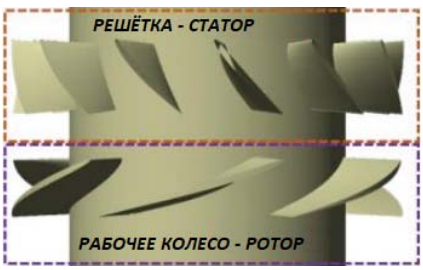


Рис. 11: Принцип передачи количества движения с решётки на лопасти рабочего колеса

4. *Совмещение турбинного водовода со средненапорной гидротурбиной.*

Совмещение посредством рабочей (направляющей) решётки – статора, формирующего направленный на лопасти поток как из диффузора (рис. 11), требует отдельного расчёта, и после определения C_1 и *u*, выбора угла α_1, вычисляют относительную скорость W_1 на вх оде в рабочую решётку: W1=C12+u2-2C1ucos 1 , и определения угла β_1 по формуле 1=sin 1 cos 1 - uC1 , – после оценки относительной скорости на выходе W_2 и определения угла β_2 (для активных ступеней $\beta_2 \approx \beta_1$ – (2…4°)) абсолютная скорость C2=W22+u22-2W2ucos 2 , а угол α_2 – 2 =sin 2 cos 2 -uW2.

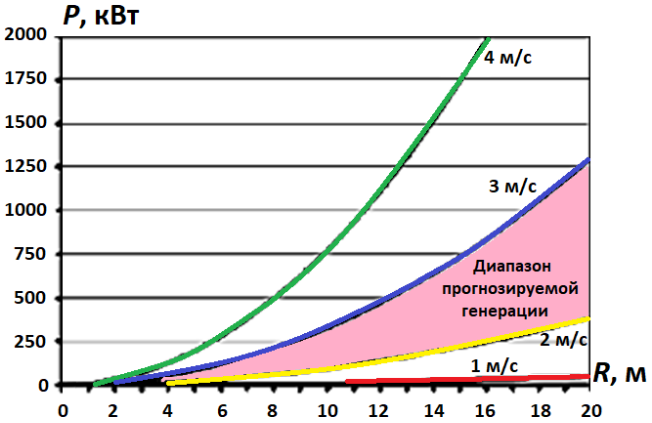


Рис. 12: Выработка электроэнергии в зависимости от диаметра ротора и скорости потока

Решение проблемы 3 – принципиальное решение по ориентации в потоке рабочего колеса, то есть выбор типа турбины.

Для ПЭС инженерная гидравлика может рассматривать турбины двух типов: *а*) с горизонтальной осью, ориентированной вдоль потока, диаметром 10-20 м и мощностью 200-700 кВт могут иметь лопасти с регулируемым шагом, подстраиваемым под скорость потока (рис. 12); *б*) с ортогональной осью и перпендикулярно ей направленным потоком способны извлекать из потока до 35% энергии (для примера, с горизонтальной осью турбины извлекают от 20%); другие преимущества: конструкция низкой материалоёмкости; недостатки: стоимость изготовления на 20% выше турбин со спиральными лопастями (при равной стоимости монтажа), конструкция прямолинейной лопасти (например, вертикальной 3-лопастной турбины Кобольда (рис. 6)) из-за неустойчивости течения с предрасположенностью к разрыву потока приводит к вибрации, но многочисленные лабораторные испытания показывают, что геликоидные лопасти турбины Горлова (рис. 2) решают проблему, и кроме того, в сравнении с прямолинейными лопатками, извлекаемая энергия на 12% больше (согласно другим данным коэффициент мощности прямолинейных лопастей на 5% выше спиральных).

Решение проблемы 4 – неравномерность выработки электроэнергии.

Получение электроэнергии ТЭС (рис. 1) при низкой цене на газ является предпочтительней ПЭС как по финансовым, так и техническим соображениям, а также по воздействию на окружающую среду, но КПД ПЭС при мощности 20-250 МВт может быть в 4 раза больше, – важнейшим фактором, снижающим экономическую эффективность ПЭС, являются паузы в работе из-за периодичности приливов/отливов. В традиционном исполнении ПЭС – *однобассейное* гидротехническое сооружение с отгораживающей

плотиной, и работа электростанции возможна в трёх режимах: 1) Генерация в прилив; заполнение бассейна морской водой начинается не сразу: некоторое время затворы турбинных водоводов закрыты, пока не возникнет достаточный гидростатический напор (в ночное время при низких спросе и тарифе вода пропускается в бассейн через дополнительные отверстия, наполняя его). 2) В отлив при минимальном напоре со стороны моря вода из бассейна выпускается через турбинные водоводы, вырабатывая электроэнергию пока гидростатический напор в бассейне не упадёт до минимального уровня, позволяющего турбинам работать эффективно. 3) Двунаправленная генерация – метод использует как фазы прилива, так и отлива: затворы турбинных водоводов остаются закрытыми до конца прилива (рис. 1), после чего воду направляют в турбины – наступает фаза генерации, длящаяся до минимального гидростатического напора – фазы отлива, – двусторонняя генерация сокращает долю пауз и снижает количество агрегатов, то есть стоимость оборудования. *Двухбассейные* ПЭС – основной бассейн может работать как один; второй предназначен для закачки и аккумуляции воды в процессе фазы откачки из первого бассейна, при этом используется часть электроэнергии, генерируемой турбинами, и такая система способна регулировать подачу электроэнергии потребителю, – преимущество систем с двойным бассейном – способность генерировать электричество в период повышенного спроса, недостатки: низкая эффективность работы турбин при низком напоре и увеличение затрат на строительство из-за удлинения плотины. Хотя неравномерность выработки ПЭС не только суточная, но и месячная, но проблема 4 определяется изменением напора в результате приливно-отливного действия волны.

Решение проблемы 5 – недостаточная эффективность преобразования энергии и оптимизация – проблема тоже инженерной гидравлики. Экономическая и энергетическая эффективности требуют оптимизации – компьютерного моделирования выработки электроэнергии от изменений уровня воды в бассейне на основе конкретных аналитических подходов, что даёт, прежде всего, оптимальное время начала и окончания генерации каждой фазы. Именно этим – нелинейной зависимостью уровня напора и мощностью определяется проблема возможности выхода станций на проектную мощность. Целью оптимизации эксплуатационных мероприятий является, в первую очередь, определение количества турбин и единых оптимальных эксплуатационных характеристик для одинаково результативной работы во время всех фаз всех приливных циклов. Заданное количество турбин заданной мощности должны обеспечить предполагаемую установленную мощность станции в заданном диапазоне; при моделировании исследуют два режима работы: двухсторонняя генерация без насосных станций и двухсторонняя с накачкой. Для улучшения оперативного управления силовыми установками во времени каждого приливного цикла в качестве исходного параметра применяют одно общее значение, и далее оптимизация моделируемой станции продолжается с последних параметров предыдущего цикла, – последовательность операций по управлению режимами работы ПЭС: 1) откачка воды в отлив (опорожнение бассейна), 2) пауза при минимальном уровне отлива (задержка в ожидании), 3) начало прилива (фаза перед наполнением бассейна), 4) начало пропуска воды через затворы, 5) наполнение бассейна, 6) накачка воды в прилив, 7) пауза на максимуме приливного уровня, 8) начало отлива (перед опорожнением), 9) пропуск воды в отлив через затворы, 10) откачка воды в отлив (опорожнение бассейна). Эффективная эксплуатация на основе целевой функции каждого цикла максимизирует выход энергии, и добавление прокачки повышает выход электричества на ≈15-20% [8], а в целом оптимизированное управление циклами приводит, за счёт более гибкого управления турбинами и затворами, к увеличению выхода электроэнергии на ≈30-35% (оптимизация повышает КПД модели четырехлопастной турбины на 5,5 и трёхлопастной на 4,5%). Полностью оптимизированный процесс управления в решении инженерных задач включает большое число переменных (начиная с гидродинамических характеристик прибрежной зоны), требующих повышенных вычислительных ресурсов.

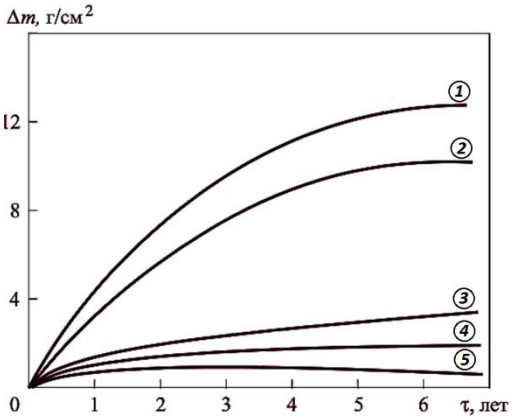


Рис. 13: Интенсивность коррозии конструкций в воде разных морей: 1 – Северном; 2 – Средиземном; 3 – с высоким содержанием Ca и загрязнённая сточными водами; 4 – без загрязнений; 5 – Чёрном[9]

Решение проблемы 6 – особые условия эксплуатации и технического обслуживания отражаются на расходах, и стоимость эксплуатации и мероприятия по техническому обслуживанию обычных ПЭС самая низкая в сравнении с другими станциями генерации энергии моря. Из всех возможных осложнений в эксплуатации, связанных с задачами инженерной гидравлики, три наиболее острые – волны, ледовые явления, коррозия. Традиционными для ГТС методами, описанными в СП (38.13330.2018), рекомендациях, справочниках являются: для снижения силы воздействия волн – волнорезы, берегоукрепление, для ледовых нагрузок – ледорезы, для защиты

сороудерживающих решёток от обмерзания – антиобледенители в виде, например, гидрофобных покрытий, для защиты за кладных частей затворов – электрообогрева, борьбы с внутриводным льдом и шуговыми коврами – запани и шугосбросы, – целесообразно гидравлическое лабораторное моделирование. Электрохимическая коррозия металлических конструкций, исполнительных механизмов, деталей турбинных агрегатов в морской воде высока из-за наличия в ней растворённых солей – катионов активных металлов: хлоридов и сульфатов натрия, магния, кальция, калия; кроме того, в морской воде высока и депассивность. Кинетика процессов определяется составом и концентрацией электролита (рис. 13): больше солёность – выше скорость коррозии и ниже надёжность, а также активностью металла конструкции в виде простого вещества или соединения (таблица 2).

Таблица 2: Электрохимический ряд активности металлов

активные	***средней активности***		***неактивные***
Li → K → Na → Ca → Ba →	Mg → Al → Mn → Zn → Cr → Fe → Ni → Sn → Pb →	H_2	Cu → Hg → Ag → Pt → Au

К примеру, высокий потенциал медных сплавов в электролитическом контакте со сплавами железа создаёт поток электронов от Fe к Cu, корродируя первый, а это требует специальных методов защиты: легирования, ингибиторов, изолирующих покрытий, электрохимической защиты; выбор метода, предотвращающего окислительно-восстановительную реакцию, определяет стоимость строительства и эксплуатационные издержки.

Сейчас накоплен достаточный опыт работы приливных электростанций, вырабатывающих электричество в сеть на протяжении многих десятилетий.

Решение проблемы 7 – воздействие на окружающую среду.

Приливная станция – вредная технология электрогенерации: ПЭС нарушает сложившуюся экосистему географического региона, формировавшуюся тысячелетиями, – наиболее показательные примеры с крупными млекопитающими[8]: в августе 2004 г. на ПЭС Аннаполис в зал. Фанди (рекордные приливы – до 18 м) взрослый горбатый кит в слабый прилив проплыл через открытые ворота шлюза в бассейн, и на несколько дней застрял в верхней части р. Аннаполис, но самостоятельно нашёл выход, однако уже весной 2007 г. там же, у г. Бриджтауна, найдено тело неполовозрелого горбатого кита, и причина гибели осталась неизвестной; впрочем, роль заграждений в данных случаях скорее положительная. ПЭС также могут стать определённой угрозой экономического развития, если в ограждаемой зоне активно развито судоходство, но и данная проблема решается при помощи инженерной гидравлики. И вместе с тем, традиционные приливно-отливные электростанции вряд ли будут иметь широкое распространение из-за критических недостатков: дороговизны, длительного срока строительства, ограниченного числа мест с высоким приливом и подходящей береговой линией, непреодолимой угрозы окружающей среде. Поиск новых технологически совершенных подходов в развитии энергетики формирует в среднесрочной перспективе политику поддержки возобновляемых источников энергии, главным образом солнечных и ветровых, а в долгосрочной – атомных реакторов на быстрых нейтронах (ядерного топлива замкнутого цикла) и ядерного синтеза (термоядерного цикла), а также производства водорода.

Решение проблемы 8 – влияние на прибрежно-морской наносный режим.

Блокирование приливно-отливного течения плотиной способно вызвать увеличение эрозии берегов как со стороны моря, так и бассейна, усилить подводные течения с подмывом сооружений. Инженерная гидравлика открывает широкие возможности в проектировании специальных сооружений, меняющих наносный режим водных объектов: методом лабораторного моделирования участков в пределах акватории можно определять параметры и строить в натуре на дне пороги, на берегах – шпоры, то есть возводить простые сооружения, изменяющие сложным образом характер течений, и формирующие отложения твёрдого стока в пределах безопасных и целесообразных, согласно проекту с учётом батиметрических особенностей бассейна.

IV. Заключение

1. Альтернативная энергетика, построенная на возобновляемых источниках, предполагает прекращение в процессе преобразования энергии выработки парниковых газов, – также немаловажным является переориентация поставок ископаемого сырья с энергетического на перерабатывающий промышленный сектор и снижение стоимости получения электроэнергии.
2. Тело плотины ПЭС отлично от устраиваемых на реках и по поперечному профилю, и по конструкционному исполнению, поскольку предназначено для одинаковых с обеих сторон гидростатических напоров, – плотина ПЭС – низконапорная, железобетонная, целесообразна – кубоидной формы, ячеистая.
3. Трёхмерные информационные модели потока проточной части гидротурбины позволяют судить о вибрации и кавитации с учётом изменения

[8] Исследования – количественные данные о передвижениив зоне заграждения иуровне гибелирыб, связанной с проходом через прямоточные турбины большого диаметра,отсутствуют.

параметров главных характеристик, например, при большем напоре – меньше вибрация и ниже вероятность возникновения усталости металла; сравнения колебаний сил и моментов, развиваемых в различных турбинных установках, позволяют проектировать конструкции с минимальными колебаниями. Структурный анализ твёрдого тела конструкций гидротурбины направлен, помимо конструкторской проработки геометрии деталей и основных элементов, таких как форма лопастей, на изучение механических свойств металла и выбор конструкционной стали.

4. Оптимизация работы ПЭС направлена не только на совершенствование течения в турбинном колесе с целью роста КПД, снижения вибрации и шума, но и решения других вопросов инженерной гидравлики: расчёт многобассейных систем, определение оптимального количества турбин, определение оптимального времени начала и окончания генерации каждой фазы, единых оптимальных эксплуатационных характеристик для одинаково результативной работы во время всех фаз всех приливных циклов.
5. Осложнения в эксплуатации, связанные с задачами инженерной гидравлики – волны, ледовые явления, коррозия. Традиционными для ГТС методами, описанными в СП, рекомендациях, справочниках являются: для снижения силы воздействия волн – волнорезы, берегоукрепление, для ледовых нагрузок – ледорезы, для защиты сороудерживающих решёток от обмерзания – антиобледенители в виде, например, гидрофобных покрытий, для защиты закладных частей затворов – электрообогрева, борьбы с внутриводным льдом и шуговыми коврами – запани и шугосбросы, – целесообразно гидравлическое лабораторное моделирование. Для предотвращения электрохимической коррозии металлических конструкций, исполнительных механизмов, деталей турбинных агрегатов в морской воде используют методы: легирования, ингибиторов, изолирующих покрытий, электрохимической защиты.
6. Системный анализ проблем, по сложности сопоставимых с ПЭС, невозможен без колоссальных вычислительных мощностей ЭВМ, поэтому стал широко доступен лишь в последние годы, и целесообразен не только в задачах КИВР, но и в проектах ПЭС, где учтены оптимизация работы электростанции, вопросы эксплуатации, охраны водных ресурсов и др.

Литература

1. Бахтиаров В.А. Электрификация СССР за годы Советской власти и пути её дальнейшего развития. Метеорология, гидрология вод суши и океанология. Вып. 39. Л.: Гидрометеорологическое издательство, 1970. – С. 179-198.
2. G. Buigues, I. Zamora, A. J. Mazón, V. Valverde and F.J. Pérez. Sea Energy Conversion: Problems and Possibilities. April 2006, Universidad del País Vasco/ Euskal Herriko Unibertsitatea. – P. 1-8.
3. Минин В.А., Дмитриев Г.С. Перспективы освоения нетрадиционных и возобновляемых источников энергии на Кольском полуострове. Мурманск: ЭПЦ «Беллона», 2007. – С. 93.
4. Ерхов А.А. Новое о кавитации в насосах. Сборник « Новые идеи в науках о Земле» / Материалы XV Межд.науч-прак.конф. – М.: РГГРУ, 2021. – С. 279-283.
5. Ерхов А.А. Тангенциальное ускорение конфузорного течения. Ученые заметки ТОГУ, № 4 2015. – С. 267-269.
6. Ерхов А.А. Гидротехнические сооружения: курс лекций. М.: МГРИ, 2019. – С. 70.
7. Бакштанин А.М., Крылов А.П., Метвеева Т.И., Беглярова Э.С. Техническая реализация проекта Северной приливной электростанции в Баренцевом море. Природообустройство № 5, 2020. – С. 59-67.
8. Kramer Stephan C., Avdis Alexandros, Piggott Matthew D. Optimising tidal range power plant operation. Applied Energy, V. 212, 15 February 2018. – P. 680-690.
9. Сидняев Н.И., Бережнова М.А. Исследование влияния морской воды на деструкцию погружных морских конструкций. Инженерный журнал: наука и инновации, 2019, вып. 10. http://dx.doi.org/10.18698/2308-6033-2019-10-1926

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Enhancement of Cement's Compressive Strength of Concrete using Mid-Infrared Ray – A Fundamental Research

By Umakanthan T, Madhu Mathi & Umadevi U

Abstract- Concrete is one of the most versatile material in building construction. Overall quality of cement is indicated by the compressive concrete strength of concrete (CSC). Many techniques are available to increase the CSC. As one of the technology, we irradiated the cement with mid-infrared rays and observed 38% CSC increase. This technology is economical, rapid, easy, user-friendly, can be used by manufacturer to client and in future may gain vast scope and utility in civil engineering.

Keywords: *cement, mid-infrared, irradiation, compressive strength of concrete, increase, safe, economical.*

GJRE-E Classification: *FOR Code: 0905*

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Enhancement of Cement's Compressive Strength of Concrete using Mid-Infrared Ray – A Fundamental Research

Umakanthan T [α], Madhu Mathi [σ] & Umadevi U [ρ]

Abstract- **Concrete is one of the most versatile material in building construction. Overall quality of cement is indicated by the compressive concrete strength of concrete (CSC). Many techniques are available to increase the CSC. As one of the technology, we irradiated the cement with mid-infrared rays and observed 38% CSC increase. This technology is economical, rapid, easy, user-friendly, can be used by manufacturer to client and in future may gain vast scope and utility in civil engineering.**

Keywords: cement, mid-infrared, irradiation, compressive strength of concrete, increase, safe, economical.

I. Introduction

About 10 billion tons of concrete used leading to natural resource decline, and increasing pollution hence research for alternative needed *(Liu et al., 2020)*. Cement price and demand are dynamic. Either saving atleast 1% of cement or increasing the compressive strength of concrete (CSC) would save economy and reduce pollution. CSC is influenced by type and source of cement, supplementary cementitious material and aggregate type *(Jared et al., 2022)*. Through various research CSC was increased upto 72.3% as cited by Liu *et al*., 2020. Most of these methods are unstable, uneconomical and difficult to follow in field conditions. We successfully tried mid-infrared irradiation and found 38% CSC increase. The effect of mid-infrared in cement's physic-chemistry is also discussed with various instrumentations.

II. Material and Methods

MIRGA *(patent no.: 401387)* is a 20 ml pocket sized atomizer *(Supplementary file – figure F1)* containing inorganic water based solution in which approximately two sextillion cations and three sextillion anions composing Sodium carbonate monohydrate, Sodium carbonate anhydrous, Potassium nitrate and Sodium chloride are present. During spraying, depending on pressure (vary with the user) applied to plunger, every spraying generates 2-6 μm mid-IR. Design of the MIRGA and emission of 2-6 μm mid-IR has been presented in detail by *Umakanthan et al., 2022a; Umakanthan et al., 2022b*. Every time spraying emits 0.06ml which contains approximately seven quintillion cations and eleven quintillion anions. *(details about MIRGA available in supplementary text T1)*

The inorganic compounds used in the generation of MIR are a perspective for biomedical applications *(Tishkevich et al., 2019; Dukenbayev et al., 2019)*. It is also a new synthesis method for preparation of functional material (2-6 μm mid-IR) *(Kozlovskiy et al., 2021; El-Shater et al., 2022)*. It is well known that the combination of different compounds, which have excellent electronic properties, leads to new composite materials, which have earned great technological interest in recent years *(Kozlovskiy et al., 2021; Almessiere et al., 2022)*.

Commercial cement and service of an expert panel (n:6) from a local cement manufacturing factory utilized. The spraying was done from 0.25 to 0.5 meter towards any type of packaged (polythene, paper, glass) material (e.g cement bags here) *(Method of MIRGA spraying in Supplementary file – video V1)*. This distance is essential for the MIRGA sprayed solution to form ion clouds, oscillation and 2-6 μm mid-IR generation. The mid-infrared can penetrate the intervening package and act on the cement inside. Close spraying doesn't generate energy. MIRGA is used like a body spray.

The instruments used to find the changes in,

Chemical compound transformation – gas chromatography mass spectrometry (GC-MS): Agilent technologies, 7820 GC system, 5977E MSD, Colomn DB-5, Over temp 100-270^{0}C, Detector MS, Flow rate 1.2, Carrier gas Helium.

Chemical bond changes – fourier-transform infrared spectroscopy (FTIR): JASCO FT-IR 4200 plus spectrophotometer with ATR (range 4000–400 cm^{-1} at 298 K); and IR AFFINITY I – FTIR Spectrophotometer, FTIR 7600, Shimadzu.

Structural changes – powder x-ray diffraction (PXRD): Rigaku RINT 2500 X-ray diffractometer (CuKα anode; λ = 1.541Å). Samples scanned at 40kV and

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30mA from 5° to 35° 2θ values and analyzed using PDXL2 software (Rigaku).

Configuration – transmission electron microscopy (TEM): High resolution transmission electron microscopy (HR-TEM) on JEOL (JEM-2100 Plus) system under an acceleration voltage of 200 kV.

Nuclear resonances – Solid state ^{27}Al nuclear magnetic resonance: The experiments were done on a 600 MHz NMR spectrometer (ECZR Series, JEOL, JAPAN) using a 3.2mm CPMAS probe at 150MHz frequency. All the samples were run at 18KHz spinning speed at room temp and with a delay of 5sec.

a) Method 1

A commercial bag containing M20 grade 50 kg cement was purchased. From that bag, 1000gms cement was taken, transferred to a polyethene pouch (more than 51 micron thickness) and its opening sealed with cellophane. Similarly, 10 more packets prepared. Among the 11 packets, one was marked as C (Control) and the remaining 10 were individually numbered from 1 to 10. The numbered pouches were respectively given 1 to 10 MIRGA sprayings from 0.25-0.50 meter towards the pouches, at a rate of 1 or 2 on one or either side of the pouches.

Using cement from each of the 11 pouches, a standard weight of ingredients aggregate prepared, cubes of same size were individually casted. Manual casting and compaction of cubes done (pair-form-technique). The cubes were separately cured by submerging in water. Compression tests were conducted with compression testing machine 1000 KN capacity at 7, 14 and 28 days. The trials were conducted in quadruplet and CSC results were compared.

b) Method 2

M20 grade 50 kg cement bag was purchased of the same brand and batch as in method 1. 4 samples of 1000 gms each were prepared. One sample was marked as C (Control) and the remaining 3 were numbered 1, 2 and 3. MIRGA salt was added at 0.5%, 0.75% and 1% (w/w) respectively to packets 1, 2 and 3. As in method 1, cubes were prepared, subjected to CSC testing. The trials were conducted in quadruplet and results were compared.

III. Results and Discussion

a) Method I

6 and 10 times MIRGA sprayed cement cubes, on 28th day was found to have increased 38-48% CSC respectively compared to control cubes *(Table 1)*.

Table 1: Compressive Strength of Concrete (an abstract table)

Number of MIRGA spraying	Compressive Strength of Concrete in N/mm2 (method 1)			Enhanced percentage of CSC in N/mm2
	7^{th} day	14^{th} day	28^{th} day	
C (non-sprayed)	13	18	21	-
2	15	19	22	5
6	15	24	29	38
10	16	25	31	48

b) Method 2

On 28th day, the 0.75% MIRGA salt added cement cubes were found to have 38% increased CSC than control. MIRGA salt as such is a bit costlier than MIRGA sprayings.

Considering 28^{th} day results of both methods, the CSC enhancement of 38% in 6 sprayed cement sample was taken as an achievement of this research.

The sensory and other parameters of control and trialed samples given as below. These changes were observed from 1-3 minutes after MIRGA spraying.

Control: Natural texture, taste bland, soft, a pinch sank very slowly in water.

2 sprayed: Smooth texture, salty, soft, sank rapidly in water.

6 sprayed: Rough texture, more salty, course, sank very rapidly in water.

10 sprayed: Very rough texture, very salty, very course, sank very slowly in water.

Instrumentation analyses (raw data of instrumentations in Supplementary file – Data D1).

i. *GCMS*

Control: The GCMS profile of the control sample shows peaks at these retention times (min): 12.8, 13.4, 15, 16.3, 17.8, 19.7, ~19.8, ~20, and ~21.8. *2 sprayed sample:* There is one additional peak in the 2 sprayed sample at about 18.4 min compared to the control sample GCMS. This additional peak is the marker of different properties of the 2 sprayed sample. *6 sprayed sample:* There is an additional apparent peak at about 20.6 min. This change is an indicator of the rough texture, etc. of 6 sprayed sample relative to the control sample. *10 sprayed sample:* The peak at ~5.2 min in the GCMS pattern of the 10 sprayed sample does not appear in the GCMS pattern of the control sample or

other samples. This peak is the unique property of the 10 sprayed sample.

Cement sample contains many aldehydes, ketone, short chain alkane & their derivatives. After 2 spraying, there was great increment in peak of dodecane (or its derivatives) while 6 and 10 sprayings and control have not shown this peak. On contrary, 6 and 10 sprayed samples have shown the peak of Cyclohexane (or its derivatives) which was not present in 2 sprayed & control samples. In the sprayed samples, 13-Octadecenal (most abundant peak) was disappeared and converted to various derivatives depending on the number of sprayings. *(Fig 1) (Table 2)*

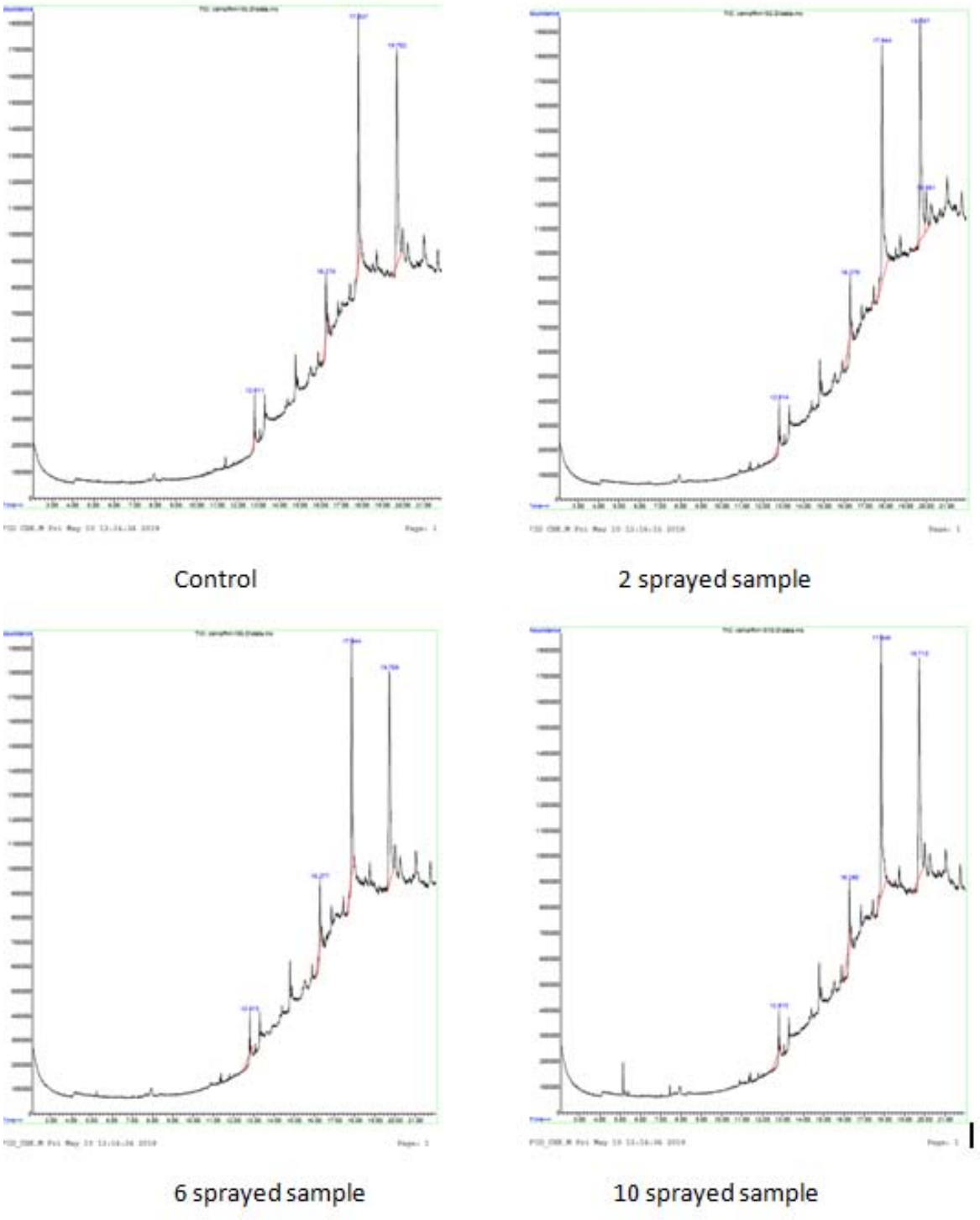

Fig. 1: GC-MS of cement samples

Table 2: GCMS spectra analysis of cement samples

R.T. (Min)	Name of Compounds in Cement	% Area presence in Sample				
		Control	2 sprayed	6 sprayed	10 sprayed	Remarks
12.809	13-Hexyloxacyclotridec-10-en-2-one	2.17	0.69	1.99	2.29	
16.270	Cyclopentadecanone, 2-hydroxy-	6.60	0.0	0.0	0.0	
16.279	13-Octadecenal, (Z)-	0.0	2.71	0.0	3.15	
16.279	2,3-Dihydroxypropyl elaidate	0.0	0.0	2.93	0.0	
17.839	Cyclopentadecanone, 2-hydroxy-	39.06	0.0	0.0	0.0	Most abundant peak in control sample
17.839	Cyclohexane, pentyl-	0.0	0.0	37.98	55.15	Most abundant peak in 10 sprayed sample
19.702	13-Octadecenal, (Z)-	52.70	0.0	0.0	0.0	Most abundant and unique peak in control sample
19.711	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester	0.0	0.0	0.0	50.29	Most abundant peak in 10 sprayed sample
17.849	Dodecane, 2-cyclohexyl-	0.0	49.07	0.0	0.0	Most abundant peak in 2 sprayed sample
19.712	Cyclopentadecanone, 2-hydroxy	0.0	46.37	61.09	0.0	Most abundant peak in 6 sprayed sample
19.995	tert-Butyl(5-isopropyl-2-methylphenoxy)dimethylsilane	0.0	7.95	0.0	0.0	

ii. *FT-IR*

a. *JASCO FT-IR 4200 plus Spectrophotometer with ATR*

Control Sample: The broad signal in the range 1100-1450 cm-1 is associated with the stretching vibration of Si-OH in the silanols functional group, although observed in the fingerprint region. Furthermore, in the functional group region, the broad signal in the range 3200-3600 cm-1 is associated with the stretching vibration of O-H.

2 sprayed Sample: In the fingerprint region, the broad signal of Si-OH in the range 1100-1450 cm-1 increases significantly. Moreover, in the functional group region, there is a further broadening of O-H in the range 3200-3600 cm-1.

6 sprayed Sample: Following the same trend in the 2 sprayed sample, in the fingerprint region, the broad signal of Si-OH in the range 1100-1450 cm-1 continues increasing. Moreover, in the functional group region, the broad signal of O-H in the range 3200-3600 cm-1 increases in value.

10 sprayed Sample: In the fingerprint region, the broad signal of Si-OH in the range 1100-1450 cm-1 drops in value. In the functional group region, the broad signal of O-H in the range 3200-3600 cm-1 also drops in value.

The observed changes in the stretching vibrations of Si-OH and O-H can be interpreted as to the 2 sprayed and 6 sprayed samples being more favorable than the control sample, and the 10 sprayed sample being less favourable. At band 1623 cm-1 and 1684 cm-1 bending vibration of water in gypsum seen. At 3554 cm-1 stretching vibration of water in gypsum seen. A broad band at ~ 1650 cm-1 is due to bending vibration of irregularly bound H2O in 6 and 10 sprayed samples as the rate of hydration is more. *(Fig 2)*

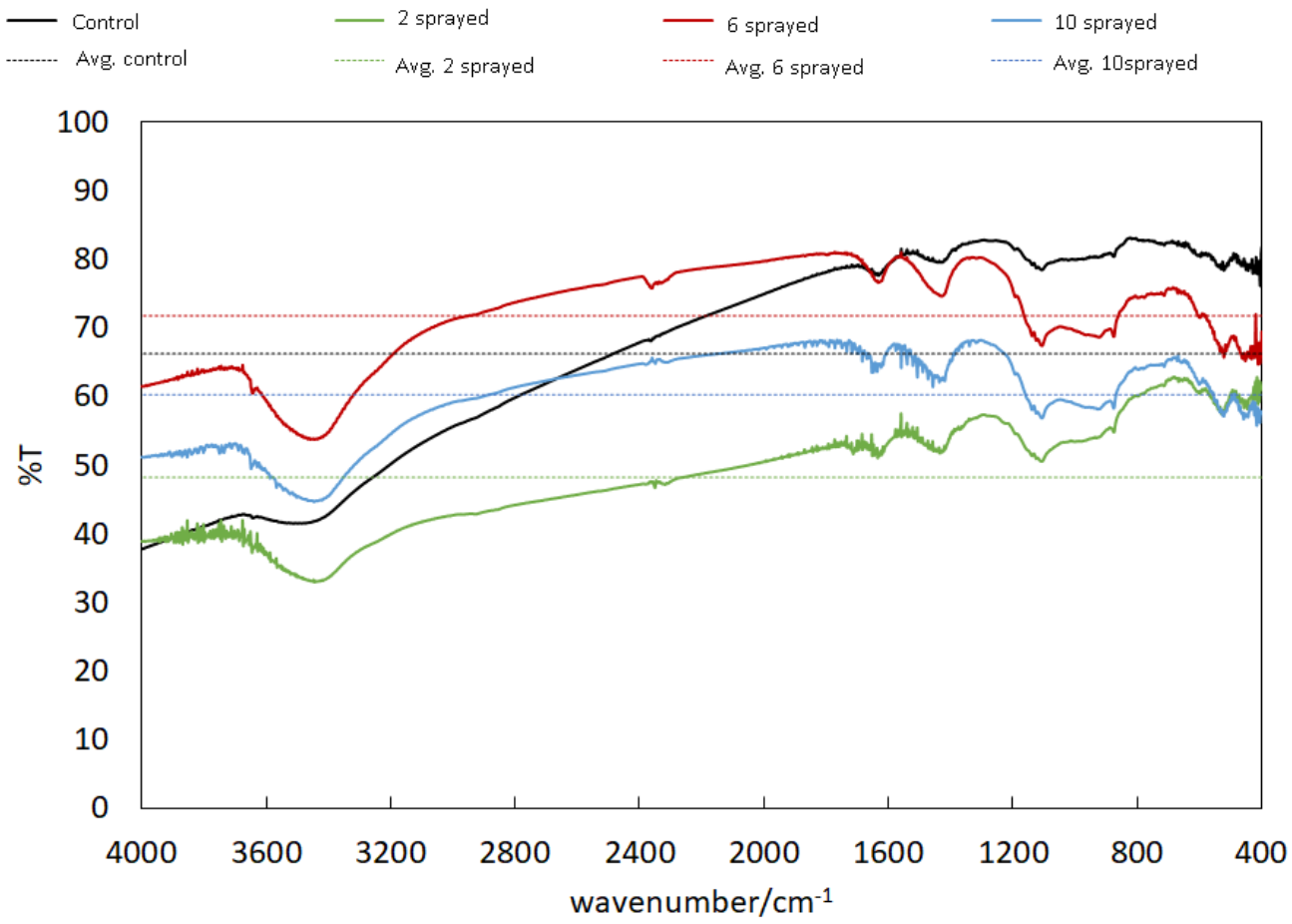

Fig. 2: FT-IR of cement

b. *IR AFFINITY I – FTIR Spectrophotometer, FTIR 7600, Shimadzu*

Cement is a mixture of different compounds. It consists of Calcium oxide (CaO), Silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3), Iron oxide (Fe_2O_3), Water (H_2O), Sulfate (SO_3) and do not have any specific formula. $Ca(OH)_2$ stretch (present in control sample) indicate Portlandite of cement and it was changed in 2 and 10 sprayed samples, but disappeared in 6 sprayed sample. While10 sprayed sample showed comparatively increased C-O stretch of $[CO_3]^{2-}$, 2 sprayed sample showed high increment for Si-O stretch. The 6 and 10 sprayed samples uniquely shown asymmetric stretching of Si-O bond while S-O stretching of SO_4^{2-} was selectively present in control and 2 sprayed samples. *(Table 3) (Fig 3)*

Table 3: FTIR spectra analysis

Frequency (1/cm)	Band characteristic	% area present in each sample				
		Control	2 sprayed	6 sprayed	10 sprayed	Remarks
3417.86	Portlandite – $Ca(OH)_2$	1.39	5.34	0.0	0.75	Increase in 2 sprayed sample
1435.04	C-O stretch of$[CO3]^{2-}$	13.33	14.06	10.58	21.97	Increase in 10 sprayed sample
1103.28	S-O stretch of $[SO4]^{2-}$	6.19	5.17	0.0	0.0	Only present in control and 2 sprayed samples
1095.57	Si-O (asymmetric stretching)	0.00	0.00	3.5	6.46	Only present in 6 sprayed and 10 sprayed samples
925.83	Al-O stretch	2.14	2.22	1.44	1.76	Decrease in 6 sprayed and 10 sprayed sample
455.20	Si-O stretch	2.76	5.34	1.46	2.14	Increase in 2 sprayed sample

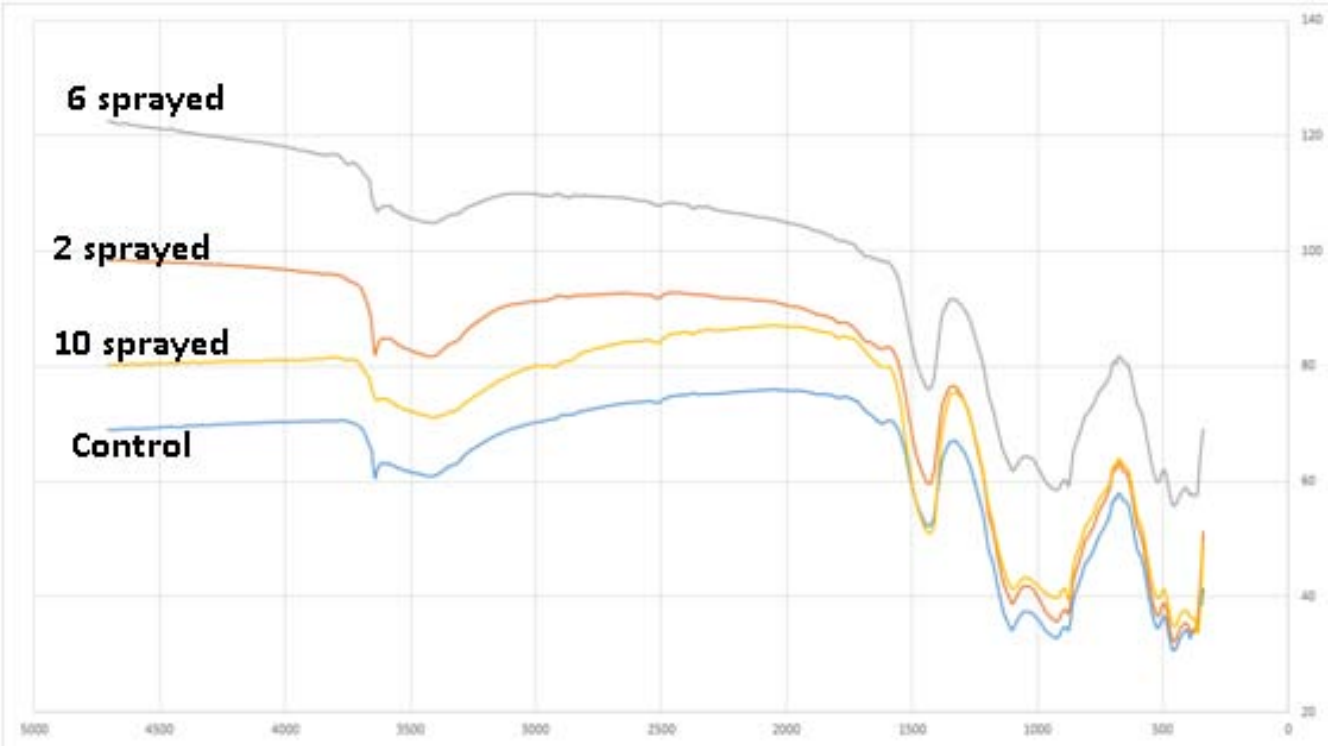

Fig. 3: FTIR of cement

iii. *PXRD*

The changes in peak intensities at 11.59° and 29.11° is due to changes in nuclear co-ordinates due to the formation of gypsum and more intense in 6 and 10 sprayed samples. The rate of hydration of the cement is increasing with the increase in the spraying number. The rate of hydration of the cement samples is in the order of control < 2 sprayed < 6 sprayed < 10 sprayed sample. *(Table 4) (Fig 4)*

Table 4: PXRD analysis

	Control		2 sprayed		6 sprayed		10 sprayed	
2θ	I	I/Imax %	I	I/Imax %	I	I/Imax %	I	I/Imax %
32.24 (Alite)	3081	100,0	3523	91,9	1911	100,0	3085	100,0
29.48 (Alite)	2837	92,1	3715	96,9	1576	82,5	2780	90,1
34.42 (Ferrite)	2582	83,8	2643	69,0	1593	83,4	2575	83,5
26.65 (Langbenite)	2418	78,5	3832	100,0	1215	63,6	2413	78,2
51.79 (Alite)	1903	61,8	1140	29,7	640	33,5	1113	36,1
18.08 (Portlandite)	1256	40,8	1321	34,5	711	37,2	1131	36,7

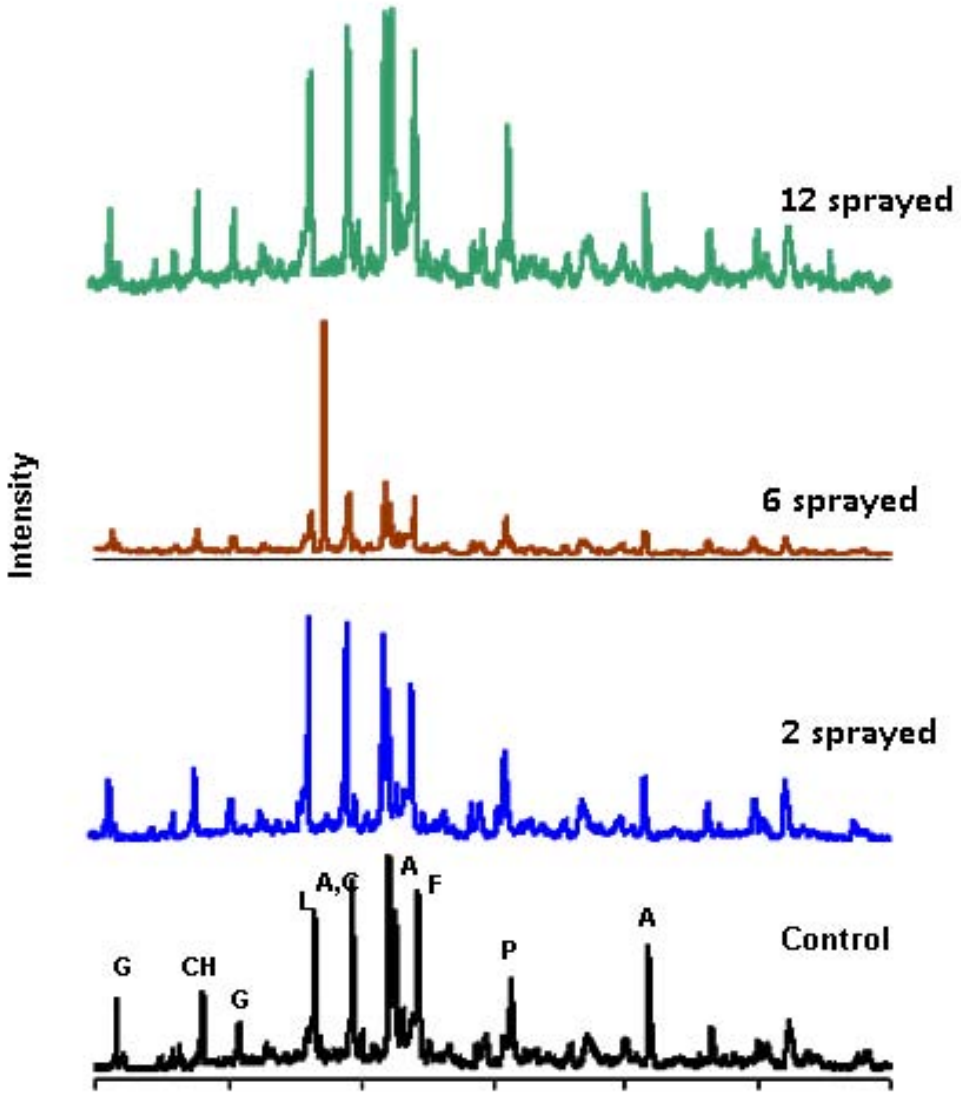

Fig. 4: PXRD of cement samples

iv. *HR-TEM*

Control sample: Mass aggregates show amorphous or ellipsoidal shape, and sizes ranging 0.4 – 1 μm. Most of these appear homogeneously dark. Bands of regularly spaced fringes suggesting Moirè patterns are visible that are typical of crystalline structures. Different particles having typical crystal shapes are visible, namely: triangular particles and needle-like particles. Concerning the triangular particles, it shows two equal-lenght sides (0.7 μm) and one shorter side (0.4 μm), recalling an isosceles triangle; it also shows bending contours at particle edges, that are typical of crystal torsions. Concerning the needle-like particles, all visible particles have same length, ranging 0.5 – 0.6 μm and show diffraction contrast evidences (including the likely Moirè patterns observed). Both types are thus compatible with crystals. Nanoparticles (average size 20 – 100 nm) are observed with prevalent squared shape and organized in clusters.

2 sprayed sample: Mass aggregates of comparable sizes and shapes organized in clusters are observed. Diffraction contrast areas are visible suggesting the presence of crystals. Different from the control, the 2 sprayed sample does not show individual particles with peculiarities typical of crystal, e.g. like those described for the control sample. Given the crystalline nature of this sample, as documented by HRTEM images, small crystals are present here, instead of large ones observed in the control. Moreover, the low frequency by which features typical of crystal structure are observed is coherent with the low frequency of areas of lattice fringe bands observed. Individual nanoparticles similar to those in the control are not visible in the 2 sprayed sample; however, in the aggregate some objects are observed which are comparable to nanoparticles observed in the control.

6 sprayed sample has different clusters of mass aggregates showing various shapes and sizes, at

increasing magnification; a cluster of rectangular crystals and a diffraction pattern image are also shown. Differently from control and 2 sprayed samples, 6 sprayed sample features typical of crystalline structures spread all over the sample mass. This sample is characterized by a large number of crystal structures. Measures of the ring radii in reciprocal lattice unit (1/nm) provide the following interplanar distances (real space, nm): 0.12, 0.16 and 0.20, comparable with measurements performed on bands of lattice fringes. In the diffraction pattern, bright spots are observed uniformly distributed along the rings, indicating that this sample has a polycrystalline texture where crystallites are random oriented; also this finding is coherent with information extracted from the HRTEM image of this sample. Sizes and shapes of mass aggregates are similar to those of control and 2 sprayed samples. However, while in aggregates of these samples diffraction contrast is observed in limited areas of the aggregate, in the 6 sprayed sample signals of diffraction contrast and of Moirè patterns are observed with very high frequency. Moirè patterns are particularly evident. Rectangular and/or squared crystals are also observed with side lengths 0.3 – 0.4 x 0.05 (μm x μm), and 110 – 130 nm respectively.

10 sprayed sample: Similarly to 6 sprayed sample, this sample features typical of crystalline structures in sample mass. This is characterized by a large number of crystal structures. Due to strong overlapping, sizes of individual crystallites are hard to be measured; however they range 50 – 130 nm approx. It has to be noted that, differently from previous samples, crystallites show ellipsoidal shape in the 15-10. Also a small squared crystal is present with side length 40 – 50 nm. Another structure is visible suggesting the presence of overlapped crystals, since dark fringes are observed suggesting diffraction contrast.

In short, degree of crystallinity increased from the control to 6 sprayings. The regularity of crystal structure is enhanced proportionally with increasing spraying from control to 10 sprayings. Concerning the regularity of the crystal structure, instead, an effective improvement is only observed from the 6 and 12 sprayed samples, due to the high degree of crystallinity observed for these two samples. *(Fig 5)*

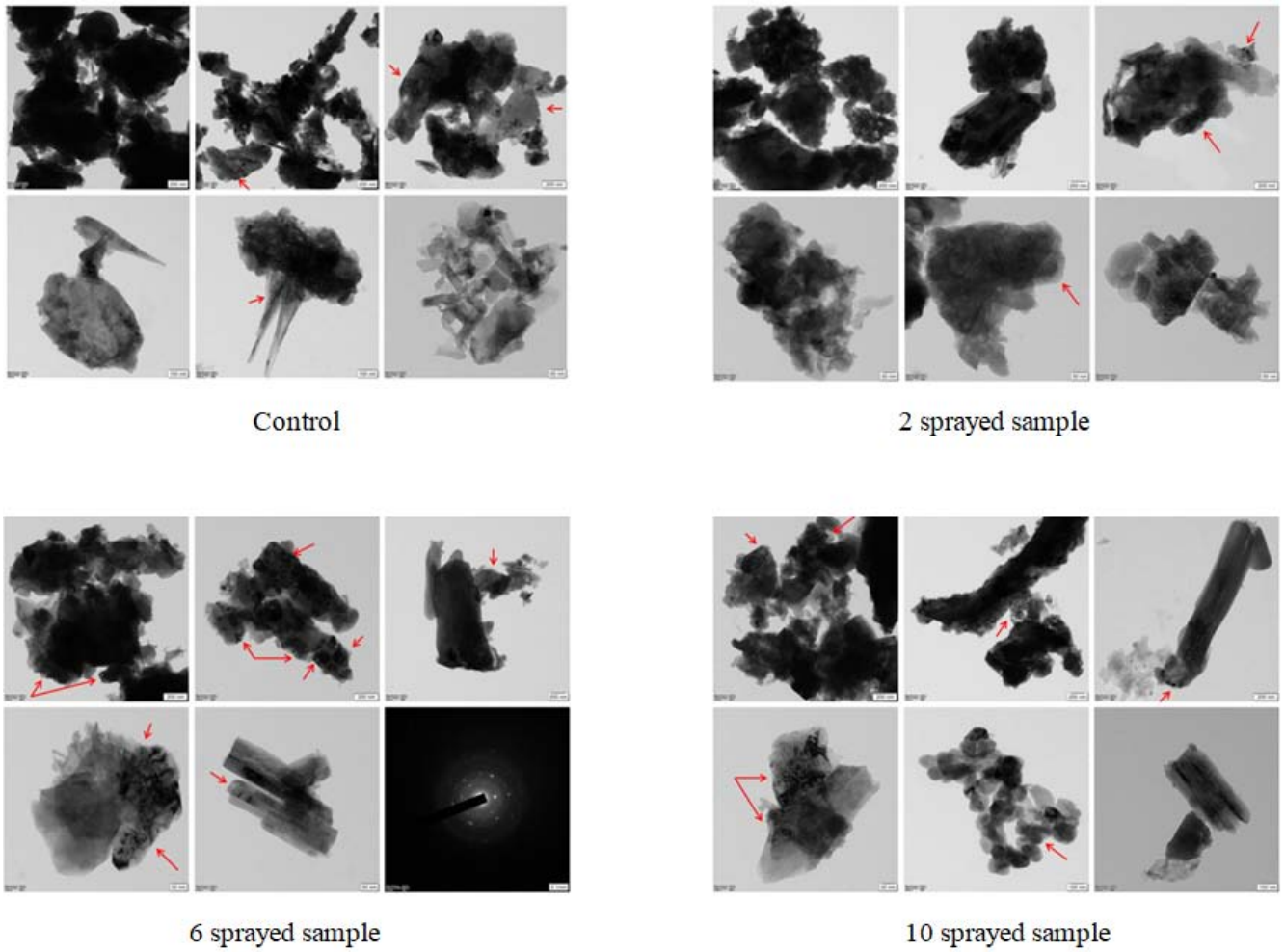

Fig. 5: HR-TEM bright field images of cement samples

v. *Solid state ^{27}Al NMR*

Since there is no significant change in the chemical shift and the integral value of the trans-1,2 disubstituted alkene–OCH3 at 130.370 ppm in control, 2, 6 and 10 sprayed samples, we used this peak as a reference to normalize the integral values in all the three data sets. With respect to the control sample, the sulfur compounds at 14.771 ppm and 61.708 ppm drop in the2 sprayed sample. But in the 6 and 10 sprayed samples theses integrals increase in value again. This behavior is concluded as the 6 and 10 sprayed samples are more favorable than control. *(Table 5) (Fig 6)*

Table 5: ^{27}Al NMR analysis

Chemical Shift Description			Control Sample			2 sprayed sample			6 sprayed sample			10 sprayed sample		
			CS	PI	NPI	CS	PI	NPI	CS	PI	NPI	CS	PI	NPI
			-100.181	0.59	1.25	-100.543	0.61	1.01	-100.543	0.62	0.98	-100.352	0.63	1.10
Sulfur Compounds	Sulfides		14.771	1.47	3.13	14.771	1.73	2.87	14.714	2.23	3.55	14.676	2.02	3.51
Sulfur Compounds	Sulfonic and Sulfinic Acids and Derivatives		61.708	8.61	18.30	61.137	8.64	14.35	61.156	9.14	14.55	61.079	9.01	15.69
trans-1,2-Disubstituted Alkenes	–OCH3	Alkenes	130.370	0.47	1.00	130.256	0.60	1.00	130.332	0.63	1.00	129.913	0.57	1.00

CS *- Chemical Shift (ppm);* ***PI*** *- Peak Integral;* ***NPI*** *- Normalized Peak Integral*

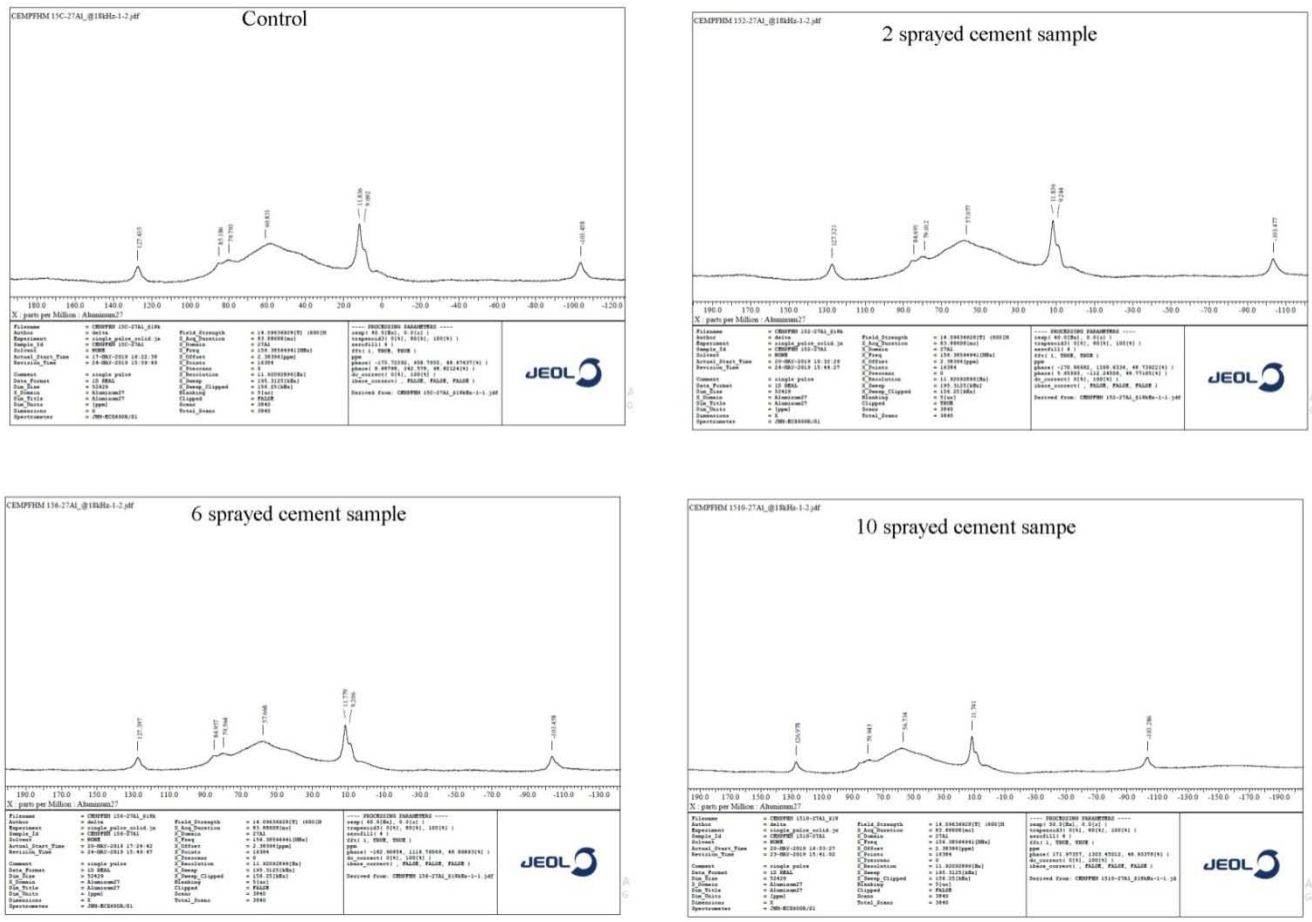

Fig. 6: NMR spectra of cement samples

To conclude, the changes in the chemical bonds thereby chemical transformation, configurational changes caused by MIRGA is the cause for inherent characteristic changes in the sprayed cement samples.

c) Future Benefits of Sprayed Cement

- Instead of 1kg of cement (1000 gm), 620 gm of MIRGA sprayed cement (as 38% CSC increased) is enough to achieve regular CSC.
- Economy saved on cements there by aggregate, water and labour also.
- Production and transport costs reduced.
- Environmental pollution and health hazards reduced.

d) Action of MIRGA Emitted 2-6 µm mid IR on Cement

Invention background, definition, technique of mid-IR generation from MIRGA, toxicological study on MIRGA, safety of the MIRGA sprayed usables and primeval and future scope of MIRGA have been described by Umakanthan *et al*., 2022a *(detailed discussion on MIRGA available in supplementary text T2)*. While spraying MIRGA, most of the mid-IR energy scatters through the air and gets absorbed by cement. Organic compounds absorb mid-IR radiation which causes a change in molecule's vibrational state to move from the lower ground state to excited higher energy state *(Girard, 2014)*. This leads to changes in cement's chemical bonds *(Shankar, 2017; Mohan, 2004)* and these bond parameter changes led to consequent changes in cement's physical and chemical characters, configuration, compound transformation depending on the dose of mid-infrared applied *(Yi, 2012; Esmaeili, 2015; Atkins, 2011; Datta et al., 2014)*.

As displayed in the results, 2-6 *µ*m MIR generated from the MIRGA equipment caused chemical and molecular level changes in the cement components (photodegradation). In this process, chemical components of the cement have absorbed the MIR and the absorbed MIR photons have altered the chemical bonds of cement molecule; thereby some of the cement molecules are degraded and transformed into another molecule/compound, as reported in GCMS analysis.

Mid-IR has unique vibrational transitions of most molecules (here cement) *(Waynant et al., 2011)* and has caused various chemical bond stretching and bendings *(Mohan, 2004; Agarwal et al., 2014)*, including new molecule formulation like gypsum formation, crystallinity and hydration *(Xu et al., 2017)*, thus lead to consequent change in physical and chemical properties of cement *(Esmaeili, 2015; Datta et al., 2014)*, hence improved CSC. Mechanical strength of cement mainly comes from accelerated hydration and chemical reaction *(Liu et al., 2020)* and also refinement of –CH crystal *(Wang et al., 2019)*. The said effects were produced by the mid-infrared as observed in the instrumentation results.

Depending on number of MIRGA spraying (energy given), a receptor's chemical bond configurations and subsequent physical and chemical characters can be altered to our desire. Such desirable results in coffee, tea, cocoa and edible salts were achieved using MIRGA spraying by *Umakanthan et al., 2022a; Umakanthan et al., 2022b; Umakanthan et al., 2023c; Umakanthan et al., 2023d.*

Since long, alternative to cement research is ongoing with merits and demerits of the results. CSC improving technologies are use of nanocements *(Brown et al., 2019)*, use of higher strength concrete (40 MPa or 50 MPa) *(Jemimah et al., 2021)*, use of metals waste *(Bacelar et al., 2022)* and mine drainage sediments, calcium sulfo-aluminate/alkaline hydroxide substances/ aluminosilicate minerals/sodium potassium silicate minerals *(Hong et al., 2016)*. CSC was also increased by various researchers by irradiation with ultraviolet *(Bo et al., 2011)*, microwave *(Dmitriev et al., 2017)*, gamma rays *(Osamu et al, 2013)*, neutron and radiation on sulphur polymer concrete *(Piotr et al., 2020)*, but these are having limitations with application and cost-effectiveness. Far-infrared rays a non-ionizing safe irradiation has also been used in CSC improvement *(Fukazawa et al., 1990)*.

Recently, cement based geopolymer materials are evolved which are technically advantageous. On contrary, cost is high, impracticable in large scale construction and unstable performance *(Liu et al., 2020)*. MIRGA technology can be placed in the literature as one of the CSC improving research.

IV. Conclusion

Mid-IR treated cast cement cubes showed 38% enhanced CSC versus non-treated. Thus, cement quantity could be reduced to 38% less than the usual requirement, saving resources and economy. If the usual quantity of cement is used, 38% more CSC would result. In the authors' opinion, this study has scope for more fruitful research on cement and its allied materials potentiation, which may result in further economy, reduced transport cost, resource saving and ecological impact.

Author Contribution

Umakanthan: Conceptualization, Methodology, Project administration, Resources, Supervision, Validation.
Madhu Mathi: Data curation, Investigation, Visualization, Writing - Original draft preparation.
Umakanthan, Madhu Mathi: Writing - Reviewing and Editing.

Competing Interest

In accordance with the journal's policy and our ethical obligation as researchers, we submit that the authors Dr.Umakanthan and Dr.Madhu Mathi are the inventors and patentee of Indian patent for MIRGA

(under-patent no.: 401387) which is a major material employed in this study.

Data and Materials Availability

All data is available in the manuscript and supplementary materials.

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References Références Referencias

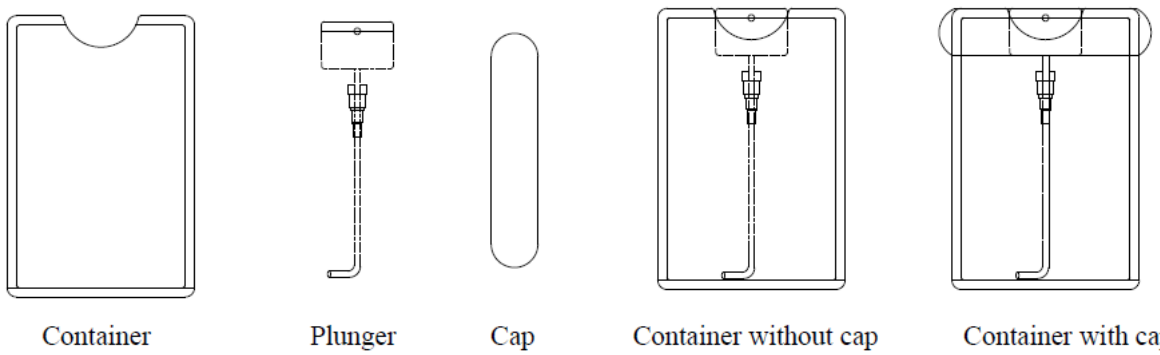
1. Liu, C., Huang, X., Wu, Y., Deng, X., Liu, J., Zheng, Z., & Hui, D. (2020). Review on the research progress of cement-based and geopolymer materials modified by graphene and graphene oxide, Nanotechnology Reviews, 9(1), 155-169. doi: https://doi.org/10.1515/ntrev-2020-0014
2. Jared L. Brown, Isaac L. Howard, and Robert Varner. Concrete compressive strength variation due to cement source change. Proceedings of the Institution of Civil Engineers - Construction Materials 2022 175:5, 213-232.
3. Umakanthan, Mathi M, 2022a. Decaffeination and improvement of taste, flavor and health safety of coffee and tea using mid-infrared wavelength rays. Heliyon, e11338, Vol 8(11). doi: 10.1016/j.heliyon.2022.e11338
4. Umakanthan T, Mathi M, 2022b. Quantitative reduction of heavy metals and caffeine in cocoa using mid-infrared spectrum irradiation. Journal of the Indian Chemical Society, Vol 100 (1). doi: 10.1016/j.jics.2022.100861
5. Tishkevich D I, Korolkov I V, Kozlovskiy A L, Anisovich M, Vinnik D A, Ermekova A E, Vorobjova A I, Shumskaya E E, Zubar T I, Trukhanov S V, Zdorovets M V, Trukhanov A V, 2019. Immobilization of boron-rich compound on Fe_3O_4 nanoparticles: Stability and cytotoxicity, J. Alloys Compd. 797, 573-581. https://doi.org/10.1016/j.jallcom.2019.05.075
6. Dukenbayev K, Korolkov I V, Tishkevich D I, Kozlovskiy A L, Trukhanov S V, Gorin Y G, Shumskaya E, Kaniukov E Y, Vinnik D A, Zdorovets M V, Anisovich M, Trukhanov A V, Tosi D, Molardi C, 2019. Fe_3O_4 nanoparticles for complex targeted delivery and boron neutron capture therapy, Nanomaterials, 494. https://doi.org/10.3390/nano9040494.
7. Kozlovskiy A L, Alina A, Zdorovets M V, 2021. Study of the effect of ion irradiation on increasing the photocatalytic activity of WO_3 microparticles, J. Mater. Sci.: Mater. Electron. 32, 3863-3877. https://doi.org/10.1007/s10854-020-05130-8
8. El-Shater R E, Shimy H E, Saafan S A, Darwish M A, Zhou D, Trukhanov A V, Trukhanov S V, Fakhry F, 2022. Synthesis, characterization, and magnetic properties of Mnnanoferrites, J. Alloys Compd. 928, 166954. https://doi.org/10.1016/j.jallcom.2022.166954
9. Kozlovskiy A L, Zdorovets M V, 2021. Effect of doping of $Ce^{4+/3+}$ on optical, strength and shielding properties of $(0.5\text{-}x)TeO_2$-$0.25MoO$-$0.25Bi_2O_3$-$xCeO_2$ glasses, Mater. Chem. Phys. 263, 124444. https://doi.org/10.1016/j.matchemphys.2021.124444
10. Almessiere M A, Algarou N A, Slimani Y, Sadaqat A, Baykal A, Manikandan A, Trukhanov S V, Trukhanov A V, Ercan I, 2022. Investigation of exchange coupling and microwave properties of hard/soft $(SrNi_{0.02}Zr_{0.01}Fe_{11.96}O_{19})/(CoFe_2O_4)_x$ nanocomposites, Mat. Today Nano, 100186. https://doi.org/10.1016/j.mtnano.2022.100186
11. Girard J E, 2014. Principles of Environmental Chemistry, 3rd edition, Jones & Bartlett Learning, USA, p99
12. Shankar D R, 2017. Remote Sensing of Soils. Germany: Springer-Verlag GmbH, p268.
13. Mohan J. Organic Spectroscopy: Principles and Applications, 2nd edition, Alpha science international Ltd., Harrow, UK, 19, (2004). Available at: *https://books.google.co.in/books?id=fA08Uy5DR0QC&printsec=frontcover&dq=Jag+Mohan.+Organic+Spectroscopy:+Principles+and+Applications&hl=en&sa=X&ved=0ahUKEwjHpcHUi9fgAhXXFIgKHXvRCpIQ6AEIKjAA#v=onepage&q=Jag%20Mohan.%20Organic%20Spectroscopy%3A%20Principles%20and%20Applications&f=false*
14. Yi G C, 2012. Semiconductor Nanostructures for Optoelectronic Devices: Processing, Characterization and Applications. Berlin, Heidelberg: Springer-Verlag, p198.
15. Esmaeili K, 2015. Viremedy, Homeopathic Remedies, and Energy Healing Remedies as Information – including Remedies; A Synopsis [Revision Aug 2015; E-pub.: Aug.2015] (First Pub: 2013). Google books, p43
16. Atkins P, Paula J, 2011. Physical Chemistry for the Life Sciences, Oxford university press, Oxford, p365
17. Datta S N, O'Trindle C, Illas F, 2014. Theoretical and Computational Aspects of Magnetic Organic Molecules. Imperial College Press, London, p224
18. Waynant R W, Ilev R K, Gannot I, 2001, Mid-infrared laser applications in medicine and biology. Phil. Trans. R. Soc. Lond. A, 359, 635-644.
19. Agarwal C M, Ong J L, Appleford M R, Mani G, 2014. Introduction to Biomaterials: Basic Theory with Engineering Applications. Cambridge university press, UK, p81.
20. Xu R, Xu Y, 2017. Modern Inorganic Synthetic Chemistry, 2nd edn., Elsevier B.V, Netherlands, UK, USA, p124.
21. Wang Q, Li S, Pan S, Cui X, Corr D, Shah S. (2019). Effect of graphene oxide on the hydration and microstructure of fly ash-cement system.

Construction and Building Materials. 198. 106-119. 10.1016/j.conbuildmat.2018.11.199.
22. Umakanthan, T, Mathi, M, 2023c. Increasing saltiness of salts (NaCl) using mid-infrared radiation to reduce the health hazards. Food Science & Nutrition, 00, 1–15. https://doi.org/10.1002/fsn3.3342
23. Umakanthan, Madhu Mathi, 2023d. Potentiation of Siddha medicine using Muppu (Universal Potentiator). International Journal of Pharmaceutical Research and Applications Volume 8, Issue 4 July-Aug 2023, pp: 2070-2084.
24. Brown, J & Howard, Isaac & Varner, Robert. (2019). Concrete compressive strength variation due to cement source change. Proceedings of the Institution of Civil Engineers - Construction Materials. 175. 1-43. 10.1680/jcoma.18.00067.
25. Jemimah, C, Milton., Prince, Arulraj, Gnanaraj. (2021). Compressive Strength of Concrete with Nano Cement. doi: 10.5772/INTECHOPEN.93881
26. B.A., Bacelar., Thalita, Cardoso, Dias., Péter, Ludvig. (2022). Reduction of the environmental impacts of reinforced concrete columns by increasing the compressive strength: a life cycle approach. Revista IBRACON de Estruturas e Materiais, doi: 10.1590/s1983-41952022000600010
27. Hong, J, Hee., Ryu, Yong, Sun., Kang, Dae, Kyu. (2016). Cement composition for durability increase.
28. Bo, Z., Yong, Zhang., Jianfeng, Zhou., Li, Chen., Deli, Li., Jianguo, Tan. (2011). UV irradiation improves the bond strength of resin cement to fiber posts.. Dental Materials Journal, doi: 10.4012/DMJ.2010-179
29. M., S., Dmitriev., M., V., D'yakonov., R., A., Krasnokutskiy., A., D., Kolyaskin., S, A, Dmitriev. (2017). Influence of microwave irradiation of cement mixtures on the strength of cement stone and concrete. doi: 10.1088/1742-6596/941/1/012101
30. Osamu, K., Shohei, Sawada., Ippei, Maruyama., Masayuki, Takizawa., Osamu, Sato. (2013). Evaluation of irradiation effects on concrete structure -gamma-ray irradiation tests on cement paste-. doi: 10.1115/POWER2013-98099.
31. Piotr, S., Joanna, Celinska., Andrzej, Gasiorowski., Rafal, Anyszka., Radoslaw, Walendziak., Michal, Lewandowski. (2020). Radiation induced strength enhancement of sulfur polymer concrete composites based on waste and residue fillers. Journal of Cleaner Production, doi: 10.1016/J.JCLEPRO.2020.122563
32. Fukazawa, T., Fukazawa, Tatsuo., Watanabe, Sumio. (1990). Manufacture of concrete or mortar member.

Supplementary Material

Supplementary data D1: Raw data files of cement instrumentations
https://drive.google.com/open?id=1Q1igeEkD5YHE0TZ-aE99MFBcALmAhMu9

Supplementary video V1: Method of MIRGA spraying
https://drive.google.com/open?id=1QoRwTESKfSdoJTfD--xIG9YpTDnVonGW



Supplementary Figure F1: MIRGA spray diagram

Supplementary Text T1: Details of MIRGA

MIRGA *(patent no.: 401387)* is a 20-mL capacity polypropylene plastic atomizer containing an inorganic (molar mass 118.44 g/mole) water-based solution in which approximately two sextillion cations and three sextillion anions are contained. The sprayer unit has dimensions 86 × 55 × 11 mm, an orifice diameter of 0.375 mm, ejection volume 0.062 ± 0.005 mL, and ejection time 0.2 s. The average pressure is 3900 Pa, and the cone liquid back pressure is 2000 N/m^2 *(Supplementary Fig (ii))*. During spraying, approximately 1-μg weight of water is lost as mist and the non-volatile material in the sprayed liquid has a concentration of 153 mg/mL. Every time spraying emits 0.06ml which contains approximately seven quintillion cations and eleven quintillion anions.

Depending on the pressure applied to the plunger, every spraying is designed to generate 2–6 μm as estimated by an FTIR (retro-reflector) interferometer instrument (Detector type D* [cm HZ1/2 - 1] MCT [2-TE cooled]) at Lightwind, Petaluma, CA, USA.

Supplementary Text T2: Detailed Discussion

1. *Detailed discussion [1]*

1.1. *Invention background*

The four observable states of matter (solid, liquid, gas, and plasma) are composed of intermolecular and intramolecular bonds. The inherent characteristics of neutrons, protons and electrons are unique, however, differences in their numbers are what constitute different atoms, and how these atoms bind together develops into different molecules with unique characteristics. In the electromagnetic wave (EMW) spectrum, the mid-IR region is vital and interesting for many applications since this region coincides with the internal vibration of most molecules [2]. Almost all thermal radiation on the surface of the Earth lies in the mid-IR region, indeed, 66% of the Sun's energy we receive is infrared[3] and is absorbed and radiated by all particles on the Earth. At the molecular level, the interaction of mid-IR wavelength energy elicits rotational and vibrational modes (from about 4500–500 cm^{-1}, roughly 2.2 to 20 microns) through a change in the dipole movement, leading to chemical bond alterations [4].

During our research we have observed: (A) In all objects, even though atoms always remain as atoms, their chemical bond parameters are continuously prone to alteration by cosmic and physical energies (e.g.: EMW, heat, pressure, and humidity) causing the bonds to compress/stretch/bend [5-8], break [9,10], or new bonds to be formed [11]. These alterations ultimately lead to changes in the physicochemical characteristics of the objects. (B) The dynamic, constant, and mutual influences of EMW among the Earth and the celestial and living bodies are continuously causing alterations in the inherent physiochemical characters of earthly objects, for instance, enhancement due to an optimum dose of energy or decrease/destruction due to a high dose of energy (detailed below). Thus, based on these concepts, MIRGA was developed to alter the bond parameters, thereby potentiating the natural characteristics of products.

1.2. *MIRGA definition*

We define MIRGA as *'a harmless, economical atomizer containing an imbalanced ratio of ions suspended in water, which influence the natural potency of target substances by generating mid-IR while spraying'*.

1.3. *Technique of mid-IR generation from MIRGA*

We designed MIRGA as to accommodate an imbalanced ratio of ions suspended in water in their fundamental state, which can move as free particles. The solution exhibits very little detectable background frequency, below even that of cosmic events. By comparison humans emit more radioactivity (around 10 microns) [12,13]. We designed MIRGA to generate energy based on various processes such as: (A) spraying leads to ionization (electrons getting separated from atoms) and many pathways for electron re-absorption; due to these two oscillatory processes, energy is generated; (B) while spraying, a water-based ionic solution gets excited/charged, which in turn leads to oscillation among the imbalanced ions [14] in their excited state, resulting in the emission of photons [15,16]; (C) although a low electromagnetic field exists between the charged particles of the MIRGA's ionic solution, during spraying the induced oscillation between these charged particles produces energy [17-21]; and (D) in the natural rainfall process, more energy is required to break the water bonds for creating smaller water droplets [22]. Therefore, these droplets should have more stored energy, which then travels down at velocity from a specific distance, thus gaining kinetic energy. When the rain hits the Earth's surface, it forms a very thin film of mid-IR (nearly 6 micron), hence there is a net heat gain [22,23]. We simulated this rainfall's energy-gaining process in MIRGA (i.e., when imbalanced ions in liquid media are atomized, the ejected smaller droplets should have higher internal energy as well as acquired kinetic energy, and the energy emitted by breaking the surface tension). From trial and error, we calibrated the ejection pressure to obtain a desired fine mist, and minimized the evaporation rate by altering the pH and density of the solution. Moreover, the accelerated ions in the sprayed ionic clouds collide among themselves and generate energy [24], thus, we incorporated these phenomena in our atomizer and designed it in such a way as to emit energy in the 2–6 μm mid-IR depending on the given plunger pressure.

Yousif et al. [25] described this process as a photodissociation of molecules caused by the absorption of photons from sunlight, including those of infrared radiation, visible light, and ultraviolet light, leading to changes in the molecular structure.

1.4. *Safety of MIRGA-sprayed products*

In our nearly two-decades of research, we have observed that MIRGA-induced bond-altered target substances do not show any adverse reaction upon consumption/use. In nature, (A) Stereochemical configuration has great influence on taste [26] (e.g., varieties of mango, grapes, rice, etc.), (B) Cooking and digestive enzymes break chemical bonds, thereby softening foods. This indicates that alterations in chemical bonds occur naturally and do not represent a risk to human health. As an example, boiled rice, puffed rice, flat rice, and rice flour have a unique aroma, taste,

texture, and shelf-life but conserving the same molecular formula ($C_6H_{10}O_5$). (C) In the food industry, sensory attributes and shelf-life are enhanced by altering the food's chemical bonds using various irradiation processes like radappertization, radicidation, and radurization [27]. (D) Upon heating, water changes from ice to liquid to steam, which are manifestations of changes in the hydrogen bonds [28] but the chemical composition (H_2O) remains the same [29].

1.5. *MIRGA's primeval and future scope*

The water-based MIRGA could be the first novel potentiating technology. This type of atomizer technology also seems to be present with the extra-terrestrials for their therapeutic use during visitations [30].

In various products, we have achieved a range from 30% to 173% potentiation. Even the smaller improvement resulted in 30% monetary and resource savings as well as health benefits. However, there is a knowledge gap between potentiation from 30% to at least 100% for all products, which can be filled-up by refining MIRGA's ionic solution, concentration, atomizer pressure, and other parameters and even formulating a better solution.

Various mid-IR emitters are now available (e.g., silicon photonic devices [31], cascade lasers quantum and interband [32], non-cascade-based lasers, chalcogenide fiber-based photonic devices [33], and suspended-core tellurium-based chalcogenide fiber photonic devices [34]). These emitters are not as cost-effective as MIRGA and are useful only in astronomy, military, medicine, industry, and research applications. These emitters are too complex for domestic application by the average user.

Because of MIRGA's wide range of applications, we believe that this technique will resonate in many scientific fields including biophotonics, therapeutics, health, ecology, and others. We are currently conducting research on MIRGA and its applications, namely MIRGA salt, MIRGA vapor and MIRGA plasma.

References Références Referencias

1. Umakanthan, Mathi M, 2022. Decaffeination and improvement of taste, flavor and health safety of coffee and tea using mid-infrared wavelength rays. Heliyon, e11338, Vol 8(11). doi: 10.1016/j.heliyon.2022.e11338
2. CORDIS, European commission. New advances in mid-infrared laser technology, Compact, high-energy, and wavelength-diverse coherent mid-infrared source. Available at: https://cordis.europa.eu/project/rcn/99977/brief/en (last accessed on 27.01.2019).
3. A. Salam, A. Ammar, A.H. Asaad, L. Yi-Chen, C. Francesco, 2019. Molecules A Comprehensive Review on Infrared Heating Applications in Food Processing. Molecules. 24, 2-21. doi: 10.3390/molecules24224125
4. J. E. Girard, Principles of Environmental Chemistry, third ed., Jones & Bartlett Learning, USA, 2014, pp. 99.
5. James E. Girard, 2014. Principles of Environmental Chemistry, 3rd edition, Jones & Bartlett Learning, USA, p99.
6. Avelion Alvarez and Miguel Prieto, 2012. Fourier Transform Infrared spectroscopy in Food Microbiology, Springer Science & Business Media, p3.
7. Brian C. Smith. Infrared Spectral Interpretation: A Systematic Approach, CRC Press, LLC, 7, (1999).
8. Dwivedi Ravi Shankar, 2017. Remote Sensing of Soils. Germany: Springer-Verlag GmbH, p268.
9. Jag Mohan. Organic Spectroscopy: Principles and Applications, 2nd edition, Alpha science international Ltd., Harrow, UK, 19, (2004). Available at: https://books.google.co.in/books?id=fA08Uy5DR0QC&printsec=frontcover&dq=Jag+Mohan.+Organic+Spectroscopy:+Principles+and+Applications&hl=en&sa=X&ved=0ahUKEwjHpcHUi9fgAhXXFIgKHXvRCpIQ6AEIKjAA#v=onepage&q=Jag%20Mohan.%20Organic%20Spectroscopy%3A%20Principles%20and%20Applications&f=false
10. Carolyn McMakin, 2011. Frequency specific Microcurrent in pain management E-book, Elsevier, China, p 30.
11. David Moss, 2011. Biomedical Applications of Synchrotron Infrared Microspectroscopy: A Practical Approach, Royal Society of Chemistry, UK, p 58.
12. Peter H. Raven, Linda R. Berg, David M. Hassenzahl, 2012. Environment, John Wiley & Sons, Inc., USA, p45. Available at: https://books.google.co.in/books?id=QVpO2R51JBIC&pg=RA1-PA45&dq=electromagnetic+waves+make+form+new+bonds&hl=en&sa=X&ved=0ahUKEwiTnO2amMbjAhUJ3o8KHSfkAJEQ6AEIMjAB#v=onepage&q=electromagnetic%20waves%20make%20form%20new%20bonds&f=false
13. Frances Ashcroft, 2000. Life at the Extremes: The Science of Survival, University of California Press, California, p122.
14. Robert H. Sanders, 2014. Revealing the Heart of the Galaxy, Cambridge University Press, USA, p70.
15. Frank Verheest. Waves in Dusty Space Plasmas, Kluwer Academic Publishers, Netherlands, 89, (2000).
16. Sun Keping, Gefei Yu. Recent developments in Applied Electrostatics (ICAES2004): Proceedings of the Fifth International Conference on Applied Electrostatics, Elsevier Ltd., UK, p87.
17. Pierre L. Fauchais, Joachim V. R. Heberlein, Maher I. Boulos. Thermal Spray Fundamentals From

Powder to Part. Springer Science & Business Media, New York, 84 (2014).
18. Manfred Wendish, Jean-Louis Brenguier. Airborne Measurements for environmental Research: Methods and Instruments, Wiley-VCH. Available at: https://books.google.co.uk/books?id=tHdwhn-c5mgC&pg=PT419&dq=A+regularly+oscillating+charge+produces+a+harmonic+electromagnetic+waves+Manfred&hl=en&sa=X&ved=0ahUKEwjBqdv75tvgAhWpSxUIHbQ_D0gQ6AEIKjAA#v=onepage&q=A%20regularly%20oscillating%20charge%20produces%20a%20harmonic%20electromagnetic%20waves%20Manfred&f=false (last accessed on 27.02.2019).
19. Kongbam Chandramani Singh, 2009. Basic Physics, PHL Learning Private Limited, New Delhi, p413.
20. Mathura Prasad. Soul, God and Buddha in Language of Science, Notion Press, Chennai (2017).
21. Stephen Pople, 1999. Complete Physics, Oxford University Press, Oxford, p166.
22. Roger Barry, Richard Chorley, 1998. Atmosphere, Weather and Climate, 7th edition, Routledge, London, p51.
23. Eniday: https://www.eniday.com/en/sparks_en/harnessing-the-energy-of-rain/ (last accessed on 06.02.2019).
24. Krishnakumar, T (2019). Application Of Microwave Heating In Food Industry. 10.13140/RG.2.2.27035.72488
25. Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers, especially polystyrene: review. SpringerPlus, 2, 398. https://doi.org/10.1186/2193-1801-2-398
26. Kenneth L., Williamson, Katherine M. Masters, 2011. Macroscale and Microscale Organic Experiments, 6th edition, Brooks/Cole C engage learning, CA, p720.
27. Sivasankar B. Food Processing and preservation, PHI Learning Private Limited, Delhi, 246, (2014).
28. Trevor Day, 1999. Ecosystems: Oceans. Routledge Taylor & Francis Group, London and New York, p44.
29. Kenneth W. Raymond, 2010. General Organic and Biological Chemistry, 3rd edition, John Wiley & Sons, Inc., USA, p176.
30. Blue planet project: Alien Technical research–25, Westchester Camp, Office of the Central Research #3.CODE: ARAMISIII–ADR3-24SM, p80-81.
31. CMOS Emerging Technologies. CMOSET 2012: Abstracts, p49. Available at: https://books.google.co.in/books?id=3XVYC-yBgksC&pg=PA49&dq=mid+infra#v=onepage&q&f=false
32. Jung, D., Bank, S., Lee, M. L., & Wasserman, D. (2017). Next-generation mid-infrared sources. Journal of Optics, 19(12), 123001. doi:10.1088/2040-8986/aa939b
33. Sincore, A. & Cook, Justin & Tan, Felix & El Halawany, Ahmed & Riggins, A. & McDaniel, S. & Cook, G. & Martyshkin, Dmitry & Fedorov, V. V. & Mirov, Sergey & Shah, L. & Abouraddy, A. & Richardson, M. & Schepler, Kenneth. (2018). High power single-mode delivery of mid-infrared sources through chalcogenide fiber. Optics Express, 26(6), 7313. doi:10.1364/oe.26.007313
34. Wu, Bo & Zhao, Zheming & Wang, Xunsi & Tian, Youmei & Mi, Nan & Chen, Peng & Xue, Zugang & Liu, Zijun & Zhang, Peiqing & Shen, Xiang & Nie, Qiuhua & Dai, Shaocong & Wang, R.P. (2018). Mid-infrared supercontinuum generation in a suspended-core tellurium-based chalcogenide fiber. Optical Materials Express, 8(5), 1341. doi:10.1364/ome.8.001341

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Evaluation and Design of Improvement of Al-Jbeiha Signalized Intersection Traffic Operation

By Batool Alaraj & Hana Naghawi

Abstract- The main objective of this paper is to design Al-jubha intersection and the Roadways approaches optimized to better level of service. Traffic design for this intersection include evaluation the current LOS for the intersection and design all possible solutions to reduce congestion, delay and low level of service in this intersection. This design will absolutely save time and money.

An intersection is a shared space that is used by more than one approach at a time. A signalized intersection is one where the shared space is used alternatively by a fixed number of approaches for a predefined time interval as per the phasing scheme used for the intersection.

In this paper, we made unconventional ideas to improve the intersection of the aljabaha signal. the intersection is analyzed as an isolated intersection in this study, using Synchro 8 and HCM 2010 standards. The simulation results the median U-Turn and signal optimization improve the intersection level of service from E-B. The delay for this intersection was reduced to 48.8%, 11.8.

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I. Introduction

The traffic performance of a roadway network is greatly influenced by the traffic flow through intersections. Many types of traffic control are being used worldwide at intersections such as yield signs, stop signs, roundabouts and signals. Similar to other countries, many traffic signals are installed in Jordan at intersections with moderate and heavy traffic volumes.

Traffic signals ensure safe and efficient traffic flow at intersections, along routes, and in street networks. They improve intersection capacity, minimize traffic delays, enhance safety by reducing specific accidents like right-angle collisions, promote orderly traffic movements, allow safe passage for minor amidst heavy traffic, and aid in establishing a signal system. Transportation professionals primarily measure the performance of signalized intersections based on vehicle delay, a crucial parameter (David 2013).

Vehicle delay is the most important parameter used by transportation professionals in evaluating the performance of a signalized intersection. This is perhaps because it directly relates to the time loss that a vehicle experiences while crossing an intersection (though we have not considered other problems like congestion due to queuing, extra fuel loss due to vehicle ignition etc.) Determining delay at intersections is challenging due to the unpredictable nature of arrival and departure processes. However, extensive research has been conducted to define delay using various analytical models, including deterministic queuing, steady state stochastic, and time dependent stochastic models. These models make assumptions that simplify the complex flow conditions, providing an approximate measure of the average delay experienced by vehicles crossing an intersection. Some studies have also aimed to predict the variance in overall delay for individual vehicles, considering the significant variations and randomness in traffic arrivals and interruptions caused by traffic signal controls (Gupta, 2005).

Vehicles exert a substantial environmental influence through emissions and the consumption of fossil fuels. The burning of gasoline and diesel generates CO2, a greenhouse gas that contributes to climate change. Additionally, vehicles release pollutants like NOx and particulate matter, negatively impacting both air quality and human health. The extraction, refining, and transportation of fossil fuels also lead to habitat destruction and water pollution. To address these issues, there is a strong focus on developing electric vehicles, enhancing fuel efficiency, and investing in alternative transportation options such as public transit and cycling infrastructure. These measures are essential for reducing emissions, improving air quality, and safeguarding the environment for future generations.

a) Project Description

Yajouz road is located in Amman, and it is considered one of the most important dynamic sites which links Amman and Zarqa. In a map is displayed which demonstrates the location of Yajouz road within the districts of Amman.

In this study, a part of the Yajouz road is considered which is Al Jubaiha intersection. The intersection has four legs and connects Yajoz street with Abdullah Al-Lawzi Street. The intersection is signalized, and it is selected because it is considered one of the most important dynamic sites. Jubaiha Intersection has a heavy daily volume of traffic, which leads to a traffic problem represented by delay,

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especially during peak hours. It is located in the north of the Jordanian capital.

Fig. 1: Aljbaha intersection

b) Problem Statement

The increase in road network by widening roads, building new tunnels and other infrastructure is costly and limited by the available spaces in Amman, therefore, the other solution is to decrease the travel demand, especially within the peak hours. The long-term solution requires developing a reliable and comprehensive transportation system and encouraging people to use it instead of private cars. However, the current situation of congested traffic requires immediate solutions with minimal costs, time, and effort. In this project, a micro-scale solution to the delay problem at the intersection is proposed. More than one alternative will be considered (including a signal optimization, median U-Turn and signal optimization with median U-turn), and then the best alternative will be selected. Although, a long-term macro scale solution is required on a network-wide level which considers the interactions between different elements of the roadway. However, the scope of this project is limited to a micro-scale solution.

c) Project Objectives

This project aims to improve the level of service at Al-Jbeiha intersection. The objectives can be summarized as follows:

1. Assessing the existing level of service at the intersection: Evaluate the current traffic conditions and determine the performance of the intersection.
2. Developing alternative solutions for improved traffic conditions: Propose various strategies and measures that can enhance the traffic flow and alleviate congestion at the intersection. Use simulation models to estimate the resulting level of service for each alternative.
3. Selecting the optimal solution: Analyze and compare the proposed alternatives based on their predicted level of service and feasibility. Determine the best alternative for implementation at the intersection.

d) Project Constrains

The main constraints involved in this project are economic and ethical. First, the selected alternative should be economically justified by considering a sequential evaluation process starting from the least disruptive option to the most disruptive option which would be more costly. Furthermore, the design follows all local and international ethical code requirements.

e) Project Standard and Codes

- Highway Capacity Manual) HCM)
- American Association of State Highway and Transportation Officials (AASHTO) 2011

II. Literature Review

Hussein (2023) conducted a study to evaluate and enhance four three-leg intersections controlled by STOP signs in various locations within Amman City. The evaluation and improvement processes utilized Highway Capacity Software (HCS-2010) and Synchro-10 software. The validation and simulation were performed using VISSIM-11 software. The evaluation with HCS-2010 and Synchro-10 indicated that the left-turn movements from the minor streets experienced significant delays and operated in a breakdown traffic condition (Level of Service LOS-F). The application of Warrant-3 (Peak Hour Volume) determined that three of the selected intersections warranted signalization under existing conditions, while the fourth intersection did not meet the requirements. For short-term conditions with a growth rate of 5.5%, both software tools indicated that all four selected intersections warranted traffic signals. The optimal cycle length for the traffic signals was determined for each intersection, considering two operation modes for the left-turn movements on the major streets: Protected and Protected-Permitted phase. The HCS-2010 and Synchro-10 software were used for this analysis, and the results were validated using VISSIM-11. The improvements in traffic and geometric conditions resulted in a reduction in vehicle delays, with improved Level of Service (LOS-C or LOS-D) at the minor approaches and the entire selected intersections (LOS-B or LOS-C).

In their study, Khalifate (2021) aimed to improve the capacity and level of service at the sixth circle in Jordan by implementing traffic signals and a roundabout metering approach. The VISSIM software and a C++ program were utilized for this purpose. The sixth circle, situated near Crown Plaza and the Jordan Gate Towers project, experiences congestion due to heavy traffic flow. The study focused on assessing the traffic situation at the sixth circle and proposed potential solutions to reduce daily traffic flow for circle users. In the second scenario, four signals were placed at the roundabout, interconnected with different cycle lengths. A 90-second cycle length resulted in a level of service

rating of D. The third scenario involved the use of adaptive signals on the roundabout, which were connected to ground detectors placed before the signals. These adaptive signals operated based on the queue length of approaching vehicles detected by the ground detectors. The opening and closing of the signals were designed using simulation and implemented through the C++ programming language. The first two signals were opened for 45 seconds, prioritizing Swefieh road with reference to King Faisal, and then closed for 45 seconds to open the signal for the next street from the fifth circle, specifically Zahran street.

III. Methodology

The methodology is summarized as follows:

1) Collecting data for the intersection; traffic volumes, geometric components, and traffic signal system.
2) Analysis of the current situation for the intersection, by finding the level of service and delay for the intersection using the Synchro software.
3) Provide solutions for the intersection.
4) Evaluate the performance of the intersection after applying the solutions, in term of level of service and delay, with the help of the Synchro software.

a) Traffic Volumes

Aljbaha intersection located at the Amman, the key traffic data were taken from the department of traffic operations at GAM. Traffic data was collected on April 4th, 2022, with attention to the 15-min peak hour volumes that happened in the morning peak from 7-8 am.

b) Model Development

SYNCHRO8 which is a microscopic level analysis software was used to analyze and evaluate.

i. *Current Situation*

The current Volumes of the current Volumes values Based on the analysis of data above, the total intersection control delay was found to be 62.1 seconds, under those circumstance the level of service was E. Moreover, the maximum volume to capacity ratio (V/C) was 1.94.

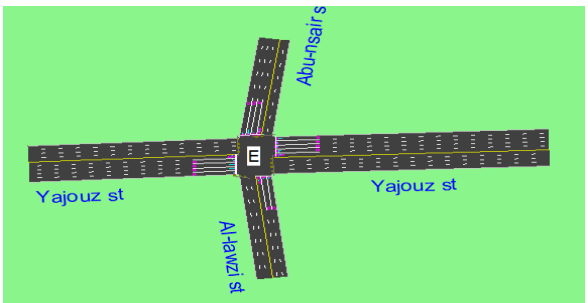

Fig. 2: Level of service

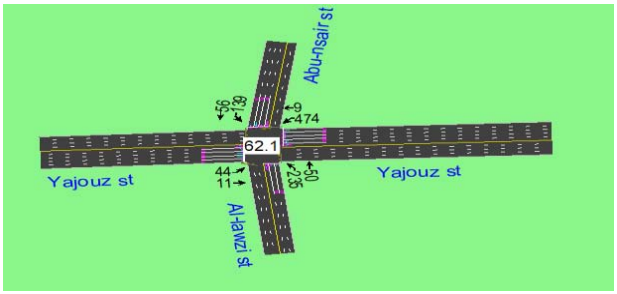

Fig. 3: The total intersection delays

IV. Project Design

The main objective of this paper is to design Al-jubha intersection and the Roadways approaches optimized to better level of service.

Traffic design for this intersection include evaluation the current LOS for the intersection and design all possible solutions to reduce congestion, delay and low level of service using Synchro 8.

a) Signal Optimization: (The FIRST Alternative)

Traffic signal optimization is one of the most cost-effective ways to improve traffic movement and make our streets safe and efficient. Signal optimization is performed for the following reasons: To adjust signal timing to account for changes in traffic patterns due to new developments and traffic growth.

LOS (D) Steady Traffic at High Density. The speed and the maneuverability are severely reduced. Low level of comfort for drivers, as collisions with other vehicles, must constantly be avoided. A slight increase in the traffic risks causing some operational problems and saturating the network.

Under the same phasing and geometric conditions, Synchro 8 results show that the cycle length has decrease to 45 seconds. Furthermore, the total intersection delay has decreased to 48.8 seconds, and the maximum volume to capacity ratio has decrease to 1.8. However, the service level turned into D.

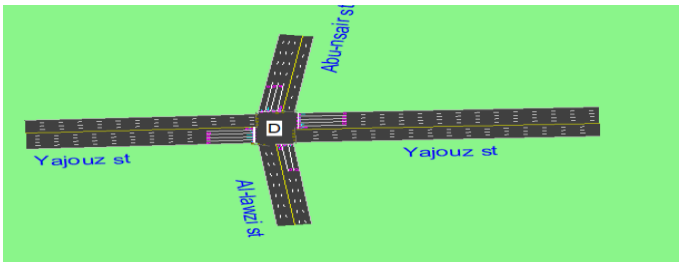

Fig. 4: Level of service

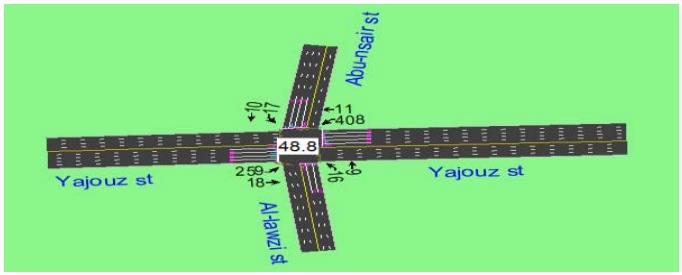

Fig. 5: The total intersection delays

b) Median U-Turn (The Second Alternative)

Median U-Turn: The main disadvantage is the added stopping and delay impact on left turning traffic. Although despite this fact, this design has been shown to improve total intersection delay and travel time conditions under certain volumes. It requires larger R.O.W. along the major roadway ¬ AASHTO recommends a 60ft to accommodate large trucks, from a non-motorized user standpoint, this design presents fewer threats to crossing pedestrians (longer time, refuge area). Level of service LOS (C) Steady Traffic but Limited. The presence of other vehicles affects drivers. The choice of the speed is affected and maneuvering requires vigilance. The level of comfort decreases quickly at this level, because drivers have a growing.

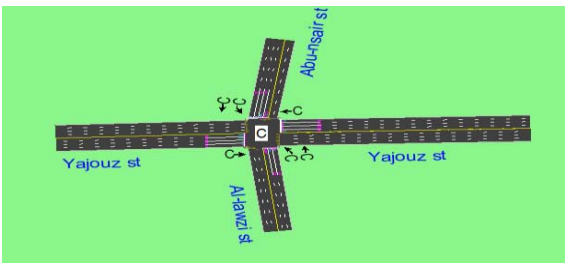

Fig. 6: Level of service

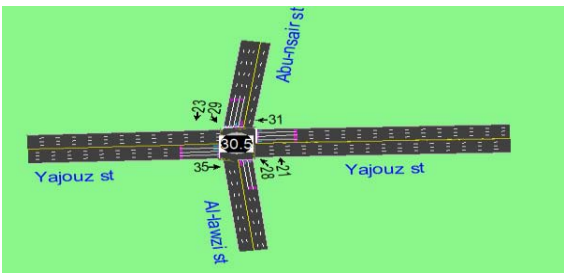

Fig. 7: The total intersection delays

c) Signal Optimization a Median U-turn (Third Alternative)

LOS (B) Steady Traffic: The presence of other vehicles begins to affect the behavior of individual drivers. The choice of the speed is free, but the maneuverability has somewhat decreased. The comfort is excellent, as drivers simply need to keep an eye on nearby vehicles. Intersection delays 11.8s.

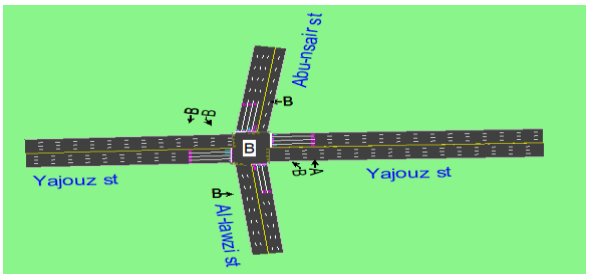

Fig. 8: Level of service

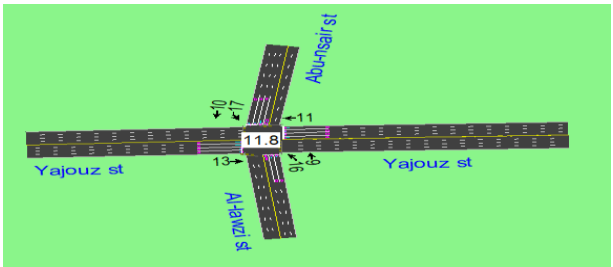

Fig. 9: The total intersection delays

V. Results

Table 1: Summary of result

	Cycle length	Maximum v/c ratio	Intersection delay	Level of service
Current situation	158	1.94	62.1	E
Signal optimization	45	1.8	48.8	D
Median U-turn	158	0.61	30.5	C
Signal optimization +Median U-turn	45	0.67	11.8	B

VI. Conclusion

1. The main object of this study is to evaluate the effect of implementing unconventional arterial intersection design.
2. These designs are regarded to be unconventional because they incorporate geometric features or movement restriction that would be accepted at 4 leg intersection.
3. Aljbaha intersection was selected to perform this study. in the final analysis, results showed a different level of improvement according to the UAID model chosen, to sum up, the level of service of Signal optimization, median U-turn and single optimization + median U-turn enhanced from E to D, C, B respectively. Moreover, the intersection delay was reduced by 48.8, 30.5, and 11.8 respectively.
4. Since the median U-turn + single optimization which improved the LOS from E to B on the main intersection the use of median U-turn + single optimization will decrease the delay by 11.8%.

References Références Referencias

1. Hadidi, T., Naghawi, H., & Jadaan, K. (2022). Unconventional Intersection Designs for Improving Traffic Operation Along Arterial Roads. Periodica Polytechnica Transportation Engineering, 50(1), 58-68.
2. Naghawi, H. H. (2014). Analyzing delay and queue length using microscopic simulation for the unconventional intersection design Superstreet. Journal of the South African Institution of Civil Engineering= Joernaal van die Suid-Afrikaanse Instituut van Siviele Ingenieurswese, 56(1), 100-107.
3. Naghawi, H., AlSoud, A., & AlHadidi, T. (2018). The possibility for implementing the superstreet unconventional intersection design in Jordan. Periodica Polytechnica Transportation Engineering, 46(3), 122-128.
4. Gupta, S. (2005). Delay at Signalized Intersection. Departmrnt of Traffic Engineering, Indian Institute of Technology, India.
5. Hussein, A. A. K., & Jrew, B. K. (2023). Evaluation and Improvement of Three-Leg Intersections: A Case Study in Amman City. Eurasian Journal of Engineering and Technology, 16, 47-58.
6. Khliefat, I., Naser, M., Alhomaidat, F., & Hanandeh, S. (2021). Improving the capacity and level of service at the sixth circle in Jordan by using traffic signals and roundabout metering approach. The Open Transportation Journal, 15(1Lee, C. E., & Savur, V. S. (1979). Analysis of intersection capacity and level of service by simulation. Transportation Research Record, 699, 34-41.
7. Papacostas C., Prevedonros P. (2008), Transportation Engineering and Planning, Fourth Edition, USA.

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High Rate Water Clarification Technology

By P. Polasek & C. J. Wantenaar

Abstract- At present the formation of flocculent suspension and its gravity separation are lengthy processes varying between 3 and 4.5 hours. Consequently this results in high capital costs. Therefore, reconsideration of the kinetics of formation of the flocculent suspension and its effect on the gravity separation of formed suspension was needed. This reconsideration revealed that an unconventional, open-minded thinking was required to develop a new water purification technology capable of solving this problem. This technology will most likely be in direct disagreement with the traditional way of thinking in water purification engineering. The reconsideration project also revealed that the current method for the use of water soluble polymers results in a deterioration of the purified water quality and detrimentally affects the operation of filters. Therefore the development of a method for using these polymers, free of side effects, is also essential. A new technology, the High Rate Clarification Technology, combining two processes developed for addressing the above shortcomings, was developed.

Keywords: inline high-density suspension formation process, degree of aggregation, organic agglomeration agent, post-orthokinetic agglomeration, HR clarifier, P-clarifier, POA process.

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Strictly as per the compliance and regulations of:

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P. Polasek [α] & C. J. Wantenaar [σ]

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Keywords: inline high-density suspension formation process, degree of aggregation, organic agglomeration agent, post-orthokinetic agglomeration, HR clarifier, P-clarifier, POA process.

I. Introduction

The traditional method for the way of formation of flocculent suspension and its gravity separation are lengthy processes varying between 3 and 4.5 hours. This requires construction of large waterworks on large lands, resulting in higher capital costs. The need to reduce the high capital costs of waterworks received appropriate attention many years ago. This required re-evaluation of the kinetics of formation of flocculent suspension and its effect on the gravity separation. The outcome highlighted the fact that the formation of flocculent suspensions under a commonly low agitation intensity and their gravity separation required an unreasonably long time. This is because the formed aggregates are large, heterogeneous, light in size and of a very low sedimentation velocity. Furthermore, it also showed that the water soluble polymers applied, in accordance to common practice, as coagulant and, or flocculant aids, do not facilitate the formation of rapidly settling aggregates. Instead, they adversely affect both the quality of purified water and the operation of filters by increasing the rate at which filter head-loss rises.

The outcome of the above re-evaluation showed that a non-traditional open-minded thinking was needed to develop a new water purification technology. Such technology that will be able to solve these problems would probably have to be in direct disagreement with the traditional way of thinking in water purification engineering. Such new technology, the High Rate Clarification Technology (HRCT), was developed [1, 2]. It consists of two developed processes, namely the Inline High Density Suspension (IHDS) formation process producing dense micro-aggregates and the Post-Orthokinetic Agglomeration (POA) process agglomerating the micro-aggregates to large, heavy, rapidly settling agglomerates. The impact of HRCT on the acceleration of the sedimentation velocity of formed agglomerates is evident from Figure 1.

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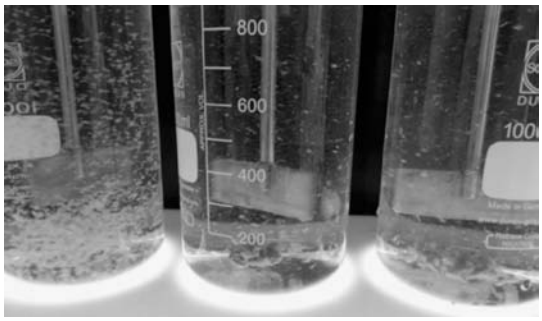


Figure 1: Suspension formed by the High Rate Clarification Technology – anionic polymer dosages from left to right: 0.1; 0.2 and 0.3 mg.L-1, picture taken at a stirrer speed of 27 RPM

The HRCT has not been described before and is presented now by this article. The principles of High Rate Clarification Technology including the method for the most effective application of water soluble polymers are described under Technological Background. The High Rate clarifiers, incorporating the HRCT, were also developed. The performance results achieved at different localities under different applications are described under the Chapter Design, Operation and Performance of High Rate Clarifiers.

The quality of purified water, to a large extent, is influenced by the type of coagulant used; hydrolyzing coagulants (salts of Al^{3+} and Fe^{3+}), if applied under the optimized reaction conditions pertaining to all monitored impurities [3], are capable of purifying water to a quality within the limits defined in the National Standard for drinking water. During this project it was established that the organic coagulants, i.e. water soluble cationic polymers, are not capable of purifying water to the quality attainable by the hydrolyzing coagulants [4-7]. Therefore, the organic coagulants are not an equivalent replacement for the hydrolyzing coagulants.

Particles of impurities consist of two size-fractions, namely the separable and the non-separable particles [8-10]. The total content of particles of impurities is the sum of the content of particles of these two size-fractions. The purpose of water purification is to change the non-separable particles to separable aggregates and then to remove the formed flocculent suspension from the water. The total residual concentration of each monitored impurity determines the overall process efficiency attained by the plant; the residual concentration of non-separable particles determines the process efficiency attainable by the technology used.

II. Technological Background

a) Formation of Aggregates

There are two different opinions about the importance of agitation intensity on aggregation. The first traditional opinion commonly accepted across the water purification field is that a low (gentle) agitation intensity is required to form large aggregates. For instance, Han and Lawler [11] described the importance of agitation intensity as follows:

- The importance of the velocity gradient *(G)* has been over-emphasized in the traditional view of aggregation, and *G* has far less importance than previously thought,
- The velocity gradient *G*, although by no means irrelevant, is relatively unimportant in aggregation.

This means that the agitation intensity actually required is that which is enough to prevent sedimentation of the aggregates being formed.

This opinion is questionable for several reasons. The low agitation intensity is not capable of facilitating continuation of the coagulant dispersion, i.e. the particle destabilization, if this is not completed in the flash mixer. Evidently, the time required to complete coagulation (aggregation) is of no importance. Therefore, the effect of completion of coagulation on the quality of purified water, is also not considered to be of importance.

The aggregates formed by the traditional low agitation intensity ($\overline{G} << 50\ s^{-1}$) are heterogeneous and of low density. They are easily affected by extraneous issues like temperature variations, and sun and wind effect. The sedimentation velocity of these aggregates is low and varies over a wide range. Due to this, the sedimentation systems to have an acceptable separation efficiency must be sized for the smallest aggregates required to settle. Therefore, the sedimentation velocity of traditionally designed clarifiers is usually based around $v_S \leq 2\ m.h^{-1}$.

The other opinion that the agitation intensity is of prime importance in the aggregation is based on Camp [12, 13]. The benefit of high agitation intensity on aggregation in its complexity is described in [1, 14-18].

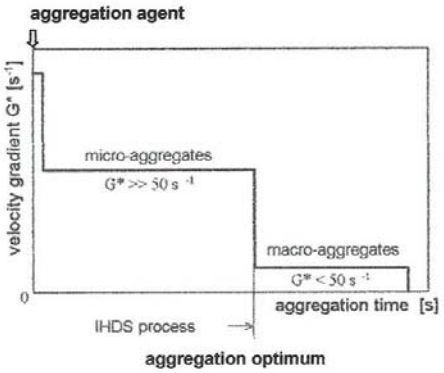


Figure 2: Illustration of the Inline High Density Suspension (IHDS) formation process (G* =)

Understanding the significance of the intensity of agitation on the course of the formation of aggregates and their properties led to the development of the Inline High Density Suspension (IHDS) formation process. The formation of aggregates under the IHDS process produces micro-aggregates fairly uniform in size and density. These micro-aggregates can be enlarged to a lower size macro-aggregates using subsequent low agitation intensity (Figure 2).

Different opinions also exist on the method of using the cationic, anionic and nonionic water soluble organic polymers. A common reason for using these different polymers are their dominant adhesion properties which are capable of facilitating the formation of larger and, therefore, a more rapidly settling suspension.

Technologically these polymers are generally used either as the coagulant aids and, or the aggregation aids and applied into a differently progressed aggregation, or as the aggregation agents (coagulants) replacing the traditional mineral coagulants, primarily the hydrolyzing coagulants. These methods have continued in use for more than 50 years [19-21]. This project proved that the cationic polymers, sometimes referred to as organic coagulants, are not an equivalent replacement for the hydrolyzing coagulants [4, 5, 7, 21].

This project also proved that the commonly accepted method for the use of anionic and non-ionic polymers does not effectively facilitate the formation of larger, and a more rapidly settling suspension. The commonly accepted method does not determine the most effective conditions under which these polymers should be applied to accelerate coagulation-aggregation-sedimentation processes and to most effectively improve the purified water quality.

Furthermore, this common method is considered inappropriate because it also produces certain serious shortcomings and side effects, such as:

- The quality of purified water is poorer than that produced without the polymer,
- The increase in the sedimentation velocity of formed suspension seems to be too low in comparison to the relatively high polymer dosage commonly applied,
- The deep-bed filtration is adversely affected if the filters are not designed for the filtration of a polymer formed suspension. The filtration shortcomings result in a rapid build-up of filter head loss causing the filter bed to operate under undesirable sub-atmospheric pressure, as well as a poorer filter backwashing efficiency, all resulting in the reduced length of the filtration cycle, and the formation of mud-balls; the use of a relatively high polymer dosage used may be one of the major contributors to this problem.

In view of the foregoing the development of a new method for the most effective application of the anionic and non-ionic polymers, became a necessity. This method had to fully utilize the adhesion properties of these polymers, and be free of any detrimental side effects. Therefore, the following aspects of the application of anionic and non-ionic polymers were investigated:

- Significance of the state of aggregation (characterized by the degree of aggregation γ) reached by the aggregation at the point of addition of polymer on the settling velocity of formed agglomerates and the purified water quality,
- Significance of the electrolyte pH at which these polymers are dissolved on their agglomeration capability,
- Effect of the maturation of the polymer solution on its agglomeration capability,
- Effect of the concentration of the polymer solution on its agglomeration capability,
- Effect of hydrodynamic conditions applied to the dispersal mixing of the polymer solution, i.e. its homogenisation throughout the aggregated water,
- Effect of inline dilution of the polymer concentrated stock solution on its agglomeration potential,

- The influence of these polymers on the dosage of the aggregation agent (coagulant).

b) Significance of Velocity Gradient on the Properties of Aggregates

During the aggregation process the destabilized particles combine into primary aggregates. These primary aggregates combine into larger spatial structures and form micro- and macro-aggregates. In these structures, there are lattice spaces filled with water. It is assumed that the total volume of these spaces, as well as the size, structural arrangement and compactness (density) of the aggregates formed are influenced during their formation by the magnitude of adhesion forces and kinetic energy of the colliding particles and the smaller aggregates. This topic is dealt with in [1, 2, 14-16].

i. *Size and Shape*

This research showed a significant difference in the character and size of aggregates formed by different mean square root velocity gradient $\overline{G}$. The aggregates formed by a low $\overline{G} << 50$ s^{-1} are macro-aggregates characterized by an anisotropic shape. The resultant aggregates formed by a higher $\overline{G}$ become micro-aggregates. The micro-aggregates are more spherical, granular and compact in their structure and of a greater uniformity in size and density than the macro-aggregates. This change in the character of aggregates clearly follows from the mechanism of particles joining into aggregates. The maximum attainable size of aggregates decreases with increasing $\overline{G}$, and the uniformity in size and compactness of aggregates increases with aggregation time *T*.

ii. *Inner structure*

During aggregation, the ratio of adhesive and tangential forces influences the arrangement of destabilized particles of impurities in the aggregates and thereby their compactness. The significance of the ratio of these forces on the structure of aggregates being formed can be described as follows: When the adhesive forces are incomparably greater than the tangential forces (low $\overline{G}$), the particles connect at the point of first contact. The resulting aggregates are large, voluminous and of anisotropic shape; they have a geometrically free, broadly branched, spatial mesh structure. Therefore, they are fragile, with a tendency to fragment. The resulting aggregates contain large volumes of voids filled with water.

In contrast, when the ratio of adhesive and tangential forces is low (high $\overline{G}$), the primary aggregates in the forming micro-aggregates slide close to one another until they occupy geometrically the most favourable and energetically the most stable position at which they best resist the influence of the applied agitation intensity. Any extension of the agitation time beyond that corresponding to the completion of aggregation does not improve the resultant compactness of aggregates simply because the primary aggregates in the micro-aggregates are already so close to one another that they cannot get any closer. The resultant micro-aggregates are spherical and very compact with a highly arranged inner structure and resistant to fragmentation. These aggregates have the smallest volumes of voids filled with water.

If the tangential forces are considerably greater than the adhesive forces, the formation of aggregates does not occur.

iii. *Porosity*

Similarity exists between the deposition of primary aggregates in the micro-aggregates and the sand grains in a filtration bed. Both are characterized by porosity. In the case of a filtration bed, the porosity changes according to deposition of the sand grains. In the case of flocculent aggregates, the porosity changes according to the velocity gradient $\overline{G}$ and time of its duration. Assuming the filter bed consists of spherical grains of the same diameter, Deb [22] described the dependence of the porosity of the filtration bed on the method of deposition as follows: the tangent planes of spherical grains at the point of their contact form a polyhedron. The most free storage of spheres exists when the polyhedron is a cube and the number of contacts is 6; in this case porosity is $\varepsilon_0 = 0.476$. The tightest deposition of these spheres exists when the tangent planes form a twelve-hedron and the number of contacts is 12; in this case porosity is $\varepsilon_0 = 0.2599$.

Furthermore, the micro-aggregates formed at high $\overline{G}$ and the completion of aggregation were observed to be spherical or close to it. Therefore, the Deb's model described above can be applied to the deposition of the destabilized particles in the primary aggregates and the primary aggregates in the micro-aggregates.

Compactness of the arrangement of the primary aggregates in the micro-aggregates, i.e. their porosity, changes depending on how close the primary particles are one to another in the micro-aggregates and this is influenced by the magnitude of $\overline{G}$. Since the porosity of micro-aggregates gradually decreases with an increasing $\overline{G}$ and *T* it can be concluded that the attainable porosity can be between $\varepsilon_{MI} = 0.48 - 0.26$ when the most compact micro-aggregates are formed by the IHDS process (Figure 2). Comparison of the porosity of these micro-aggregates with that attainable under the common low intensities of agitation $\varepsilon_{LA} = 0.80 - 0.93$ [23, 24] shows that a great potential exists for densification of aggregates formed by the IHDS method.

iv. *Density*

The aggregation produces aggregates of a lower density than that of the particles of impurities from

which they are formed. While the density of aggregates is low in comparison to that of water, the aggregates are multifold larger than the particles of impurities. Obviously, the density of aggregates is dependent on the relative content of suspended solids in their structure.

Explanation of the significance of agitation conditions on the inner structure of aggregates and consequently their density is evident from the mechanisms of their formation which is dependent on the ratio of adhesion and tangential forces. As described in the foregoing the aggregates formed at low $\overline{G}$ are anisotropic and contain large volumes of water in their voids. Therefore, their porosity is great and hence their density is low. The aggregates formed at high $\overline{G}$ are micro-aggregates that are nearly spherical and very compact. Therefore, they are of low porosity and of great density [14, 15].

c) Two Size Fractions of Particles of Impurities

For the purpose of this article it is necessary to emphasize that the particles of impurities consist of two fractions, separable and non-separable particles. The total content of all particles remaining in the purified water determines the overall quality to which water is purified, while the content of the non-separable particles indicates the best attainable quality limit to which the water can be purified by the technology used, with respect to the particular impurities concerned. Concentration of the non-separable particles is measured in a sample of water after all separable particles are removed by centrifugation taking place under specific conditions [8, 10].

d) Degree of Aggregation

The formation of aggregates in different waterworks takes place under different hydrodynamic conditions and usually ends before the aggregation is completed. Therefore, to assess the state of aggregation achieved before the polymer addition a criterion called the Degree of Aggregation γ was developed [1]. It is expressed with sufficient accuracy by the ratio of aggregation achieved at the point of polymer addition, characterized by $\overline{G}\ T_A$ and $\overline{G}\ T_{CA}$ at which aggregation is completed. The $\overline{G}\ T_{CA}$ value is aggregation agent dependent.

The Degree of Aggregation γ is calculated as follows:

$$\gamma = \frac{\overline{G}\ T_A}{\overline{G}\ T_{CA}} \quad (1)$$

were

γ - Degree of aggregation (-),

$\overline{G}$ - Mean square root velocity gradient used throughout aggregation (s^{-1}),

T_{CA} - Time at which aggregation is completed (s),

T_A - Actual aggregation time - time of aggregation before polymer is applied (s).

The degree of aggregation γ permits quantification of the level of aggregation achieved at the time of polymer addition in comparison to completion of aggregation. If $\gamma = 1$ the aggregating system operates under optimized conditions and the best attainable quality of purified water attainable with the coagulant used, is produced. If $\gamma < 1$ the system is under-aggregated; this adversely affects the purified water quality. If $\gamma > 1$ the system is over-aggregated; the purified water quality is not adversely affected but the plant operates uneconomically at a higher power consumption.

III. Classification of Water-Soluble Polymers

The water-soluble polymers can be classified according to their origin, chemical characteristics and applicability as shown in Table 1 [25]. All the polymers used in the purification of water for domestic supply are restricted to a non-toxic quality.

Table 1: Classification of Polymers used in Water Purification

<table>
<tr><th colspan="2">ORIGIN</th><th colspan="2">CHEMICAL CHARACTERISTIC</th><th colspan="2">APPLICATION</th></tr>
<tr><td>CHEMICALLY TREATED</td><td rowspan="2">NATURAL POLYMER</td><td rowspan="3">POLYELECTROLYTE</td><td>CATIONIC</td><td>ORGANIC COAGULANT (OC)</td><td rowspan="4">ORGANIC FILTRATION AID (OFiA)</td></tr>
<tr><td>CHEMICALLY UNTREATED</td><td>ANIONIC</td><td rowspan="3">ORGANIG AGGLOMERATION AGENT (OAA)</td></tr>
<tr><td colspan="2" rowspan="2">SYNTHETIC POLYMERS</td><td>MIXED</td></tr>
<tr><td>NONELECTROLYTE</td><td>NON-IONIC</td></tr>
</table>

IV. Materials and Methods

a) Raw Water

The raw water from three different surface sources was used to verify validity of the results obtained. The raw water quality from these water sources is shown in Table 2.

Table 2: The Average Quality of Different Raw Waters used in this Study

DETERMINANT	UNITS	LOCH ATHLONE DAM	SAULS.POORT DAM	VAAL DAM
Temperature	^{O}C	12 - 25	12 – 25	10 - 26
pH	-	7.7	7.4 – 8.2	6.9 – 8.5
Turbidity	NTU	50 - 690	30 - 250	80 - 225
Color	mg Pt. L^{-1}	5 – 15	10 - 40	15 - 25
Total Hardness	mg $CaCO_3$. L^{-1}	108	90 - 160	37 - 105
Total alkalinity	mg $CaCO_3$. L^{-1}	75	75 – 140	42 – 110
COD_{Mn}	mg O_2. L^{-1}	3.4	6.5	4.0
THM – potential value	μg $CHCl_3$.L^{-1}	-	878	-

The performance results achieved by the HRCT purifying water from these three sources were very similar and differed only in their absolute values.

b) Aggregation Agents

The aggregation agents, namely hydrolyzing coagulants such as Fe^{3+} and Al^{3+} salts, and the organic coagulants (cationic polymers) of trade name Floccotan and Superfloc SF-577], were used. Floccotan is a partially condensed product of a commercial wattle tannin extract and treated to produce active amine groups along the polymerized molecule [26]. Superfloc SF-577 is a polyquarternary amine type [27]. Each hydrolyzing coagulant was applied at a dosing rate corresponding to its optimised reaction conditions [3] to remove its cation and water turbidity.

Since the character of the results concerning formation of micro-aggregates, obtained with aggregation agents of both types is very similar, only the results obtained with ferric chloride and Floccotan are presented.

c) Anionic and Non-Ionic Polymers

The anionic and non-ionic polymers are hydrophilic colloids. In water purification, they are used for their dominant adhesive properties. Therefore, the conditions of their optimal application resulting in the formation of large, rapidly settling agglomerates are investigated in this article. The optimal application of these polymers is intended to facilitate the greatest attainable acceleration of the kinetics of sedimentation of formed agglomerates and thereby to reduce the sizes of technological plants and the capital cost of waterworks.

These polymers are of a molecular weight up to 50 million made up of repeating units of a small molecular weight. Each of these repeating units carries one or more ionised groups distributed along the fibrous molecule. A single molecule can be imagined as a longitudinally stretched fiber with a ratio of width to length ranging up to 1:1,000 (the width varies between 0.0003 – 0.0007 µm and the length between 0.4 – 0.8 µm) [28].

The fibrous molecules of these polymers are sensitive to mechanical action and can easily be broken during dissolution, if not handled with care. Therefore, the intensity of mixing applied during polymer dissolving together with the efficiency of dispersal mixing of the dosed polymer solution to achieve its homogenisation with the aggregated water is of significance, as they can considerably affect the agglomeration efficiency of the polymers. These conditions are also dealt with as one of the topics of this article.

Different polyacrylamides available on market under the trade names of Superfloc, Magnafloc, Ultrafloc, BTI, and LTA, were tested. The method of their application is considered correct when the residual turbidity of the purified water produced by the separable and non-separable particles do not exceed the value obtained by the blind test after 60 min sedimentation. Since the character of results obtained with these polymers was practically the same, only the results obtained with the most efficient Superflocs are presented.

The Superflocs provided by Cyanamid Co. of USA (Table 3) were tested, because the branch office supporting service was on the highest professional level. The Superflocs were supplied as powders, emulsions, or solid blocks. Those supplied as emulsions were found to have a very low agglomeration efficiency; therefore, the results obtained are not presented. Those provided in solid blocks are dosed by way of submergence into the stream of water being purified, thus allowing the gradual dissolution of polymer without any meaningful control of its dosage rate. Therefore, only the results obtained with those supplied as powders are presented in this article.

Dissolution of these polymers is a very slow process. It is facilitated by slowly and carefully pouring the polymer powder into the gently agitated electrolyte to prevent the formation of lump clusters, which are difficult to dissolve. Dissolution begins with swelling of macro-molecules. This includes penetration of water molecules into the space between the single layers of polymer, resulting in the formation of a gel-like mass. The single layers expand and disengage. This process is facilitated by mixing at a suitable intensity, preventing breakage of the polymer chains. Mixing should continue until the solution is homogenous and free of "fish eyes". Non-homogenous solutions containing “fish eyes” have a much lower agglomeration efficiency.

Table 3: General Information about the Superflocs Tested [29]

Polymer (OAA)	Type	Form	Molecular weight at pH of typical 0,5% solution at 25 °C		Contains in %		Recommended dosage
			molecular weight	pH	amide group	carboxyl group	[mg.L^{-1}]
SF 900	N	Powder	-	-	-	-	0,05 – 1,0
SF 901	N	Powder	-	-	-	-	0,05 – 1,0
SF 902	N	Powder	-	-	-	-	0,05 – 1,0
SF-905s	N	Powder	1,5 x 10^6	5,0	99	1	0,05 – 1,0
SF 210	A	Powder	-	-	-	-	0,05 – 1,0
SF 212	A	Powder	-	-	-	-	0,05 – 1,0
SF A-110	A	Powder	1,0 – 1,2 x 10^6	-	83	17	0,05 – 1,0
SF A-130	A	Powder	1,0 – 1,2 x 10^6	-	68	32	0,05 – 1,0
SF A-150	A	Powder	-	-	-	-	0,05 – 1,0

d) Jar Tests

Jar tests were carried out under the conditions of the IHDS process at G > 50 s^{-1} until the completion of aggregation $\gamma = 1$ (Figure 2).

Two different flocculators were used:

a) Standard Phipp & Bird 6-station flocculator 225, maximum speed 100 RPM, complete with a fully adjustable, variable speed controller common to all 6-stations and a revolution counter,
b) Standard CPI 4-station flocculator, maximum speed 160 RPM, complete with fully adjustable variable speed controller for each station.

The Phipp & Bird flocculator was used in most of the jar tests. The CPI flocculator was only used when the verification of conclusions at a higher stirrer speed was required.

All jar tests used 2-liter standard Pyrex beakers with a 1.5 litre volume of raw water. The stirrer is a double paddle type with a spinning diameter d = 62 mm and a height h = 58 mm.

The effect of the polymers on the quality of purified water was evaluated by residual turbidity produced by both separable and non-separable particles and compared with the blind test. Turbidity produced by both separable and non-separable particles was measured by a Hach 2100A turbidity meter. A Labofuge-1 laboratory centrifuge was used to remove the separable particles from tested samples to determine the content of the non-separable particles in these samples [8-10].

The completion of aggregation of different aggregation agents and the raw waters tested are determined in [1, 13-15].

Depending on the type of test, the jar tests were carried out by one of two modes:

Mode 1: The anionic and non-ionic polymers were applied as an aggregation aid to establish whether or not they functioned as an aggregation aid. The jar tests were carried out as follows: Two sets of six beakers, reaction and service, sited next to one another, were used. The reaction beakers received the same optimised dosage of the same aggregation agent at the same time whereas the polymer solution was dosed into five beakers at different γ = 0.0, 0.25, 0.50, 0.75 and 1.0; the sixth beaker was a blind test. Each reaction beaker was placed into the flocculator and the stirrer was then inserted into each beaker. The set of service beakers, filled with 1.5 litre of raw water is placed next to the reaction beakers. Water from the service beakers was quickly poured into the reaction beakers to disperse and homogenize the aggregation agent throughout the

raw water. The flocculator was switched-on, stirrer speed set up to the maximum RPM and the position of individual beakers adjusted to produce the smallest vortex characterized by the smoothest water surface in each beaker. These operations were completed within a few seconds. The stirrer speed either remained the same or was reduced to the RPM generating the required $\overline{G}$. As mentioned in the foregoing, aggregation took place at a high agitation intensity of $\overline{G} \geq 50$ s^{-1} over the entire aggregation. The aggregation time was measured from the moment the raw water was poured into the reaction beakers with the polymer dosage applied into the first beaker, $\gamma = 0$. As soon as the aggregation time corresponding to $\gamma = 0.25$, 0.50 and 0.75, the polymer solution was added to the second, third and fourth beaker respectively. As soon as the aggregation reached its completion, $\gamma = 1$, the polymer solution was dosed to the fifth beaker; the flocculator continued to operate at the same speed for another 20 seconds to facilitate homogenization of the polymer solution throughout the aggregated water. After this time the flocculator speed was reduced to an agitation intensity of $\overline{G} = 10$ s^{-1} (27 RPM). Agitation continued at this low intensity for 4 minutes to enable agglomerates to fully develop. The flocculator was then switched-off, stirrers were removed immediately from all beakers, and the measurement of sedimentation time began. The samples of purified water were taken after 1, 3, 5, 10 and 30 minute sedimentation and sample from the blind test also after 60 minutes sedimentation. The samples of water were taken with a pipet from a depth of 30 mm below the water surface; this was usually completed within 15 seconds.

Mode 2: The anionic and non-ionic polymers were applied as an agglomeration agent. The jar tests were performed as described in Mode 1 with the following difference. When aggregation was completed, $\gamma = 1$, the predetermined dosages of polymer solution were dosed into five reaction beakers (the sixth one was BT). The flocculator continued to operate for a predetermined time, usually 20 seconds, to complete the dispersion and homogenization of the polymer solution with the aggregated water. The agitation was then reduced to a low intensity of $\overline{G} = 10$ s^{-1} (27 RPM) to enable the full development of agglomerates.

The polymer's interaction with progressing aggregation and its influence on the purified water quality and the kinetics of sedimentation of formed agglomerates was evaluated by comparing the changes in the total residual turbidity and turbidity produced by the non-separable particles only, with those measured in the blind test after 60 min sedimentation.

e) Velocity Gradient

The mean square root velocity gradient $\overline{G}$ was calculated from the power input transmitted by the stirrer into the water. The power input was measured by torque for different stirrer RPM. The velocity gradient $\overline{G}$ was calculated from the averaged values of the torques measured at specific RPM [14]. The conversion of stirrer RPM to velocity gradient $\overline{G}$ is in Figure 3.

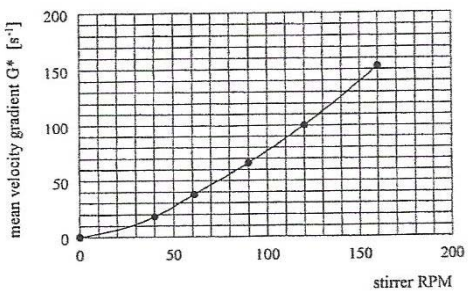


Figure 3: Preparation of Anionic and Non-Ionic Polymer Solutions and Homogenization of Dosed Solutions with Aggregated Water

The polymers were dissolved in electrolytes prepared from distilled water, and their pH was adjusted over a wide range using NaOH or HCl. The viscosity of the polymer solutions and pH were measured by an Engler type viscosity meter and a pH meter available at the laboratory used.

Most of the polymer solutions used in the tests were prepared at a concentration $C = 150$ $mg.L^{-1}$ in a 0.025 N NaOH electrolyte and matured for at least 24 hours, if not stated otherwise.

A magnetic mixer under a gentle mixing was used for polymer dissolution. The mixing intensity was adjusted to prevent breakage of polymer chains. The mixing continued until the solution was clear and free of "fish eyes", if this was attainable.

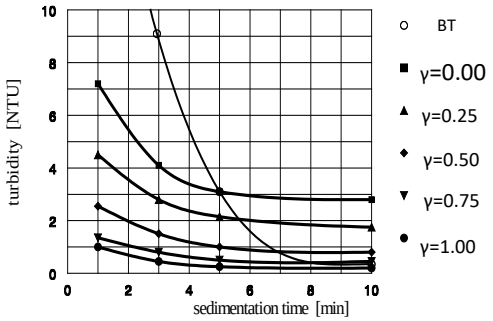
Since the characteristics of the dispersal mixing in beakers and clarifiers are very different, only the effect of its duration at the maximum 100 RPM on the agglomeration capability and efficiency, was investigated by jar tests.

V. Results and Discussion

a) *Influence of the Achieved Degree of Aggregation Γ on the Quality of Purified Water and the Kinetics of Sedimentation of Agglomerates Formed*

The effect of the anionic polymer applied as aggregation aid and agglomeration agent on the kinetics of sedimentation of formed suspensions and the quality of purified water is shown in Figure 4. Both, the settleability of suspension, and the residual turbidity, improve with increasing γ–value at which the polymer is applied. The fastest settling velocity and the lowest residual turbidity are achieved when the polymer is applied at the aggregation optimum, $\gamma = 1$. This means that these polymers function as agglomeration agents and not as aggregation aids. The residual turbidity of the settled water did not improve after 10 min. sedimentation.

The individual turbidity readings at 1 min sedimentation shows vast differences in comparison to the blind test (BT). The greatest difference, more than 25-fold, was measured between the readings corresponding to BT and the polymer applied at $\gamma = 1$. This difference indicates the great potential of polymers for accelerating the sedimentation process.



($FeCl_3$, $\overline{G}$ = 78 s^{-1}, SF-A110, D_{OAA} = 0.10 $mg.L^{-1}$)

Figure 4: Significance of the γ-value reached prior to polymer addition on the kinetics of sedimentation of formed agglomerates and residual turbidity of the purified settled water

A similar situation exists regarding the settled water turbidity. The readings after 10 min. sedimentation showed that the lowest residual turbidity produced was achieved by BT, which equals to $\gamma = 1$. It follows from Figure 4 that the higher the γ-value at which the polymer is dosed the faster the settling agglomerates are formed, producing the lowest residual turbidity of the settled water. Differences in the residual turbidity readings taken at different γ-values between 1 and 10 minute sedimentation compare as follows:

Degree of aggregation γ	(-)	0	0.25	0.50	0.75	1.0
Differences in turbidity between 1 and 10 min. sedimentation	(NTU)	4.4	2.75	1.75	0.9	0.8

The significance of γ-values at which the polymer is introduced into the aggregating water is also evident by comparing the differences in residual turbidity of the settled water measured after 10 min sedimentation with that of BT (Figure 4). These differences are the result of the polymer's adverse influence on aggregation efficiency. The differences read as follows:

Degree of aggregation γ	(-)	0	0.25	0.50	0.75	1.0
Differences in total turbidity at 10 min. sedimentation in comparison to the blind test	(NTU)	2.6	1.4	0.6	0.2	0.0

The turbidity produced only by the residual non-separable particles follows the same pattern of separable particles (Figure 5). The highest residual turbidity produced by all particles and the non-separable particles remaining in the purified water exist when the polymer is applied as coagulation aid, $\gamma = 0$. The lowest residual turbidity is produced when the aggregation is completed, $\gamma = 1$, before the polymer addition. This means, the aggregation efficiency and the residual turbidity of purified water produced by both types of particles are not detrimentally affected only when the polymer is applied as an agglomeration agent. Hence, the current method for using these polymers as aggregation aids is unsuitable as it detrimentally affects the purified water quality.

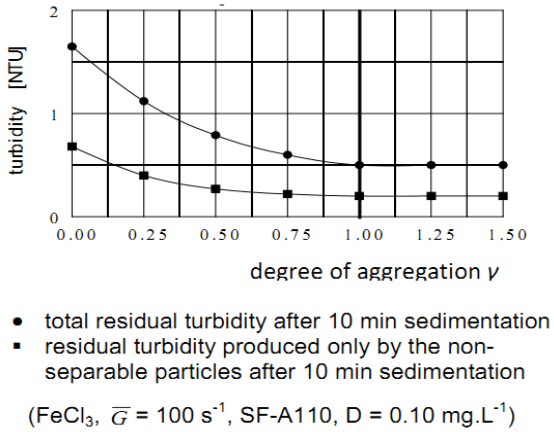


Figure 5: Influence of the γ-value on Residual Turbidity of the Purified Water and Produced by the Separable and non-Separable Particles

The reasons for the poorer quality of the purified water when an anionic, or non-ionic polymer is applied as aggregation aid, $\gamma < 1$, can be explained by:

a. Interference of the polymers with the destabilization of the particles of impurities that leaves a greater quantity of the non-destabilized, non-separable particles in the purified water,
b. Re-stabilization caused by the polymers of some of the particles of impurities already destabilized but not yet aggregated.

b) Influence of the degree of aggregation γ and polymer dosage on the quality of purified water

Jar tests were also carried out to establish the effect of different polymer dosages on the quality of purified water. The typical pattern of total residual turbidity of the purified water is illustrated in Figure 6. Again, it transpires from this Figure that the lower the γ-values at which the polymer is applied and the higher the polymer dosage is applied, the poorer the purified water quality becomes. With increasing γ-value, irrespective of the polymer dosing rate, the quality of purified water becomes better, and the differences disappear at $\gamma = 1$.

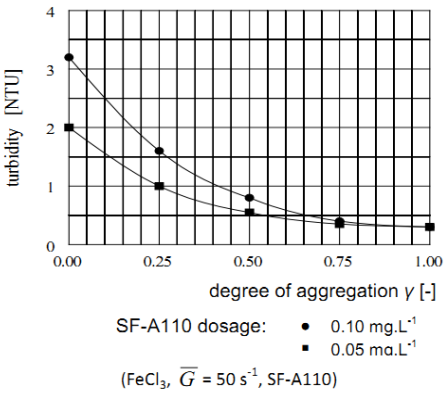


Figure 6: Influence of polymer dosages and γ-values reached prior to polymer addition on total turbidity of the purified water after 10 min. sedimentation

c) Post-Orthokinetic Agglomeration

It is evident from Figures 4 to 6, the anionic and non-ionic polymer, when applied as an aggregation aid, reduces the aggregation capability of the aggregation agent. This detrimental effect is the greatest when the polymer is applied together or shortly after the aggregation agent and decreases as aggregation progresses before polymer addition.

Figures 4 to 6 also show that the best-purified water quality is always produced when the anionic and non-ionic polymers are applied at $\gamma = 1$. This proves that these polymers function as an agglomeration agent (OAA) and not as an aggregation aid as commonly practiced. Therefore, the best results are achieved when aggregation is already completed, $\gamma = 1$, prior to

polymer addition. This method is called the Post-Orthokinetic Agglomeration (POA) process [1].

It was observed that the POA also improves the strength and resistance to fragmentation of the agglomerates formed.

d) Effect of OAA dosage on the sedimentation kinetics of agglomerates

The effect of different OAA dosing rates on the sedimentation kinetics of agglomerates is illustrated in Figure 7.

Figure 7a shows how the POA process increases the size of the agglomerates and their sedimentation velocity with an increasing OAA dosing rate. The OAA dosing rate D_{OAA} varied between 0.01 and 0.1 mg.L^{-1}. At a dosage $D_{OAA} \geq 0.03$ mg.L^{-1} the agglomerates were already so large that they began to settle during the agglomeration agitation; the higher the OAA dosage the larger and the more rapidly settling agglomerates were formed. It follows from this Figure that the dosing rate of OAA determines the sedimentation velocity of the agglomerates formed.

Figure 7: The effect of OAA dosing rate on settleability of agglomerates from right to left: NIL, 0.01; 0.03; 0.05; 0.07; 0.10 mg.L-1 (TuRW = 140 NTU, γ ≈1, = 78 s-1, aggregation agent: Floccotan, OAA: SF-A130)

(a) Development of agglomerates during the POA process,
(b) Sedimentation kinetic immediately after removal of stirrers,
(c) The character of sediments produced

Figure 7b shows the effect of different OAA dosages on settleability of agglomerates immediately after the flocculator was switched-off and the stirrers removed from the beakers.

Figure 7c shows the effect of different OAA dosages on the character of sludge produced; the consistency of sludge increases with increasing OAA dosage.

e) Significance of Electrolyte Ph on the Agglomeration Capability of OAA

Different OAA were dissolved in electrolytes of different pH to investigate the effect of pH on their agglomeration capability.

Anionic and non-ionic polymers were dissolved over a wide pH range in alkaline and acidic electrolytes. The effect of the different electrolyte pH values on the dissolution of these polymers at a concentration C = 150 mg.L^{-1} was investigated by comparing pH values measured in both the electrolyte and the solution.

pH of electrolyte	2,8	4,8	9,0	11,0	12,4
pH of SF-905s solution	3,0	6,3	7,5	8,2	11,8

The difference between the two readings corresponds to the absorption of single ions from the electrolyte into the polymer macroions. In other words, these differences show the extent to which the electrolyte becomes a donor to the charged groups of the counter ions. This absorption contributes to development of a rodlike configuration of the polyvalent macroions, i.e. the enhancement of the agglomeration potential of OAA.

Similar results were also obtained with the anionic polymers.

f) Effect of the Electrolyte pH on the OAA Solution

During the dissolution of different OAA it was found that their solubility was to a great extent dependent on the electrolyte pH and the brand of OAA (anionic or non-ionic).

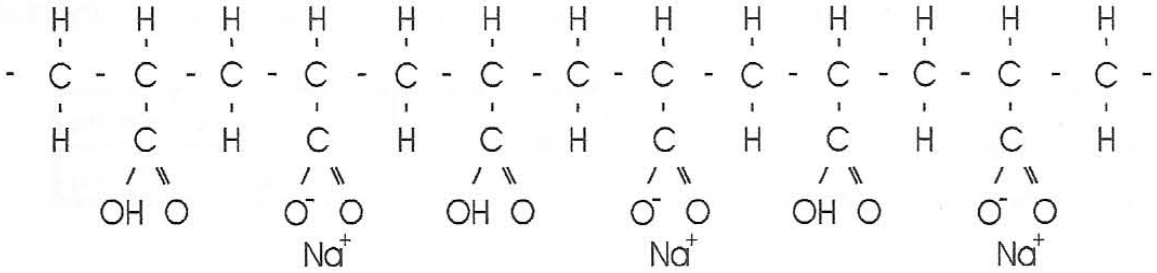
Solubility of the anionic polymers increased with an increasing alkaline pH over the full range of pH tested. It was observed that a homogeneous solution free of "fish eyes" was only obtained at a pH > 10; the solution is not homogeneous in the range of pH = 7 to 10. "Fish eye" clusters could not dissolve even after prolonged mixing. The quantity of "fish eye" clusters decreased as the pH increased, and only at a pH > 10 they completely disappeared. For example, the dissolution of SF-A110 at a concentration of C = 150 $mg.L^{-1}$ in a 0.025 N NaOH electrolyte (pH ≈ 11) to a homogeneous solution free of "fish eyes" was completed in about 4 hours. In an acidic range between a pH = 7 to 4, solubility is so low that the anionic polymers could not dissolve into a homogeneous solution not even during 10 hours dissolving.

Generally, the time required for dissolution of any OAA increases with increasing solution concentration.

All polymers must be dissolved to a clear and homogeneous solution to prevent reduction in their agglomeration capability. For this reason the clarity of electrolyte is very important. The water used for the electrolyte must be soft, or softened to prevent the formation of a precipitate after its alkalization before polymer dissolution. In the event of a precipitate being formed, the agglomeration capability of the polymer solution is considerably reduced.

g) Effect of the Electrolyte pH on the Chemical Structure of OAA

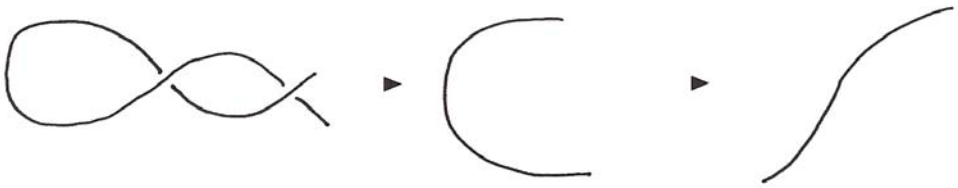
During dissolution the OAA produces either non-ionised molecules or clusters of molecules, or dissociates into polyvalent macroions, polyions, and a great number of single ions of opposite charge, the counter ions. The counter ions of the same charge distributed along the macroion repel each other and this results in the stretching of the fibrous molecule. The macro-molecules in their elongated, rodlike configuration have the greatest agglomeration efficiency while the coil-like macro-molecules have the lowest efficiency. The degree of dissociation, and the stretching of the macro-molecules, is influenced by the electrolyte pH and the concentration of the OAA solution.



The effect of the electrolyte pH on the chemical structure of the macromolecule of polyacrylic acid is explained by Oosawa [28] as follows. With polyacrylic acid the degree of dissociation of the carboxyl group is small in pure water. By adding an alkali (NaOH) the number of negative charges producing Na^+ counter ions increases. The quantity of the added alkali is reflected in the pH value of the solution. Likewise, the chemical structure of the macroions in the solution may be expressed as a copolymer of monomers having $COOH^-$ and COO^- groups. At a given pH value and concentration of macroions, the pH value indicates the average proportion of these groups because the solution is a mixture of macroions that have noticeable distributions of two thermally fluctuating groups. When alkali is added on an equimolar basis to the acidic groups, the sodium polyacrylate macroions in the resulting solution are almost entirely dissociated.

The strong charge of the macroions produces a strong electric field, which attracts the counter ions. The charged macroions can assume various random coil configurations over a wide range of extensions, which are dependent on the charge of the environment. In an environment they may take on a rodlike or cylindrical configuration. At low charge densities or in the absence of a charge, the coil configuration can take on a coil-like or spherical configuration. The spherical random coil can have a wide range of apparent radii. For example,

the polyacrylic acid whose degree of polymerization is 1000, takes on a spherical random coil form with a radius of about 200 Ä at a low pH. With an increasing pH the macroion extends first spherically and then becomes rodlike, and its resultant length is 2500 Ä in its most elongated form. The average local curvature of the chain decreases gradually, as shown below:



h) Effect of the Electrolyte pH on the Viscosity of OAA Solutions

The anionic SF-A110 and non-ionic SF-905s were dissolved at a concentration $C = 150$ mg.L^{-1} in electrolytes of pH varying between 3 and 12. The viscosities of these solutions are plotted in Figure 8.

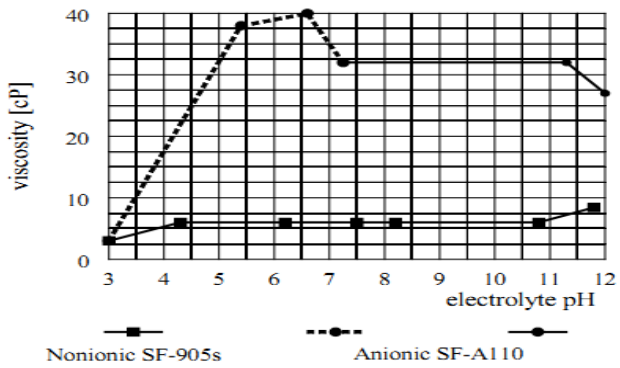


Figure 8: The effect of electrolyte pH on the OAA solution viscosity

The anionic SF-A110 could not be dissolved in the acidic pH range and, therefore, its viscosity is shown by a dashed line. In the alkaline pH range, the viscosity remained stable up to a pH around 11 and decreased slightly at a pH > 11.3. In contrast to that, the viscosity of the non-ionic SF-905s solution remained very steady between pH = 4.3 and 10.8. At a pH > 11 it increased slightly, and at a pH < 4.3 it decreased slightly. The viscosity measurements were repeated several times. The measured viscosities varied slightly in the absolute values, however the pattern remained the same.

i) The Effect of pH of OAA Solutions on their Agglomeration Potential

The influence of the solution pH value for enhancing agglomeration capability of both anionic and non-ionic OAA is evident from the comparison of the sedimentation kinetics in Figures 9 and 10. Figure 9 illustrates the effect of the solution pH of anionic SA-A110, and Figure 10 of the non-ionic SF-905s. The lowest agglomeration capability of the anionic OAA, characterized by the highest residual turbidity (the lowest sedimentation velocity), is reached at pH = 3.2 (Figure 9). At this low pH the configuration of polymer molecules corresponds to their most coil-like spherical configuration. The agglomeration capability gradually improves over the full range of pH tested. The highest agglomeration capability exists at the lowest turbidity (the highest sedimentation velocity) and the highest pH = 12. At this high pH the configuration of polymer molecules corresponds to its most stretched rod-like configuration.

The lowest agglomeration capability of the non-ionic OAA, characterized by the highest residual turbidity (the lowest sedimentation velocity), is reached at around neutral pH = 7 (Figure 10). At this pH the configuration of polymer molecules corresponds to their most coil-like spherical configuration. The agglomeration capability gradually improves in both directions up to the highest pH = 11.5 and the lowest pH = 3.0. The polymer molecules configuration corresponds of to their most stretched rod-like configuration at the highest and lowest pH values.

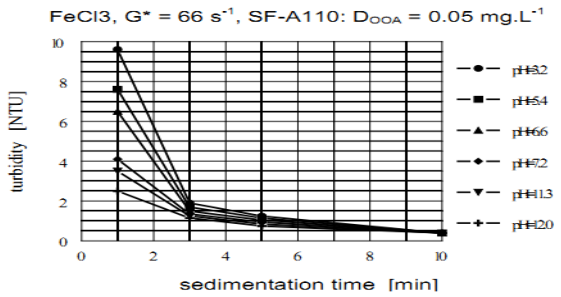


Figure 9: The effect of pH of the anionic OAA solution on the sedimentation kinetics of agglomerates

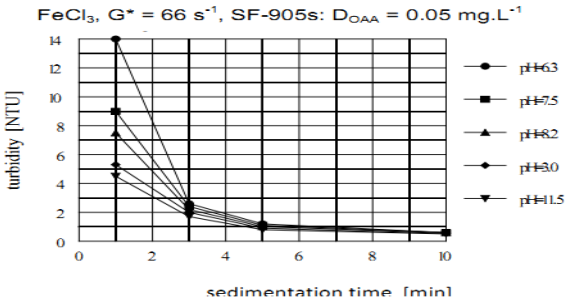


Figure 10: The effect of pH of the non-ionic OAA solution on the sedimentation kinetics of agglomerates

j) Effect of the Concentration of OAA Stock Solution on the Sedimentation Kinetics

The concentration of the polymer stock solution is also an important factor influencing the agglomeration capability of OAA. The effect of the concentration of OAA stock solution on its agglomeration capability was investigated with the concentrations of 150 mg. L^{-1} and 1500 mg.L^{-1}; the stock solution matured for 24 hours. The results obtained with SF-A110 are shown in Figure 11 and can be considered typical for any OAA. These results show that agglomeration capability decreases with increasing concentration of stock solution.

Figure 11 also shows how the inline dilution of the concentrated stock solution is very ineffective. This can be explained as follows: Inline dilution of the concentrated stock solution cannot produce a homogenous solution within the short time available during inline dilution. The diluted solution contains droplets of the concentrated stock solution and the dilution water. Such diluted solution tends to retain the agglomeration efficiency close to the concentration of stock solution. To achieve the same agglomeration efficiency as that attainable with the stock solution of low concentration, a greater OAA dosage is required.

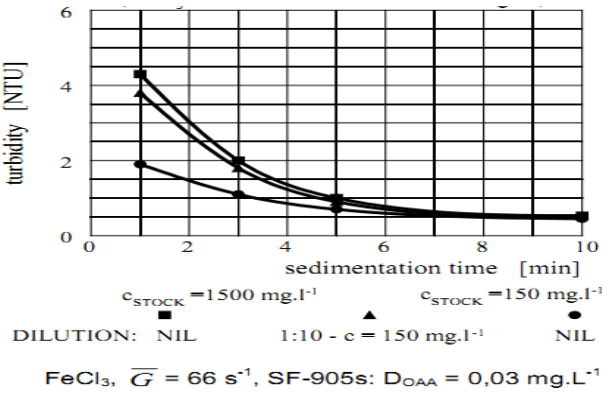
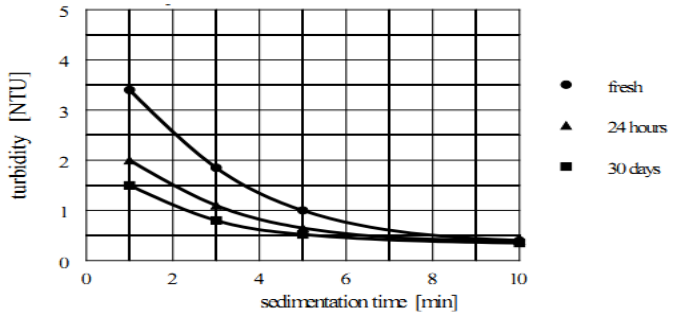


Figure 11: The effect of inline dilution of the OAA solution on the kinetics of sedimentation of agglomerates

The use of a high concentration stock solution is very inefficient and uneconomical and, therefore, cannot be recommended. As evident from the above, the stock solution should be prepared at a concentration at which it will be applied to the purification process, preferably not exceeding 1.0 g.L^{-1}.

k) Effect of the Maturation Time of OAA Solution

The effect of maturation (aging) time of OAA solution is yet another factor that was investigated to discover whether it had any effect on the agglomeration efficiency. In this regard, similar results were obtained with both the anionic and non-ionic OAA. The results plotted in Figure 12 were obtained with three SF-A130 solutions of the same concentration but of three different maturation times; one is freshly prepared, the other is 24 hours old and the last one is 30 days old.



$FeCl_3$, $\overline{G}$ = 66 s^{-1}, SF-A130: D_{OAA} = 0.03 $mg.L^{-1}$

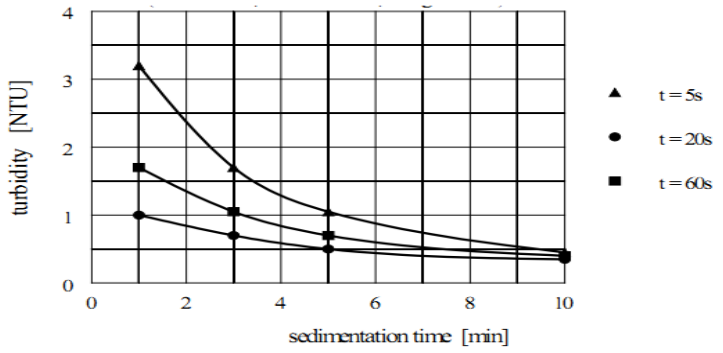
Figure 12: The effect of maturation time of the OAA solution on the sedimentation kinetics of agglomerates formed

The settling curves in Figure 12 show the fresh solution applied immediately after its preparation has the lowest agglomeration efficiency. A significant improvement is achieved when the solution matures for 24 hours before its usage. At a maturation longer than 24 hours the rate of efficiency increase slows down. Therefore, it is advisable to mature OAA solution preferably for 24 hours before its usage. In the event this is not possible then the solution should mature at least for 12 hours before its usage.

Furthermore, it was found that the viscosity of solutions slightly increased with maturation time.

l) Significance of Homogenization of the OAA Solution with the Aggregated Water

Yet another factor affecting the agglomeration efficiency is the speed of the dispersal mixing required to achieve homogenization of the dosed OAA solution with the aggregated water. Such dispersion should be completed as fast as possible to ensure that all aggregates are individually exposed to OAA to achieve the highest agglomeration efficiency.



$\overline{G}$ = 78 s^{-1}, $FeCl_3$, SF-A130, D_{OAA} = 0,05 $mg.L^{-1}$

Figure 13: The effect of dispersion mixing time of the OAA solution on sedimentation kinetics of agglomerates

The typical effect of different times of dispersal mixing on the agglomeration efficiency is shown in Figure 13. It follows from this Figure, the sedimentation kinetics of the formed agglomerates improves until the homogenization of OAA solution with the aggregated water is completed. It also shows that the optimum dispersal mixing time peaked at about 20 s as the most rapidly settling agglomerates were formed. Furthermore, it follows from Figure 13 the dispersal mixing lasting longer than the optimum time is less harmful to the efficiency of the POA process than is a shorter time at which homogenization is not yet completed.

It was also established, although the results are not shown, that the time required to complete homogenization depends not only on the intensity of dispersal mixing but also on the concentration of the dosed solution. A longer time is needed for the solution of higher concentration.

m) Comparison of the Agglomeration Efficiency of Different Kinds of OAA

The agglomeration capability of different anionic and non-ionic OAA is compared in Figures 14 and 15.

Figure 14 compares the sedimentation kinetics of different anionic OAA and Figure 15 different non-ionic OAA. The dosage of all OAA was the same, D = 0.03 $mg.L^{-1}$. The most efficient anionic OAA are SF-A110 and SF-A130 and non-ionic OAA is SF-905s, all provided by Cyanamid Co. of USA. The LT-26 provided by the Allied Colloids of UK was found to equal the Superflocs

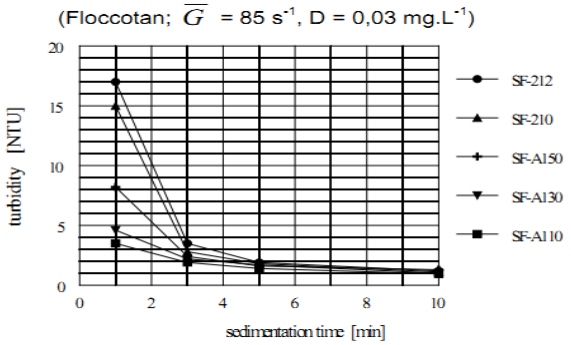


Figure 14: Comparison of sedimentation kinetics of different anionic OAA

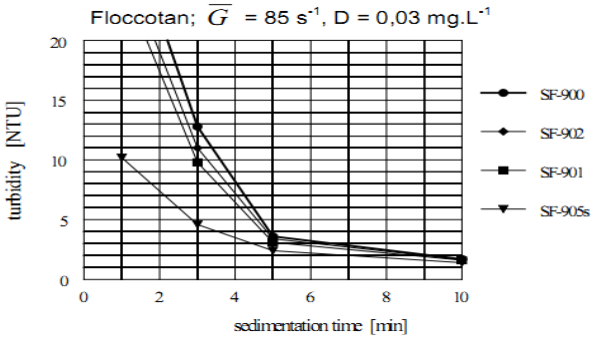


Figure 15: Comparison of sedimentation kinetics of different non-ionic OAA

n) High Rate Clarification Technology

Innovations emanating from this project resulted in the development of the High Rate Clarification Technology (HRCT) (Figure 16).

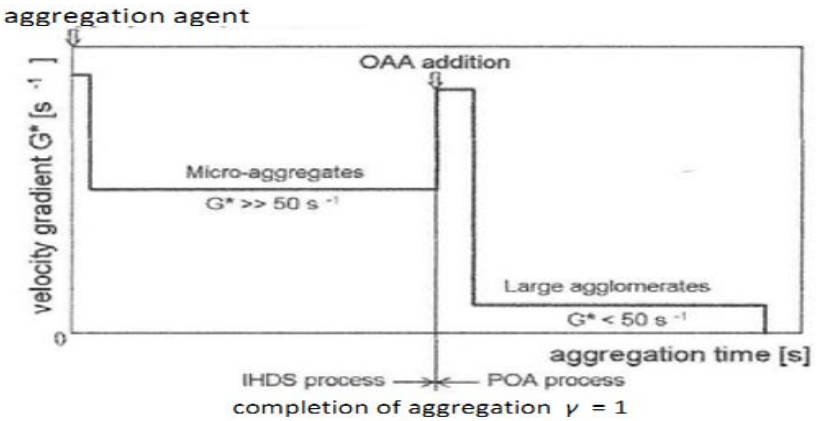


Figure 16: Formation of agglomerates by High Rate Clarification Technology incorporating the IHDS and POA processes (G* =)

The HRCT combines two processes developed for this purpose, namely:

(a) The Inline High Density Suspension formation process producing dense micro-aggregates,
(b) The Post-Orthokinetic Agglomeration process agglomerating these micro-aggregates to large rapidly settling agglomerates by means of OAA.

The feasibility of all these innovations was verified under long operation of the pilot HR clarifiers and subsequently under the operation of a large capacity plant. The results achieved are presented in the following Chapter.

VI. Design, Operation and Performance Results of High Rate Clarifiers

a) High Rate Clarifiers

Two types of clarifiers, the High Rate clarifiers incorporating the principles of the HRCT, were developed, namely:

(a) HR clarifier (Figure 17) is a vertical flow type fully fluidized sludge blanket clarifier; this clarifier is particularly suitable for continuous operation under both a steady flowrate, and a relatively slow and gradual fluctuation of the raw water quality,
(b) P-Clarifier (Figure 18) is a radial flow type clarifier with the removal of settled sludge by hydraulic means; this clarifier is suitable for intermittent operation; the formation of micro-aggregates is carried out to completion in a Flocculator installed next to the P-Clarifier.

Three types of suspension can be handled by the High Rate Clarifiers, namely:

(a) the conventionally formed flocculent suspension,
(b) the micro-aggregates formed by aggregation under the IHDS process,
(c) solid particles up to the finest size contained in the surface water and underground mine water.

i. *HR Clarifier*

The best hydraulically balanced clarifier, the CSAV type [30], incorporating flocculation, a fully fluidized sludge blanket, clarified water and sludge thickening compartments, was converted to the HR Clarifier (Figure 17).

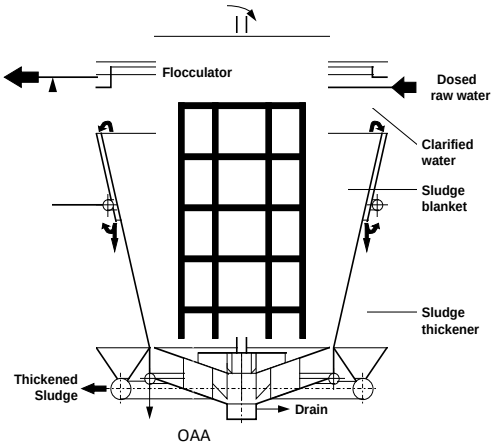


Figure 17: The HR Clarifier

From a process point of view, this conversion includes:

a) Uprating of the aggregation process from taking place under conventional low intensity agitation to the IHDS process taking place at high intensity agitation and completing aggregation ($\gamma = 1$) within the Flocculator and completing it in the Flocculator,
b) Changing the sludge blanket function from continuation of aggregation to the POA process where the micro-aggregates formed in the Flocculator are agglomerated to large, rapidly settling agglomerates by means of OAA (organic agglomeration agent); the OAA are anionic or non-ionic water-soluble polymers.

Conversion of the CSAV clarifier arrangement involved modification of the Flocculator to incorporate:

a) Installation of a double-frame, double-anchor, n-tier type stirrer driven by a variable speed drive,
b) Installation of OAA dosing points above the Flocculator bottom and
c) Installation at the Flocculator bottom of a system of deflector baffles to neutralize the rotary motion of the water before entering the sludge blanket compartment.

Raw water containing dispersed coagulant (aggregation agent) discharged from a flash mixer enters the Flocculator. In this compartment, the aggregation takes place under the IHDS process at a high agitation intensity ($\overline{G} >> 50\ s^{-1}$); the aggregation is completed ($\gamma = 1$) within the Flocculator. The OAA solution is dosed into the Flocculator bottom above the deflector baffles to facilitate its homogenization throughout the aggregated water within the Flocculator before entering the sludge blanket. The deflector baffles neutralize the effect of the rotary motion of water before entering the sludge blanket compartment. The attainable up flow velocity in the sludge blanket, at which the agglomerates are separated, can be varied over a wide range by changing the OAA dosing rate. This is because OAA dosage influences the size of agglomerates formed and their attainable sedimentation velocity. The aggregated water with evenly dispersed OAA enters the conically shaped sludge blanket compartment via an inlet slot. Here, under a low agitation intensity ($\overline{G} << 50\ s^{-1}$), produced by the turbulent fluctuations of the inflowing water, the micro-aggregates are agglomerated to large and rapidly settling agglomerates. No agglomerates are allowed to settle and deposit at the bottom of the sludge blanket compartment as this would facilitate disturbance of the hydraulic balance throughout the sludge blanket compartment and detrimentally affect the clarifier performance. The formed agglomerates are separated from the purified water at the sludge blanket level by continuously draining-off the excess suspension from the sludge blanket level by means of the induced flow into the sludge compartment. In this compartment the suspension settles and thickens by way of compression. The flow of decanted water from the sludge compartment is combined with the main outlet of purified water discharged from the clarifier. The accumulated sludge is periodically drained-off through the perforated pipe. The sludge compartment is provided with a few sampling pipes to monitor the sludge level and its concentration at different levels. The purified water discharged from the sludge blanket flows through the purified water compartment, where it is evenly collected over the compartment level and discharged from the clarifier at its outlet.

ii. *P- Clarifier*

The P-Clarifier (Figure 18) is a circular, horizontal flow, sedimentation type clarifier, suitable for

intermittent operation. It incorporates aggregation, sedimentation, purified water and sludge accumulation / thickening compartments. When used as a high rate type, the aggregation takes place to completion in a separate Flocculator installed next to the clarifier. When used for dewatering of thin sludge, the function of the Flocculator changes to the POA process. The sludge compartment is designed to deposit and thicken the settled sludge by compression and to prevent a back-lifting of sludge into the sedimentation compartment during desludging. The sludge is periodically drained-off by hydraulic means through a perforated pipe.

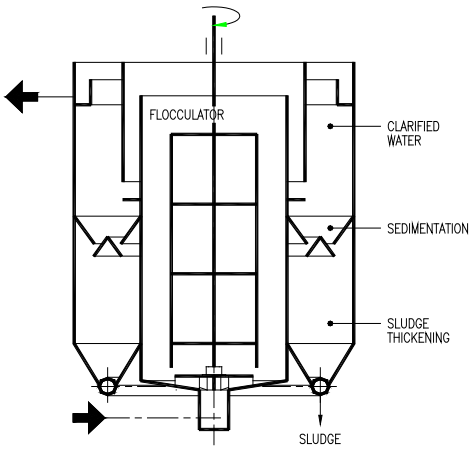


Figure 18: P-clarifier

b) Methods and Procedures

The performance efficiency of the clarifiers was evaluated by changes in the content of the cation (Me) of the Fe^{3+} or Al^{3+} salt, when a hydrolyzing type of aggregation agent was used. Furthermore, changes in natural organic matter (NOM) were measured as COD_{Mn}, TOC or DOC in both the raw water and the settled water, irrespective of the kind of aggregation agent used.

The total concentration of the specific impurity measured in the raw water is designated by C_0, and C_0F, at the clarifier outlet by C_C and C_CF, and in the filtrate by C_F and C_FF. The quantities C_0, C_C and C_F mean total concentration of the particular impurity produced by all particles. Abridger F means the content of such impurity is produced only by the non-separable particles. The concentration of non-separable particles C_0F, C_CF and C_FF was determined in the tested samples from which the separable particles were removed under specific conditions of centrifugation [8-10].

Turbidity produced by the total content of all particles and the content of non-separable particles was measured by a Hach turbidity meter model 2100A. The concentration of the cation of the aggregation agent was measured colorimetrically by a Bausch & Lomb Spectronic model 70.

The NOM was measured colorimetrically as Com_{den} (oxidizability) by oxidation of the organic matter in a boiling mixture of potassium permanganate ($KMnO_4$) and sulphuric acid.

The size distribution of formed aggregates was determined by the Test of Aggregation using a Labofuge 1 laboratory centrifuge. The Test of Aggregation ascribes the aggregates formed to one of the following four basic technological size-fractions, namely: non-aggregated (non-separable) particles (NA), primary aggregates (PR), micro-aggregates (MI) and macro-aggregates (MA). Coagulation efficiency was evaluated by the degree of destabilization $\boldsymbol{\delta}$. The concentration of any type of the monitored impurity is measured by the total concentration of all particles C and by concentration of its non-separable fraction CF. The removal of individual impurities was evaluated by the attained $\boldsymbol{\varphi}$ and attainable $\overline{\varphi}$ separation efficiency [1, 8-10].

The degree of destabilization is the basic criterion of destabilization of the particles of impurities. It is defined as the ratio of the number of particles destabilized in the course of aggregation N_D to the number of aggregately-stable (non-separable) particles in the raw water N_{NS} [8-10].

The aggregation agents, namely ferric chloride and aluminium sulphate (hydrolyzing coagulants) and Floccotan and SF-577 (organic coagulants), were used. These organic coagulants are described under Aggregation Agents.

The OAA used are polyacrylamides, mainly Superflocs SF-110 and SF-A130, provided by the Cyanamid Co. of USA.

i. *Raw Water*

The HR clarifiers purified water from three different surface sources. The raw water quality in these sources is summarized in Table 1.

Table 1: Average quality of different raw waters purified by the pilot HR clarifiers

DETERMINANT	UNITS	VAAL DAM	LOCH ATHLONE DAM	SAULSPOORT DAM
Temperature	^{O}C	10 - 26	12-25	12 – 25
pH	-	6.9 – 8.5	7.7	7.4 – 8.2
Turbidity	NTU	150 - 200	50 - 690	30 – 250
Color	mg Pt. L^{-1}		5 – 15	10 – 40
Total Hardness	mg $CaCO_3$. L^{-1}	37 - 105	108	90 – 160
Total alkalinity	mg $CaCO_3$. L^{-1}	42 – 110	75	75 – 150
COD_{Mn}	mg O_2. L^{-1}	4.0	3.4	5.8 – 6.5
THM – potential value	μg $CHCl_3$.L^{-1}	-	-	878

ii. *Velocity Gradient*

The mean square root velocity gradient $\overline{G}$ is a parameter ascertaining the average intensity of agitation applied to aggregation. From an operational point of view it is important to evenly distribute the intensity of agitation throughout the Flocculator and to best utilize the retention time in the Flocculator by preventing short circuiting. Hence, great attention has been given to developing a stirrer facilitating these requirements. Such stirrer, a double-frame, double-anchor, n-tier type generating flow in a plane perpendicular to the stirrer shaft, was developed. This stirrer is driven by a variable speed drive thus ensuring the intensity of agitation required to complete aggregation within the Flocculator can be maintained at all times.

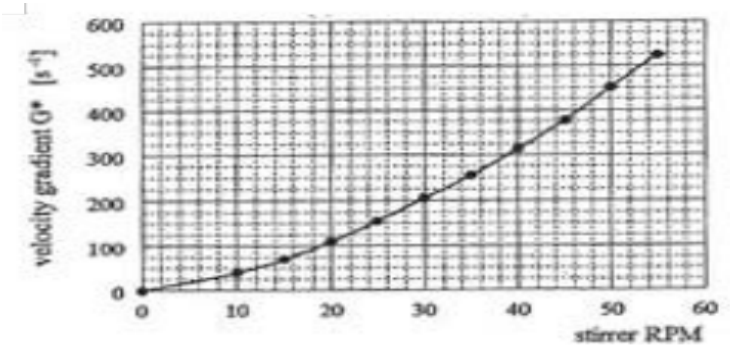


Figure 19: 3 m HR Clarifier - Conversion of Stirrer RPM to Mean Square Root Velocity Gradient G* =

The power input, shaft-to-water, was determined from the energy consumed by the stirrer revolving at different revolutions in the Flocculator filled with water, and then again, at the same revolutions when it is empty. The difference between these two power readings is the actual power input, shaft-to-water, dissipated by the stirrer into the water under operating revolutions. From these power inputs, the mean square root velocity gradients $\overline{G}$ were calculated. Conversion of the stirrer speed to the velocity gradient $\overline{G}$ is shown in Figure 19.

iii. *Concentration of Drained Sludge*

The concentration of sludge discharged from the clarifiers was determined as an average concentration established from samples taken either from sludge discharged at the beginning, middle and at the end of desludging, or directly from the samples taken from the sludge compartment at different heights. Sludge concentrations varied depending on the retention time in the sludge compartment.

VII. Results and Discussion

a) Pilot Hr Clarifiers

Two 3.0 m diameter pilot HR clarifiers were installed at two different localities to demonstrate the potential of the HRCT and to eliminate any doubts about the feasibility of this progressive technology.

The design parameters of the pilot HR clarifiers are as follows [1]:

- Clarifier diameter — D_C = 3000 mm,
- Overall height of the clarifier — H_C = 4.0 m
- Clarifier volume — V_C = 24 m^3,
- Design capacity (flow rate) — Q = 21.15 $m^3.h^{-1}$ = 507.60 $m^3.d^{-1}$
- Agitation intensity during IHDS aggregation process — $\overline{G}$ = 100 - 400 s^{-1}
- Area of the sludge blanket at its separation level — F_{SB} = 4.7 m^2,
- Design upflow velocity at the sludge blanket level — v_{UP} = 4.5 $m.h^{-1}$,
- Area of separation level in the sludge compartment — F_{ST} = 3.0 m^2,
- Retention time in the clarifier at the design flow — T_C = 68 min.

b) *Installation, Operation and Performance of the First Pilot HR Clarifier*

The first pilot HR clarifier was installed at the Rand Water Board Zuikerbosch Waterworks (Figure 20) and operated for about one year during 1970 to 1971. Vaal Dam water was purified (Table 1). Either aluminium sulphate or Floccotan was used as the aggregation agent. The OAA used was SF-A110. It was dissolved at a concentration of 1.0 $g.L^{-1}$ in 0.025 N NaOH electrolyte prepared from distilled water.

The clarifier performance results were remarkable even though its full potential could not be established due to the low flow rate of the raw water delivery pump.

The clarifier operation and performance capability is summarized as follows [1]:

- Flowrate - limited by the raw water pump capacity — Q = 500 to 1150 $m^3.d^{-1}$
- Upflow velocity at the sludge blanket level: — v_{UP} = 4.5 to 10.2 $m.h^{-1}$,
- Total retention time in the clarifier at the maximum flow — T_C = 30 min,
- Raw water turbidity: — C_0 = 150 to 200 NTU
- Residual turbidity at the clarifier outlet: — C_C = 1 to 5 NTU

Figure 20: Installation of the pilot HR clarifier at the RWB Zuikerbosch waterworks

c) *Installation, Operation and Performance Results of the Second Pilot HR Clarifier*

The second pilot HR clarifier (Figure 21) was installed at the municipal waterworks of the City of Bethlehem, Orange Free State, purifying water from the Loch Dam or Saulspoort Dam or a mixture of both (Table 1). This clarifier was operated for seven years during the period of 1974 to 1980 by the waterworks staff. The purified water (on average higher than about 1500 $m^3.d^{-1}$) was used to supplement the shortfall in the waterworks capacity.

Aluminium sulphate alternating with Floccotan or Superfloc SF-577 were used as Aggregation agents. SF-A110 was solely used as the OAA; it was dissolved at a concentration of 1.0 $g.L^{-1}$ in plain tap water because distilled water could not be secured at the daily quantities required. Another OAA, the Allied Colloids LT-25, was also successfully tested, even though for a very short time only. The performance efficiency of both OAA was very similar.

In conformity with the requirements of SABS 241 and common practice in South Africa, the clarifier's performance was monitored by residual turbidity only. Other determinants, such as the residual concentration of the cation (Me) of the aggregation agent used, and NOM (TOC, DOC, COD_{Mn}) could not be routinely monitored because the waterworks laboratory was not equipped for such analysis.

The raw water to the HR clarifier was delivered by gravity; it was branched off from the delivery pipeline to the waterworks. Depending on the volume of the purified water in the reservoirs, the throughput of the waterworks regularly changed. This often happened during the night hours. As a result, the HR clarifier throughput often changed without warning and consequently without adjustment of the dosing rates and, or intensity of agitation in the Flocculator. Higher residual turbidity in the clarifier outlet is usually a direct consequence of such a situation. Under the optimized operational conditions the residual turbidity at the clarifier outlet did not exceed 5 NTU even at the clarifier's highest upflow velocities. The higher residual turbidity resulted from $\gamma < 1$ and, or sub-dosages of aggregation agent (producing a poorer quality of purified water) or OAA (resulting in a greater remaining concentration of suspension in the clarifier outlet).

Figure 21: Installation of the second pilot HR clarifier at the municipal waterworks of the City of Bethlehem

This HR clarifier performed as follows [1, 31]:

- Flowrate:
- Upflow velocity at the sludge blanket level:
- Retention time in the clarifier:
- Clarifier outlet turbidity:
- IHDS process
- Volume of drained sludge:
- The highest concentration of SS in drained sludge

Q = 500 - 2877 $m^3.d^{-1}$,
v_{UP} = 4.5 – 25.5 $m.h^{-1}$,
T_C = 68 – 12 mins,
Cc = 2 - 9 NTU,
$\overline{G}$ = 100 - 380 s^{-1},
V_S = 0.245 % Q,
C_S = 73.05 $g.L^{-1}$ (7.305%).

The maximum hydraulic loading Q = 120 $m^3.h^{-1}$, corresponding to an upflow velocity v_{SB} = 25.5 $m.h^{-1}$, which occurred accidentally, as the pressure in the feed pipe to the HR Clarifier increased, due to reduced flow to the waterworks. Under this flowrate the HR clarifier operated as follows: C_0 = 108 NTU, C_0F = 58 NTU, D_{OC} = 5.94 $mg.L^{-1}$, D_{OAA} = 0.126 mg SF-A110.L^{-1}, $\gamma \approx 0.22$, $C_C \leq 21$ NTU, $C_CF \leq 5.2$ NTU. The high residual turbidity is the consequence of the system being underdosed, both with the aggregation agent and SF-A110 and being extremely under-aggregated as $\gamma \approx 0.22$. After the agitation intensity and dosages of the aggregation agent and OAA were optimized the performance efficiency improved and returned to its usual level of $C_C < 5$ NTU. The total retention time in the clarifier between the point of addition of the aggregation agent and the clarifier outlet was only T_C = 11.9 min.

d) Comparison of Performance of the HR Clarifier with Conventional Clarifiers

The pilot HR clarifier was operated in parallel with three Clariflocculators (2 x D = 10.5 m and 1 x D = 14.0 m) and a Pretreator clarifier (D = 18.5 m). The Clariflocculator is a radial flow type sedimentation clarifier with the flocculation compartment sized for about 20 min retention time and a very low intensity mechanical agitation. The Pretreator is a radial flow type sludge blanket clarifier with continuously forced internal sludge recirculation to keep the sludge blanket fluidized.

When comparing performance efficiency, these clarifier systems were operated under the following

conditions to produce the same total residual turbidity of the purified water:

- The Clariflocculator (dia 14.0 m) – operated at the design and sedimentation velocity v_S = 1.2 m.h^{-1} and retention time of about T_C = 4 hours.
- The Pretreator – operated at the design upflow velocity v_{UP} = 1.5 m.h^{-1} and retention time of about T_C = 3.5 hours.
- The HR clarifier – operated at an upflow velocity v_{UP} = 15.5 m.h^{-1} and retention time of about T_C = 20 minutes.

The Clariflocculators and the Pretreator were supplied with water pre-aggregated in a shared hydraulically operated flocculation basin, where aggregation took place under the regular low intensity agitation and a retention time of about 20 mins. The discharge from this basin to the Pretreater was over a hydraulic jump (height of about 600 mm). In the case of the HR clarifier the aggregation agent was dosed into an inline flash mixer installed upstream of the clarifier Flocculator. The IHDS process in the HR clarifier took place with $\overline{G}$ = 330 s^{-1}.

The waters purified by the HR clarifier and the Clariflocculators were combined and filtered together while the water purified by the Pretreator was filtered in a dedicated filtration plant.

The aluminium sulphate dosage, purifying water to the same total residual turbidity in all three clarifiers, was about 13% lower for the HR clarifier than that applied to the Clariflocculators and Pretreator (Table 2). This proves the importance of the rapid dispersion of the aggregation agent at the flash mixer together with the subsequent high intensity agitation during aggregation facilitating completion of destabilization of particles of impurities and their aggregation.

The performance of these three clarifier systems, evaluated by the Test of Aggregation, is compared in Table 2, and the distribution particle size-fractions is illustrated in Figure 22.

A drop in residual turbidity C_CF measured at the outlets of different sections of the clarifier system (Table 2) indicates the extent of the efficient improvement of the purification process. The HR clarifier produced the lowest turbidity C_CF = 1.4 NTU, while the Pretreator was very close to it, C_CF = 1.5 NTU. A considerably higher turbidity was produced by the Clariflocculator, C_CF = 2.9 NTU. The relatively high C_C *and* C_CF values at the outlet from the HR clarifier are due to a 13% lower dosage of the aggregation agent than the optimum applied to the other clarifiers. The low C_CF value of the Pretreator in comparison to the Clariflocculators was partly due to the hydraulic jump at the end of pre-aggregation enhancing destabilization of impurities and partly due to the enhancing effect of the sludge blanket. Undoubtedly, the highest C_CF value produced by the Clariflocculator proves that a low agitation intensity applied to the aggregation process does not favourably affect enhancement of the processes of destabilization of particles of impurities and their aggregation.

Table 2: Comparison of the performance efficiency of different clarifiers installed at the municipal waterworks of the City of Bethlehem, OFS [1, 31]

Source of raw water:	Mixture of Saulspoort Dam and Loch Athlone Dam waters
Raw water turbidity:	C_0 = 102 NTU
	C_0F = 54 NTU
Date of plant operation:	November 12, 1978
Aggregation agent:	Aluminium sulphate
Optimum dosage (Tu removal):	D_{Al} = 60 mg.L^{-1}

NA - non-separable (non-aggregated) particles
PR - primary-aggregates
MI - micro-aggregates
MA - macro-aggregates

TYPE OF CLARIFIER	DOSING RATE		UPFLOW VELOCITY	POINT OF MEARUREMENTS	TURBIDITY		DEGREE OF DESTABILISATION δ
	Aluminium sulphate [mg.L^{-1}]	SF-A110 [mg.L^{-1}]	[m.h^{-1}]		C_c [NTU]	C_CF [NTU]	[-]
				Raw Water	102	54	-
Pretreator (Retention time about 3.5 hrs)	60	0	1.5	Pre-aggregation chamber outlet	102	4.9	0.909
				Hydraulic jump	102	4.0	0.926

				Clarifier outlet	7.1	1.5	0.972
Clariflocculator (Retention time about 4 hrs)	60	0	1.2	Pre-aggregation chamber outlet	102	4.9	0.909
				Clarifier outlet	7.2	2.9	0.946
HR Clarifier (Retention time about 20 min)	52	0.172	15.5	Flocculator outlet	102	1.7	0.969
				Clarifier outlet	7.0	1.4	0.974

SF-A110 was dissolved in tap water

TYPE OF CLARIFIER	POINT OF MEARUREMENT	TURBIDITY		TEST OF AGGREGATION PARTICLE SIZE-FRACTION				SEPARATION EFFICIENCY	
		Cc [NTU]	CcF [NTU]	*MA* [%]	*MI* [%]	*PR* [%]	*NA* [%]	φ [-]	$\bar{\varphi}$ [-]
	Raw Water	102	54	-	-	-	-	-	-
Pretreator (Retention time about 3.5 hrs)	Pre-aggregation chamber outlet	102	4.9	75.5	14.7	6.2	3.6	-	0.9592
	Hydraulic jump	102	4.0	17.6	57.9	22.3	2.2	-	0.9608
	Clarifier outlet	7.1	1.5	1.5	2.5	1.6	1.4	0.9304	0.9853
Clariflocculator (Retention time about 4 hrs)	Pre-aggregation chamber outlet	102	4.9	75.5	14.7	6.2	3.6	-	0.9592
	Clarifier outlet	7.2	2.7	1.2	1.9	1.4	2.9	0.9294	0.9716
HR Clarifier (Retention time about 20 min.)	Flocculator outlet	102	1.7	50.0	32.6	16.1	1.3	-	0.9833
	Clarifier outlet	7.0	1.4	2.6	1.9	1.4	1.2	0.9314	0.9863

φ – attained separation efficiency, $\bar{\varphi}$ - attainable separation efficiency

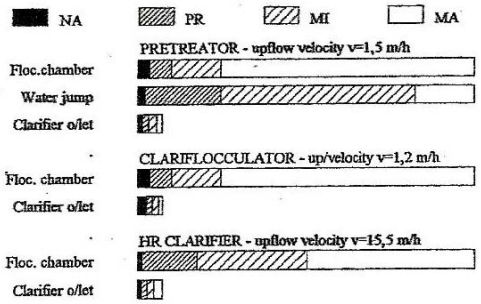


Figure 22: Particle size-fraction distribution in water purified by different clarifier systems, calculated from turbidity

e) Large Capacity HR Clarifiers at the Saulspoort Waterworks

At the end of the seventies, the City Council of Bethlehem approved the installation of a 20 ML.d^{-1} new waterworks to purify Saulspoort Dam water. The intended ultimate design capacity of the waterworks was 60 ML.d^{-1}, the design of the purification system should make provision for semi-automatic operation and allow for a plant overload of 50%.

The waterworks staff had gained a good knowledge and experience of the HRCT. The pilot HR clarifier proved to be efficient, simple and user friendly in operation and, unlike the old waterworks, allowed the process controllers (plant operators) to remain master of the plant at all times. Owing to this outstanding experience with the HRCT, the City Council decided to accept the concept of the HRCT for their new Saulspoort waterworks.

The design parameters of the HR clarifiers installed at the Saulspoort Waterworks (Figure 23) are as follows:

- Design capacity $Q = 10\ ML.d^{-1} = 417\ m^3.h^{-1}$,
- Diameter $D_C = 8650$ mm,
- Height of the clarifier $H_C = 8200$ mm,
- Intensity of agitation in the Flocculator $\overline{G} = 100 - 400\ s^{-1}$
- Total clarifier volume $V_C = 315\ m^3$,
- Area of the sludge blanket at its separation level $F_{SB} = 37.9\ m^2$,
- Upflow velocity at the sludge blanket level $v_{UP} = 11.0\ m.h^{-1}$,
- Separation area at the sludge thickener $F_{ST} = 33.0\ m^2$,
- Retention time in the clarifier at design flow $T_C = 45$ min,
- Average concentration of drained sludge $C_S > 40\ g.L^{-1}$.
- The clarifier de-sludge pipe is fitted with a pneumatically operated butterfly valve. Operation of this valve can be initiated either manually or by a timer.
- The water softened for dissolution of OAA in 0.025 N NaOH electrolyte is prepared in in situ.
- OAA is dissolved at a stock solution concentration 1.0 $g.L^{-1}$, and the solution matures for 24 hours before its use.

Figure 23: The Saulspoort waterworks – the HR clarifier, design capacity 10 ML.d-1

f) Performance Results

The Saulspoort waterworks was put into operation in 1980 [32]. It was commissioned using both types of aggregation agent, namely aluminium sulphate and Floccotan. It should be pointed out that ferric chloride, because of greater raw water alkalinity is a more efficient coagulant than aluminium sulphate; however, aluminium sulphate was used during plant commissioning because ferric chloride was not available.

Commissioning of the waterworks was carried out under two sets of four runs, each set verifying certain aspects of the clarifier operation and performance. The operation with Floccotan was aimed at proving the importance of completion of aggregation in the Flocculator ($\gamma = 1$) before the addition of OAA. During these trial runs the clarifiers operated at an upflow velocity $v_{UP} = 6.5$ and 12.0 $m.h^{-1}$ and $\gamma = 0.34$ to 1.0. The significance of the degree of aggregation (γ-value) achieved before the addition of OAA on the quality of purified water is best demonstrated by comparing the differences in the residual turbidity produced by the non-aggregated (non-separable) particles and measured at the outlet from the flash mixer $C_{FM}F$ and the outlet from the clarifier C_CF. Evidently the lower the γ-value the poorer the purified water quality, while the hydraulic loading of the clarifier has no effect in this regard. The results obtained are shown in Table 3.

Table 3: The HR clarifiers commissioning results from the first set of tests [33]

Source of raw water: Saulspoort Dam
Raw water turbidity: C_0 = 36 – 115 NTU
C_0F = 23 – 42 NTU
Aggregation agent: Floccotan

RUN No.	PERIOD OF OPERATION	UPFLOW VELOCITY v_{UP} [m.h^{-1}]	γ-VALUE [-]	DOSING RATE		TURBIDITY				
				FLOCCOTAN [mg.L^{-1}]	SF-A110 [mg.L^{-1}]	RAW WATER		FLASH MIXER	CLARIFIER	
						C_0 NTU	C_0F NTU	$C_{FM}F$ NTU	C_C NTU	C_CF NTU
1	4/9 – 15/10/80	6.5	1.00	12	0.05	45	24	-	1.4	0.35
2	15/10 – 21/12/80	12.0	0.85	12	0.05	36	23	-	2.1	0.52
3	21/12 – 10/2/81	12.0	0.34	20	0.10	115	42	1.3	5.8	0.98
4	10/2 – 20/2/81	12.0	0.75	20	0.10	115	42	1.3	2.8	0.57

During the second set of commissioning runs with aluminium sulphate the clarifiers were operated at four different hydraulic loadings under optimized reaction conditions and at almost completed aggregation, $\gamma \approx 1.0$. These runs were aimed to verify the clarifier's capability to operate safely and efficiently up to a 50% hydraulic overload, i.e. up to an upflow velocity v_{UP} = 16.5 m.h^{-1}. The results obtained are shown in Table 4.

Table 4: The HR Clarifiers Commissioning Results from the Second Set of Tests [33]

Source of raw water: Saulspoort Dam Raw water turbidity: C_0 = 65 – 70 NTU
Aggregation agent: Aluminium sulphate C_0F = 28 – 34 NTU

RUN No.	PERIOD OF OPERATION	UPFLOW VELOCITY v_{UP} [m.h^{-1}]	γ-VALUE	DOSING RATE		TURBIDITY		
				$Al_2(SO_4)_3$ [mg.L^{-1}]	SF-A110 [mg.L^{-1}]	RAW WATER	CLARIFIER	
						C_0 NTU	C_C NTU	C_CF NTU
1	4/11 – 5/11/81	11.1	0.98	75	0.10	68	1.8 – 3.5	0.20 – 0.22
2	5/11 – 7/11/81	13.6	0.93	72	0.12	65	3.2 – 5.5	0.20 – 0.25
3	7/11 – 9/11/81	15.0	0.99	73	0.15	70	4.0 – 7.0	0.22 – 0.28
4	9/11 – 12/11/81	16.5	0.95	78	0.18	68	4.0 – 7.0	0.22 – 0.30

The residual turbidity produced by non-aggregated particles and measured in the clarifier outlet was low with small differences irrespective of the upflow velocity. This is because, the γ-value was very close to 1 and the alum dosage to optimum. The performance results proved that the clarifier can consistently purify water to a good potable quality, in terms of the National Standard (SANS 241), even at the highest hydraulic loadings and shortest retention times providing $\gamma = 1$.

It can be concluded that the waterworks commissioning was very successful. The clarifier performance met all performance expectations and demonstrated that the HRCT can be the technology of the future.

At the beginning the waterworks was operated with Floccotan and a filtrate of sparkling clarity was produced, even at the highest flow, corresponding to an upflow velocity v_{SB} = 16.5 m.h^{-1} in the clarifier. During 1982 it was discovered by Van Steenderen [34] that Floccotan presents a potential health risk. Therefore, due to a dedicated check-up by Van Steenderen [35] (Table 5) it was discovered that the concentration of organohalogens in the raw water increased in the filtrate from TOH_0 = 37 µg $CHCl_3$.L^{-1} to TOH_F = 52 µg $CHCl_3$.L^{-1}. The TOH_P potential value increased even more from 878 to 1209 µg $CHCl_3$.L^{-1} as shown in Table 5. The *TOH* and TOH_P values in potable water should be lower and not exceeding that of the raw water. Therefore, Floccotan was immediately replaced with ferric chloride applied under optimized reaction conditions with regard to the monitored impurities [3].

Table 5: Secondary organic pollution of the purified water produced by natural OC (Floccotan) at the Saulspoort Waterworks (Van Steenderen) [35]

Point of measurement	*DOC* [mg C.L^{-1}]	*TOH* [µg $CHCl_3$.L^{-1}]	*TOH_P* [µg $CHCl_3$.L^{-1}]
Raw water	5.2	37	878
Flocculated water	4.8	-	1211
Filtrate	4.6	52	1209

Regrettably based on the advice of an organic coagulant supplier and without receiving any technological justification and proof that the water would not be purified to a poorer quality, the Municipality replaced ferric chloride with organic coagulant L-100 (assumed to be Poly DADMAC). Appraisal of treatability of the raw water attainable with ferric chloride and L-100 is shown in Table 6.

Table 6: Coagulation efficiency and treatability of the Saulspoort Dam water attained by optimized dosages of $FeCl_3$ and L-100 (organic coagulant) [36]

Coagulant	Dosage	pH	Turbidity		NOM (COD_{Mn})		Me	Degree of destabilisation **δ**	
			C	CF	C	CF	C	Tu	NOM
	[mg.L^{-1}]	[-]	NTU	NTU	mg O_2.L^{-1}	mg O_2.L^{-1}	mg.L^{-1}	%	%
Raw water at dosing point of:	$FeCl_3$	7.85	66	33	5.93	5.34	-	-	-
	L-100	7.95	74	38	6.18	5.42	-	-	-
Water purified by :									
$FeCl_3$	100	5.8	0.25	0.18	1.45	1.40	0.02	0.996	0.755
L-100	1.5	7.92	3.0	1.6	4.48	4.41	-	0.959	0.275

It is evident from the comparison of the values of the degree of destabilization **δ** (coagulation efficiency) and the quality of purified water that L-100 is not an equivalent replacement for ferric chloride. This is because the efficiency of organic pollution removal is extremely poor and L-100 cannot purify water to the wholesome potable quality suitable for a lifelong consumption.

Due to the influx of people from the Kingdom of Lesotho at the end of the eighties, the waterworks operated up to a 50% hydraulic overload for about 5 years. During this time the clarifiers were operating between v_{UP} = 11.0 and 16.5 m.h^{-1} until 1993, when the waterworks was extended to the present capacity of 40 ML.d^{-1}.

g) Mechanical Dewatering of the HR Clarifier Sludge

The suitability of sludge produced by the HR clarifiers for mechanical dewatering by centrifugation was investigated (Figures 24,25). The tests were carried out with a Sharples PM 30000 Polymizer centrifuge in March 1981. The clarifier sludge was produced from raw water having a turbidity C_0 = 115 NTU using Floccotan as coagulant under the IHDS process at $\overline{G}$ = 200 s^{-1} followed by the POA process with SF-A110 at a dosage D_{OAA} = 0.07 mg.L^{-1}. The concentration of sludge discharged from the clarifier was about 40 g.L^{-1} (4.0 %).

Figure 24: Sharples Polymizer 30000 centrifuge at the Saulspoort waterworks

Figure 25: Centrifuge cake produced from HR clarifier sludge – cake dry solids 34,4% w/w, DOAA = 0,68 kg. (tss)-

The polymer LT-26 (a low toxicity grade recommended by Allied Colloids) was used to condition the clarifier sludge; it was dissolved in 0.025 N NaOH electrolyte. The concentration of the LT-26 solution was 1.0 $g.L^{-1}$. The optimum feed rate of sludge to the centrifuge was established at 5.4 $m^3.h^{-1}$. The centrifuge operated at a bowl speed of 3150 RPM and a scroll differential speed of 8.2 RPM [37]. The solids content in the sludge discharged from the centrifuge, and the solids concentration in the liquid discharged from the centrifuge, were measured.

Two tests using different LT-26 dosages were carried out. In both cases, sludge of spadeable consistency were discharged from the centrifuge. At LT-26 dosage D_{OAA} = 0.68 kg/tss the discharged sludge contained 34.4% w/v dry solids and the liquid discharged contained 120 mg $SS.L^{-1}$. When the LT-26 dosage was reduced to D_{OAA} = 0.37 kg/tss, the sludge discharged was less thick, nevertheless contained 31.2% dry solids and the liquid discharged was tinged brown containing 370 mg $SS.L^{-1}$ [37]. This excellent economic dewatering properties of the clarifier sludge is yet another significant benefit of the HRCT.

h) Filterability of OAA Formed Agglomerates

The agglomeration of aggregates and deep-bed filtration are interrelated processes as the effectiveness of filtration is determined by the properties of the suspension formed in the preceding processes. However, the properties of agglomerates that are favorable for effective sedimentation may not be the most suitable for economic filtration and vice versa [38].

The purpose of agglomeration is not only the formation of a rapidly settleable suspension but also the formation of a suspension that is effectively and economically filterable to achieve long filtration cycles.

The filterability of the OAA formed agglomerates could not be investigated under the pilot HR clarifier operation. This could only be established during the operation of the Saulspoort waterworks. Similarly, the rise rate of filter headloss resulting from OAA application could not be assessed at the design stage. Therefore, an operational water height of 1500 mm above the filter bed was designed to produce an adequate safety margin for the operational pressure head to prevent operation under sub-atmospheric pressure conditions. Under these conditions the length of filtration cycle was longer than seven days. For hygienic reasons however, the length of filtration cycle was limited to a maximum of 72 hours. At the end of the reduced cycle the filter head loss did not exceed 1000 mm and on average it was below 600 mm.

i) The Saulspoort Waterworks

The remarkable benefit of the HRCT is the major reduction in the footprint and compact layout of the waterworks compared to traditional designs. It efficiently solved operational problems such as the elimination of well-known detrimental effect of the sun and wind on the performance stability of the clarifiers as well as the harsh climatic conditions that exist at the waterworks site, by the installation of a fully roofed-over waterworks (Figure 26). Further benefits resulting from the roofed-over plant are steady ambient conditions for the operation of the plant and equipment and for a pleasant working environment.

Another essential component of this waterworks is the inclusion of staff housing for the operating personnel. This feature together with the simple operation and effective functioning of the waterworks are the reasons for an almost non-existent staff turnover.

The Saulspoort waterworks (Figure 26) consists of three Buildings attached and mutually interconnected, namely:

- Administration and Operation Building,
- Technology Building,
- Pump Building.

The Administration and Operation Building is sized to service the ultimate waterworks capacity of 60 $ML.d^{-1}$. Buildings of Technology and Pumps are

designed to consist of three modules of 20 ML.d^{-1} capacity each.

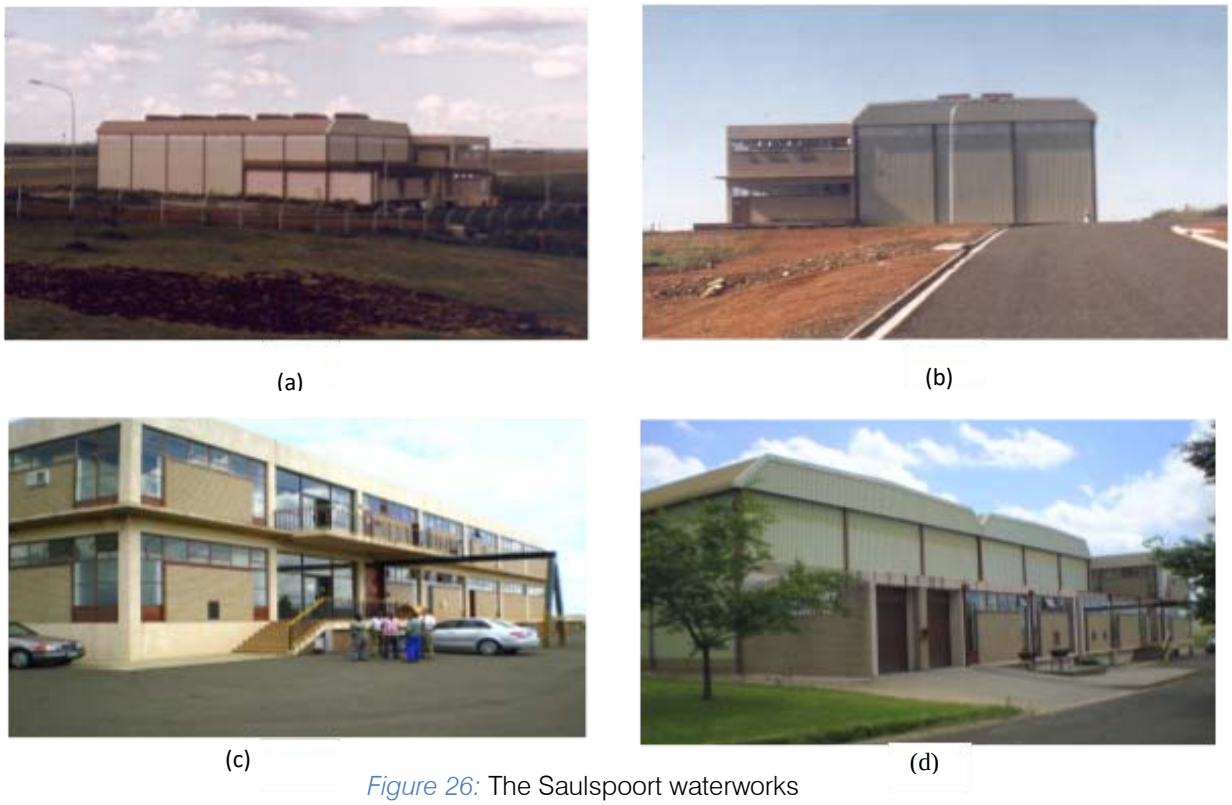


Figure 26: The Saulspoort waterworks

The impact of the reduced footprint on the waterworks layout is best evident by the double story Buildings shown in Figure 26 and their dimensions:

a) Technology Building (18 x 36 m) combined with Pumps Building (6 x 18 m) create one module,
b) Side view of Administration and Operation Building and Building of Technology, one modulus capacity 20 ML.d^{-1},
c) Building of Administration and Operation (9.6 x 42 m),
d) Buildings of Technology and Pumps enlarged to two modules – capacity 40 ML.d^{-1}.

The Technology Building accommodates raw water flow measurement, hydraulic flash mixer, flow division box, two HR clarifiers and the filtration plant. The filtration plants in both modules consists of four dual media rapid gravity filters. The filters are designed for a filtration velocity v_F = 10 m.h^{-1}; filter media consist of filter sand $d_{50\text{-}S}$ = 0.9 mm and height L_S = 600 mm and hydroantrazite $d_{50\text{-}A}$ = 1.6 mm and height L_A = 300 mm.

Operation of the filtration plant proved that a low concentration of suspension, conditioned with a small OAA dosage, entering the filters does not adversely affect the length of filtration cycles. However, the length of filtration cycles is affected by the efficiency of filter backwashing (the intensity of air scour and water backwash should be based on the grain size of the filter medium), and proper filter geometry, which are often ignored in the filter design.

The benefit of HRCT concerning the reduction of capital costs is evident from the reduced waterworks footprint.

VIII. P-Clarifier Recovering Water from Eutrophic Sludge

The City of Salisbury, Rhodesia (now the City of Harare, Zimbabwe) operated the Hunyani waterworks. This waterworks purifiers water from the Hunyani dam. The Hunyani dam water is highly eutrophic and of low turbidity; for most of the time it seldom exceeds 15 NTU.

This raw water was purified in Pulsator clarifiers. These are vertical flow sludge blanket clarifiers. Pulsators were designed to operate at an upflow velocity v_{UP} = 2.5 m.h^{-1}. Aluminium sulphate was used as aggregation agent. The maximum sludge concentration in the Pulsator sludge blanket did not exceed 1500 mg SS.L^{-1}, and its performance was very unstable. Stabilization of the plant performance required up to 50% of the inlet flow to the Pulsators to be drained. In order to maintain the required waterworks capacity, the water contained in the clarifier sludge had to be recovered and delivered to filtration. For this reason the municipality issued a tender for the installation of a plant that would recover 70% of the water from the drained Pulsator sludge; the maximum concentration of the

suspended solids permitted in the recovered water was 25 mg SS.L^{-1}.

For this project, a 13.0 m diameter P-Clarifier sized for an upflow velocity of v_{UP} = 3.4 m.h^{-1} was proposed and installed by E L Bateman Ltd. The dewatering process was based on the POA of the Pulsator sludge; the SF-A110 was used as the OAA. It was anticipated that OAA dosage would not exceed D_{OAA} = 1.5 mg.L^{-1}. Obviously, the actual OAA dosage had to be determined by the quality and the concentration of sludge entering the P-Clarifier and the required SS content at its outlet.

The P-Clarifier performed as follows [40]:

- Capacity
- Concentration of suspended solids at the inlet to P-Clarifier varied between
- Average SF-A110 dosage
- Upflow velocity
- Average water recovery
- Residual suspended solids in the recovered water
- The content of SS in the P-Clarifier underflow

Q	=	10 ML.d^{-1}
SS_{in}	=	400 - 1090 mg.L^{-1}
average SS_{in}	=	860 mg.L^{-1}
D_{OAA}	=	0.5 mg.L^{-1}
v_{UP}	=	3.4 m.h^{-1}
R	=	82%
SS_{out}	≤	4.0 mg.L^{-1}
SS_S	=	2.42 – 4.08 g.L^{-1}

The storage time of the Pulsator sludge before its delivery to the P- Clarifier had to be very short due to its tendency to become septic.

a) Performance Results

The P-Clarifier was operated from 1976 to 1993, when it was taken out of service [39]. The results below were obtained during the acceptance testing carried out continuously at the maximum rated capacity Q = 10 ML.d^{-1} during March 2 to 9, 1979. The SF-A110 stock solution of a concentration C_{OAA} = 1.0 g.L^{-1} was prepared in 0.025 N NaOH electrolyte prepared from soft water. The OAA stock solution was matured for a minimum of 12 hours before its use.

The P-Clarifier proved capable dewatering the highly eutrophic sludge effectively in a simple and reliable operation. During its service life the volume of the Pulsator's sludge gradually increased as the waterworks capacity expanded. Owing to that the P-Clarifier was finally running successfully at about three times its design capacity [39].

IX. P-Clarifier Desilting Underground Gold Mine Water

A pilot P-Clarifier was installed to test its efficiency for removing the high content of suspended solids from the underground mine water before pumping to the surface. Because this clarifier and the OAA dissolving and dosing plant would be installed underground next to the sedimentation system to reduce pumping cost, required the smallest footprint for this system.

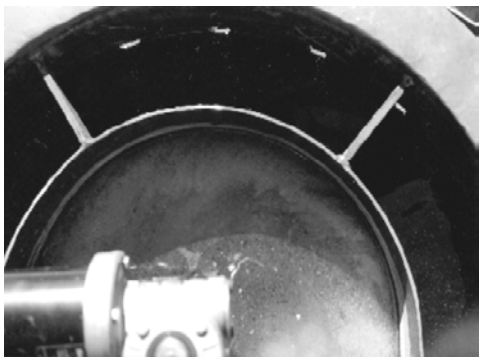


Figure 27: The pilot P-Thickener dewatering underground mine water

The pilot P-Clarifier (600 mm diameter) was installed at No. 10 Shaft, Vaal Reefs Gold Mine and was operated at an upflow velocity v_S = 34.4 m.h^{-1} (Figure 27). The content of suspended solids at the inlet to the

P-Clarifier varied up to 20,000 mg.L^{-1}. The OAA (N351) was dissolved in 0.025 N NaOH electrolyte at a concentration of 0.5 g.L^{-1}. The flow through the plant was by gravity and varied considerably as it depended on the pumping arrangement from the mine; likewise concentration of suspended solids in the mine water varied considerably. At a C_0 = 5,000 mg SS.L^{-1}, D_{OAA} = 1.5 mg.L^{-1} and an upflow velocity v_S = 34.4 m.h^{-1} the content of suspended solids at the P-Clarifier outlet was $C_C < 20$ mg.L^{-1}.

A significant benefit of the P-Clarifier design is its ability to effectively float, collect and remove oil from the underground water at the top of the agglomeration compartment.

Important Notice

The great potential of HRCT evident from the presented results may probably not be duplicated in full extent as shown in this article. The reason is that the water soluble polymers used in the operation of High Rate Clarifiers were Superflocs provided by Cyanamid Co. of USA which no longer exists. Unfortunately, these Superflocs in the quality provided by Cyanamid Co. are no longer available. We believe the USA Cytec Co. manufactured the Superflocs for Cyanamid Co. and the Cytec Co. was acquired by Kemira Water Solutions, Inc. Based on our experience the polymers now supplied as Superflocs are remarkably of a poorer quality differing from the quality originally provided by Cyanamid Co. as day and night. If Kemira Water Solutions is the manufacturer / supplier of Superflocs they should return the Superflocs to their original quality. If they are not capable of doing it then they should supply the polymers of present-day quality under a different name to prevent any adverse and misleading information to their users.

X. Conclusions

1. A new water purification technology, the High Rate Clarification Technology, significantly accelerates the formation of flocculent suspension and its gravity separation never achieved before. This technology consists of two processes, namely the Inline High Density Suspension formation process, which takes place under a very high agitation intensity ($\overline{G} >> 50$ s^{-1}) until the aggregation is completed followed by the Post-Orthokinetic Agglomeration process under which the dense micro-aggregates are agglomerated to large, heavy and rapidly settling agglomerates utilizing water soluble anionic or non-ionic polymers.
2. It was proven that the customary method of application of the water soluble polymers as coagulation and/or flocculant aids results in an impairment of the quality of purified water and the performance of rapid gravity filters. In addition, it does not form the most rapidly settling flocculent suspension. Therefore, this is not the most effective method for the use of water soluble polymers. The optimum method for the use off anionic and non-ionic polymers is when they are applied as agglomeration agents and not as coagulation or flocculation aids, which is present common practice. The agglomeration capability of anionic and non-ionic polymers is influenced by the physical-chemical conditions under which they are dissolved and their solution applied.
3. Degree of aggregation γ has been developed as a simple tool for assessing the level of aggregation reached at the point of addition of anionic or non-ionic polymers. The optimum is that at which aggregation is completed, $\gamma = 1$; the $\overline{G}\ T_0$ value used for calculation of γ value is aggregation agent dependent.
4. Two different types of clarifiers incorporating principles of the HRCT were developed:

   a) HR clarifier, a fully fluidized sludge blanket type, incorporating flocculation, sludge blanket, clarified water and sludge thickening compartments,
   b) P-clarifier, a circular, horizontal flow, sludge scraper free, high rate sedimentation type clarifier, incorporating the following compartments: flocculation, sedimentation, clarified water and sludge accumulation / thickening compartments; when it should operate as a high rate clarifier the function of the internal Flocculator is changed to the POA process and the Flocculator is installed externally next to the P-Clarifier.

5. A 3.0 m diameter HR clarifier was continuously operated by waterworks staff for a period of 7 years. Experience gained with the operation of this pilot plant can be summarized as follows:

   a) The purified water produced was filtered with waters discharged from three Clariflocculators installed at the waterworks. On average this pilot HR clarifier purified more than 1500 m^3.d^{-1} of dam water and this water was used to cover the waterworks shortfall capacity.
   b) The highest operational flow rate of 2877 m^3.d^{-1} corresponds to an upflow velocity at the sludge blanket level of 25.5 m.h^{-1} (83.66 ft.h^{-1}) and total retention time in the clarifier of 11.9 minutes. The highest concentration of sludge discharged from the clarifier was 73.05 g.L^{-1} (7.305 %). This indicates the significant positive effect of high intensity agitation on the density of formed flocculent suspension.
   c) The operation pilot HR clarifier proved to be very efficient, simple and user friendly and, unlike the old waterworks, allowed the process controller (plant operator) to remain master of the plant at all times.

d) Owing to the outstanding experience with the HRCT, the City Council decided to accept the HRCT and the HR Clarifiers for their new Saulspoort waterworks.

6. Two 10 ML.d^{-1} capacity HR clarifiers were initially installed and about 13 years later another two HR clarifiers were installed. The experience gained with operation of this waterworks can be summarized as follows:

a) The HR clarifiers were designed for an upflow velocity of 11.0 m.h^{-1} and retention time of 45 mins. However, they were successfully operated for 6 years at an upflow velocity between 11.0 and 16.5 m/h^{-1}, retention time in the clarifier between 45 and 30 minutes and consistently produced a very good quality purified water, when a hydrolyzing coagulant was used. The use of organic coagulants proved they are not an equivalent replacement for the hydrolyzing coagulants.
b) The operation of the waterworks also proved, the best purified water quality is produced when the degree of aggregation $\gamma = 1$ before addition of OAA.
c) The HR clarifiers sludge can very effectively and economically be dewatered to spadeable consistency by centrifugation.
d) The low dosages of OAA applied to the POA process did not produce any filterability problems because the filter media grading and filter backwashing system were appropriately designed.

7. A 10 ML.d^{-1} P-clarifier designed for POA process was installed for the recovery of water from the Pulsator clarifier sludge; the Pulsators purified highly eutrophic dam water. The experience gained with this installation is summarized as follows:

a) The employer requested to recover at least 70% of water to contain less than 20 mg SS.L^{-1} as the recovered water is delivered to filtration. The P-clarifier was successfully recovering 82% of water containing less than 4 mg SS.L^{-1}.
b) Over the years the P-clarifier flow increased about three times. It was taken out of service after some 25 years of operation.

8. A small pilot P-clarifier designed for desilting of the gold mine underground water was tested. The underground water containing up to about 20,000 mg SS.L^{-1} was pumped to surface. Outstanding performance results were obtained. The underground water containing about 5 000 mg SS.L^{-1} was desilted to contain less than 20 mg SS.L^{-1} at an OAA dosage D_{OAA} = 1.5 mg.L^{-1}. Another significant benefit of the P-clarifier is its ability to float, collect and remove oil from the desilted water at the top of the agglomeration compartment.

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a) To continue testing a great variety of different polymers and thus contributing to the development of the POA method,
b) To Dr R. Wells for convincing RWB management to install the first 3 m diameter pilot HR clarifier.

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4. The City of Salisbury, Rhodesia (now the City of Harare, Zimbabwe) for accepting the P-Clarifier for dewatering the eutrophic sludge from the Pulsator clarifiers installed at their Hunyani waterworks and its staff for the most successful operation of this plant.

Dedication

This article is dedicated to:

- *The memory of our dear friend and colleague Dr Silvestr Mutl of the Institute for Hydrodynamics of the Czech Academy of Sciences who developed, among others, the Test of Aggregation which is an indispensable tool for the evaluation of aggregation efficiency as well as the performance efficiency of waterworks. Dr Mutl also contributed, through his knowledge and laboratory investigations carried out with his team of doctoral students, to the explanation of certain characteristics of the micro-aggregates formed under high agitation intensity. Some of these findings were subsequently included in the PhD thesis of Martin Pivokonsky.*
- *The memory of our dear friend and colleague Dipl. Ing. Arch. Vladimir Selzer who did the architectural design of the Saulspoort waterworks.*
- *all open-minded water purification specialists and waterworks operators.*

Abreviations

BT	-	Blind test
COD_{Mn}	-	Chemical oxygen demand determined by oxidation of the organic matter in a boiling mixture of potassium permanganate ($KMnO_4$) and sulphuric acid
CSAV	-	Czechoslovak Academy of Sciences
DOC	-	Dissolved organic carbon
HR clarifier	-	High Rate sludge blanket clarifier
HRCT	-	High Rate Clarification Technology
IHDS	-	Inline High Density Suspension formation process
MA	-	Macro-aggregates
Me	-	Cation of hydrolyzing coagulant
MI	-	Micro-aggregates
NA	-	Non-aggregated, non-separable particles of impurities
NOM	-	Natural organic matter determined
NTU	-	Nephelometric turbidity unit
OAA	-	Organic agglomeration agent (anionic or non-ionic water-soluble polymer)
POA	-	Post-orthokinetic agglomeration process
PR	-	Primary aggregates
SS	-	Suspended solids
TOC	-	Total organic carbon
Tu	-	Turbidity

References Références Referencias

1. POLASEK P. (1980): Methods and testing procedures for monitoring and evaluating waterworks performance. *Proc. Int. Conf. on Filtration and Separation, SAFIL, Johannesburg.*
2. POLASEK P., MUTL S. (2005): High Rate Clarification technology. *Proc. IWA Spec.*
3. POLASEK P. and MUTL S. (2005): Optimisation of reaction conditions of particle aggregation in water purification – back to basics. *J.Water SA, Vol. 31, No. 1, 61-72, 2005.*
4. POLASEK P. and MUTL S. (2002): Cationic polymers in water treatment, Part 1: Treatability of water with cationic polymers. *Water SA, Vol 28, No. 1, p.69-82*.
5. POLASEK P and MUTL S (2002): Cationic polymers in water treatment, Part 2: Filterability of CPE-formed suspension. *Water SA* 28 (1) 83–88. https://doi.org/10.4314/wsa.v28i1.4871
6. AMRAN A.H., ZAIDI N.S., MUDA K., LOAN L.W. (2018): Effectiveness of Natural Coagulant in Coagulation Process: A Review. *International Journal of Engineering & Technology, 7 (3.9) (2018) 34-37 International Journal of Engineering & Technology, Website: www.sciencepubco.com/index.php/IJET Research paper*
7. POLASEK P. and WANTENAAR C.J. (2023): Technical paper: The inability of organic coagulants of purifying potable water to its best attainable quality. *Water SA, 49, 3, p. 311 – 319, July 2023.* https://doi.org/10.17159/wsa/2023.v49.i3.3906.
8. HEREIT F., MUTL S.and VAGNER V. (1977): Hodnoceni provozu upraven vody (Evaluation of waterworks performance), *J. Vodni hospodarstvi-B, 4, 27, p.80-86*.
9. POLASEK P. (2014): Methodology for evaluating and monitoring of waterworks performance efficiency - Part 1: Methods and testing procedures. *Advances in Chemical Engineering. and Science, 2014, 4, pp.208-220*; http://dx.doi.org/10.4236/aces.2014.42024.
10. POLASEK P. (2014): Significance and determination of portion of non-separable particles of impurities in water purification. *J. Water SA, 40,1, January 2014, pp. 89-94.*
11. HAN M.Y. and LAWLER D.F. (1992): the (Relative) Insignificance of G in flocculation. *JAWWA, 84, p.79-91*.
12. CAMP T.R. and STEIN P.C. (1943): Velocity gradient and Internal Work in Fluid Motion. *Jour. of Boston Soc. Civil Engrs., 30, p. 219.*
13. SOUCEK J. and SINDELAR J. (1967): The use of a dimensionless criterion in the Characterization of flocculation. *Prace a Studie – Sesit 119, VUV, Praha Podbaba, Czechoslovakia.*
14. POLASEK P. (2011): Influence of velocity gradient on optimisation of the aggregation process and physical properties of formed aggregates: Part 1: Inline high density suspension (IHDS) aggregation process. *J. Hydrol. Hydromech., 59, 2, 107–117;*
15. POLASEK P. (2011): Influence of velocity gradient on optimisation of the aggregation process and physical properties of formed aggregates: Part 2:

Quantification of the influence of agitation intensity and time on the properties of formed aggregates. *J. Hydrol. Hydromech, 59, 3, 196–205*.
16. PIVOKONSKY M. (2002): Influence of the velocity gradient and time of its application on the size characteristic of the aggregates formed during agitation (Czech). *Ph.D. Thesis, Faculty of Sciences, Institute for Environmental studies, Charles University, Prague*.
17. PIVOKONSKY M., BUBAKOVA P., PIVOKONSKA L. and KNESL B. (2011): Tvorba suspense pri uprave vody – theory a praxe (Forrnation of suspension in water purification – theory and practice). *Sovak CR, Praha 2011*.
18. PIVOKONSKY M., VASATOVA P., NACERADSKA J. and PIVOKONSKA L. (2020): Koagulace pri uprave vody, Teorie a praxe (Coagulation in water purification, Theory and practice). *Academia Praha, 2020.*
19. BOLTO B. and GREGORY J. (2007): Organic polyelectrolytes in water purification. *IWA Water Research 41, p.2301-2324*.
20. SHATAT R.S., NIAZI S.K. and AL BATATI F.S. (2019): Synthetic polyelectrolytes based on polyacrylamide: non-ionic, anionic and cationic polyelectrolytes and their application in water and waste water treatment: Literature Review. *Chemical Science International Journal*, *25*(4), *1–8. https://doi.org/10.9734/CSJI/2018/46483.*
21. AMRAN A.H., ZAIDI N.S., MUDA K. and LOAN L.W. (2018): Effectiveness of Natural Coagulant in Coagulation Process: A Review. *International Journal of Engineering & Technology, 7 (3.9) (2018) 34-37 International Journal of Engineering & Technology, Website: www.sciencepubco.com/index.php/IJET Research paper*
22. DEB A.K. (1965): Theory of Water Filtration – Discussion. *J. San.Eng.Div.-SA 1 Feb., 1965.*
23. HEREIT F., MUTL S. & VÁGNER V. (1980): The formation of Separable Suspensions and the Methods of its Assessment. *Aqua, No 5, p. 95-99, 1980*.
24. MUTL S. (1995): Private communication. *Institute for hydrodynamics, The Czech Academy of Sciences.*
25. MORAVEC J. (1969): Intensifikace ciriciho procesu pomoci organickych flokulantu (Intensification of clarification process by organic flocculants). *Proc. Conf. CsVTS DEMI 69, Pardubice, Czechoslovakia.*
26. FLOCCOTAN (PTY.) LTD. (1971): Product specification. *Floccotan (Pty) Ltd*.
27. CYANAMID CO. (SA) (PTY) LTD (1976): Private communication*. Cyanamid Co. USA*
28. OOSAWA F. (1969*):* Polyelectrolytes*. M.Dekker Inc., New York.*
29. 29 CYANAMID CO. (1971): Product Specifications. *Cyanamid Co*. USA.
30. MACKRLE S (1965): Hydrodynamic principles of sludge blanket. *J. Effluent Water Treatment 5, 10, p. 505.*
31. The Bethlehem Waterworks logbook for the relevant period.
32. POLASEK P. and VAN DUUREN F.A. (1981): The performance results from the operation of High Rate Clarifiers at Bethlehem Municipal waterworks. Proc. Int. Conf. Water Industry '81, Brighton, UK
33. The Saulspoort Waterworks logbook for the relevant period.
34. VAN STEENDEREN R.A, THERON S.J. and ENGELBRECHT A.C.W. (1982): An investigation into the occurrence and concentration of trihalomethanes and their precursors in South African drinking waters. *Report to the Water Research Commission by the Division of Water Technology, CSIR - WRC Report No. 194/1/89*
35. Van STEENDEREN R.A. (1983): Analytical results of water quality. *Private communication.*
36. POLASEK P, and MUTL S (1995): Guidelines to coagulation and flocculation for surface waters, Volume 2: Evaluation of treatment process of different waterworks, Case studies. *Private publication of PPA, Hydro and Watercare Consulting Engineers.*
37. AVERY C.G. (1981): Sharples Polymizer for dewatering sludge from the water purification process. *Technical Report, Penwalt, Johannesburg, South Africa*.
38. HEREIT F. and POLASEK P. (2014): Methodology for evaluating and monitoring of waterworks performance efficiency - Part 2: Test of filterability. *Advances in Chemical Engineering and Science, 4, pp. 470-48222*.
39. NORTJE N (1995): Private communication. *Hydroproject Pvt. Ltd. Bulawayo, Zimbabwe*.
40. SMITH C D L (1977): Hunyani water augmentation scheme 1971 - *Contract ASM 7A/1973, Sludge Thickener Performance Tests, Handing-over Report, Bateman.*

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Response Spectra Study of High Rise Structure with RC Shear Wall by Considering Lateral Loads and Storey Stiffness

By Mahdi Hosseini
Nanjing Forestry University

Abstract- The present study aims at evaluation of the behavior of a high rise structure with dual system for estimation of structural response lateral loads and storey stiffness has been studied. To meet this objective, G+29 storey building with C shape, Box shape, E shape, I shape and plus shape of RC shear wall, at the center in concrete frame structure with fixed support conditions under different types of soil for high earthquake zone are analyzed by dynamic analysis in ETABS software. It was found that the building with box shape shear walls provided at the center core showed very significant performance in terms of lateral loads and storey stiffness. It was found that the behavior of new shape (plus shape) of shear wall is similar to I and box shape.

For severe lateral loads caused by wind load and or earthquake load, the RC shear wall is obvious.

Keywords: dynamic analysis, structural response, soil conditions, high earthquake zone, ETABS software.

GJRE-E Classification: LCC: TA658.44

Strictly as per the compliance and regulations of:

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I. Introduction

Shear wall is a structural element used to resist lateral/horizontal/shear forces parallel to the plane of the wall by:

- Cantilever action for slender walls where the bending deformation is dominant.
- Truss action for squat/short walls where the shear deformation is dominant.

Shear walls resist two types of forces: shear forces and uplift forces. Connections to the Structure above transfer horizontal forces to the shear wall. This transfer creates shear forces throughout the height of the wall between the top and bottom shear wall connections. The strength of the lumber, sheathing and fasteners must resist these shear forces or the wall will tear or "shear" apart uplift forces exist on shear walls because the horizontal forces are applied to the top of the wall. These uplift forces try to lift up one end of the wall and push the other end down. In some cases, the uplift force is large enough to tip the wall over. Uplift forces are greater on tall short walls and less on low long walls. Bearing walls have less uplift than non-bearing walls because gravity loads on shear walls help them resist uplift. Shear walls need holdown devices at each End when the gravity loads cannot resist all of the uplift. The holdown device then provides the necessary uplift resistance.

a) Site Selection

The seismic motion that reaches a structure on the surface of the earth is influenced by local soil conditions. The subsurface soil layers underlying the building foundation may amplify the response of the building to earthquake motions originating in the bedrock.

For soft soils the earthquake vibrations can be significantly amplified and hence the shaking of structures sited on soft soils can be much greater than for structures sited on hard soils. Hence the appropriate soil investigation should be carried out to establish the allowable bearing capacity and nature of soil. The choice of a site for a building from the failure prevention point of view is mainly concerned with the stability of the ground. The very loose sands or sensitive clays are liable to be destroyed by the earthquake, so much as to lose their original structure and thereby undergo compaction. This would result in large unequal settlements and damage the building. If the loose cohesion less soils are saturated with water they are likely to lose their shear resistance altogether during ground shaking. This leads to liquefaction. Although such soils can be compacted, for small buildings the operation may be too costly and the sites having these soils are better avoided.

For large building complexes, such as housing developments, new colonies, etc. this factor should be thoroughly investigated and the site has to be selected appropriately. Therefore a site with sufficient bearing capacity and free from the above defects should be chosen and its drainage condition improved so that no water accumulates and saturates the ground especially close to the footing level.

b) Bearing Capacity of Foundation Soil

Three soil types are considered here:

I. *Hard* - Those soils, which have an allowable bearing capacity of more than 10t/m2.
II. *Medium* - Those soils, which have an allowable bearing capacity less than or equal to 10t/m2.

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III. *Soft* - Those soils, which are liable to large differential settlement or liquefaction during an earthquake.

II. Methodology

a) Dynamic Analysis

Dynamic analysis shall be performed to obtain the design seismic force, and its distribution in different levels along the height of the building, and in the various lateral load resisting element, for the following buildings: Regular buildings: Those greater than 40m in height in zones IV and V, those greater than 90m in height in zone II and III.

Irregular Buildings: All framed buildings higher than 12m in zones IV and V, and those greater than 40m in height in zones II and III.

The analysis of model for dynamic analysis of buildings with unusual configuration should be such that it adequately models the types of irregularities present in the building configuration. Buildings with plan irregularities, as defined in IS code: 1893-2002 cannot be modeled for dynamic analysis.

Dynamic analysis may be performed either by the TIME HISTORY METHOD or by the RESPONSE SPECTRUM METHOD.

b) Response Spectrum Method

The word spectrum in engineering conveys the idea that the response of buildings having a broad range of periods is summarized in a single graph. This method shall be performed using the design spectrum specified in code or by a site-specific design spectrum for a structure prepared at a project site. The values of damping for building may be taken as 2 and 5 percent of the critical, for the purposes of dynamic of steel and reinforce concrete buildings, respectively. For most buildings, inelastic response can be expected to occur during a major earthquake, implying that an inelastic analysis is more proper for design. However, in spite of the availability of nonlinear inelastic programs, they are not used in typical design practice because:

1. Their proper use requires knowledge of their inner workings and theories. design criteria, and
2. Result produced are difficult to interpret and apply to traditional design criteria, and
3. The necessary computations are expensive.

Therefore, analysis in practice typically use linear elastic procedures based on the response spectrum method. The response spectrum analysis is the preferred method because it is easier to use.

c) Response Spectrum Analysis

This method is also known as modal method or mode superposition method. It is based on the idea that the response of a building is the superposition of the responses of individual modes of vibration, each mode responding with its own particular deformed shape, its own frequency, and with its own modal damping.

According to IS-1893(Part-I):2002, high rise and irregular buildings must be analyzed by response spectrum method using design spectra. There are significant computational advantages using response spectra method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves only the calculation of the maximum values of the displacements and member forces in each mode using smooth spectra that are the average of several earthquake motions. Sufficient modes to capture such that at least 90% of the participating mass of the building (in each of two orthogonal principle horizontal directions) have to be considered for the analysis. The analysis is performed to determine the base shear for each mode using given building characteristics and ground motion spectra. And then the storey forces, accelerations, and displacements are calculated for each mode, and are combined statistically using the SRSS combination. However, in this method, the design base shear (V_B) shall be compared with a base shear (V_b) calculated using a fundamental period T. If is less than response quantities are (for example member forces, displacements, storey forces, storey shears and base reactions) multiplied by V_B/ Response spectrum method of analysis shall be performed using design spectrum. In case design spectrum is specifically prepared for a structure at a particular project site, the same may be used for design at the discretion of the project authorities.

III. Modeling of Building

a) Details of the Building

A symmetrical building of plan 38.5m X 35.5m located with location in zone V, India is considered. Four bays of length 7.5m & one bays of length 8.5m along X - direction and Four bays of length 7.5m & one bays of length 5.5m along Y - direction are provided. Shear Wall is provided at the center core of building model.

Structure 1: G+29 storey building with plus shape shear wall at the center of structure.
Structure 2: G+29 storey building with box shape shear wall at the center of structure.
Structure 3: G+29 storey building with C-shape shear wall at the center of structure.
Structure 4: G+29 storey building with E-shape shear wall at the center of structure.
Structure 5: G+29 storey building with I-shape shear wall at the center of structure.

b) Load Combinations

As per IS 1893 (Part 1): 2002 Clause no. 6.3.1.2, the following load cases have to be considered for analysis:

1.5 (DL + IL)
1.2 (DL + IL ± EL)
1.5 (DL ± EL)
0.9 DL ± 1.5 EL

Earthquake load must be considered for +X, -X, +Y and –Y directions.

Table 1: Details of the Building

Building Parameters	Details
Type of frame	Special RC moment resisting frame fixed at the base
Building plan	38.5m X 35.5m
Number of storeys	30
Floor height	3.5 m
Depth of Slab	225 mm
Size of beam	(300 × 600) mm
Size of column (exterior)	(1250×1250) mm up to story five
Size of column (exterior)	(900×900) mm Above story five
Size of column (interior)	(1250×1250) mm up to story ten
Size of column (interior)	(900×900) mm Above story ten
Spacing between frames	7.5-8.5 m along x - direction 7.5-5.5 m along y - direction
Live load on floor	4 KN/m2
Floor finish	2.5 KN/m2
Wall load	25 KN/m
Grade of Concrete	M 50 concrete
Grade of Steel	Fe 500
Thickness of shear wall	450 mm
Seismic zone	V
Important Factor	1.5
Density of concrete	25 KN/m3
Type of soil	Soft, Medium, Hard Soil Type I=Soft Soil Soil Type II=Medium Soil Soil Type III=Hard Soil
Response spectra	As per IS 1893(Part-1):2002
Damping of structure	5 percent

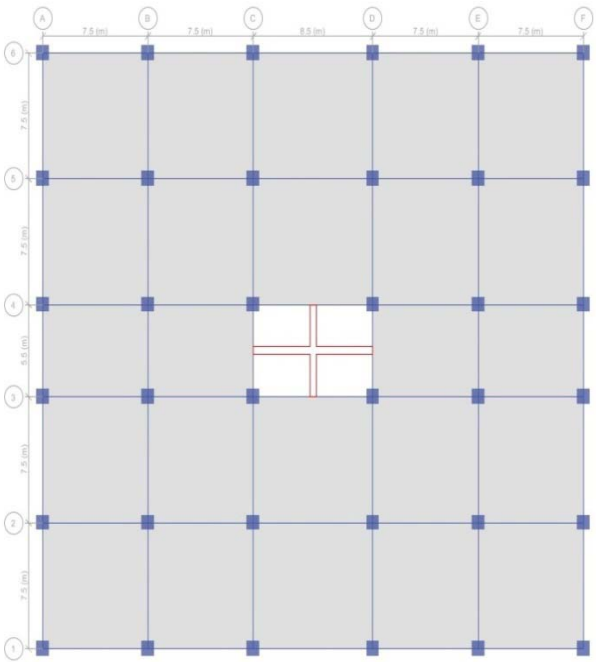


Figure 1: Plan of the Structure 1

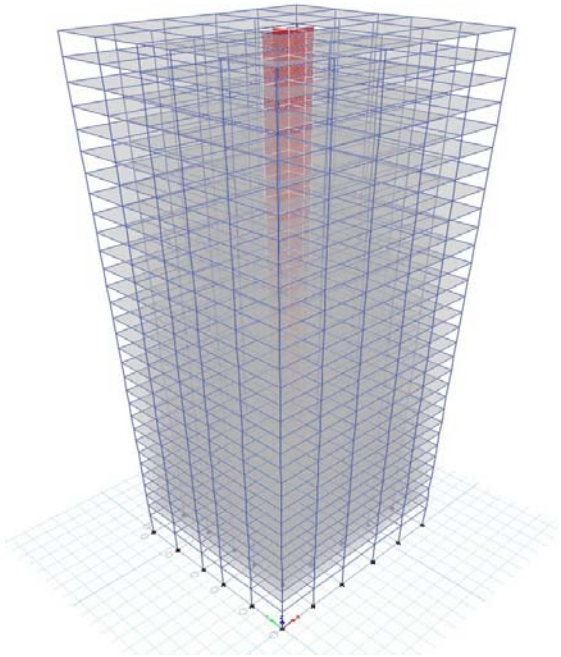


Figure 2: 3D view showing shear wall location for Structure 1

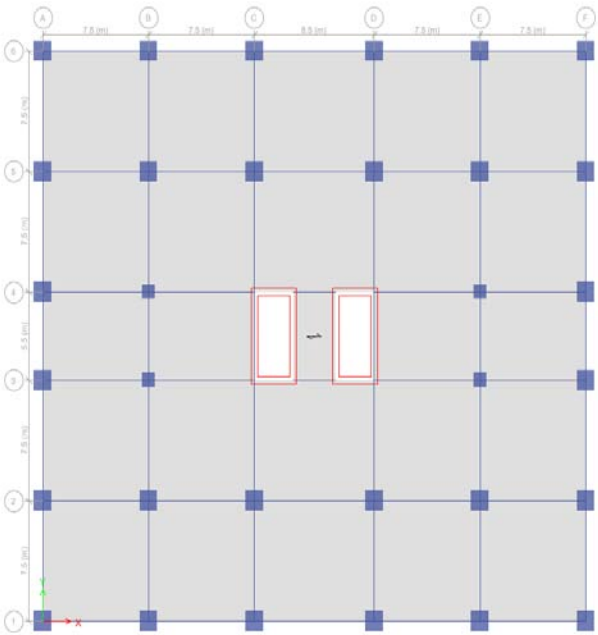


Figure 3: Plan of the Structure 2

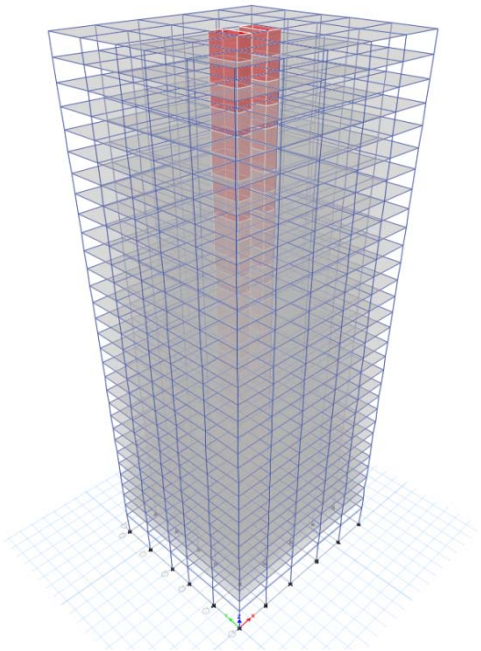


Figure 4: 3D view showing shear wall location for Structure 2

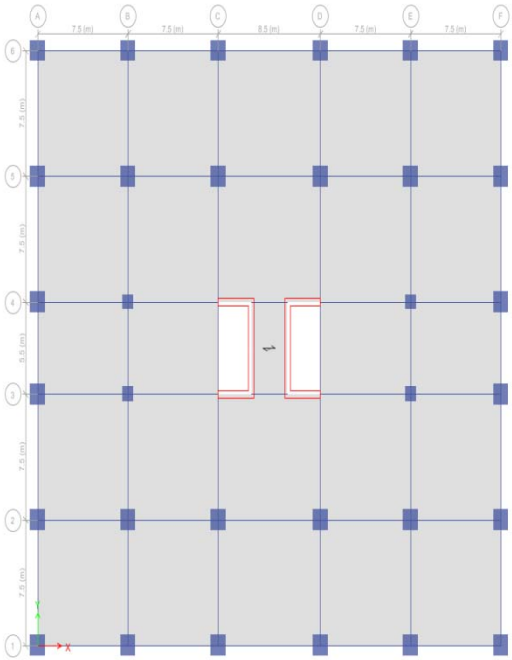


Figure 5: Plan of the Structure 3

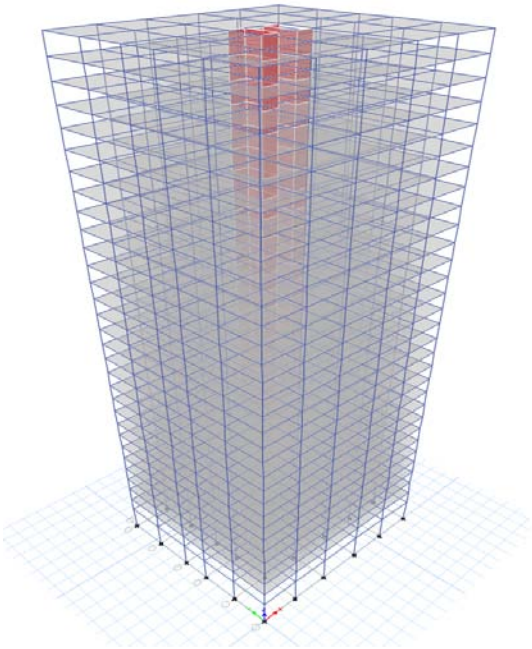


Figure 6: 3D view showing shear wall location for Structure 3

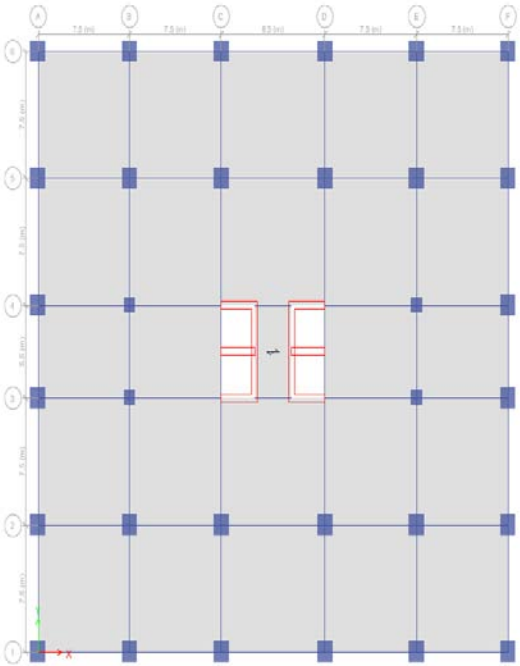


Figure 7: Plan of the Structure 4

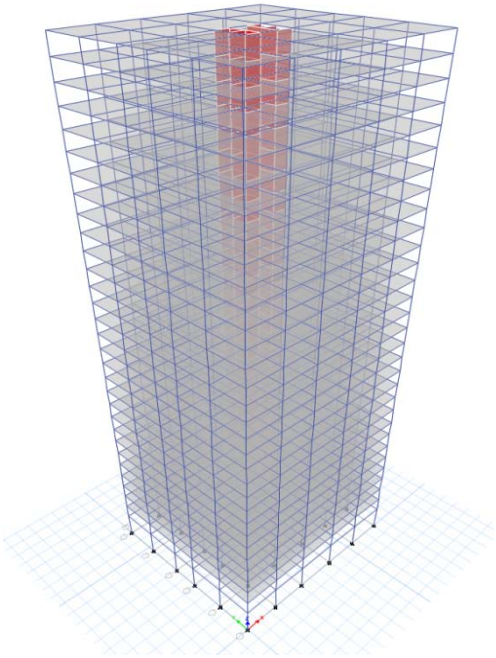


Figure 8: 3D view showing shear wall location for Structure 4

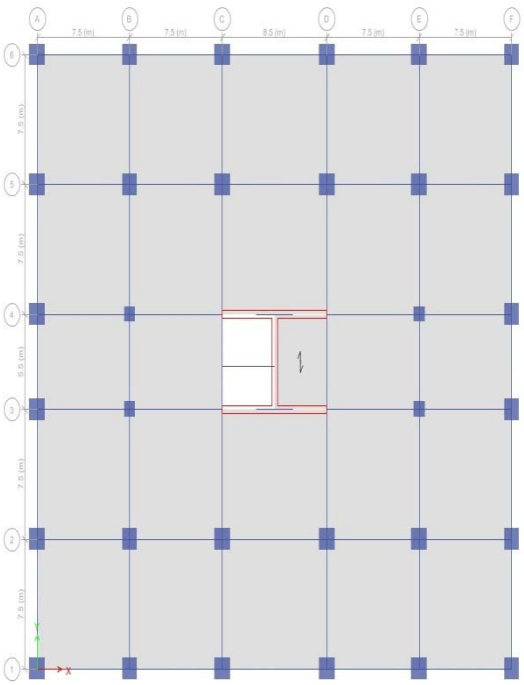


Figure 9: Plan of the Structure 5

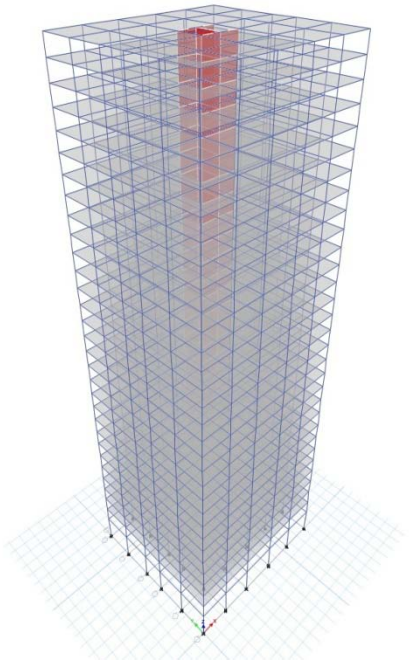


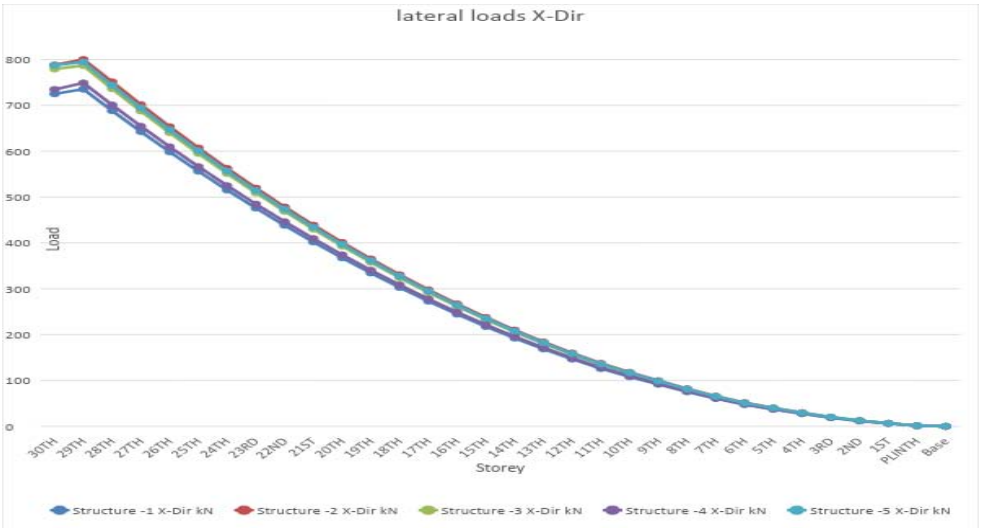
Figure 10: 3D view showing shear wall location for Structure 5

IV. Results and Discussions

Table 2: Lateral loads of structures in soft soil in X - direction with load cases EQXP"kN"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	725.0746	788.0822	779.3094	734.6607	787.3047
29TH	107.5	Top	735.3706	802.651	786.6752	748.8055	794.5243
28TH	104	Top	688.2655	751.2361	736.2837	700.8398	743.6301
27TH	100.5	Top	642.7194	701.523	687.5601	654.4617	694.4203
26TH	97	Top	598.7324	653.5115	640.5042	609.671	646.8949
25TH	93.5	Top	556.3045	607.2018	595.1161	566.4679	601.054
24TH	90	Top	515.4355	562.5936	551.3959	524.8523	556.8975
23RD	86.5	Top	476.1256	519.6872	509.3435	484.8242	514.4255
22ND	83	Top	438.3747	478.4824	468.9588	446.3836	473.6379
21ST	79.5	Top	402.1829	438.9793	430.242	409.5306	434.5348
20TH	76	Top	367.5501	401.1779	393.1929	374.265	397.1161
19TH	72.5	Top	334.4763	365.0781	357.8117	340.587	361.3818
18TH	69	Top	302.9615	330.68	324.0983	308.4965	327.332
17TH	65.5	Top	273.0058	297.9836	292.0526	277.9935	294.9666
16TH	62	Top	244.6091	266.9889	261.6748	249.0781	264.2857
15TH	58.5	Top	217.7715	237.6958	232.9648	221.7501	235.2892
14TH	55	Top	192.4929	210.1044	205.9225	196.0097	207.9772
13TH	51.5	Top	168.7733	184.2147	180.5481	171.8567	182.3496
12TH	48	Top	146.6128	160.0266	156.8415	149.2913	158.4064
11TH	44.5	Top	126.0113	137.5403	134.8027	128.3134	136.1477
10TH	41	Top	108.2038	117.9886	115.6639	110.1585	116.8056

9TH	37.5	Top	91.6609	99.8447	97.8991	93.2966	98.8543
8TH	34	Top	75.3493	82.0768	80.4774	76.6939	81.2626
7TH	30.5	Top	60.6347	66.0484	64.7614	61.7167	65.3932
6TH	27	Top	47.517	51.7595	50.7509	48.3649	51.2461
5TH	23.5	Top	37.0427	40.255	39.4902	37.6855	39.8653
4TH	20	Top	27.6428	29.9683	29.4137	28.1087	29.6854
3RD	16.5	Top	18.8144	20.3971	20.0197	19.1315	20.2046
2ND	13	Top	11.6791	12.6616	12.4273	11.8759	12.5421
1ST	9.5	Top	6.2369	6.7616	6.6365	6.342	6.6978
PLINTH	6	Top	1.3465	1.4296	1.3634	1.3978	1.3887
Base	0	Top	0	0	0	0	0

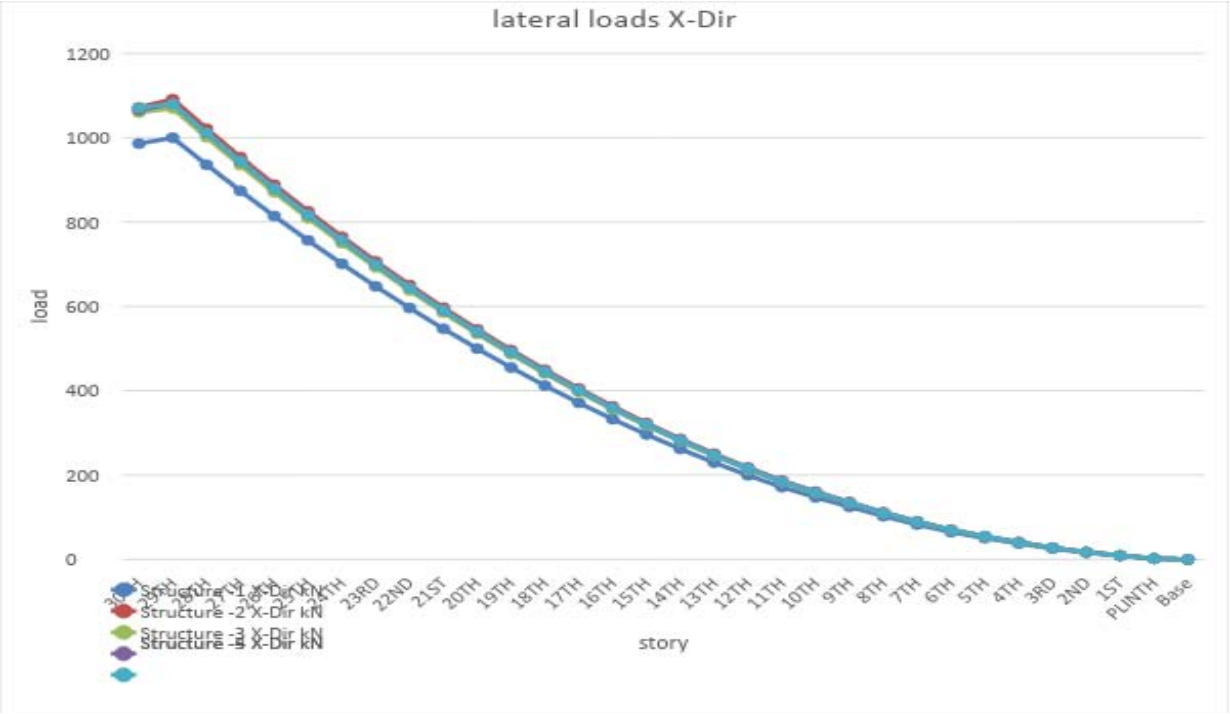


Graph 1: Lateral loads of structures in soft soil in X - direction with load cases EQXP

Table 3: Lateral loads of Structures in Medium Soil in X - Direction with load cases EQXP"kN"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	986.1014	1071.7918	1059.8608	1065.8278	1070.7344
29TH	107.5	Top	1000.104	1091.6053	1069.8782	1080.7416	1080.5531
28TH	104	Top	936.0411	1021.6812	1001.3458	1011.5134	1011.3369
27TH	100.5	Top	874.0984	954.0713	935.0817	944.5763	944.4116
26TH	97	Top	814.2761	888.7757	871.0857	879.9306	879.7771
25TH	93.5	Top	756.5741	825.7944	809.358	817.5761	817.4335
24TH	90	Top	700.9923	765.1273	749.8984	757.5128	757.3806
23RD	86.5	Top	647.5308	706.7746	692.7071	699.7407	699.6187
22ND	83	Top	596.1896	650.7361	637.784	644.2599	644.1476
21ST	79.5	Top	546.9687	597.0119	585.1291	591.0704	590.9673
20TH	76	Top	499.8681	545.6019	534.7424	540.1721	540.0779
19TH	72.5	Top	454.8877	496.5062	486.6239	491.565	491.4793
18TH	69	Top	412.0277	449.7248	440.7736	445.2492	445.1715
17TH	65.5	Top	371.2879	405.2577	397.1916	401.2246	401.1546
16TH	62	Top	332.6684	363.1049	355.8777	359.4912	359.4285

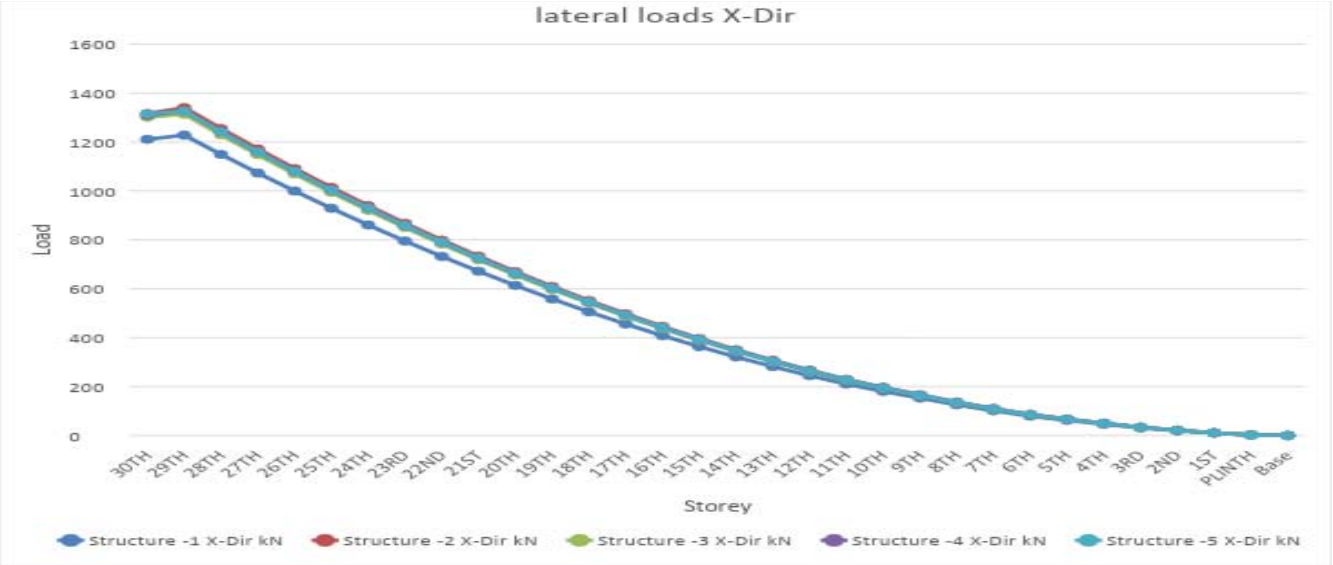
15TH	58.5	Top	296.1692	323.2663	316.8321	320.0491	319.9933
14TH	55	Top	261.7903	285.742	280.0547	282.8983	282.8489
13TH	51.5	Top	229.5317	250.532	245.5454	248.0387	247.9954
12TH	48	Top	199.3934	217.6362	213.3044	215.4703	215.4327
11TH	44.5	Top	171.3753	187.0547	183.3316	185.1932	185.1609
10TH	41	Top	147.1571	160.4645	157.3029	158.8837	158.8557
9TH	37.5	Top	124.6588	135.7888	133.1428	134.4658	134.4418
8TH	34	Top	102.4751	111.6245	109.4493	110.5369	110.5172
7TH	30.5	Top	82.4632	89.8258	88.0755	88.9506	88.9348
6TH	27	Top	64.6231	70.3929	69.0212	69.7071	69.6946
5TH	23.5	Top	50.3781	54.7468	53.7067	54.2268	54.2168
4TH	20	Top	37.5942	40.7568	40.0027	40.3798	40.3722
3RD	16.5	Top	25.5876	27.7401	27.2268	27.4835	27.4783
2ND	13	Top	15.8836	17.2198	16.9011	17.0604	17.0572
1ST	9.5	Top	8.4822	9.1958	9.0256	9.1107	9.109
PLINTH	6	Top	1.8312	1.9442	1.8543	1.8992	1.8886
Base	0	Top	0	0	0	0	0



Graph 2: Lateral loads of structures in medium soil in X - direction with load cases EQXP

Table 4: Lateral loads of structures in hard soil in X- direction with load cases EQXP"kN"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	1210.8746	1316.0973	1301.4467	1308.7739	1314.7989
29TH	107.5	Top	1228.0688	1340.4271	1313.7475	1327.0871	1326.8556
28TH	104	Top	1149.4034	1254.5644	1229.5938	1242.0789	1241.8623
27TH	100.5	Top	1073.3415	1171.5434	1148.2253	1159.8842	1159.6819
26TH	97	Top	999.8832	1091.3643	1069.642	1080.503	1080.3145
25TH	93.5	Top	929.0284	1014.0269	993.844	1003.9353	1003.7602
24TH	90	Top	860.7773	939.5314	920.8311	930.1811	930.0189
23RD	86.5	Top	795.1297	867.8776	850.6036	859.2405	859.0906
22ND	83	Top	732.0858	799.0656	783.1612	791.1133	790.9753
21ST	79.5	Top	671.6454	733.0955	718.5041	725.7997	725.6731
20TH	76	Top	613.8086	669.9671	656.6322	663.2995	663.1838
19TH	72.5	Top	558.5754	609.6805	597.5455	603.6129	603.5076
18TH	69	Top	505.9458	552.2357	541.2441	546.7398	546.6444
17TH	65.5	Top	455.9197	497.6326	487.7279	492.6802	492.5943
16TH	62	Top	408.4973	445.8714	436.9969	441.4341	441.3571
15TH	58.5	Top	363.6784	396.952	389.0512	393.0015	392.933
14TH	55	Top	321.4631	350.8744	343.8906	347.3825	347.3219
13TH	51.5	Top	281.8514	307.6385	301.5154	304.5769	304.5238
12TH	48	Top	244.8433	267.2445	261.9253	264.5849	264.5387
11TH	44.5	Top	210.4388	229.6922	225.1205	227.4063	227.3667
10TH	41	Top	180.7003	197.041	193.1587	195.0998	195.0654
9TH	37.5	Top	153.0737	166.7407	163.4916	165.1161	165.0867
8TH	34	Top	125.8334	137.0683	134.3973	135.7328	135.7086
7TH	30.5	Top	101.26	110.3008	108.1515	109.2262	109.2067
6TH	27	Top	79.3534	86.4384	84.754	85.5962	85.5809
5TH	23.5	Top	61.8614	67.2259	65.9487	66.5873	66.5751
4TH	20	Top	46.1635	50.047	49.1209	49.584	49.5746
3RD	16.5	Top	31.42	34.0632	33.4329	33.7481	33.7417
2ND	13	Top	19.5041	21.1449	20.7536	20.9492	20.9453
1ST	9.5	Top	10.4156	11.2919	11.0829	11.1874	11.1853
PLINTH	6	Top	2.2486	2.3874	2.2769	2.3321	2.3191
Base	0	Top	0	0	0	0	0

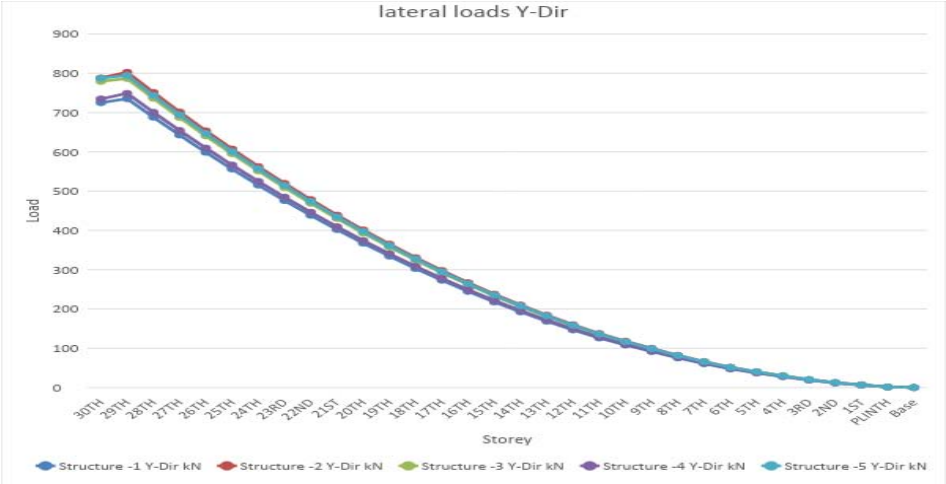


Graph 3: Lateral loads of structures in hard soil in X - direction with load cases EQXP

Table 5: Lateral loads of structures in soft soil in Y - direction with load cases EQYP"kN"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	725.0746	788.0822	779.3094	734.6607	787.3047
29TH	107.5	Top	735.3706	802.651	786.6752	748.8055	794.5243
28TH	104	Top	688.2655	751.2361	736.2837	700.8398	743.6301
27TH	100.5	Top	642.7194	701.523	687.5601	654.4617	694.4203
26TH	97	Top	598.7324	653.5115	640.5042	609.671	646.8949
25TH	93.5	Top	556.3045	607.2018	595.1161	566.4679	601.054
24TH	90	Top	515.4355	562.5936	551.3959	524.8523	556.8975
23RD	86.5	Top	476.1256	519.6872	509.3435	484.8242	514.4255
22ND	83	Top	438.3747	478.4824	468.9588	446.3836	473.6379
21ST	79.5	Top	402.1829	438.9793	430.242	409.5306	434.5348
20TH	76	Top	367.5501	401.1779	393.1929	374.265	397.1161
19TH	72.5	Top	334.4763	365.0781	357.8117	340.587	361.3818
18TH	69	Top	302.9615	330.68	324.0983	308.4965	327.332
17TH	65.5	Top	273.0058	297.9836	292.0526	277.9935	294.9666
16TH	62	Top	244.6091	266.9889	261.6748	249.0781	264.2857
15TH	58.5	Top	217.7715	237.6958	232.9648	221.7501	235.2892
14TH	55	Top	192.4929	210.1044	205.9225	196.0097	207.9772
13TH	51.5	Top	168.7733	184.2147	180.5481	171.8567	182.3496
12TH	48	Top	146.6128	160.0266	156.8415	149.2913	158.4064
11TH	44.5	Top	126.0113	137.5403	134.8027	128.3134	136.1477
10TH	41	Top	108.2038	117.9886	115.6639	110.1585	116.8056
9TH	37.5	Top	91.6609	99.8447	97.8991	93.2966	98.8543
8TH	34	Top	75.3493	82.0768	80.4774	76.6939	81.2626
7TH	30.5	Top	60.6347	66.0484	64.7614	61.7167	65.3932
6TH	27	Top	47.517	51.7595	50.7509	48.3649	51.2461
5TH	23.5	Top	37.0427	40.255	39.4902	37.6855	39.8653

4TH	20	Top	27.6428	29.9683	29.4137	28.1087	29.6854
3RD	16.5	Top	18.8144	20.3971	20.0197	19.1315	20.2046
2ND	13	Top	11.6791	12.6616	12.4273	11.8759	12.5421
1ST	9.5	Top	6.2369	6.7616	6.6365	6.342	6.6978
PLINTH	6	Top	1.3465	1.4296	1.3634	1.3978	1.3887
Base	0	Top	0	0	0	0	0

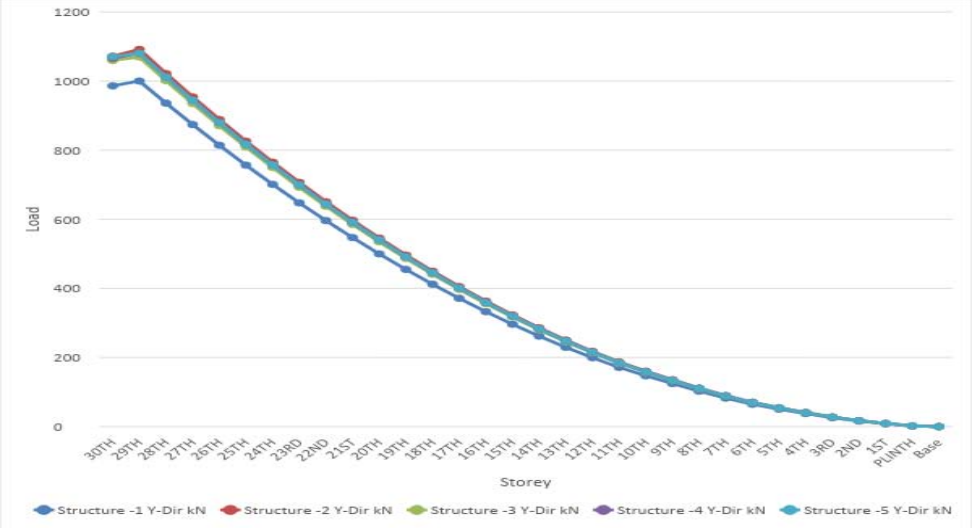


Graph 4: Lateral loads of structures in soft soil in Y - direction with load cases EQYP

Table 6: Lateral loads of structures in medium soil in Y - direction with load cases EQYP"kN"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	986.1014	1071.7918	1059.8608	1065.8278	1070.7344
29TH	107.5	Top	1000.104	1091.6053	1069.8782	1080.7416	1080.5531
28TH	104	Top	936.0411	1021.6812	1001.3458	1011.5134	1011.3369
27TH	100.5	Top	874.0984	954.0713	935.0817	944.5763	944.4116
26TH	97	Top	814.2761	888.7757	871.0857	879.9306	879.7771
25TH	93.5	Top	756.5741	825.7944	809.358	817.5761	817.4335
24TH	90	Top	700.9923	765.1273	749.8984	757.5128	757.3806
23RD	86.5	Top	647.5308	706.7746	692.7071	699.7407	699.6187
22ND	83	Top	596.1896	650.7361	637.784	644.2599	644.1476
21ST	79.5	Top	546.9687	597.0119	585.1291	591.0704	590.9673
20TH	76	Top	499.8681	545.6019	534.7424	540.1721	540.0779
19TH	72.5	Top	454.8877	496.5062	486.6239	491.565	491.4793
18TH	69	Top	412.0277	449.7248	440.7736	445.2492	445.1715
17TH	65.5	Top	371.2879	405.2577	397.1916	401.2246	401.1546
16TH	62	Top	332.6684	363.1049	355.8777	359.4912	359.4285
15TH	58.5	Top	296.1692	323.2663	316.8321	320.0491	319.9933
14TH	55	Top	261.7903	285.742	280.0547	282.8983	282.8489
13TH	51.5	Top	229.5317	250.532	245.5454	248.0387	247.9954
12TH	48	Top	199.3934	217.6362	213.3044	215.4703	215.4327

11TH	44.5	Top	171.3753	187.0547	183.3316	185.1932	185.1609
10TH	41	Top	147.1571	160.4645	157.3029	158.8837	158.8557
9TH	37.5	Top	124.6588	135.7888	133.1428	134.4658	134.4418
8TH	34	Top	102.4751	111.6245	109.4493	110.5369	110.5172
7TH	30.5	Top	82.4632	89.8258	88.0755	88.9506	88.9348
6TH	27	Top	64.6231	70.3929	69.0212	69.7071	69.6946
5TH	23.5	Top	50.3781	54.7468	53.7067	54.2268	54.2168
4TH	20	Top	37.5942	40.7568	40.0027	40.3798	40.3722
3RD	16.5	Top	25.5876	27.7401	27.2268	27.4835	27.4783
2ND	13	Top	15.8836	17.2198	16.9011	17.0604	17.0572
1ST	9.5	Top	8.4822	9.1958	9.0256	9.1107	9.109
PLINTH	6	Top	1.8312	1.9442	1.8543	1.8992	1.8886
Base	0	Top	0	0	0	0	0

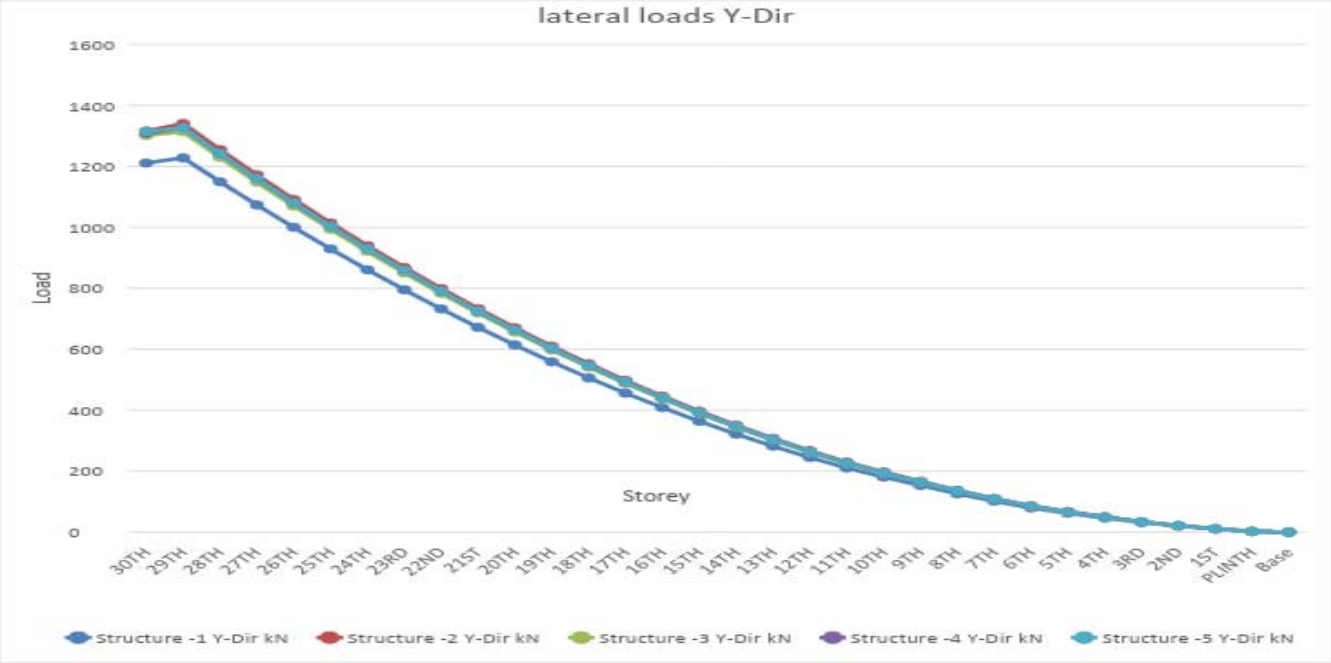


Graph 5: Lateral loads of structures in medium soil in Y - direction with load cases EQYP

Table 7: Lateral loads of structures in hard soil in Y - direction with load cases EQYP"kN"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	1210.8746	1316.0973	1301.4467	1308.7739	1314.7989
29TH	107.5	Top	1228.0688	1340.4271	1313.7475	1327.0871	1326.8556
28TH	104	Top	1149.4034	1254.5644	1229.5938	1242.0789	1241.8623
27TH	100.5	Top	1073.3415	1171.5434	1148.2253	1159.8842	1159.6819
26TH	97	Top	999.8832	1091.3643	1069.642	1080.503	1080.3145
25TH	93.5	Top	929.0284	1014.0269	993.844	1003.9353	1003.7602
24TH	90	Top	860.7773	939.5314	920.8311	930.1811	930.0189
23RD	86.5	Top	795.1297	867.8776	850.6036	859.2405	859.0906
22ND	83	Top	732.0858	799.0656	783.1612	791.1133	790.9753
21ST	79.5	Top	671.6454	733.0955	718.5041	725.7997	725.6731
20TH	76	Top	613.8086	669.9671	656.6322	663.2995	663.1838

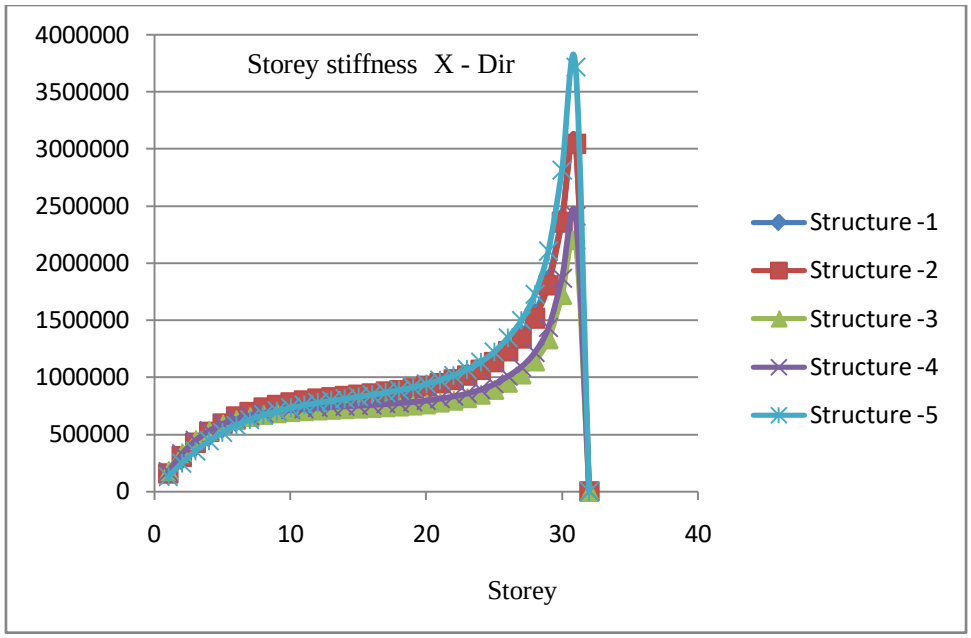
19TH	72.5	Top	558.5754	609.6805	597.5455	603.6129	603.5076
18TH	69	Top	505.9458	552.2357	541.2441	546.7398	546.6444
17TH	65.5	Top	455.9197	497.6326	487.7279	492.6802	492.5943
16TH	62	Top	408.4973	445.8714	436.9969	441.4341	441.3571
15TH	58.5	Top	363.6784	396.952	389.0512	393.0015	392.933
14TH	55	Top	321.4631	350.8744	343.8906	347.3825	347.3219
13TH	51.5	Top	281.8514	307.6385	301.5154	304.5769	304.5238
12TH	48	Top	244.8433	267.2445	261.9253	264.5849	264.5387
11TH	44.5	Top	210.4388	229.6922	225.1205	227.4063	227.3667
10TH	41	Top	180.7003	197.041	193.1587	195.0998	195.0654
9TH	37.5	Top	153.0737	166.7407	163.4916	165.1161	165.0867
8TH	34	Top	125.8334	137.0683	134.3973	135.7328	135.7086
7TH	30.5	Top	101.26	110.3008	108.1515	109.2262	109.2067
6TH	27	Top	79.3534	86.4384	84.754	85.5962	85.5809
5TH	23.5	Top	61.8614	67.2259	65.9487	66.5873	66.5751
4TH	20	Top	46.1635	50.047	49.1209	49.584	49.5746
3RD	16.5	Top	31.42	34.0632	33.4329	33.7481	33.7417
2ND	13	Top	19.5041	21.1449	20.7536	20.9492	20.9453
1ST	9.5	Top	10.4156	11.2919	11.0829	11.1874	11.1853
PLINTH	6	Top	2.2486	2.3874	2.2769	2.3321	2.3191
Base	0	Top	0	0	0	0	0



Graph 6: Lateral loads of structures in hard soil in Y - direction with load cases EQYP

Table 8: Storey stiffness of structures in X - direction with load cases EQXP "kN/m"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	143022.831	158381.126	181178.624	172953.339	127169.993
29TH	107.5	Top	270359.127	304820.61	337174.461	327254.392	248172.464
28TH	104	Top	381794.982	426099.529	452428.891	444924.118	354071.082
27TH	100.5	Top	472732.209	521829.67	532910.668	530105.692	443372.828
26TH	97	Top	545503.246	596139.507	588332.598	590667.978	517614.83
25TH	93.5	Top	603792.812	653296.417	626524.22	633562.623	578646.371
24TH	90	Top	650454.136	697244.731	653166.633	664160.849	628581.824
23RD	86.5	Top	688057.119	731243.736	672113.127	686302.445	669461.512
22ND	83	Top	718725.486	757866.004	685929.768	702657.154	703133.112
21ST	79.5	Top	744162.046	779096.613	696324.49	715067.826	731206.128
20TH	76	Top	765727.986	796459.142	704448.847	724816.109	755057.429
19TH	72.5	Top	784518.418	811132.376	711098.396	732811.079	775860.721
18TH	69	Top	801430.979	824047.802	716844.342	739719.634	794626.165
17TH	65.5	Top	817225.311	835968.22	722121.338	746057.058	812242.984
16TH	62	Top	832574.637	847551.522	727288.787	752252.191	829522.4
15TH	58.5	Top	848111.52	859404.644	732677.128	758697.633	847240.753
14TH	55	Top	864462.491	872134.49	738629.876	765794.668	866186.754
13TH	51.5	Top	882365.473	886388.491	745533.46	773989.455	887202.279
12TH	48	Top	902632.028	903005.62	753948.505	783882.482	911331.37
11TH	44.5	Top	925075.51	922254.804	764089.67	795870.555	939235.164
10TH	41	Top	956816.406	948997.572	779932.279	813399.858	975316.477
9TH	37.5	Top	988643.743	977803.611	796504.379	832552.458	1015663.136
8TH	34	Top	1030418.09	1015463.943	818704.224	857870.998	1067325.405
7TH	30.5	Top	1083371.397	1064358.095	848785.417	891839.923	1133147.012
6TH	27	Top	1154692.733	1130715.464	891201.329	939154.717	1220632.072
5TH	23.5	Top	1258596.787	1226013.876	953467.383	1007354.759	1343308.893
4TH	20	Top	1375721.385	1339481.13	1025949.531	1089305.176	1494603.693
3RD	16.5	Top	1560244.267	1516467.16	1140460.746	1217443.451	1727466.79
2ND	13	Top	1857338.108	1806840.251	1334049.241	1432837.445	2105070.037
1ST	9.5	Top	2395459.119	2358089.455	1721543.629	1866169.209	2813604.443
PLINTH	6	Top	3052958.805	3044220.373	2202808.66	2409798.589	3716538.982
Base	0	Top	0	0	0	0	0

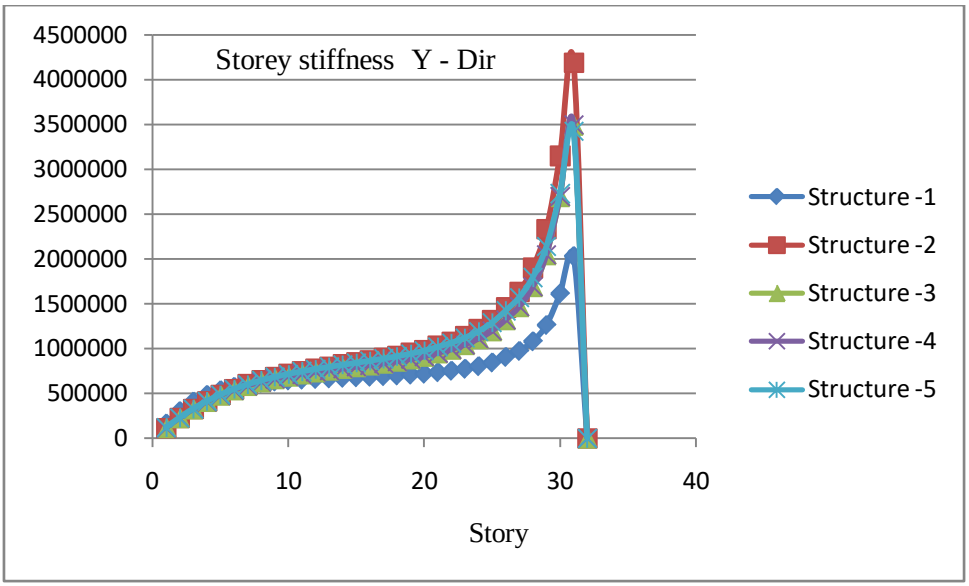


Graph 7: Storey stiffness of structures in X - direction with load cases EQXP

Table 9: Storey stiffness of structures in Y - direction with load cases EQYP "kN/m"

Story	Elevation (m)	Location	Structure -1	Structure -2	Structure -3	Structure -4	Structure -5
30TH	111	Top	164522.123	114244.812	117056.012	116081.044	119164.119
29TH	107.5	Top	302993.412	225651.248	227824.991	227134.567	229810.931
28TH	104	Top	408677.202	325183.311	325767.682	325289.284	328402.199
27TH	100.5	Top	483340.501	411537.184	409355.2	409057.523	413473.499
26TH	97	Top	535680.552	485686.066	479807.335	479661.571	486134.555
25TH	93.5	Top	572640.814	548807.058	538651.644	538628.011	547831.972
24TH	90	Top	599109.141	602365.639	587629.396	587701.998	600146.012
23RD	86.5	Top	618482.871	647862.407	628449.358	628596.387	644624.109
22ND	83	Top	633043.22	686736.82	662687.248	662891.088	682702.979
21ST	79.5	Top	644330.251	720312.671	691743.325	691990.14	715677.877
20TH	76	Top	653399.721	749782.672	716840.128	717119.319	744700.513
19TH	72.5	Top	660994.311	776214.996	739041.147	739344.806	770793.357
18TH	69	Top	667657.281	800572.833	759279.767	759602.203	794872.745
17TH	65.5	Top	673808.885	823741.302	778392.658	778730.008	817776.659
16TH	62	Top	679800.36	846559.21	797155.23	797505.172	840295.4
15TH	58.5	Top	685957.017	869854.874	816318.844	816680.403	863205.201
14TH	55	Top	692607.423	894490.095	836652.716	837026.241	887306.209
13TH	51.5	Top	700142.534	921398.569	858984.397	859371.155	913466.212
12TH	48	Top	709147.826	951743.906	884315.986	884720.614	942691.624
11TH	44.5	Top	719304.159	986339.518	913212.154	913640.643	975623.28
10TH	41	Top	736444.19	1029690.263	951180.036	951607.325	1019626.35
9TH	37.5	Top	752520.322	1078251.194	991814.364	992308.273	1064004.896
8TH	34	Top	774346.165	1139475.911	1043844.75	1044407.058	1120733.923
7TH	30.5	Top	803524.748	1216576.372	1109749.81	1110394.829	1192207.735
6TH	27	Top	844489.543	1317689.178	1197560.369	1198282.023	1287976.983
5TH	23.5	Top	906254.456	1457780.887	1321130.921	1321932.941	1422330.025
4TH	20	Top	973343.501	1633059.784	1466950.928	1468099.344	1570334.519

3RD	16.5	Top	1080765.084	1900437.015	1690646.807	1692303.93	1794350.918
2ND	13	Top	1262128.804	2332077.853	2046043.726	2048530.453	2138462.884
1ST	9.5	Top	1611231.402	3148215.488	2694593.565	2698550.737	2728249.129
PLINTH	6	Top	2029896.11	4184894.988	3491010.809	3496978.337	3423591.625
Base	0	Top	0	0	0	0	0



Graph 8: Storey stiffness of structures in Y - direction with load cases EQYP

Table 10: Comparation percentage of story lateral loads in soft soil of structures 2,3,4,5 with structure -1

Story lateral loads		Structure -2	Structure -3	Structure -4	Structure -5
Load Case	Direction	Percentage	Percentage	Percentage	Percentage
EQXP	X	8%	6%	2%	7%
EQYP	Y	8%	6%	2%	7%

Table 11: Comparation percentage of story lateral loads in medium soil of structures 2,3,4,5 with structure -1

Story lateral loads		Structure -2	Structure -3	Structure -4	Structure -5
Load Case	Direction	Percentage	Percentage	Percentage	Percentage
EQXP	X	8%	6%	7%	7%
EQYP	Y	8%	6%	7%	7%

Table 12: Comparation percentage of story lateral loads in hard soil of structures 2,3,4,5 with structure -1

Story lateral loads		Structure -2	Structure -3	Structure -4	Structure -5
Load Case	Direction	Percentage	Percentage	Percentage	Percentage
EQXP	X	8%	6%	7%	7%
EQYP	Y	8%	6%	7%	7%

a) Discussion on Results

When a structure is subjected to earthquake, it responds by vibrating. An example force can be resolved into three mutually perpendicular directions-two horizontal directions (X and Y directions) and the vertical direction (Z). This motion causes the structure to vibrate or shake in all three directions; the predominant direction of shaking is horizontal. All the structures are primarily designed for gravity loads-force equal to mass time's gravity in the vertical direction. Because of the inherent factor used in the design specifications, most structures tend to be adequately protected against vertical shaking. Vertical acceleration should also be considered in structures with large spans those in which

stability for design, or for overall stability analysis of structures. The basic intent of design theory for earthquake resistant structures is that buildings should be able to resist minor earthquakes without damage, resist moderate earthquakes without structural damage but with some non-structural damage. To avoid collapse during a major earthquake, Members must be ductile enough to absorb and dissipate energy by post elastic deformation. Redundancy in the structural system permits redistribution of internal forces in the event of the failure of key elements. When the primary element or system yields or fails, the lateral force can be redistributed to a secondary system to prevent progressive failure. The structures are supported on soil, most of the designers do not consider the soil structure interaction and its subsequent effect on structures during an earthquake. When a structure is subjected to an earthquake excitation, it interacts with the foundation and the soil, and thus changes the motion of the ground. This means that the movement of the whole ground-structure system is influenced by the type of soil as well as by the type of structure. Understanding of soil structure interaction will enable the designer to design structures that will behave better during an earthquake.

V. Conclusions

In this paper, reinforced concrete shear wall buildings were analyzed with the procedures laid out in IS codes. Seismic performance of building model is evaluated. In this study, regular shaped structures have been considered. Estimation of structural response was carried out for Dual frame system with shear wall structure.

From the above results and discussions, following conclusions can be drawn:

- Building with box shape shear walls provided at the center core showed better performance in term of storey stiffness and lateral loads.
- Provision of the shear wall, generally results in reducing the displacement because the shear wall increases the stiffness of the building.
- It is observed that the value of stiffness in X & Y-direction is same for all models with a different type of soil.
- The value of the lateral loads in x-direction for all models decreases with increase in storey level and also The value of the lateral loads in x-direction for all models in soft soil is less compared with the structure in medium soil and hard soil, lateral loads in X-direction for all models in soft soil <Medium soil < hard soil.
- Percentage of lateral load for all three type of soil is same.
- For severe lateral loads caused by wind load and or earthquake load, the reinforced shear wall is obvious. Because, it produces less deflection and less bending moment in connecting beams under lateral loads than all others structural system.
- It is evident that shear walls which are provided from the foundation to the rooftop, are one of the excellent mean for providing earthquake resistant to multistory reinforced building with different type of soil.
- ETABS is the advanced software which is used for analysing any kind of building structures. By its fast and accuracy it can easily analyses buildings up to 40 floors, ETABS can analyse any building structure with pre-determined load conditions and load combinations for shear walls regarding IS codes.

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Conflict of Interest

The author declare no conflict of interest.

Data Availability Statement

All data generated or analysed during this study are included in this article.

References Références Referencias

1. Duggal, S.K., "*Earthquake Resistant Design of Structures*" Oxford University Press, New Delhi 2010.
2. Chopra, A.K., "*Dynamics of Structures: Theory and Application to Earthquake Engineering*", Pearson Education, 4th edition, 2012.
3. Bureau of Indian Standars, IS 456: 2000, "*Plain and Reinforced Concrete-Code of practice*", New Delhi, India.
4. Bureau of Indian Standards: IS 13920: 1993, "*Ductile detailing of reinforced concrete structures subjected to seismic forces— Code of Practice*", New Delhi, India.
5. Bureau of Indian Standards: IS 875 (part 1): 1987, "*Dead loads on buildings and Structures*", New Delhi, India.
6. Bureau of Indian Standards: IS 875 (part 2): 1987, "*Live loads on buildings and Structures*", New Delhi, India.
7. Bureau of Indian Standards: IS 1893 (part 1): 2002, "*Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings*", New Delhi, India.
8. Berkeley "*ETABS Integrated Building Design Software*", Computers and Structure, Inc., California, USA, February 2003.

9. Hosseini, M., *Effect of Seismic Load on Column Forces in RC Structures by Response Spectrum Analysis*, Global Journal of Researches in Engineering: E Civil And Structural Engineering, 23(3), Version 1.0, pp. 1-27, 2023.
10. Hosseini, M., and N.V. Ramana Rao, *Impact of Dynamic Analysis of High Rise Structure With Dual System Under Different Type of Soil Conditions, Different Type Of RC Shear Wall & Different Load Combination, Load Cases*, Global Journal of Researches in Engineering: E, Civil and Structural Engineering, 19(1), 1, Version 1.0, pp. 9-14, 2019.
11. Hosseini, M., and Z.N. Asad, *Seismic Analysis Of High Rise Structures Under Different Type Of RC Shear Walls For Estimation Of Structural Response; Storey Displacements, Time Period And Frequency For An Earthquake Resistant Building*, International Journal of Innovative Research in Advanced Engineering, 6(4), pp. 299-326, 2019.
12. Hosseini, M., and N.V. Ramana Rao, *Study The Impact of The Drift (Lateral Deflection) of The Tall Buildings Due To Seismic Load in Concrete Frame Structures With Different Type of RC Shear Walls*, Global Journal of Researches in Engineering: E, Civil and Structural Engineering, 18(1), Version 1.0, pp.59-83, 2018.
13. Hosseini, M., and A. N. A. Askari, *Dynamic Analysis of Multi-Storey Building with Openings in Shear Wall*, International Journal of Emerging Trends in Engineering and Development (IJETED), 8(5), pp.31-61, 2018.
14. Hosseini, M., M. Farookh, and H. Hosseini, *Earthquake Analysis of Multi-Storey Building with Effect of Shear Walls (Shear Walls at the Centre Core and Corners*, International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), 6 (6), pp. 12136-12157, 2017.
15. Hosseini, M., and N.V. Ramana Rao, *Dynamic Analysis of High Rise Building with C Shape RC Shear Wall at the Center in Concrete Frame Structure*, International Journal of Recent Technology and Engineering, 6 (5), pp. 7-30, 2017.
16. Hosseini, M., *Effective of Seismic Load on Behavior of Rectangular Shear Wall in RC Frame structure" Global Journal of Researches in Engineering: E, Civil And Structural Engineering*, 17 (3), Version 1.0, pp.19-30, 2017.
17. Hosseini, M., and N.V. Ramana Rao., *Earthquakes Analysis of High Rise Buildings with Effect of Box Shape RC Shear Walls at the Center*, International Journal of Engineering and Advanced Technology (IJEAT), 7 (2), pp. 50-74, 2017.
18. Hosseini, M., A. Askari., and N.V. Ramana Rao., *Earthquake Risks and Effective of Earthquake Load and Wind Load on Behavior of Shear Wall in Frame Structure*, International Journal of Civil Engineering and Technology, 5 (8), pp. 04-19, 2014.
19. Rahangdale, H., and Satone, S.R., Design and analysis of multi-storied building with effect of shear wall, International journal of engineering research and application, 3 (3), pp. 223-232, 2013.
20. Chandurkar, P.P., and Pajgade, P.S., Seismic analysis of RCC building with and without shear wall, International, Journal of Modern Engineering Research. 3 (3), pp. 1805-1810, 2013.

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The use of Oil Shale in Cement Manufacturing

By Mohamed Amine Alouani, Dennoun Saifaoui, Abdelkader Alouani, Younes Alouani, Mouaad Alouani & Chaimaa Belkarkor

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Abstract- The world's strong economic growth and increasing populations have generated a remarkably growing demand for resources, especially energy. Current conventional sources cannot meet the future needs. Efforts are being focused on renewable energies, deep-sea oil and the development of new techniques to value heavy oils, tar sands and oil shale. This could bridge the gap between energy demand and supply. In our study and research program, we have developed solutions to exploit oil shale deposits as part of sustainable development, using renewable energy sources, unconventional water and CO2 capture techniques, in addition to the integration of other uses. The objective is to make the overall exploitation of oil shale deposits profitable, remarkably reducing the impact on the global environment.

To make the exploitation of oil shale deposits profitable, our research was directed towards the development of other possibilities of use concerning the coating of roads and runways, the production of cement and the manufacture of carbon plates. In this article, we develop the use of shale for cement manufacturing.

Keywords: oil shale, coating of roads, sustainable development, cement manufacturing, deposits resources.

GJRE-E Classification: LCC Code: TN870.O5, TD195.E49, TN881.A3, TD885.5

Strictly as per the compliance and regulations of:

The use of Oil Shale in Cement Manufacturing

Mohamed Amine Alouani [α], Dennoun Saifaoui [σ], Abdelkader Alouani [ρ], Younes Alouani [ω], Mouaad Alouani [¥] & Chaimaa Belkarkor [§]

Abstract- The world's strong economic growth and increasing populations have generated a remarkably growing demand for resources, especially energy. Current conventional sources cannot meet the future needs. Efforts are being focused on renewable energies, deep-sea oil and the development of new techniques to value heavy oils, tar sands and oil shale. This could bridge the gap between energy demand and supply. In our study and research program, we have developed solutions to exploit oil shale deposits as part of sustainable development, using renewable energy sources, unconventional water and CO2 capture techniques, in addition to the integration of other uses. The objective is to make the overall exploitation of oil shale deposits profitable, remarkably reducing the impact on the global environment.

To make the exploitation of oil shale deposits profitable, our research was directed towards the development of other possibilities of use concerning the coating of roads and runways, the production of cement and the manufacture of carbon plates. In this article, we develop the use of shale for cement manufacturing.

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I. General Introduction and Background

The world's strong economic growth and increasing populations have generated a remarkably growing demand for resources, especially energy. Current conventional sources cannot meet the future needs. Efforts are being focused on renewable energies, deep-sea oil and the development of new techniques to value heavy oils, tarsands and oil shale. This could bridge the gap between energy demand and supply. Several countries with oil shale deposits have launched projects to examine the possibility of exploiting these deposits. Morocco is one of these countries, with significant oil shale deposits in the Middle Atlas (Timahdit), Tarfaya, Tangier and Grand Atlas regions (Fig. 1) [1].

Morocco has a reserve of around 53 billion barrels of oil shale, in addition to a rich capacity for shale gas and oil. The exploration works for these unconventional hydrocarbons, which began several years ago, has proved highly encouraging. The first research into the development of oil shale in Morocco began in Tangier, with the creation of the oil shale company of Tangier. The company built a pilot plant with a daily capacity of 80 tons of oil shale. The Timahdit and Tarfaya deposits were discovered in the 1960's. These last two deposits have been the subject of several geological and mining studies, laboratory studies, as well as pyrolysis and direct combustion tests. Their oil shales have been tested by several pyrolysis processes throughout the world mainly in the United States, Europe, the former USSR, Canada and Japan. They have been the subject of numerous technical and economic feasibility studies.

This geological, mining and laboratory work, which began in 1975 and continues to this day, has enabled us to identify the characteristics of these reserves in the deposits of Timahdit and Tarfaya oil shales. These studies showed that Moroccan shales could be upgraded by pyrolysis to produce hydrocarbons. This led Morocco to launch its own experiment and develop the T3 process (Acronym of the three deposits of Tangier, Tarfaya and Timahdit) [2].

Morocco has significant oil shale resources, ranking 6th worldwide after the USA, Russia, the Democratic Republic of Congo, Brazil and Italy, with a potential of 53 billion barrels of oil in field. This includes over 37 billion barrels in the two main deposits of Timahdit and Tarfaya.

Oil shale is used for a number of purposes, including conversion into hydrocarbons through the chemical process of pyrolysis and low-grade combustion for power generation. It is equally used as a raw material (chemical industries, agriculture, construction) for heavy oils particularly suited to diesel engines, lubricating oils and tar used in the manufacture of sealants and asphaltites.

At the international level, oil shale is exploited at a limited scale despite how important the reserves are. This is related to a double-fold problematic. The first one concerns economic challenges; the production of petroleum from oil shale does not become economically viable unless the price of a barrel is at a profitability threshold. The second issue is related to environmental challenges: the combustion and thermal processing of oil shale generate waste and emit carbon dioxide into the atmosphere.

In our study and research program, we have developed solutions to exploit oil shale deposits as part of sustainable development, using renewable energy sources, unconventional water and CO2 capture techniques, in addition to the integration of other uses.

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The objective is to make the overall exploitation of oil shale deposits profitable, remarkably reducing the impact on the global environment.

To make the exploitation of oil shale deposits profitable, our research was directed towards the development of other possibilities of use concerning the coating of roads and runways [4], the production of cement and the manufacture of carbon plates. In this article, we develop the use of shale for cement manufacturing.

II. Definition and Characterization of Bituminous Shale

The distribution of oil shale deposits in Morocco is shown in the figure (Fig. 1) below:

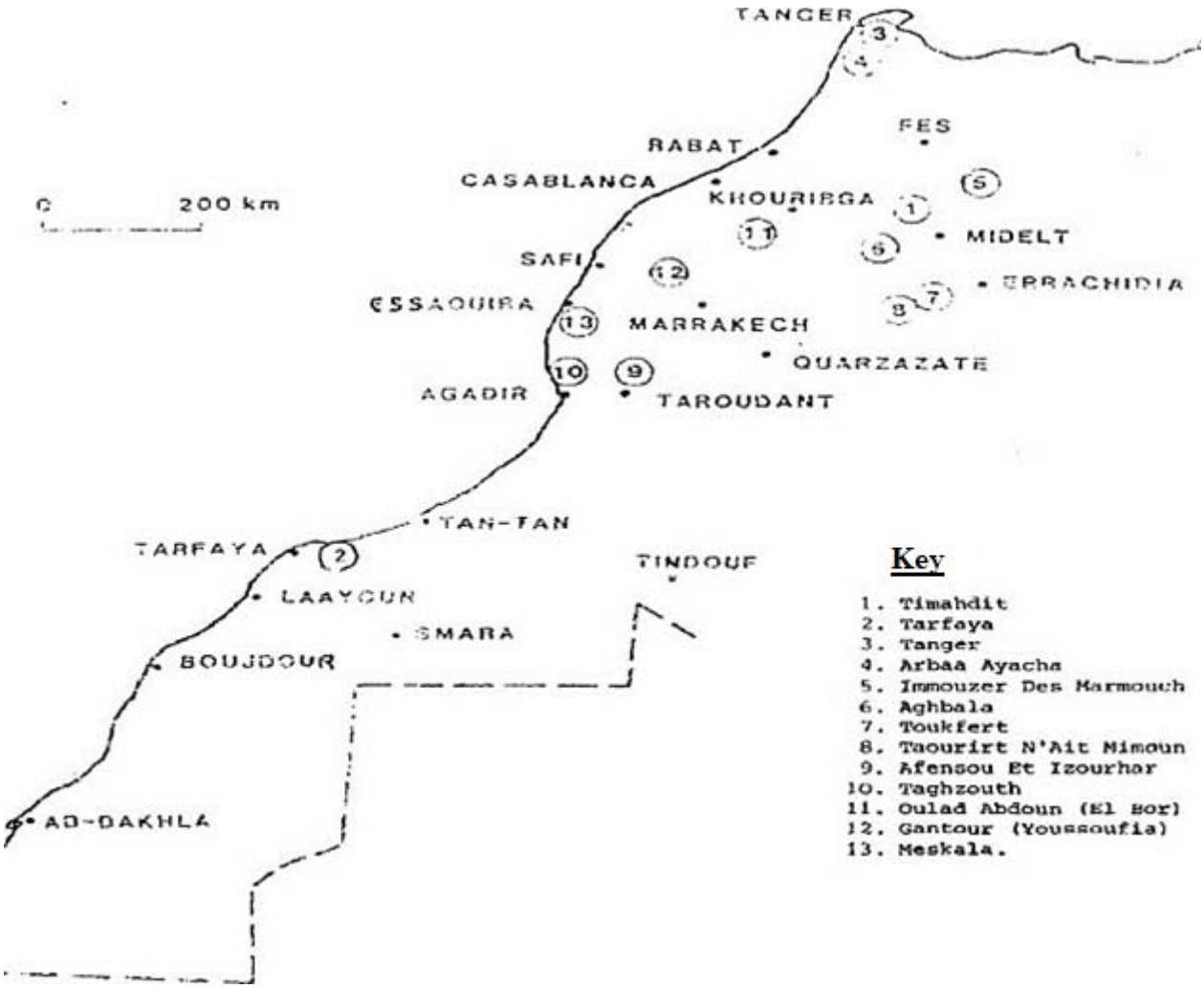

Fig. 1: Distribution of oil shale deposits in Morocco [1]

1) *General Definition of Bituminous Shale*

Bituminous shales are rocks capable of producing oil in commercial quantities when subjected to pyrolysis. A sedimentary rock containing an insoluble organic substance is referred to as pyro schist, pyrobitumen shale, kerogen rock or, more commonly, bituminous shale. It releases an oil with a generalcappearance similar to crude oil by non-oxidizing heat treatment at a temperature of between 400 and 500°C [3].

2) *Nature and Composition of Bituminous Shale*

- Organic and mineral matter. Despite certain similarities, the composition of the organic matter contained in oil shale varies from one deposit to another.
- Kerogen is a mixture of high-molecular-weight compounds containing mainly carbon, hydrogen, nitrogen, oxygen and sulfur. The oxygen and nitrogen content are generally higher than crude oils.

The organic matter in oil shale is richer in aromatic sulfur compounds (benzothiophene derivatives) and above all in resins and asphaltenes. They are normally heavy but constitute minority constituents in conventional oils (0 to 2% by weight), and a majority in shale.

3) *Chemical Reactions Produced during Shale Combustion*

The chemical reactions that occur during shale combustion can be presented as follows [1]:

For organic matter

$$C_nH_n + \frac{5n}{4}O_2 \rightarrow nCO_2 + \frac{n}{2}H_2O + Q \text{ (Exothermic)}$$

For terrigenous matter:

$$SiO_2 \rightarrow Si + O_2$$

For carbonate matter:

$$CaCO_3 \rightarrow CaO + CO_2 - Q \text{ (Endothermic)}$$

For other elements:

$$2FeS_2 + \frac{11}{2}O_2 \rightarrow 4SO_2 + Fe_2O_3 + Q \text{ (Exothermic)}$$

4) *The Timahdit Oil Shale Case in Morocco*

The oil shales of Timahdit (Morocco) may constitute significant hydrocarbon resources, amounting to more than nineteen billion tons of raw rock. This is equivalent to around 8.9 billion barrels [1]. These argilocarbonate sedimentary rocks were formed at the end of the secondary period.) They are essentially made up of [3]:

- 30 to 75% terrigenous (clayey) material: aluminosilicates predominate
- 25-50% carbonate matter: calcite is the main constituent
- Organic matter from 12 to 24%. One part is soluble in organic solvents, the other is insoluble in the same solvents and constitutes kerogen.

The mineral composition of an average sample of Timahdit oil shale [1] is shown in Table 1 below:

Table 1: Mineral composition of the Timahdit shale

Mineral	Pourcentage (%)
Dolomite (CaMg (CO3)2)	15,9
Calcite (CaCO3)	41,5
Quartz (SiO2)	19,5
Illite ((OH)4K2 (Si6Al2) Al4O20)	13,4
Pyrite (FeS2)	1,8
FeCO3 + FeO3	1,8
TiO2 + Phosphate	2,4
Other elements	3,7

The concentration of dolomite is low when compared with that generally found in the Colorado shale in the USA. Thermal decomposition of dolomite and calcite is a highly endothermic reaction. Maximum temperatures in the combustion zone are, therefore, higher for Timahdit shales than for Colorado shales when the applied process is direct heating. Similarly, the kerogen composition of a sample of Timahdit shale [1] is shown in Table 2.

Table 2: Elemental composition of Timahdit and Colorado kerogen

Elements	% for Timahdit kerogen	% for Colorado kerogen
Carbon	69,2	80,5
Hydrogen	6,5	10,3
Azote	2,9	2,4
Sulfur	8,4	1,0
Oxygen	12,9	5,8

III. The use of Oil Shale in Cement Production

In our study and research program, we have developed solutions to exploit oil shale deposits as part of sustainable development, using renewable energy sources, unconventional water and CO2 capture techniques, in addition to the integration of other uses. The objective is to make the overall exploitation of oil shale deposits profitable, remarkably reducing the impact on the global environment.

To make the exploitation of oil shale deposits profitable, our research was directed towards the development of other possibilities of use concerning the coating of roads and runways [4], the production of cement and the manufacture of carbon plates. In this article, we develop the use of shale for cement manufacturing.

a) Cement Manufacturing Processes

Cement is composed of a finely ground powder which has the property of hardening and becoming mechanically resistant when mixed with water. The raw materials used for the manufacture of cement are limestone and clay, which are heated at a sintering temperature of 1500°C after grinding.

Fuel consumption is a main component in the production cost matrix. It is averagely estimated at 40% of the overall cost. Cement manufacturers use rotary kilns that are fueled with coal, petroleum coke or natural gas.

The raw materials consisting of limestone and clay are extracted from the quarries. They include oxides such as CaO, SiO2, Al2O3 and Fe2O3, which are necessary for the manufacture of cement. The raw material is finely ground and homogenized in order to promote chemical reactions between the different constituents during firing. There are four ways of preparing the raw material mixture [5]:

- *The humid method:* The principle is based on the mixing of limestone and clay previously ground with a water content that varies between 25 and 40% so as to obtain a humid paste. The paste is directly fed into the kiln. This method generates significant energy consumption to eliminate excess water.
- *The semi-humid method:* The preparation of the raw mixture by the semi-humid method is the same as that of the humid method with a moisture content that does not exceed 15%.
- *The dry method:* The principle of this method is based on the homogenization of previously ground raw materials. Before being fed into the kiln, the mixture is transported.
- To a cyclone-preheating tower with gases circulating in opposite directions in the cyclones for powder preheating. The temperature can reach 800°C, which allows the reduction of part of the CO2 and water contained in the mixture. After preheating, the powder is fed into the kiln.
- *The semi-dry method:* Starting from the dry method.

The main steps in the manufacture of cements are as follows:

- The production of raw material at quarry level
- Pre-homogenization of raw materials
- Grinding and homogenization of raw materials
- Preheating raw materials
- Firing and cooling the clinker
- Cement grinding with addition of gypsum, setting regulator and other constituents
- Quality control and storage of cement.

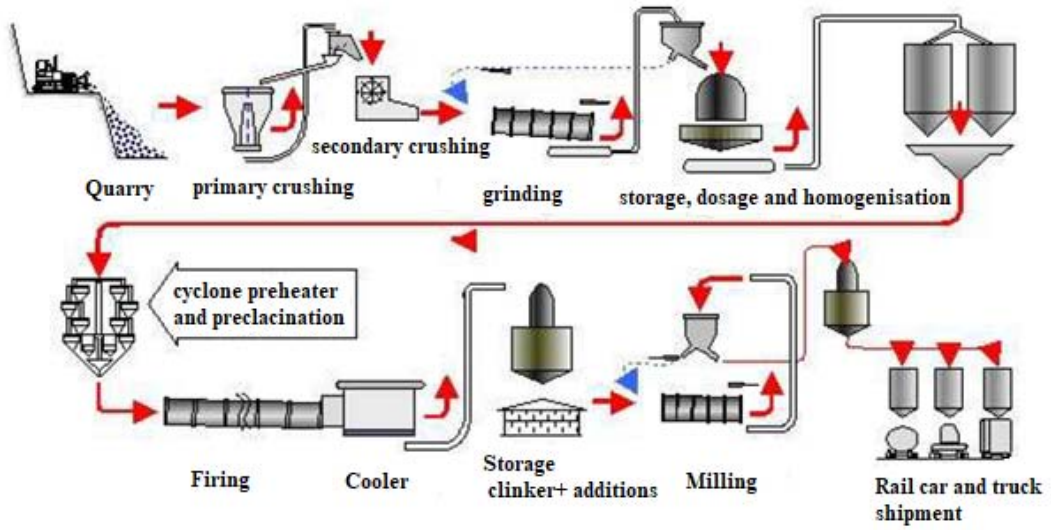

Fig. 2: Cement manufacturing diagram [6]

b) Characteristics of Cement [6]

i. *The Setting*

After mixing the anhydrous cement with water, hydration begins and the properties of the paste obtained become scalable over time.

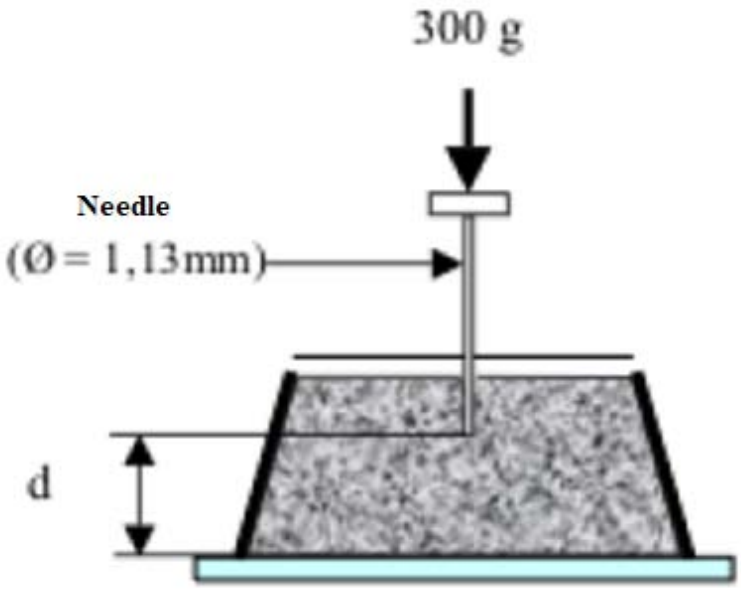

Fig. 3: Determination of the setting start time

The start of setting begins with the observation of the increase in viscosity, or hardening of the paste, which is measured by a standardized needle (Vicat device). It corresponds to the time elapsed from the mixing of the paste until the moment when the needle stops at a distance (d = 4 mm ±1 mm) from the bottom of the ring of 40 mm in height filled with pure cement paste.

The end of the setting corresponds to the moment when the needle no longer penetrates into the ring.

The setting of cement phenomenon is related to the following parameters:

- The nature of cement
- The fineness of grinding of the cement; the finer is its grinding, the shorter is setting time
- The temperature; the higher the ambient temperature is, the faster the setting is. For example, the start of setting will be 18 hours at 2°C, 5 hours at 10°C, 3 hours 30 at 20°C and 30 min at 35°C
- The presence of organic matter in the water or in one of the other constituents of the concrete that slows down the setting
- Excess of mixing water that delays setting

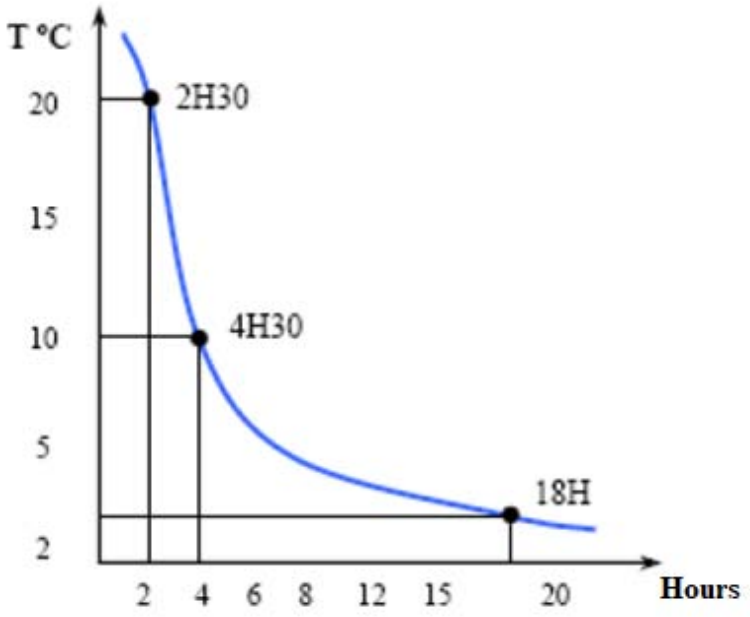

Fig. 4: Change in setting time in relation to temperature

ii. *Hardening*

Hardening is the period that comes after the setting and during which the hydration of the cement continues. Hardening is temperature sensitive.

iii. *Fineness of the Grind*

The grinding fineness is characterized by the specific surface area of the cement particles, expressed in (cm2/g). In common cases, it is of 3000 to 3500 cm2/g. The greater the fineness of grinding is, the higher the speed of the hydration reactions is and the greater the mechanical strengths are at an early age. The fineness of the grinding influences the plasticity and cohesion of the cement paste in the fresh state, as well as its water retention capacity.

iv. *Shrinkage*

The cement paste shrinks in dry air and swells in water. This phenomenon happens over time when cement pieces are massive. It is the shrinkage that causes cracks that are seen in concrete parts. There are several types of shrinkage: early age (before setting) shrinkage, hydraulic and thermal.

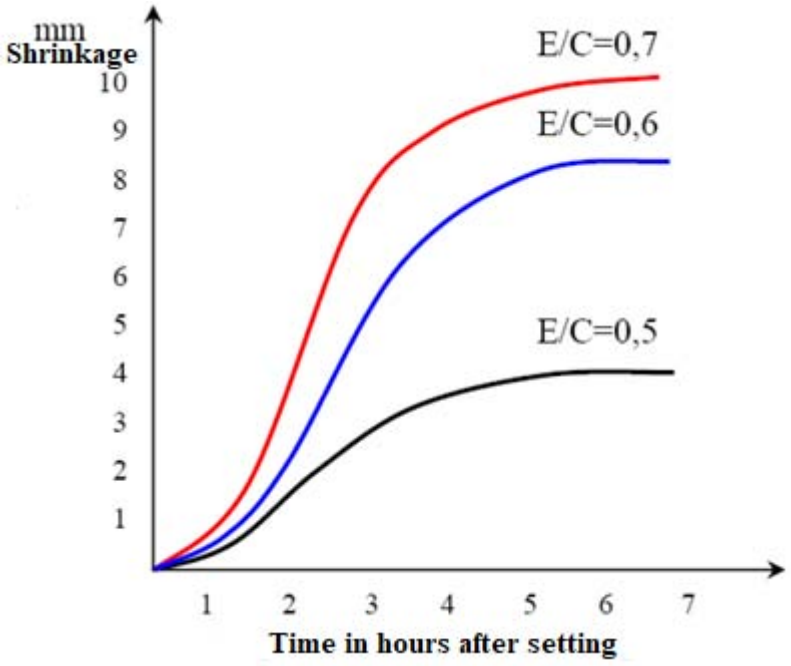

Fig. 5: Influence of E/C on the plastic shrinkage of mortars

v. *Compression Strength*

The mechanical strength of cement is determined by tests on so-called "normal" mortar, at 28 days of age in tension and compression of the 4 x 4 x 16 cm specimens. The strength of the mortar then signifies the strength of the cement mixture. It depends on the cement class, expressed in MPa.

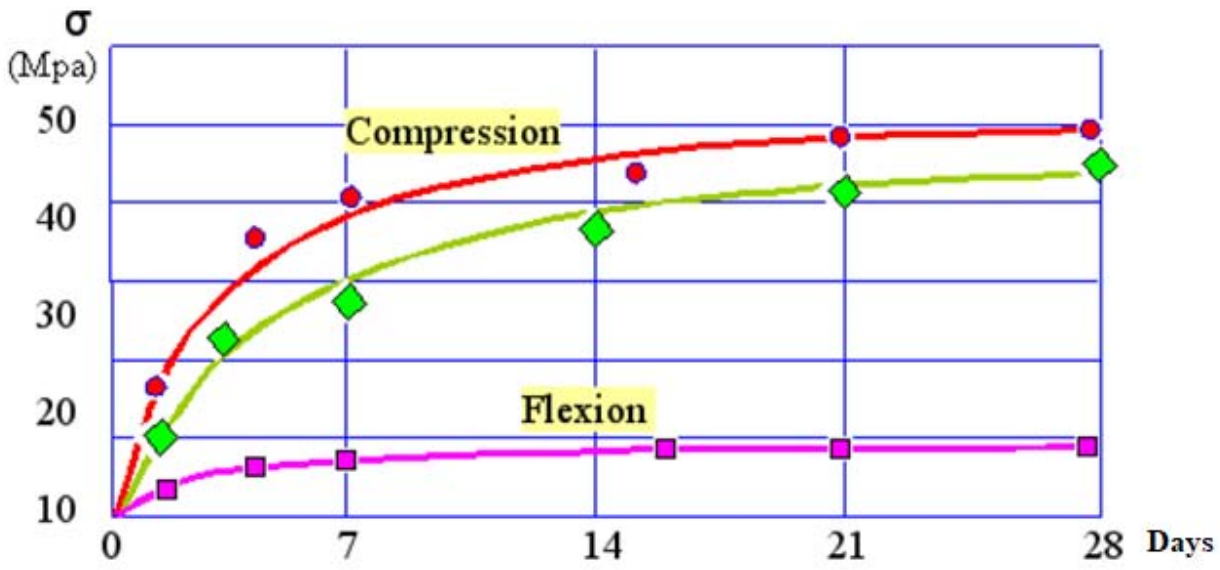

Fig. 6: Normal Mortar Strength

c) *Integration of Oil Shale into Cement Manufacturing*

With a multiple objective of combining the production of high quality cement with the optimization of energy cost, we proposed the integration of oil shale into cement manufacturing matrix as fuel and raw material.

The methodology of the tests was based on the preparation of the raw formulations with and without the addition of oil shale and the characterization of the cements produced in order to understand the effects of the addition of shale on the properties of the cement. The quantity of each raw material in the raw of each formulation was calculated using the values of the LSF, AR, SR modules that are usually used in the cement industry [5]. Then, all the raw materials were mixed by adding water in order to obtain a more homogeneous mixture. In order to facilitate the firing process in kiln, pellets have been made. They were then baked in the furnace according to the following approach:

- Baking at 200°C for 20 minutes
- Temperature increase up to 1450°C with a ramp
- Maintain level at 1450°C for 15-minute
- Cooling in the oven to ambient temperature.

The compressive strength remains acceptable by the standard corresponding to CPJ35 Cement with the following advantages:

- Improved grinding efficiency.
- Improvement of the quality of the cement produced by the workability of the concrete, reduction of shrinkage during drying with better chemical resistance of the concrete.
- The high silica and alumina content promotes use as a raw material in the manufacture of cement.
- Reduced production costs based on oil shale integration percentages.

A follow-up program is necessary for the plant and its surroundings, concerning the following points:

- Continuous monitoring of chimney gas opacity.
- Periodic measurement of particles in chimneys.
- Monitoring of furnace dust, flue gases and cement, to detect burnt hazardous materials, pH, total dissolved salt content, suspended solids, alkalinity and potassium and sulphate content of liquid effluents.
- Monitoring of working conditions regarding noise intensity and the presence of dust.
- Ambient air quality monitoring for particulate matter.
- Verification of compliance with safety and environmental protection rules.

Two other areas of effort are committed to improving strength as needed by adding chemical additives and to avoiding the risk of corrosion of steel reinforcements in very humid environments with relative humidity greater than 80%. This is the case knowing that the use of Cement produced inside buildings and protected areas does not raise any problem.

In order to assess the effects of the new mixture in terms of CO2 emissions, a life cycle analysis was carried out with and without the addition of oil shale. The life cycle analysis relied on the ecological saturation method. This method uses eco-factors to quantify the environmental burden due to the emission of a pollutant. The method also relies on the global warming potential based on the CO2 equivalent.

The analysis showed a considerable reduction in the environmental impact depending on the dosage

of the oil shale without affecting the quality of the cement produced.

Shale ash contains constituents such as calcite, quartz, iron oxide and aluminum oxide, which are very important for the manufacture of Cement with an ability to improve the durability of concrete. In addition to the sedimentary organic matter rich in shale oil, Oil shale contains part of the mineral matter composed of calcite, dolomite, silicates and other minerals.

The use of the experimental design in methodology has facilitated the analysis of the research results carried out and the evaluation of the mechanical characteristics relating to the mechanical resistance to compression and flexion. It additionally helped us in the modelling of the rheological parameters concerning the shear threshold and the plastic viscosity of the cement mixtures produced with the addition of oil shale [5]. The experimental results have shown that the mechanical characteristics of the cements produced with the integration of oil shale remain within acceptable ranges with economic and environmental benefits.

It should be noted that in addition to the aforementioned use of oil shale, this latter can be used in the manufacture of carbon fibers, activated carbons, adsorbents, carbon black matter, phenols, resins, sealants, road bitumens, bricks, building blocks and Pharmaceuticals products basis. However, the quantities produced remain very low and in the majority of cases is in the experimental phase.

Depleted shale can be used in the preparation of bricks and cements. The mineral residue in some shales retains a large proportion of the carbon fixed in finely divided form. As this carbon is combustible, the shale can be used as it is, provided the carbon content exceeds 6% [7].

d) Summary of Work Carried out on the use of Oil Shale in Cement Manufacture

Based on various reserve evaluation studies, geophysical, geological, mining, geochemical and chemical studies, we have characterized the deposits according to profitable exploitation zones. In addition to the use of bituminous layers as a source of energy, we have identified their use in cement manufacturing.

The testing methodology was based on the preparation of raw mix formulations with and without the addition of bituminous shale, and the characterization of the cements produced in order to understand the effects of shale addition on cement properties. All the raw materials were mixed by adding water to obtain a more homogeneous mixture. In order to facilitate firing in the kiln, pellets were made and fired in the kiln according to the approach presented.

The use of the experimental design as a method helped us to facilitate the analysis of the research results and the evaluation of mechanical characteristics related to compressive and flexural strength. It also helped in the modeling of rheological parameters concerning the shear threshold and plastic viscosity of cement mixes produced with the addition of oil shale [8]. The experimental results showed that the mechanical characteristics of cements produced with the integration of oil shale remain within acceptable ranges with economic and environmental benefits.

A fourth phase was devoted to studying the technical feasibility and economic viability of industrial applications at existing plants.

In addition to the economic benefits and local availability, the results of the work carried out lead to the following conclusions:

- Cements produced with oil shale blends have characteristics comparable to those of standard cements.
- The physic-chemical characteristics obtained were in line with the requirements.
- The integration of bituminous shale in cement production is feasible in existing plants, subject to adaptation.
- Reduction in production costs depending on the percentage of oil shale integration.

In addition to the technical feasibility of using oil shale in cement manufacture, the overall study showed that the economic profitability was confirmed. The findings of the experiment, which is the subject of this article, will contribute to the development of oil shale value chain derivatives and to the overall profitability of projects aiming to exploit and add value to oil shale deposits within the framework of sustainable development.

Bibliography

1. Ahmed Saoiabi. Contribution à étude physico-chimique des schistes bitumineux de Timahdit (MAROC). Matières organiques et Métalloporphyrines, Juin 1982, Pages 04 - 39.
2. Y. DAAFI. Les Schistes bitumineux au MAROC. Etat des lieux et potentialités. ENERGIES/MINES et CARRIERES Magazine 12 Octobre 2020.
3. A. Saoiabi. Comportement thermique des schistes bitumineux de Timahdit (MOROCCO) oïl shales.
4. Mohamed Amine Alouani, Dennoun Saifaoui, Abdelkader Alouani, & Younes Alouani. (2023). The use of Oil Shale for Road Coating. Global Journals of Research in Engineering, 23(E2), 43–46.
5. Duc Chinh Chu. Valorisation des sédiments de dragage dans l'industrie cimentaire. Génie civil. Ecole nationale supérieure Mines-Télécom Lille Douai, 2021. Français. NNT: 2021MTLD0008.
6. Le monde de Génie Civil, Les Ciments P 11-22. 2014.
7. G. de GRAND RY. Etude sur les schistes bitumineux P 593–601. 1950.

8. A. Alouani, A Arbaoui, K. benkhouja, A. Khmich, K. Sbiaai. Optimization of flottation Reagent's Specific Consumption By Modeling Global Journal of Researches in Engineering (J). Volume 17. Issue 5, Version 1.0 year 2017 P 10-20.

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Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

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The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

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The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

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Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

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Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

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Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

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6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

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10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
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- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

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References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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