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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, изучаются 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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Введение

Ограничение ресурсов по ископаемому топливу и глобальное потепление, вызванное эмиссией парниковых газов, 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 в при КПД преобразования 35 %, что позволяет уловить на мировой спрос на электроэнергию, однако, хотя глобальный приливный 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 различной глубины зон, - отраслевое значение имеют приливы. Энергию приливом даёт асимметрия гравитационных возмущений и океанические течения: 1) согласно модели Ньютона-Лапласа, линейная гравитация из-за значительного диаметра Земли и Солнца, ширины в ближних и дальнних точках и неравномерно воздействует на её поверхность, и такое притяжение образует перемещающаяся 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 водовороты зоны

1 Увеличение выпаротки электроэнергии в мире более чем в два раза за последние 30 лет с преобладанием доли горючих ископаемых связано исключительно со странами Азии, где наиболее ошутим и ожидалось прогнозируется рост численности населения; за тот же период концентрация диоксида углерода в атмосфере воздушно-розшей на 25%.

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 выскоком экономическом 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 искомое 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.


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 исследовательской 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 работ3; для реализации проектов, помимо главных экономических, должны быть решены частные инженерные задачи.

**Таблица 1:** Проекты ПЭС РСФСР

<table>
<thead>
<tr>
<th>Станция</th>
<th>Прилив ср. (м)</th>
<th>Площадь бассейна (км²)</th>
<th>Установленная мощность (МВт)</th>
<th>Годовой объем электроэнергии (ТВтч/г)</th>
<th>Годовой Коефициент загрузки (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Северная</td>
<td>4,2</td>
<td>5,6</td>
<td>12</td>
<td>0,024</td>
<td>24</td>
</tr>
<tr>
<td>Лумбовская</td>
<td>4,2</td>
<td>70</td>
<td>320</td>
<td>0,7</td>
<td>24</td>
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<tr>
<td>Тугурская</td>
<td>4,7</td>
<td>1800</td>
<td>8000</td>
<td>27,6</td>
<td>24</td>
</tr>
<tr>
<td>Мезенская</td>
<td>10</td>
<td>2640</td>
<td>11400</td>
<td>39</td>
<td>34</td>
</tr>
<tr>
<td>Пенжинская</td>
<td>11 и 13,4</td>
<td>20530</td>
<td>108500</td>
<td>250</td>
<td>25</td>
</tr>
</tbody>
</table>

*В том же заливе проектировались Кулойская и Беломорская станции.

**Суммарно два бассейна.*

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

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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, определяемого составом внешней среды и изменением свойств частич конструкций при старении материалов, биологических процессов в виде биодеградации из-за действия грибов, водорослей, микроорганизмов, определяется совокупностью напряжений и деформаций, целком характеризующих напряжённое состояние части 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 $H$, глубина $h$, плотность бетона $\gamma$ [кг/м$^3$], предел прочности грунта основания $[\text{МПа}]$, коэффициент трения бетона о грунт $f$, удельное сцепление грунта $c$ [кПа], заложение откосов $m$, класс сооружения [KC]; искомая характеристика – ширина плотины $B$. Расчёт сил и их плеч ведут относительно середины основания на основе действия группы сил: вертикальных: a) собственный вес плотины, определяемый по площадям плоских геометрических фигур, получаемым разбиикой её поперечного профиля, умноженным на плотность бетона, b) 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 глунихи противофильтрационной и дренажной завесы $h_{\text{зав}}$). В решении составленного уравнения необходимо учитывать нормативные показатели коэффициентов устойчивости и минимальные значения главных напряжений у верха плотины. Особенности конструкции плотин ПЭС рассмотрены в следующем разделе.

![Горловая (геликоидная) – эффективность 35%](image1)

![Банки (ортогональная) – от 2 м–1кВт-15кВт](image2)

![Колбовая (капсульная, грушеобразная, трубчатая) – от 3 до 10 м](image3)

Рис. 2: Низконапорные гидротурбины

Проблема 2 – необходимость эффективного управления скоростным напором
Рабочие скорости приливного течения – 2-3 м/с (дают 4-13 кВт/м$^2$), большие (>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 ротора двигателя на внешнем контуре рабочего колеса и статором в
центр, что имеет преимущества при переменном напоре, дешевле и проще в монтаже и обслуживании, теоретически имеет большую инерцию и, значит, более устойчива, но может работать только в отлив, и не может применяться для накачки; 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) колновую турбину, названную из-за формы гидрорегулятора, на ГЭС применяют чаще из-за высокого КПД при низком напоре (до 90%), малого размера, низкой стоимости и реверсивности, позволяющей вырабатывать энергию как в прилив, так и в отлив, они отличаются надёжностью и высокими рабочими характеристиками, имеют низкие эксплуатационные затраты, – технология коллобовых турбин хорошо отработана; 4) турбины средней скорости вращения (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 турбины/насоса), 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 решается, поскольку не возникают пульсации давления и кавитация; 5) высоконапорные (рис. 4) отличаются высокой скоростью при низком расходе: если удельная скорость выходит за критический диапазон, вращение замедляется и мощность падает.
Проблема 3 – необходимость выверенной ориентации рабочего колеса турбины в водоводе

Общее наблюдение – вертикальная ориентация вала гидротурбин большого диаметра лучше подходит для реактивных – Каплана, Дериаза, горизонтальное – импульсных – Пелтона (рис. 5); впрочем, изменение формы лопасти по длине – от центра к периферии – способно обеспечивать в одном колесе оба режима, что для требующих повышенных технических характеристик турбин, работающих в составе современного технологического оборудования необходимо. a) 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. b) 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 турбин, 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, обеспечивающей 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. Оптимизация 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, бассейн-море, как одна электростанция; и также станция может дооснащаться гидроаккумуляторами.

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 рациональной нагрузкой (рис. 7), – при неполном или перегрузке КПД падает, и рекомендуют турбины Дериаза или Каплана.

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

Требует изменения свойств материалов или характера процессов путём особых технологических
мероприятий – для повышения надежности 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, соприкасающихся 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, перекрывающая вход в естественную бухту/залив/фьорд/губу/лиман/эстуарий и даже лагуну, но не пролив, образует бассейн, отделенный от моря, и имеющий различный с ним гидрологический режим (рис. 1), нарушая сложившуюся экосистему и в определенных 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 счет отложений твердого стока рек.

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

Эти проблемы с разной степенью важности определяются потоками относительно 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 (ориентированную турбину), соединённую с отводом (турбинное оборудование в случае «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 ячейстые плотины с плоскими перекрытиями, в гидротехнике обычно называемые «обделочными»; по материалу – бетонные/железобетонные сооружения.

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

а) Решение проблемы 1 – расчёт конструкции плотины

В зарубежной литературе плотину ПЭС чаще называют «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 ячейстые плотины с плоскими перекрытиями, в гидротехнике обычно называемые «обделочными»; по материалу – бетонные/железобетонные сооружения.

Рис. 9: 3-D модель saVRee обычного заграждения ПЭС с в ряд расположенным турбинами

Ячейстые низконапорные плотины стали разрабатывать в СССР с середины 30-х годов; размеры ячек – 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 м³
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.

Помимо экономики 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 водохранилища гидротурбины.

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 приливной волны в исходных данных расчёта водохранилища гидротурбины.


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 м² и времени прилива 6 ч, – E = 0,54ρgHh² = 0,5·20 530 000 000 [м²]·1025 [кг/м³]·9,8 [м/с²]·12,2² [м] = 1,53472·10¹⁰ [Дж], P = E/t = 1,53472·10¹⁰ [Дж]/6 [ч] = 5,6·10⁹ [кВт·ч]/[Дж] ≈ 710 517 [МВт], при том что плотинные гидротурбины 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 Nt=gQHт[kВт], где Hт=С1усс=С2усс=С3усс – рабочий напор турбины, позволяет турбине развить мощность Nт=Мо, где М=gQ1cos1R1–C2cos2R2 – момент количества движения и N – угловая скорость рабочего колеса, С1, С2 – абсолютные скорости на входе и выходе [м/с], и – окружная скорость на внутренней окружности рабочего колеса, R1, R2 – размеры окружностей рабочего колеса (рис. 10), a1, a2 – углы между касательными и кривой линии к наружной окружности на входе и выходе [°], η=NtNп – гидравлический КПД, и при низком напоре турбины с пропеллерными лопастями, как, например, Каплана, не могут обеспечить высокую мощность, Q – расход через гидротехническое сооружение: Q = СаA2gHт, где Са – коэффициент расхода, A – площадь проходного сечения через сооружение.

3. Гидравлические характеристики осевых гидротурбин в конструктивных параметрах мощности.

Сегодня «испытания» концепта начинают с компьютерной модели, выполняя структурный анализ (ставшим ведущим методом конечных элементов – FEA, широко применяющимся в расчёте плитонов) ветхих характеристик конструкции, отдельных деталей и элементов, например, лопастей, и применения вычислительной гидродинамики (CFD) для оценки набегания и взаимодействия потока с граничными поверхностями. Кинематическая характеристика движения потока в 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, – лопаты колеса неподвижные, то есть угол их наклона не может изменяться (на рис. 10 показана изогнутая лопасть с входом и выходом струйного потока под заданными

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углами, векторно представляющего треугольника скоростей). Чтобы рассчитать крутящий момент, действующий на водяную турбину, необходимо оценить обмен импульсом, то есть обмен импульсом происходит за счёт изменения направленияектора 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 \( F = dm \cdot v \cdot dt \), то есть определив его получаем силы на лопатках. – методика расчёта представляет алгоритм: 1) для расчёта эффективной силы, действующей на лопатки, необходимо рассчитать величину и направление относительной скорости набегающей патки; определение компонент \( x \) и \( y \) вектора относительной скорости на входе: \( vx_1 = v_1 \cdot \cos \), \( vy_1 = v_1 \cdot \sin \) и на выходе: \( vx_2 = -v_x \cdot \cos \), \( vy_2 = -v_2 \cdot \sin \), где \( v_1 \) и \( v_2 \) – относительные скорости входящего и выходящего потока струи, представляющие сумму векторов скоростей лопасти \( u \) (окружная составляющая скорость \( u = \pi \cdot d \cdot n \), где \( d \) – диаметр [м], \( n \) – частота вращения [с–1]) и абсолютной на входе \( C_1 \) и выходе \( C_2 \) [м/с], \( \theta \), \( \beta \) – углы между соответственно \( v_1 \), \( u \) и \( \theta \); 2) сила, передаваемая реактивным потоком лопатке в направлении \( x \), равна массовому расходу \( Q \) [кг/с], который равен плотности жидкости \( \rho \) [кг/м³] на площадь поперечного сечения струи \( A \) [м²] и на скалярное значение скорости набегания \( v \): \( Q = \rho \cdot Av \cdot c \); сила, передаваемая реактивным потоком лопатке в направлении оси \( Y \): \( F_Y = \rho \cdot Av \cdot vy_1 = \rho \cdot Av \cdot \sin + v_1 \cdot \cos \); полная сила, приложенная к лопатке, равна результирующей: \( F_x = F_x + F_y \), а угол правилидействующей силы – \( \beta = \alpha \); выходная мощность: входящая сила турбины \( F_x \) = \( \rho \cdot Av \cdot vx_2 \cdot v_1 \cdot \rho \cdot Av \cdot vy_2 \cdot v_2 \cdot \sin \); 3) КПД водяной турбины – отношение выходной мощности к кинетической энергии движения: \( \eta = \frac{Av \cdot vy_2 \cdot vy_1}{Av \cdot vx_2 \cdot v_1 \cdot \sin + v_1 \cdot \cos} \cdot \rho \cdot Av \cdot \sin + v_1 \cdot \cos \).
плотиной, и работа электростанции возможна в трёх режимах: 1) Генерация в прилив; заполнение бассейна мorskой водой начинается не сразу: некоторое время затворы турбинных водоводов закрыты, пока не возникнет достаточное гидростатическое напор (в чачное 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) Двухпредпоследняя генерация — метод использует как фазы прилива, так и отлива: затворы турбинных водоводов оставляются закрытыми до конца прилива (рис. 1), после чего воду направляют в турбины — наступает фаза генерации, длившаяся до минимального гидростатического напора — фазы отлива, — двухсторонняя генерация сокращает долю пауз и снижает количество агрегатов, то есть стоимость оборудования. Двухфазные ПЭС — основной бассейн может работать как один; второй предназначен для закачки и аккумуляции воды в процессе фазы откачки из первого бассейна, при этом используются часть электроэнергии, генерируемой турбинами, и такая система способна регулировать подачу электроэнергии потребителю, — преимущество систем с двойным бассейном — способность генерировать электроэнергия 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 сутупч, но и месячная, но проблема 4 определяется изменением напора в результате приливо-отливного действия волн.

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 однakovo волнонаправленной 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 насосной. 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 \( \approx 15-20\% [8] \), а в целом оптимизированное управление циклами приводит, за счёт более гибкого управления турбинами и затворами, к увеличению выхода электроэнергии на \( \approx 30-35\% \) (оптимизация повышает КПД модели четырёхлопастной 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 Са и загрязнённые сточными водами; 4 — без загрязнений; 5 — Чёрном[9]

Решение проблемы 6 — особые условия эксплуатации и технического обслуживания отражаются на расходах, и стоимость эксплуатации и мероприятий 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 — антиблокированные в виде, например, гидрофобных покрытий, для защиты за кладных частей затворов — экраторогрева, борьбы с внутренним льдом и шуговыми коврами — запаны 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 простоя вещества или соединения (таблица 2).

Таблица 2: Электрохимический ряд активности металлов

<table>
<thead>
<tr>
<th>Активные</th>
<th>Средней активности</th>
<th>Неактивные</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li → K → Na →</td>
<td>Mg → Al → Mn → Zn → Cr →</td>
<td>H₂</td>
</tr>
<tr>
<td>Ca → Ba →</td>
<td>Fe → Ni → Sn → Pb →</td>
<td>Pt → Au</td>
</tr>
</tbody>
</table>

К примеру, высокий потенциал медных сплавов в электролитическом контакте со сплавами железа создаёт поток электронов от Fe к Cu, корролида 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, формирующееся тысячелетиями, — наиболее показательные примеры с крупными мелkopитающими

в августе 2004 г. на ПЭС Анапополь 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. Анапополь, но самостоятельно нашёл выход, однако его весной 2007 г. там же, у г. Бриджтана, 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, непредсказуемой угрозы окружающей среды. Поиск новых технологических совершенных подходов в развитии энергетики формирует в среднесрочной перспективе политику поддержки возобновляемых источников энергии, главным образом солнечных и ветровых, а в дальнейшей — 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 наноный режим.

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

1. Альтернативная энергетика, построенная на возобновляемых источниках, предполагает преобразование в процессе преобразования энергии выработки парниковых газов, — также немаловажным является переориентация поставок 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, целесообразная — кубоидной формы, ячеистая.

3. Трёхмерные информационные модели потока воды промежуточной части гидротурбины позволяют судить о взаимодействии с коэффициентом изменения

8 Исследования — количественные данные о передвижении зоны загрязнения на уровне гидробионт, связанной с проходом через прямолинейные турбину 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 гидротурбин, определение оптимального количества турбин, определение оптимального времени начала и окончания генерации каждой фазы, единого оптимального эксплуатационных характеристик для одинаковых конструкций твёрдого тела.

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 многообъёмных 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 шутовыми коврами – запани и шутсбросы; целесообразно гидравлическое лабораторное моделирование. Для предотвращения электрохимической коррозии металлических конструкций, исполнительных механизмов, деталей турбинных агрегатов в морской воде используют методы: легирование, 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**


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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.

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GJRE-E Classification: FOR Code: 0905

Strictly as per the compliance and regulations of:
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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.

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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, Column DB-5, Over temp 100-270°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

* Corresponding author.
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30mA from 5° to 35° 2 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 27Al 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 1

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)

<table>
<thead>
<tr>
<th>Number of MIRGA spraying</th>
<th>Compressive Strength of Concrete in N/mm² (method 1)</th>
<th>Enhanced percentage of CSC in N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7th day</td>
<td>14th day</td>
</tr>
<tr>
<td>C (non-sprayed)</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>25</td>
</tr>
</tbody>
</table>

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 28th 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 instrumentation 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](image-url)
Table 2: GCMS spectra analysis of cement samples

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

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 H\(_2\)O in 6 and 10 sprayed samples as the rate of hydration is more. (Fig 2)
Cement is a mixture of different compounds. It consists of Calcium oxide (CaO), Silicon dioxide (SiO₂), Aluminum oxide (Al₂O₃), Iron oxide (Fe₂O₃), Water (H₂O), Sulfate (SO₃) 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. While 10 sprayed sample showed comparatively increased C-O stretch of [CO₃]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 SO₄²⁻ was selectively present in control and 2 sprayed samples. (Table 3) (Fig 3)

**Table 3:** FTIR spectra analysis

<table>
<thead>
<tr>
<th>Frequency (1/cm)</th>
<th>Band characteristic</th>
<th>% area present in each sample</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3417.86</td>
<td>Portlandite – Ca(OH)₂</td>
<td>Control 1.39</td>
<td>2 sprayed 5.34</td>
</tr>
<tr>
<td>1435.04</td>
<td>C-O stretch of [CO₃]²⁻</td>
<td>Control 13.33</td>
<td>2 sprayed 14.06</td>
</tr>
<tr>
<td>1103.28</td>
<td>S-O stretch of [SO₄]²⁻</td>
<td>Control 6.19</td>
<td>2 sprayed 5.17</td>
</tr>
<tr>
<td>1095.57</td>
<td>Si-O (asymmetric stretching)</td>
<td>Control 0.00</td>
<td>2 sprayed 0.00</td>
</tr>
<tr>
<td>925.83</td>
<td>Al-O stretch</td>
<td>Control 2.14</td>
<td>2 sprayed 2.22</td>
</tr>
<tr>
<td>455.20</td>
<td>Si-O stretch</td>
<td>Control 2.76</td>
<td>2 sprayed 5.34</td>
</tr>
</tbody>
</table>

**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 (SiO₂), Aluminum oxide (Al₂O₃), Iron oxide (Fe₂O₃), Water (H₂O), Sulfate (SO₃) 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. While 10 sprayed sample showed comparatively increased C-O stretch of [CO₃]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 SO₄²⁻ was selectively present in control and 2 sprayed samples. (Table 3) (Fig 3)

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<td>455.20</td>
<td>Si-O stretch</td>
<td>Control 2.76</td>
<td>2 sprayed 5.34</td>
</tr>
</tbody>
</table>

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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>
<thead>
<tr>
<th>2θ</th>
<th>Control</th>
<th>2 sprayed</th>
<th>6 sprayed</th>
<th>10 sprayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.24 (Alite)</td>
<td>3081</td>
<td>100,0</td>
<td>3523</td>
<td>91,9</td>
</tr>
<tr>
<td>29.48 (Alite)</td>
<td>2837</td>
<td>92,1</td>
<td>3715</td>
<td>96,9</td>
</tr>
<tr>
<td>34.42 (Ferrite)</td>
<td>2582</td>
<td>83,8</td>
<td>2643</td>
<td>69,0</td>
</tr>
<tr>
<td>26.65 (Langbeinite)</td>
<td>2418</td>
<td>78,5</td>
<td>3832</td>
<td>100,0</td>
</tr>
<tr>
<td>51.79 (Alite)</td>
<td>1903</td>
<td>61,8</td>
<td>1140</td>
<td>29,7</td>
</tr>
<tr>
<td>18.08 (Portlandite)</td>
<td>1256</td>
<td>40,8</td>
<td>1321</td>
<td>34,5</td>
</tr>
</tbody>
</table>
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 Moiré 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-length 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 Moiré 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 Moiré patterns are observed with very high frequency. Moiré 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 spraysings. The regularity of crystal structure is enhanced proportionally with increasing spraying from control to 10 spraysings. 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–OCH$_3$ 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 the 2 sprayed sample. But in the 6 and 10 sprayed samples these 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>
<thead>
<tr>
<th>Chemical Shift Description</th>
<th>Control Sample</th>
<th>2 sprayed sample</th>
<th>6 sprayed sample</th>
<th>10 sprayed sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS</td>
<td>PI</td>
<td>NPI</td>
<td>CS</td>
</tr>
<tr>
<td>Sulfonic and Sulfinic Acids and Derivatives</td>
<td>61.708</td>
<td>8.61</td>
<td>18.30</td>
<td>61.137</td>
</tr>
<tr>
<td>trans-1,2 Disubstituted Alkenes</td>
<td>130.370</td>
<td>0.47</td>
<td>1.00</td>
<td>130.256</td>
</tr>
</tbody>
</table>

*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 usable 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 µm 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.

**Funding**

The authors received no specific funding for this research.

**REFERENCES Références Referencias**


Supplementary Material

Supplementary data D1: Raw data files of cement instrumentations
https://drive.google.com/open?id=1Q1igeEkD5YHE0TZ-aE99MFBcALmA3Mu9
Supplementary video V1: Method of MIRGA spraying
https://drive.google.com/open?id=1QoRwTESKISdoJtfd--xlg9ypTDnVonGW

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/m² (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 physicochemical 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]. 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 \((\text{C}_6\text{H}_{10}\text{O}_5)\). (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 \((\text{H}_2\text{O})\) 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.

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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.

GJRE-E Classification: LCC Code: TA1-2040

Strictly as per the compliance and regulations of:
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1. 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,
especially during peak hours. It is located in the north of the Jordanian capital.

![Fig. 1: Aljbaha intersection](image)

**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
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.

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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.

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.
V. Results

Table 1: Summary of results

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<td>E</td>
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<tr>
<td>Signal optimization</td>
<td>45</td>
<td>1.3</td>
<td>48.3</td>
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<tr>
<td>Median U-turn</td>
<td>158</td>
<td>0.61</td>
<td>30.5</td>
<td>B</td>
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<tr>
<td>Signal optimization + Median U-turn</td>
<td>45</td>
<td>0.67</td>
<td>11.8</td>
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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. Aljbahe 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%.

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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.
  - In every section of your document, use standard writing style, including articles ("a" and "the").
  - Keep paying attention to the topic of the paper.

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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.

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Approach:
When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.
Describe generally acknowledged facts and main beliefs in present tense.

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