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Chemical Storage Facility

Potential of Rain Water Harvesting

Highlights

Mass Balance Mathematical Model

Formaldehyde Plant from Flared Gas

Discovering Thoughts, Inventing Future

VOLUME 25 ISSUE 1 VERSION 1.0

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Chemical Warehouse 101: Establishing a Functional Chemical Storage Facility from Scratch

By Hussain I. Al Hussain

Abstract- This paper provides a foundational guide to establishing a chemical warehouse from ground up, focusing on essential elements such as site selection, regulatory compliance, infrastructure, safety protocols, and operational workflows. The aim is to present a concise, practical introduction not only for engineers and project managers, but also for warehousing companies, logistics service providers, and entrepreneurs planning to enter the chemical storage industry.

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Chemical Warehouse 101: Establishing a Functional Chemical Storage Facility from Scratch

Hussain I. Al Hussain

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Introduction Background and Literature Review

The importance of chemical warehouse safety and efficiency has been well-documented in both regulatory and academic literature. Studies have highlighted the risks of chemical mismanagement, including fire hazards, toxic exposure, and environmental contamination (Zhao et al., 2018; OECD, 2021). Regulations such as the OSHA Hazard Communication Standard (HCS) and the NFPA's classification system provide detailed guidelines, yet the practical implementation often varies widely between facilities. Third-party warehousing and logistics services are increasingly used in the chemical industry to improve compliance and operational efficiency.

Furthermore, recent advancements in warehousing technologies, such as the integration of IoT-based monitoring and predictive analytics, are beginning to reshape operational standards (Jarašūnienė et al., 2023). However, there remains a lack of cohesive literature that consolidates these developments into a step-by-step framework accessible to both technical and non-technical audience. This paper aims to address that gap by synthesizing regulatory principles, industry best practices, and modern tools into an actionable guide for various stakeholders in the chemical storage ecosystem.

The safe and efficient storage of chemicals is vital across multiple industries. From pharmaceuticals to manufacturing, a well-organized warehouse minimizes risk while maximizing accessibility and compliance. Mismanagement in chemical storage can lead to catastrophic accidents, environmental harm, and regulatory penalties. This paper introduces six (6) key considerations and steps to establish a chemical warehouse tailored to safety and operational standards, serving as an introductory yet comprehensive blueprint for warehousing organizations, logistics providers, and engineering professionals alike.

I. Site Selection and Design

Selecting an appropriate site is critical to both safety and logistics. Factors to consider include:

- *Location:* Choose a site away from residential zones but accessible via major transportation routes (road, rail, or port). Proximity to emergency services and ease of containment in case of a spill or leak should also be assessed.
- *Zoning and Environmental Considerations:* Ensure the area is zoned for hazardous material storage and assess environmental risks such as flood zones or seismic activity. Environmental impact assessments (EIAs) may be required.

Layout Design: The layout should provide distinct zones for different chemical classes, with buffer zones and barriers to prevent cross-contamination. It should include:

- Designated areas for flammable liquids, corrosives, oxidizers, and toxic materials.
- Ventilation systems designed to reduce accumulation of hazardous vapors.
- Clearly marked emergency exits and access routes for fire and medical services.
- Spill containment features integrated into the floor plan.

II. Regulatory Compliance

Compliance with environmental protection regulations is equally essential. The U.S. Environmental Protection Agency (EPA) provides guidance on hazardous waste management, secondary containment systems, and stormwater runoff under laws such as the Resource Conservation and Recovery Act (RCRA) and the Clean Water Act (CWA). Warehouses must comply with spill prevention, control, and countermeasure (SPCC) regulations when handling threshold quantities of hazardous substances (EPA, 2024).

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Compliance with international and local regulations is non-negotiable. Key frameworks include:

- The Occupational Safety and Health Administration (OSHA) regulations (29 CFR 1910.1200) for hazard communication (OSHA, 2023).
- National Fire Protection Association (NFPA) Code 400 for hazardous materials (NFPA, 2023).
- Globally Harmonized System (GHS) for chemical classification and labeling.

Facilities must maintain updated permits, conduct periodic inspections, and ensure documentation (e.g., SDSs) is readily accessible to staff and regulators. A compliance matrix or checklist is highly recommended to track ongoing obligations and ensure ongoing and full compliance with regulatory requirements.

III. Infrastructure and Equipment

The infrastructure must be engineered to support safe storage and handling:

- *Spill Response Kits:* Each storage zone should be equipped with clearly marked spill kits. These should include absorbent pads, neutralizers, and containment pallets designed for the specific chemicals stored. Spill kits must be maintained in accessible locations and inspected regularly to ensure readiness for minor leaks or incidental spills.
- *PPE Storage Cabinets:* Designated cabinets must be installed near work zones to store personal protective equipment (PPE). PPE requirements should be determined based on the chemical hazard classification and material compatibility. At a minimum, PPE kits should include chemical-resistant gloves, safety goggles, face shields, coveralls, and respirators. Cabinets should be clearly marked, easily accessible, and regularly inspected for completeness and condition.
- *Emergency Safety Systems:* The facility must be equipped with emergency shower and eyewash stations in accordance with ANSI/ISEA Z358.1 standards. These should be located near areas where hazardous chemicals are handled to provide immediate decontamination in the event of accidental exposure.
- *Drainage System:* Design the floor with a chemical-resistant drainage system capable of containing and directing spills to a containment sump. The drainage plan must also comply with EPA spill containment and stormwater runoff requirements under the Clean Water Act (EPA, 2024). This helps prevent environmental contamination and facilitates cleanup.
- *Emergency Lighting:* Install battery-powered emergency lights that activate during power outages, ensuring safe navigation toward exits and safety equipment.
- *Fire Protection:* Install sprinklers, extinguishers, and smoke detectors rated for chemical environments. Class D fire extinguishers may be required for combustible metals.
- *Storage Systems:* Use corrosion-resistant, ventilated shelving. Flammable chemicals should be housed in explosion-proof cabinets and bonding/grounding should be installed to prevent static discharge.
- *Climate Control:* Some chemicals require temperature and humidity control to prevent degradation or hazards. For example, organic peroxides and isocyanates must be stored below specific temperature thresholds with humidity mitigation.
- *Signage:* Display clear, standardized signage for all hazardous materials stored in the facility. This includes symbols and labels for corrosive, flammable, toxic, reactive, and environmentally hazardous substances, consistent with GHS and NFPA standards. Signage should be prominently posted on doors, storage cabinets, and individual containers.

Additionally, install safety awareness posters in visible areas such as entryways, locker rooms, and near handling zones to reinforce key procedures like spill response, PPE usage, and emergency actions. These posters can also be referenced and reinforced through employee training programs. Access to PPE should be immediate and accompanied by training.

IV. Safety and Risk Management

Proactive safety planning reduces liability and improves response time:

- *Training:* Employees must be trained on chemical hazards, safe handling, and emergency response. Refresher training should be conducted semi-annually, and competency should be verified through assessments. Training should also include hands-on exercises for using spill kits, including identifying appropriate absorbents and deploying containment pallets. Employees should be familiar with minor spill containment techniques and understand the escalation protocol for larger incidents, in accordance with OSHA HAZWOPER and EPA SPCC guidelines. Additionally, organizations seeking structured training may consider enrolling employees in certified courses. One example is the OSHA HAZWOPER training provided by the OSHA Education Center, which includes modules on chemical spill response and safety protocols (OSHA Education Center, 2024). Other reputable providers include the National Safety Council (NSC), Hazmat School, and Global

HazMat, all of which offer in-person and online training aligned with SPCC and OSHA standards.

- *Emergency Response Plan:* Must include evacuation procedures, contact lists, and spill containment protocols. Periodic drills should simulate real scenarios. Coordination with local emergency responders is encouraged.
- *Storage Protocols:* Store chemicals based on compatibility matrices (e.g., acids separate from bases) and segregate by flammability, toxicity, and reactivity. Use of color-coded labeling systems and QR-linked SDS access can enhance clarity. Guidelines from the National Research Council's 'Prudent Practices in the Laboratory' recommend grouping chemicals by hazard class, ensuring proper ventilation, and maintaining separation between incompatible substances (National Research Council, 2011).

Step-Up Recommendation: Consider integrating mobile apps for on-the-go hazard reporting and digitized incident logs. These tools increase responsiveness and support real-time safety oversight without requiring full-scale simulation technologies. Notable examples include iAuditor by SafetyCulture, which enables real-time hazard reporting and inspection tracking, and ChemAlert Mobile, a chemical management app that provides QR-access to SDS and safety protocols. These tools enhance situational awareness and help standardize incident documentation.

V. Operational Procedures

Smooth operations depend on well-documented procedures:

- *Inventory Control:* Employ systems like barcode or RFID to monitor stock levels, expiration dates, and usage logs. Include monitoring of chemical shelf life to ensure expired substances are flagged and removed from circulation. Implement first-expire-first-out (FEFO) protocols.
- *Receiving and Dispatch:* Inspect all incoming materials for integrity and verify documentation. Outgoing shipments must be labeled and packaged per transport regulations (e.g., DOT, ADR).
- *Maintenance:* Periodic calibration of sensors, inspection of containment units, HVAC servicing, and review of SDSs should be scheduled. Maintain an up-to-date master material list that documents all chemicals on-site, their hazard classifications, storage requirements, and expiration dates. This list should be reviewed and updated regularly in coordination with inventory audits. Maintenance logs should be digitized for traceability.

VI. Advanced Enhancements and Cost Feasibility

While not part of minimum regulatory requirements, several modern practices can significantly enhance the performance and safety of a chemical warehouse.

- *Digital Tools and Automation:* Warehouse Management Systems (WMS) improve visibility and accuracy in inventory tracking. IoT sensors can monitor temperature, humidity, and leakage in real time, enabling early intervention. AI-powered analytics can predict demand trends, flag compliance risks, and optimize space allocation (Boston Consulting Group, 2022).
- *Cost Considerations and Feasibility:* Establishing a chemical warehouse involves significant capital and operating expenses. Capital expenditures (CapEx) include land acquisition, structural upgrades for fire safety, temperature control systems, and installation of regulatory-compliant fixtures. Operating expenditures (OpEx) include utility costs, employee training, PPE replenishment, insurance, and periodic third-party audits.

Conclusion

Starting a chemical warehouse requires strategic planning, regulatory awareness, and a safety-first mindset. This guide serves as a starting point; while further expansion and customization would depend on warehouse size, function, and chemical type. Future revisions may include real-world case studies or digital simulation tools to further contextualize warehouse implementation strategies. With increasing environmental and safety expectations, integrating smart technologies and strict compliance protocols will be key to long-term operational success. Whether the initiative is led by a private enterprise, a logistics firm, or an internal industrial team, a standardized and proactive approach to chemical warehousing is essential.

References Références Referencias

1. Zhao, Y., Zhu, Q., & Li, Y. (2018). Risk assessment of chemical logistics centers using fuzzy fault tree analysis. *Journal of Loss Prevention in the Process Industries*, 55, 225-233. https://doi.org/10.1016/j.jlp.2018.06.010
2. Organisation for Economic Co-operation and Development (OECD). (n.d.). Chemical accident prevention, preparedness and response. https://www.oecd.org/chemicalsafety/chemical-accidents/
3. Jarašūnienė, A., Čižiūnienė, K., & Čereška, A. (2023). Research on Impact of IoT on Warehouse Management. Sensors, 22(19), 7213. https://www.mdpi.com/1424-8220/22/19/7213

4. Occupational Safety and Health Administration (OSHA). (n.d.). Hazard Communication. https://www.osha.gov/hazcom
5. National Fire Protection Association (NFPA). (n.d.). Code 400: Hazardous Materials. https://www.nfpa.org/Codes-and-Standards/All-Codes-and-Standards/List-of-Codes-and-Standards
6. National Research Council. (2011). Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards. https://www.ncbi.nlm.nih.gov/books/NBK55873/
7. Boston Consulting Group (BCG). (2022). Benefits of AI-Driven Supply Chains. https://www.bcg.com/publications/2022/benefits-of-ai-driven-supply-chain
8. U.S. Environmental Protection Agency (EPA). (2024). Oil Spills Prevention and Preparedness Regulations. https://www.epa.gov/oil-spills-prevention-and-preparedness-regulations
9. U.S. Environmental Protection Agency (EPA). (2024). National Pollutant Discharge Elimination System (NPDES). https://www.epa.gov/npdes
10. OSHA Education Center. (2024). HAZWOPER Training. https://www.oshaeducationcenter.com/hazwoper/
11. National Safety Council (NSC). (2024). Safety Training Courses. https://www.nsc.org/safety-training
12. Hazmat School. (2024). OSHA Spill Response Training. https://www.hazmatschool.com/osha-first-responder-awareness-with-spill-cleanup-training/
13. Global HazMat. (2024). Hazardous Spill Management. https://www.globalhazmat.com/workplace-safety-training/hazardous-spill-management/
14. SafetyCulture. (2024). iAuditor. https://safetyculture.com/iauditor/
15. ChemAlert (RMT). (2024). ChemAlert Mobile. https://www.rmt.com.au/products/chemalert/

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Variations in the Concentration of CO_2 in Associated Gases: Evaluation of the Performance of a Conditioning Process with Turboexpander

By Leandro Vargas, Andrea Gonzalez & Giovanni Morales

Abstract- Herein we disclose an evaluation of the performance of a Turboexpander unit for the conditioning of associated gasses with different CO2 contents. The performance evaluation was carried out by the comparison of the results from a simulation in Aspen Hysys v10 with the specifications established in the national gas transportation policy for natural gas (RUT). The Turboexpander unit was designed for the conditioning of an associated gas defined by the scenario of medium production for the Valle Medio del Magdalena, according to the prospects of the Mining and Energy Planning Unit (UPME). The conditioning unit considered the sections: stabilization, sweetening, dehydration, and separation by distillation. Similarly, the range for CO2 content variation was defined between 3 - 12% mol, based on enhanced recovery (EOR) pilots of air injection and CO2 injection. The results of the simulations showed an adequate performance of the Turboexpander unit for the conditioning of associated gasses with up to 6% mol of CO2 contents, fulfilling the quality parameters of the RUT.

Keywords: *turboexpander, gas transportation policy, associated gas, carbon dioxide, valle medio del magdalena, Aspen Hysys.*

GJRE-C Classification: *LCC: TP761, TP359*

Variations in the Concentration of CO_2 in Associated Gases: Evaluation of the Performance of a Conditioning Process with Turboexpander

Variaciones en la concentración de CO_2 en gases asociados: Evaluación del desempeño de un proceso de acondicionamiento con Turboexpander

Leandro Vargas [α], Andrea Gonzalez [σ] & Giovanni Morales [ρ]

Resumen- Este documento presenta una evaluación de los desempeños de una unidad con Turboexpander, en el acondicionamiento de gases asociados con diferentes contenidos de CO_2. La evaluación de los desempeños fue efectuada por comparación de los resultados de una simulación desarrollada en Aspen Hysys v10 y las especificaciones establecidas en el Reglamento Único de Transporte de Gas Natural (RUT). Para esto, la unidad fue diseñada para el acondicionamiento del gas asociado definido por el escenario medio de producción de la cuenca del Valle Medio del Magdalena, según prospectivas de la Unidad de Planeación Minero-Energética; la unidad de acondicionamiento consideró las secciones: estabilización, endulzamiento, deshidratación y separación por destilación. De igual manera, el intervalo de variación de contenido de CO_2 entre 3 y 12% mol fue establecido, con base en reportes de literatura de pilotos de recobro mejorado (EOR) por inyección de aire e inyección de CO_2. Los resultados de las simulaciones mostraron un desempeño adecuado de la unidad con Turboexpander, en el acondicionamiento de gases asociados con concentraciones de CO_2 de máximo 6% mol, cumpliendo los parámetros de calidad estipulados en el RUT. Asimismo, los resultados de las simulaciones muestran que el perfil de temperatura en la torre de absorción, de la sección de endulzamiento, es alterado cuando se tratan gases con mayor contenido de CO_2. Esta alteración del perfil de temperatura en la torre de absorción conduciría al bajo desempeño en el retiro de CO_2. Lo anterior sugiere rediseños en la sección de endulzamiento o cambio de la respectiva tecnología, con lo cual, los gases tratados puedan cumplir los parámetros de calidad especificados en el RUT.

Palabras claves: turboexpander, RUT, gas asociado, dióxido de carbono, Valle Medio del Magdalena, Aspen Hysys.

Abstract- Herein we disclose an evaluation of the performance of a Turboexpander unit for the conditioning of associated gasses with different CO_2 contents. The performance evaluation was carried out by the comparison of the results from a simulation in Aspen Hysys v10 with the specifications established in the national gas transportation policy for natural gas (RUT). The Turboexpander unit was designed for the conditioning of an associated gas defined by the scenario of medium production for the Valle Medio del Magdalena, according to the prospects of the Mining and Energy Planning Unit (UPME). The conditioning unit considered the sections: stabilization, sweetening, dehydration, and separation by distillation. Similarly, the range for CO_2 content variation was defined between 3 - 12% mol, based on enhanced recovery (EOR) pilots of air injection and CO_2 injection. The results of the simulations showed an adequate performance of the Turboexpander unit for the conditioning of associated gasses with up to 6% mol of CO_2 contents, fulfilling the quality parameters of the RUT. Likewise, the simulation results showed that the temperature profile in the absorption tower (sweetening section) changed when gasses with CO_2 contents greater than 6% mol were treated. This temperature profile change appeared to be responsible for poor CO_2 removal performance. The foregoing would suggest adjustments for the sweetening section or a shift of the respective technology in order to fulfill the quality parameters specified in the RUT.

Keywords: turboexpander, gas transportation policy, associated gas, carbon dioxide, valle medio del magdalena, Aspen Hysys.

I. Introducción

El gas natural y la gasolina son productos de importancia en la canasta energética nacional, utilizados en diferentes sectores como el residencial, industrial, transporte y electricidad. El gas asociado de los yacimientos de crudo puede ser acondicionado para su uso como gas natural; adicionalmente, un flujo de gasolina natural es derivado como un subproducto. El acondicionamiento del gas asociado permite la disminución de contaminantes y líquidos condensables, a niveles adecuados para su aprovechamiento como fuente de energía térmica. Estos niveles están definidos en el Reglamento Único de Transporte de Gas Natural (Resolución CREG-071 de 1999 y su modificación posterior del año 2019).

Dentro de los contaminantes a retirar del gas asociado se encuentra el CO_2. Este gas es conocido por su participación en el cambio climático. El accionar del CO_2 en el aire impide la salida de calor de las capas

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bajas de la atmósfera (efecto invernadero), lo cual ha generado un aumento progresivo en la temperatura promedio de la superficie del planeta (Osborn *et al.*, 2021). Debido a esta problemática, los gobiernos se han comprometido con la disminución en las emisiones de CO_2. En Colombia, el sector minero energético ha propuesto una meta de disminución en emisiones de 11,2 millones de toneladas de CO_2 equivalentes para el año 2030.

El retiro del contenido de CO_2 en los procesos de acondicionamiento de gas (endulzamiento), es usualmente realizado por absorción con monoetanolamina (MEA) (Elbashir *et al.*, 2019; Mokhatab & Poe, 2012); la MEA gastada es regenerada por calentamiento para su recirculación en el proceso. Posteriormente, el gas endulzado es sometido a un enfriamiento, que puede ser aplicado con un Turboexpander, para una posterior separación de los líquidos condensables, por medio de destilación fraccionada a baja temperatura (Mokhatab & Poe, 2012). Es importante anotar que, Colombia tiene instalada una importante cantidad de unidades de acondicionamiento de gases con Turboexpander (Martínez, 2018). Recientemente, Camacho (2021) desarrolló un análisis técnico-económico para la implementación de una unidad Turboexpander de acondicionamiento del gas asociado generado en el Valle Medio del Magdalena, considerando las proyecciones de producción definidas por la UPME (2018). Los resultados reportados por este autor indican factibilidad técnico-económica en la implementación de la unidad Turboexpander. Lo anterior manifiesta posibilidades futuras en el país, de nuevas unidades de acondicionamiento, basadas en Turboexpander.

Por otra parte, la aplicación de métodos de recobro mejorado (EOR, *enhanced oil recovering*) ha aumentado la producción de crudo (Jiang *et al.*, 2022; Mokheimer et al., 2019), principal contribuyente del mercado energético mundial actual (Baumeister *et al.*, 2020). Uno de estos métodos EOR, basado en inyección de gases, ha conducido al aumento de la concentración de CO_2 en el gas asociado (Barbosa *et al.*, 2012; Escobar, 2006; Jiang *et al.*, 2022). Por consiguiente, se han realizado seguimientos a pilotos EOR de inyección de gases, implementados en diferentes yacimientos del país. Análisis cromatográfico de gases han reportado aumentos en los niveles de CO_2, hasta 12% mol en el gas asociado del campo Chichimene, por aplicación de EOR con inyección de aire (Díaz Molina *et al.*, 2019), y hasta 19% mol en el gas asociado del campo San Fernando, por aplicación de EOR por inyección de CO_2 (Diaz *et al.*, 2018). Este aumento en el contenido de CO_2, en gases asociados de pozos sujetos a EOR, puede ser progresivo en la respectiva ventana de operación (Marinov, 2015).

Este incremento en los contenidos de CO_2 afecta los desempeños resultantes de un proceso de acondicionamiento de gas, especialmente en las etapas de endulzamiento y de recuperación de líquidos (Langé & Pellegrini, 2016; Rufford *et al.*, 2012). En la etapa de endulzamiento, una elevación en el contenido de CO_2 conduciría a un aumento en los requerimientos energéticos de la regeneración del absorbente (Langé & Pellegrini, 2016; Rufford *et al.*, 2012). Por su parte, los contenidos de CO_2 pueden afectar el equilibrio de fases en la etapa de separación de los hidrocarburos líquidos (Rufford *et al.*, 2012). Además, la presencia de CO_2 puede conducir a la formación de hidratos, a ciertas condiciones de presión y temperatura, ocasionando taponamiento en las líneas de flujo (Carroll, 2003).

Ante esta situación de incremento en los contenidos de CO_2, la mayoría de la literatura consultada dirige la atención en la proposición de alternativas de retiro simultáneo de líquidos condensables junto con el CO_2 (Arinelli *et al.*, 2019; Luyben, 2013; Maqsood et al., 2014). Sorpresivamente, un número escaso de documentos reportaron análisis de los desempeños de las plantas con Turboexpander ante aumentos en el contenido de CO_2 en el gas asociado. Getu *et al.* (2013) compararon, por simulación con Aspen Hysys, los desempeños de diferentes procesos de separación de líquidos condensables en gases asociados con concentraciones de CO_2 de hasta 3.65% mol. Los autores mostraron factibilidad técnica en los procesos de retiro de líquidos (incluyendo Turboexpander) para las diferentes concentraciones analizadas, mencionando que las mayores recuperaciones de etano fueron obtenidas en los gases con menores concentraciones de CO_2. De igual manera, El-Husseiny *et al.* (2021) analizaron las variaciones energéticas del acondicionamiento con Turboexpander para gases asociados con concentraciones de CO_2 hasta 3.91% mol. Los autores reportaron factibilidad en el proceso de acondicionamiento para las diferentes concentraciones. Los trabajos de Getu *et al.* (2013) y El-Husseiny *et al.* (2021) presentan la característica de análisis para bajas concentraciones de CO_2; sin embargo, en unidades Turboexpander instaladas, esta condición de bajas concentraciones de CO_2 puede cambiar con los requerimientos de aplicación de EOR por inyección de gases. Asimismo, estos autores omiten los análisis de los perfiles de temperatura en las torres de endulzamiento y de separación de líquido. Estos análisis pueden ayudar en la explicación de los desempeños del proceso de acondicionamiento.

Las variaciones en los contenidos de CO_2 pueden conducir al incumplimiento de los requisitos mínimos para el transporte y la venta del gas, acondicionado en una determinada unidad. Un gas que no cumple con el RUT conlleva a pérdidas económicas y a contaminación ambiental; usualmente este gas es quemado en teas (Elehinafe *et al.*, 2022; Petri *et al.*, 2018). Lo anterior podría ser evitado con la predicción

de los desempeños de las unidades de acondicionamiento, previo al tratamiento de los gases asociados. Una predicción de los desempeños de las unidades instaladas conduciría a la selección de la unidad con mayor efectividad, en el acondicionamiento de un gas con determinado contenido de CO_2.

Considerando la problemática planteada, el presente documento expone un análisis sobre el desempeño de una unidad Turboexpander en el acondicionamiento de gases asociados con diferentes contenidos de CO_2. El análisis fue desarrollado considerando las proyecciones de producción de la UPME (2018) y los resultados de una simulación en Aspen Hysys v10.

II. Metodología

El flujo de gas asociado correspondió al definido en el escenario medio de producción para la Cuenca del Valle Medio del Magdalena, según las proyecciones de la UPME (2018). Este escenario estableció un flujo promedio de 11,8 MMSCFD al año 2044. Por su parte, la composición de los gases en este escenario fue asumida como la típica de los gases producidos en los campos Bonanza y Lisama de ECOPETROL S.A (Camacho, 2021); una característica de los gases en estos campos es la ausencia de H_2S (Camacho, 2021; Sáchica, 2012), lo cual facilita el respectivo proceso de endulzamiento. La Tabla 1 resume las condiciones de entrada y la composición del gas asociado.

La Tabla 2 compara la composición y las propiedades del gas asociado con los requisitos solicitados por el RUT. Según esta tabla, la composición de agua y de CO_2, así como el contenido de líquidos condensables (definido por el punto *Cricondentherm*) se encuentran fuera de especificación para el transporte y la comercialización del gas asociado; con lo anterior, el gas asociado requiere del respectivo acondicionamiento. Las secciones consideradas en el diseño estándar y en la simulación del proceso de acondicionamiento fueron: estabilización, endulzamiento, deshidratación y enfriamiento con Turboexpander, con una posterior separación por destilación.

Tabla 1: Condiciones y composición del gas asociado (Camacho, 2021)

Flujo, MMSCFD	**11,8**
Temperatura, ºF	**99,8**
Presión, psi	**500**
Metano, % mol	77,06
Etano, % mol	7,20
Propano, % mol	4,87
n-butano, % mol	1,78
i-butano, % mol	1,59
n-Pentano, % mol	0,41
i-Pentano, % mol	0,57
2,2-Mpropano, % mol	0,03
n-Hexano, % mol	0,50
n-Heptano, % mol	0,12
n-Octano, % mol	0,04
n-Nonano, % mol	0,01
n-Decano, % mol	0,01
H_2O, % mol	0,21
Oxígeno, % mol	0,03
Nitrógeno, % mol	1,66
CO_2, % mol	3,91

Tabla 2: Verificación de la composición y las propiedades del gas asociado con los requerimientos del RUT (en paréntesis)

Componente	Gas de entrada (RUT)
H_2O, mg/m^3	58669,5 (<97)
O_2, % vol.	0,03 (<0,1)
N_2, % vol.	1,66 (<3)
Inertes, % vol.	5,60 (<5)
CO_2, % vol.	3,91 (<2)
H_2S, mg/m^3	0,00 (<6)
Poder calorífico, MJ/m^3	41,02 (35,4 – 42,8)
Cricondentherm, ºF	114,0 (<45)

El paquete termodinámico Peng-Robinson fue utilizado para la mayoría de las corrientes y equipos en la simulación; este paquete ha reportado resultados concordantes con diferentes datos de procesamiento

de hidrocarburos simples (Poe & Mokhatab, 2017). Por su parte, el paquete termodinámico "Acid Gas – Chemical Solvents" fue seleccionado para la sección de endulzamiento; este paquete aplica cálculos basados en el modelo NRTL en reacciones en fase acuosa, necesarias para el cálculo riguroso del proceso de absorción con MEA (Irina & Watanasiri, 2015). También, el paquete termodinámico "Glycol Package" fue definido para la sección de deshidratación; el "Glycol Package" aplica la ecuación de estado TST (Twu-Sim-Tassone) en la determinación del equilibrio de fases, con resultados consistentes para la mezcla agua-TEG (trietilenglicol) (Hasan *et al.*, 2020).

Por otro lado, los equipos de proceso estándar fueron especificados con base en los trabajos de Benitez *et al.* (2015), Camacho (2021), Elbashir *et al.* (2019), Kherbeck & Chebbi (2015), Mokhatab *et al.* (2019), Mokhatab & Poe (2012) y Tristancho (2017). Para la etapa de estabilización, donde se aplica un tratamiento inicial, los equipos definidos fueron dos separadores *flash*, un compresor y un calentador. La sección de endulzamiento considera una absorción con MEA al 20% molar a 120°F y 847 psi, en una torre de 10 platos y de diámetro de 2,3 ft; es importante mencionar que la temperatura fue definida para una mayor absorción, a partir de pruebas con la simulación. También, la sección de endulzamiento considera una recuperación de MEA gastada, en una torre de destilación de 5 platos y diámetro de 3,9 ft.

La sección de deshidratación utiliza una solución de TEG al 99% p/p, en una torre de absorción con 20 platos y diámetro de 4,9 ft. El TEG gastado es recuperado en una torre de destilación de 5 platos, operando a presión atmosférica. El gas dulce y seco es enviado a la sección de enfriamiento con Turboexpander (criogenización). En esta sección, el gas es recibido por un enfriador, disminuyendo su temperatura hasta -31°F; el enfriamiento a esta temperatura conduce a una mayor recuperación de etano. Después del enfriador, la sección consideró dos torres de destilación para la generación del gas acondicionado, un flujo de etano y un flujo de GLP. La primera torre es llamada como demetanizadora, la cual es definida a una presión de 450 psia y temperaturas de -139°F en el tope hasta 85°F en el fondo de la torre, con un diseño de 17 platos y un diámetro de 4,9 ft. La segunda torre se denomina desetanizadora y es configurada con 28 platos, diámetro de 4,9 ft y operada a presiones en el rango de 200 a 210 psi y temperaturas desde -11°F en el tope hasta 130°F en el fondo de la torre. El diagrama de proceso (PFD) diseñado en Aspen Hysys es presentado en la Figura 1. En esta figura se definen las propiedades de los flujos principales de entrada y salida de la unidad, así como las secciones codificadas en el PFD.

Con el PFD desarrollado, un total de cinco (5) simulaciones fueron ejecutadas, considerando diferentes concentraciones de CO_2 en el gas asociado. La Tabla 3 presenta las concentraciones del gas asociado para cada simulación; la simulación No 1 corresponde al caso base, con la composición de la Tabla 1. Las concentraciones de metano, del gas asociado del caso base, fueron ajustadas para la consecución de las composiciones mostradas en la Tabla 3. El gas de la simulación No 5 presenta una composición de CO_2 cercana a la máxima del gas asociado del campo Chichimene (EOR por inyección de aire), reportada por Díaz Molina *et al.* (2019). Por otro lado, cada simulación fue ejecutada, considerando las mismas especificaciones y condiciones de operación de los equipos, definidas anteriormente.

Tabla 3: Variación del contenido de CO_2 en el gas de entrada

No. Simulación	1	2	3	4	5
Metano % mol	77,0	75,1	73,3	71,4	69,5
Etano % mol	7,2	7,2	7,2	7,2	7,2
C_3+ % mol	9,9	9,9	9,9	9,9	9,9
H_2O % mol	0,21	0,21	0,21	0,21	0,21
O_2 % mol	0,03	0,03	0,03	0,03	0,03
N_2 % mol	1,66	1,66	1,66	1,66	1,66
CO_2 % mol	3,91	5,79	7,68	9,58	11,4

Nota: La simulación No 1 corresponde al caso base (Tabla 1).

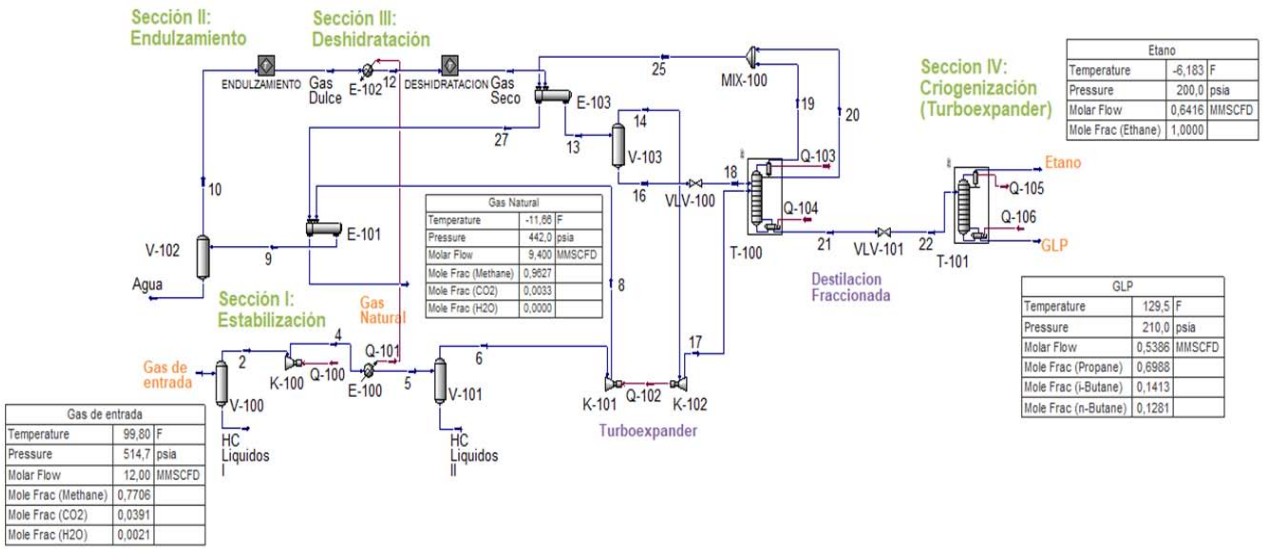

Figura 1: Diagrama de flujo en Aspen HYSYS del proceso de tratamiento de gas asociado

III. Resultados y Discusión

a) Validación simulación para el caso base

El PFD de la simulación desarrollada en Aspen Hysys v10 es mostrado en la Figura 1. La simulación reportó convergencia con las composiciones del caso base. La Tabla 4 reporta las características del gas de salida de cada sección de la simulación. Según esta tabla, el proceso diseñado alcanza una disminución en el contenido de CO_2 al valor de 0,28% mol, en el gas de salida de la sección de endulzamiento. Para la sección de deshidratación, la simulación muestra una disminución en la concentración de agua, en el gas de salida, al valor de 53,8 mg/m^3. La Tabla 4 resume las propiedades del gas de salida, reportadas por la simulación, en cada una de las secciones de la unidad. Según esta tabla, los valores obtenidos por la simulación presentan los mismos órdenes de magnitud que los resultados de Camacho (2021). De igual manera, las variables operacionales obtenidas por la simulación, para las diferentes secciones, (Tabla 4) coinciden con diferentes reportes de literatura (ver Chebbi *et al.*, 2010; Getu *et al.*, 2013; Swaidan, 2016; Tristancho, 2017).

Asimismo, una de las variables más importantes dentro del proceso criogénico con un Turboexpander corresponde a la recuperación de etano. El proceso Turboexpander de una sola etapa está diseñado para obtener recuperaciones en el rango 70-80% (Bogoya & Díaz, 2014; Chebbi et al., 2010); el proceso exhibe posibilidades de maximización, según el caso, a valores por encima del 90% (Chebbi et al., 2010; Kherbeck & Chebbi, 2015). Los resultados de la simulación con el caso base, de producción de gas asociado de la cuenca del Valle medio del Magdalena, indican una recuperación de etano del 74,3%, lo cual se encuentra dentro del rango reportado anteriormente.

Con base en la coincidencia entre los valores de la simulación con lo reportado en la literatura y con la recuperación de etano, es posible afirmar que la simulación desarrollada reproduce los valores de operación industrial para el proceso de acondicionamiento de gases asociados, con una unidad Turboexpander.

Tabla 4: Comparación de los resultados de la simulación con la literatura

		Camacho (2021)	Este Trabajo
Sección I: Estabilización	T, °F	120,0	120,0
	P, psi	748,0	762,7
	F, MMSCFD	11,98	11,98
	CO_2, %vol	3,91	3,90
	H_2O,mg/m^3	49611,1	49542,4
	Cricon., °F	103,2	102,5
Sección II: Endulzamiento	T, °F	111,2	85,0
	P, psi	847,0	900
	F, MMSCFD	11,55	11,51
	CO_2, %vol	0,41	0,28
	H_2O,mg/m^3	49000,7	49189,8
	Cricon., °F	105,4	104,6
Sección III: Deshidratación	T, °F	22,1	28,55
	P, psi	590,0	597,8
	F,MMSCFD	11,53	10,58
	CO_2, %vol	0,41	0,29
	H_2O,mg/m^3	65,5	53,8
	Cricon., °F	11,2	6,7
Sección IV: Gas de Salida	T, °F	-13,5	-11,66
	P, psi	445,0	442,0
	F,MMSCFD	10,36	9,40
	CO_2, %vol	0,45	0,33
	H_2O,mg/m^3	73,9	46,3
	Cricon., °F	-80,8	-112,2

b) Simulaciones con los otros casos

La convergencia en las simulaciones con los demás casos fue conseguida por aumento en el flujo de solución acuosa de MEA en un 17%. Este aumento no afecta el diámetro de la torre de endulzamiento; el diámetro se encuentra en función del flujo de gas y la presión de la torre (Elbashir et al., 2019; Kolmetz, 2020; Mitra, 2015). Además, Kolmetz (2020) sugiere que, la relación entre el flujo de gas a flujo de MEA sea fijada entre 0,3 y 0,4 mol/mol, relación cumplida en todos los casos. Las otras secciones de deshidratación y criogenización no reportaron inconvenientes de convergencia con lo especificado para el caso base.

Por otra parte, pruebas en la simulación especificando gases asociados con concentraciones superiores de 11,4% mol de CO_2 reportaron fallas de convergencia en las torres de la sección de endulzamiento. Lo anterior sugiere modificaciones en los diseños de las torres en esta sección, en unidades convencionales, para el tratamiento de gases ácidos con contenidos molares de CO_2 superiores a 11,4%.

c) Perfiles en las torres

La Figura 2 expone los perfiles de temperatura de la torre de absorción, sección de endulzamiento, obtenidos por la simulación para los gases con diferentes contenidos de CO_2. Según esta figura, para los gases con contenidos de 3,91% mol y 5,79% mol, los perfiles de temperatura presentan un máximo en el plato número dos (numeración desde el plato de fondo; el gas ingresa por el fondo, mientras la solución de MEA ingresa por la cima), con valores de 225°F y 223°F, respectivamente. Este máximo se debe al comportamiento exotérmico de la absorción de CO_2 en MEA. Posteriormente, los perfiles muestran una disminución monotónica de la temperatura de los platos superiores, hasta el valor de 112°F (plato 10), debido a la evaporación de agua (Biliyok *et al.*, 2012; Mores *et al.*, 2012; Rashid *et al*., 2014) y a la temperatura de entrada de la solución de MEA. El comportamiento de estos perfiles de temperatura es consistente con el estudio de Giri *et al.* (2011) y con las mediciones experimentales de Rashid *et al.* (2014).

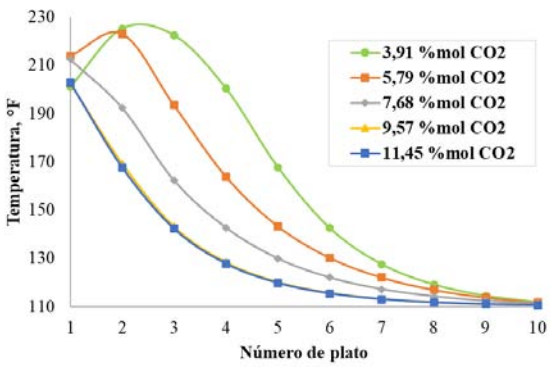

Figura 2: Perfiles de temperatura en la torre de absorción con MEA (20%) para diferentes concentraciones de CO_2

Asimismo, la Figura 2 manifiesta que, a mayores concentraciones de CO_2 en el gas de entrada

(*i.e.* 7,68%, 9,57% y 11,54%), el perfil de temperatura presenta un decrecimiento monotónico desde el primer plato. Esta tendencia se debe a la variación del calor de absorción con la carga de CO_2. Reportes experimentales de Kim *et al.* (2014) y Kothandaraman (2010) indican que el calor de absorción disminuye drásticamente en soluciones con cargas superiores a 0,4 mol CO_2/mol MEA. Precisamente, la operación de la torre con gases de contenido 7,68%, 9,57% y 11,54% exhibe una relación mol CO_2/mol MEA superior a 0,4 en la solución de fondo (bajo calor de absorción). De otro lado, la simulación reporta que, en la operación de la torre con gases de contenido 3,91% y 5,79%, la solución acuosa en los platos de fondo muestra una relación mol CO_2/mol MEA inferior a 0,4 (elevado calor de absorción). Con lo anterior, el calor de absorción liberado es menor en la operación con mayores contenidos de CO_2, conduciendo al perfil de temperatura sin punto máximo en los platos de fondo.

Por su parte, la Figura 3 presenta los perfiles de temperatura en la torre deshidratadora; la numeración inicia en el plato de cima. Según esta figura, la temperatura del gas experimenta un aumento en su recorrido, desde el fondo a la cima de la torre, debido a la disminución en su contenido de humedad. El flujo de TEG pobre ingresa en contracorriente a 120°F al plato 1, mientras el flujo de gas ingresa al plato 20, en promedio a 90°F. La condensación del agua contenida en el gas envuelve un enfriamiento en el respectivo plato de contacto, por lo cual, el TEG disminuye su temperatura en su recorrido (de arriba hacia abajo), mientras el gas aumenta su temperatura (de abajo hacia arriba). El incremento de temperatura del plato 19 al plato 2 es de tipo lineal, a razón de 1°F/plato. Del plato 2 al plato de cima, el gas experimenta un calentamiento brusco, con un incremento de 4°F debido a la temperatura del flujo de TEG pobre. Este perfil es característico para las diferentes concentraciones de CO_2. Según la Figura 3, el perfil presenta un desplazamiento vertical hacia abajo (menores valores de temperatura) con el aumento en la concentración de CO_2. Este desplazamiento se debe a la disminución en la capacidad calorífica del gas, con el aumento en el contenido de CO_2 (Cp_{CO2}=0,19 BTU/lb/°F a 35°F; Cp_{CH4}=0,52 BTU/lb/°F a 35°F). Los perfiles de la Figura 3 coinciden con lo reportado por Garmendia (2019), con base en una simulación en PROII/ PROVISION de una planta de deshidratación con TEG.

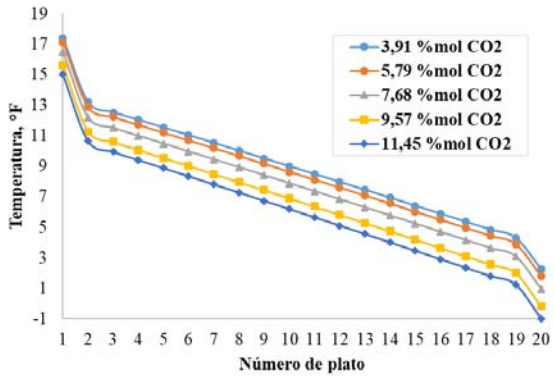

Figura 3: Perfil de temperatura torre deshidratadora con TEG

Por su parte, los perfiles de las Figuras 4 y 5 corresponden a las variaciones en las temperaturas en las torres demetanizadora (Figura 1, T100) y desetanizadora (Figura 1, T101), respectivamente. La numeración en estas torres inicia en el plato de cima; el plato de alimentación en la demetanizadora corresponde al 17, mientras en la desetanizadora, el flujo es alimentado al plato 14. Según las Figuras 4 y 5, la temperatura de cima, como se esperaba, resulta menor en la demetanizadora debido a su mayor presión de operación (450 psia, comparado con 200 psia en la desetanizadora). Asimismo, es posible apreciar que, en cada figura, los perfiles varían en los platos de cima, debido al cambio en el contenido de CO_2 del gas

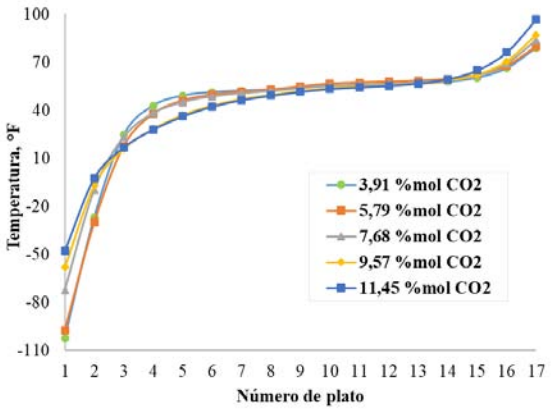

Figura 4: Perfil de temperatura torre demetanizadora

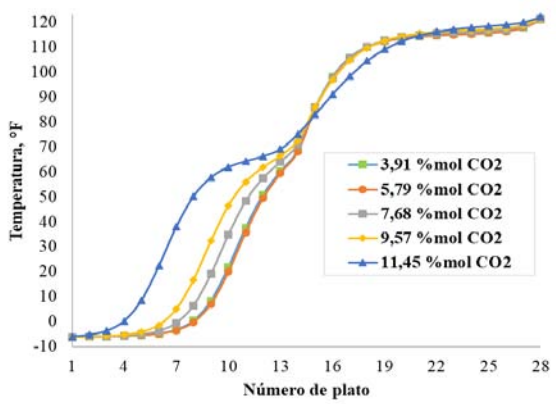

Figura 5: Perfil de temperatura torre desetanizadora

de alimentación. Los perfiles en estas zonas presentan menores temperaturas para menores contenidos de CO_2 (mayores contenidos de CH_4); lo anterior se debe a la diferencia entre las capacidades caloríficas del CO_2 (0,18 BTU/lb/°F a -55°F) y el CH_4 (0,50 BTU/lb/°F a -55°F); a mayor contenido de CO_2 menor requerimiento de flujo calórico para el aumento en las temperaturas de cima. Las tendencias de los perfiles mostrados en la Figura 4 coinciden con lo mostrado por ZareNezhad & Eggeman (2006), autores que analizaron los resultados de la aplicación de la ecuación de estado Peng-Robinson en procesos de recuperación de NGL de mezcla de hidrocarburos. De igual manera, los perfiles presentados en la Figura 5 coinciden con lo obtenido por Binous & Bellagi (2013).

d) Consumos energéticos

Según los resultados de las simulaciones, un aumento en la concentración de CO_2 del gas asociado conduce a una disminución en la potencia generada por el Turboexpander, debido a la respectiva disminución en el flujo de metano (Tabla 3); un menor flujo disminuye la energía disponible en la expansión del gas de entrada. La Figura 6 muestra que la potencia obtenida en la etapa de expansión del Turboexpander es inversamente proporcional con respecto al incremento en la concentración de CO_2. Según esta figura, un aumento en el 1% en el contenido de CO_2 conduce a una disminución de 0,1 hp de potencia generada en el Turboexpander.

Asimismo, y en contraste, la Figura 6 expone también un aumento en el requerimiento calórico del proceso, con el aumento en el contenido de CO_2. Este aumento se debe principalmente a la etapa de regeneración de la MEA, lo cual es consistente con lo reportado por Feng *et al.* (2010).

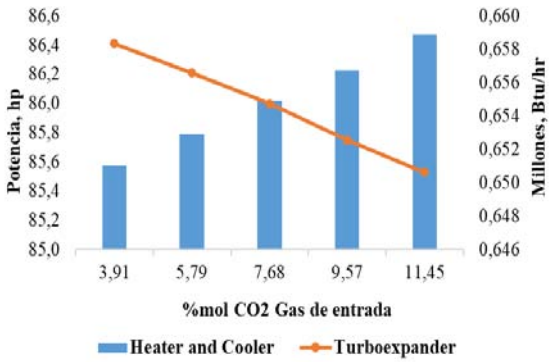

Figura 6: Variación en el requerimiento calórico y de potencia

e) Flujos de salida del proceso

Los flujos de salida del proceso comprenden: el gas asociado acondicionado (Gas Natural), los hidrocarburos condensables (GLP), el etano, el agua de la sección de endulzamiento, el CO_2 de la sección de Endulzamiento y el agua de la

Tabla 5: Calidad del Gas natural obtenido a diferentes concentraciones de CO_2

Componente	% mol CO_2 gas asociado de entrada					RUT*
	3,91	5,79	7,68	9,57	11,45	
H_2O, mg/m^3	46,27	44,62	40,73	36,40	33,68	<97
O_2 % vol	0,04	0,04	0,04	0,04	0,04	<0,1
N_2 % vol	2,10	2,12	2,09	2,07	2,05	<3
Inertes % vol	2,47	3,90	6,09	8,77	10,77	<5
CO_2 % vol	0,33	1,74	3,96	6,66	8,68	<2
H_2S, mg/m^3	0,00	0,00	0,00	0,00	0,00	<6
Poder calorífico bruto, MJ/m^3	38,2	37,6	41,6	41,8	40,2	35,4 – 42,8
Cricondentherm, °F	-112,2	-175,0	-98,3	-89,1	-79,5	<45

** Valores límites según el RUT (Resolución CREG-071 de 1999 y su modificación posterior del año 2019).*

sección de Deshidratación. La Tabla 5 compara los parámetros de calidad del Gas Natural predicho por simulación, según el contenido de CO_2 del gas asociado de entrada. De esta tabla es posible mencionar que, el contenido de agua (humedad) disminuye en el Gas Natural, con el aumento en el contenido de CO_2 del gas asociado de entrada. Es decir, un aumento en el CO_2 desplaza favorablemente el equilibrio termodinámico en el proceso de deshidratación del gas asociado. Azmi *et al.* (2011) también reportan un desplazamiento favorable en el equilibrio termodinámico, en su estudio sobre la formación de hidratos en gases con diferentes concentraciones de CO_2. De igual manera, el desplazamiento del equilibrio afecta la propiedad *Cricondentherm* (punto de rocío), aumentando su valor por un incremento en el contenido de CO_2 del gas asociado. El aumento en el contenido de CO_2 desplaza el equilibrio, aumentando los niveles de etano en el Gas Natural, con el consecuente aumento en el *Cricondentherm*. El aumento de etano en el gas natural sintético con contenidos de CO_2 ha sido también reportado por Davalos *et al.* (1976) y Mørch *et al.* (2006); por su parte, el incremento en el *Cricondentherm* ha sido reportado por Brown *et al.* (2009), El-Maghraby *et al.* (2022), Louli *et al.* (2012) y Mørch *et al.* (2006), entre otros.

Asimismo, de la Tabla 5 es posible mencionar que, la disminución en la humedad del Gas Natural corresponde con un aumento en su poder calorífico bruto. Por otro lado, el contenido de O_2 en el Gas Natural resultó constante con la variación de CO_2 en el gas asociado de entrada.

Según la Tabla 5, las propiedades del Gas Natural resultante del tratamiento con la unidad Turboexpander, simulada en Aspen Hysys, cumple con los requisitos del RUT, cuando el gas asociado de entrada presenta concentraciones de CO_2 inferiores del 6% mol. Para contenidos superiores, el Gas Natural resultante se encuentra fuera de especificaciones de contenido de Inertes y contenido de CO_2. Según la Sección 3.3., los perfiles de temperatura en la torre de absorción con MEA (Figura 2) presentan diferencias, según el contenido de CO_2 del gas de entrada. Específicamente, si el contenido supera el valor del 6% mol, el perfil muestra valores bajos de temperatura, lo cual resulta como consecuencia de una relación mol CO_2/mol MEA superior a 0,4 en los platos de fondo. Según esto y la Tabla 5, la relación mol CO_2/mol MEA define el cumplimiento en las especificaciones del Gas Natural tratado.

Con lo anterior, las etapas diseñadas para la unidad Turboexpander estándar (con los parámetros definidos en la Sección 2) permiten el tratamiento de gases asociados con contenidos de CO_2 por debajo del 6% mol, obteniendo un gas con calidad adecuada para su transporte y comercialización. Para contenidos superiores, las limitaciones en el calor de absorción (relación mol CO_2/mol MEA superior a 0,4) restringen la obtención de un gas con cumplimiento del RUT. Un rediseño de la torre y de sus condiciones operativas o un aumento en la concentración de MEA podría conllevar al cumplimiento de una relación mol CO_2/mol MEA inferior a 0,4 para un tratamiento adecuado de gases con contenidos de CO_2 superiores del 6% mol. Asimismo, los avances en el área de captura de CO_2 podrían conllevar a la proposición de un absorbente más eficiente para el endulzamiento, por ejemplo, los fluidos iónicos (Hasib-ur-Rahman *et al.*, 2010).

Por otra parte, los resultados obtenidos con el diseño propuesto en este documento son superiores a los presentados por Tristancho (2017), quien reporta un acondicionamiento adecuado para gases con concentraciones de CO_2 de hasta 4% mol. Por otro lado, las propiedades del flujo de Etano no presentan cambios significativos con la composición de CO_2 en el gas asociado. Según la Tabla 6, para todos los casos, el flujo de Etano cumple las especificaciones de calidad dispuestos por DOF (2016). Sin embargo, el aumento en la concentración de CO_2 en el gas asociado impacta en la producción de Etano, según lo mostrado en la Figura 7. La disminución del flujo se deduce del desplazamiento del equilibrio en la torre demetanizadora. Este resultado coincide con lo documentado por Fernandez *et al.* (1991).

Tabla 6: Condiciones de salida del flujo de Etano, según simulación

Etano	% mol CO_2 en el Gas de entrada				
	3,91	5,79	7,68	9,57	11,45
Temperatura, °F	-6,2	-6,2	-6,2	-6,2	-6,1
Presión, psia	200	200	200	200	200
Flujo, MMSCFD	0,64	0,63	0,51	0,43	0,31
Etano,% mol	100	100	99,99	99,99	99,95
CO_2, % mol	0,00	0,00	0,01	0,01	0,01
Propano, % mol	0,00	0,00	0,00	0,00	0,04

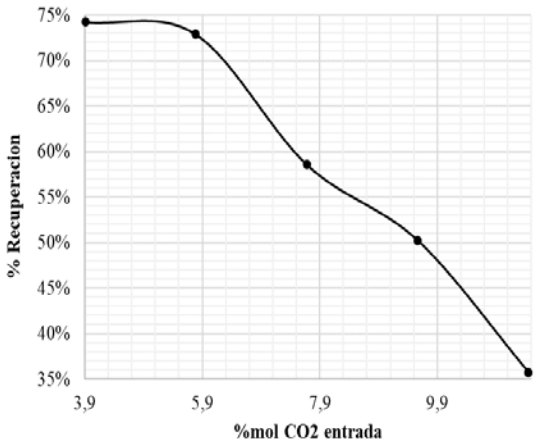

Figura 7: Recuperación de etano en el proceso para diferentes concentraciones de CO_2

Otro subproducto resultante del proceso Turboexpander es el gas licuado del petróleo (GLP). En su mayor proporción, el GLP se compone de propano y butano. La norma técnica colombiana (Ministerio de minas y energía, 2015), establece que las fracciones pesadas (C_{5+}) del GLP presenten un contenido máximo de 2% mol; lo anterior conlleva a un almacenamiento eficiente a altas presiones (UPME, 2013). La Tabla 7 presenta las propiedades para el flujo de GLP resultante del tratamiento del gas asociado, con la unidad Turboexpander.

Tabla 7: Condiciones de salida del GLP obtenido en las cinco simulaciones

GLP	% mol CO_2 en el Gas de entrada				
	3,91	5,79	7,68	9,57	11,45
Temperatura, °F	129,5	129,3	129,0	128,7	128,4
Presión, psia	210	210	210	210	210
Flujo, MMSCFD	0,539	0,528	0,515	0,500	0,487
Etano % mol	0,00	0,00	0,00	0,00	0,03
Propano % mol	69,88	70,16	70,48	70,84	71,14
n-Butano % mol	12,81	12,69	12,54	12,36	12,21
i-Butano % mol	14,13	14,06	13,95	13,83	13,73
n-C5 % mol	0,98	0,96	0,94	0,92	0,9
i-C5 % mol	1,65	1,6	1,57	1,55	1,51
2,2-MC3 % mol	0,16	0,15	0,15	0,15	0,14
n-C6 % mol	0,36	0,35	0,34	0,33	0,32
n-C7 % mol	0,02	0,02	0,02	0,02	0,02

Según esta tabla, el contenido de hidrocarburos pesados (C_{5+}) supera el límite de 2% mol, en los cinco casos de simulación. Lo anterior sugiere un tratamiento posterior de la corriente de GLP en una torre de destilación para la síntesis de gasolina natural (Abdel-Aal *et al.*, 2003; Ahmad *et al.*, 2011). El diseño y el análisis del desempeño de esta torre de purificación de gasolina natural son recomendados para trabajos futuros en el tema.

f) Formación de Hidratos

Para finalizar, unos comentarios finales sobre la formación de hidratos, tema de importancia en el aseguramiento de flujo. La Figura 8 presenta los resultados de la herramienta de detección de formación de hidratos, disponible en Aspen Hysys (Abdulmutalib & Abdulmalik, 2022; Alnaimi *et al.*, 2020); la herramienta detalla en rojo aquellas corrientes con un potencial elevado de formación de hidratos. Según esta figura, la formación de hidratos resulta probable en las corrientes del tope de la torre demetanizadora; esto acontece en los cinco escenarios de evaluación de contenido de CO_2. El tipo de hidratos que potencialmente puede ser formado corresponde al tipo II, el cual envuelve el encapsulamiento de nitrógeno y CO_2 a las condiciones de salida del gas (Abdulmutalib & Abdulmalik, 2022; Carroll, 2003).

A pesar de esta detección de hidratos, por parte de Aspen Hysys (Figura 8), las concentraciones de agua son bajas en todos los casos, con lo cual, la formación de hidratos sería indetectable a nivel industrial, sin consecuencias importantes para el proceso. Abdulmutalib & Abdulmalik (2022) reportan una regla heurística de alrededor de 35 mg de agua por m^3 de gas, como contenido ideal para el transporte de gas. La Tabla 5 muestra que la mayoría de los Gases Naturales generados cumplen esta regla heurística. Para el caso de gases con concentraciones un poco más elevadas de 35 mg de agua por m^3 de gas, el contenido bajo de CO_2 evitaría la formación apreciable y detectable de hidratos (Van-Denderen *et al.*, 2009). Por otra parte, en caso de una formación importante de hidratos, esta puede ser inhibida por diferente tipo de compuestos como metanol, etanol y glicol (Abdulmutalib & Abdulmalik, 2022; Bharathi *et al.*, 2021; Koh *et al*., 2011).

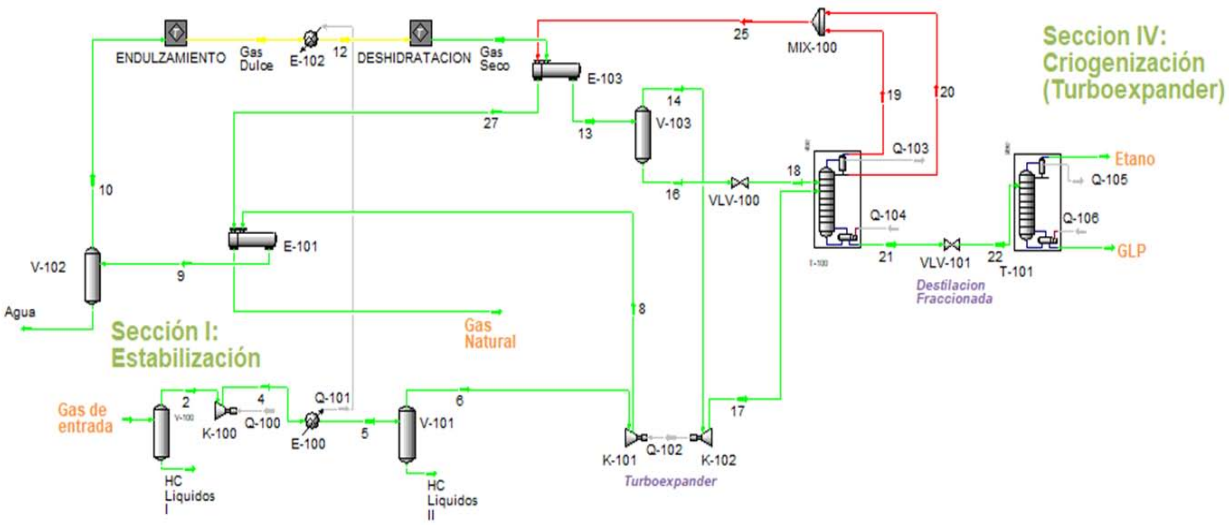

Figura 8: Estado de formación de hidratos a una concentración de 7,68% mol de CO_2 en el gas de entrada. Las corrientes en color verde indican que no hay formación de hidratos. En color rojo advierten que hay formación de hidratos y las corrientes en color amarillo indican que el modelo seleccionado no calculó la formación de hidratos

IV. Conclusiones

El acondicionamiento de gases asociados está condicionado por la normativa del Reglamento Único de Transporte (RUT). Las unidades de acondicionamiento con Turboexpander pueden recibir gases asociados con incrementos en las condiciones de diseño, que superan los respectivos contenidos de CO_2. Estos incrementos pueden conllevar a un acondicionamiento parcial, generando gases por fuera de especificaciones del RUT. Según los resultados del presente documento, una unidad Turboexpander estándar conduciría a un acondicionamiento satisfactorio del gas asociado, supuesto por el escenario medio de proyección para la Cuenca del Valle Medio del Magdalena. Asimismo, los resultados de las simulaciones con Aspen Hysys indican que, la secuencia de etapas de la unidad con Turboexpander podría acondicionar el respectivo gas asociado con contenidos de CO_2 de hasta 6% mol, cumpliendo lo requerido para su comercialización. Un aumento adicional del contenido de CO_2 en el gas asociado afectaría el desempeño del proceso de endulzamiento, generando un gas fuera de especificaciones, en lo referente al contenido de CO_2 e inertes. Por último, la comercialización de los flujos de GLP generados con la unidad requeriría de una torre de destilación adicional, logrando los límites de C_{5+}, según la respectiva norma.

Aportes

Vargas-Reyes, L.: Simulación de la sección de deshidratación y destilación. Escritura del artículo.
González-Martínez, A.: Simulación de la sección de endulzamiento y escritura del artículo.
Morales-Medina, G.: Verificación de resultados, escritura y edición del artículo.

References Références Referencias

1. Abdel-Aal, H. K., Aggour, M., & Fahim, M. A. (2003). *Petroleum and Gas Field Processing*. Marcel Dekker, Inc. https://portal.tpu.ru/SHARED/b/BELINSKAYA/UchWork/PPAYAmaster/abdelaal_h_k_aggour_m_fahim_m_a_petroleum_and_gas_field_.pdf
2. Abdulmutalib, A., & Abdulmalik, F. (2022). Investigation of Hydrate Formation in Natural Gas Transmission Pipelines. *International Journal of Advances in Engineering and Management (IJAEM)*, *4*(5), 2040–2055. https://doi.org/10.35629/5252-040520402055
3. Ahmad, R., Hladky, M., Far, A. S., & Usman, M. (2011). *Fractionation of Natural Gas Liquids to produce LPG* [Norwegian University of Science and Technology]. https://portal.tpu.ru/SHARED/b/BELINSKAYA/UchWork/PPAYAmaster/abdelaal_h_k_aggour_m_fahim_m_a_petroleum_and_gas_field_.pdf
4. Alnaimi, F. B. I., Lim, H. C. L., Sahed, A., Al Salim, H. S., & Nasif, M. S. (2020). Investigation on the suitability of natural gas hydrate formation prediction simulation packages and its implementation conditions. *Pertanika Journal of Science and Technology*, *28*(Special Issue 1), 83–97. http://www.pertanika.upm.edu.my/resources/files/Pertanika PAPERS/JST Vol. 28 (S1) 2020/06 JST(S)-0545-2020.pdf
5. Arinelli, L. de O., de Medeiros, J. L., de Melo, D. C., Teixeira, A. M., Brigagão, G. V., Passarelli, F. M., Grava, W. M., & Araújo, O. de Q. F. (2019). Carbon capture and high-capacity supercritical fluid processing with supersonic separator: Natural gas with ultra-high CO2 content. *Journal of Natural Gas Science and Engineering*, *66*(November 2018), 265–283. https://doi.org/10.1016/j.jngse.2019.04.004

6. Azmi, N., Mukhtar, H., & Sabil, K. M. (2011). Purification of Natural Gas with High CO2 Content by Formation of Gas Hydrates: Thermodynamic Verification. *Journal of Applied Sciences*, *11*(21), 3547–3554. https://doi.org/10.3923/jas.2011.3547.3554
7. Barbosa, M. C., de Medeiros, J. L., Araújo, O. Q. F., & Nunes, G. C. (2012). NGL Recovery from CO 2 - EOR Streams. In *Computer Aided Chemical Engineering* (Vol. 31, Issue July). Elsevier Masson SAS. https://doi.org/10.1016/B978-0-444-59507-2.50110-4
8. Baumeister, C., Korobilis, D., & Lee, T. K. (2020). Energy Markets and Global Economic Conditions. *National Bureau of Economic Research*, *5*(3), 248–253. https://www.nber.org/system/files/working_papers/w27001/w27001.pdf
9. Benitez, L., Gutierrez, J., Ale Ruiz, L., Erdmann, E., & Tarifa, E. (2015). Análisis de las simulaciones del proceso de deshidratación del gas natural con Aspen Hysys y Aspen Plus. *Revista de La Facultad de Ciencias Químicas*, *0*(12), 20–29. http://dspace.ucuenca.edu.ec/bitstream/123456789/23875/1/3_articulo_revista_12.pdf
10. Bharathi, A., Nashed, O., Lal, B., & Foo, K. S. (2021). Experimental and modeling studies on enhancing the thermodynamic hydrate inhibition performance of monoethylene glycol via synergistic green material. *Scientific Reports*, *11*(1), 1–10. https://doi.org/10.1038/s41598-021-82056-z
11. Biliyok, C., Lawal, A., Wang, M., & Seibert, F. (2012). Dynamic modelling, validation and analysis of post-combustion chemical absorption CO 2 capture plant. *International Journal of Greenhouse Gas Control*, *9*(2012), 428–445. https://doi.org/10.1016/j.ijggc.2012.05.001
12. Binous, H., & Bellagi, A. (2013). *Simulation of the separation of industrially important hydrocarbon mixtures by different distillation techniques using mathematica*. *January 2016*.
13. Bogoya, S., & Díaz, S. (2014). *Comparación del nivel de recuperación de etano de los procesos Turboexpander: GSP, CRR, RSV Y RSVE, por medio del uso de un simulador numérico* [Universidad Industrial de Santander]. http://tangara.uis.edu.co/biblioweb/tesis/2014/155391.pdf
14. Brown, A. S., Milton, M. J. T., Vargha, G. M., Mounce, R., Cowper, C. J., Stokes, A. M. V., Benton, A. J., Lander, D. F., Ridge, A., & Laughton, A. P. (2009). Measurement of the hydrocarbon dew point of real and synthetic natural gas mixtures by direct and indirect methods. *Energy and Fuels*, *23*(3), 1640–1650. https://doi.org/10.1021/ef8009469
15. Camacho, F. (2021). Estudio de viabilidad para la aplicación de una unidad Turboexpander en el acondicionamiento de gases y la recuperación de condensados generados en un campo del Magdalena medio. In *Universidad Industrial de Santander* (Vol. 3, Issue 1). http://journal.unilak.ac.id/index.php/JIEB/article/view/3845%0Ahttp://dspace.uc.ac.id/handle/123456789/1288
16. Carroll, J. J. (2003). Natural Gas Hydrates: A Guide for Engineers. In *Natural Gas Hydrates: A Guide for Engineers*. https://doi.org/10.1016/B978-0-7506-7569-7.X5000-0
17. Chebbi, R., Al-Amoodi, N. S., Abdel Jabbar, N. M., Husseini, G. A., & Al Mazroui, K. A. (2010). Optimum ethane recovery in conventional turboexpander process. *Chemical Engineering Research and Design*, *88*(5–6), 779–787. https://doi.org/10.1016/j.cherd.2009.11.003
18. Davalos, J., Anderson, W. R., Phelps, R. E., & Kidnay, A. J. (1976). Liquid-Vapor Equilibria at 250.00K for Systems Containing Methane, Ethane, and Carbon Dioxide. *Journal of Chemical and Engineering Data*, *21*(1), 81–84. https://doi.org/10.1021/je60068a030
19. Diaz, J., Gamboa, S., Morales, A., Torres, M., & Sánchez, M. (2018). Caracterización de la composición de los gases de pozos petroleros, después de una prueba de conectividad con nitrógeno. Caso de estudio: Piloto de inyección de aire en la formación San Fernando (Meta - Colombia). *Congreso Internacional de Ciencias Básicas e Ingeniería – CICI*, 1–6.
20. Díaz Molina, J. M., Morales Toscano, A. C., Fernández Rojas, M., Briceño-Gamba, N., Villalba Rey, D., & Sánchez, M. del R. (2019). Determinación y análisis estadístico de la composición de los gases producidos en un piloto de recobro mejorado. *Revista ION*, *32*(1), 63–73. https://doi.org/10.18273/revion.v32n1-2019006
21. DOF. (2016). Comision reguladora de energia. *Diario Oficial de La Federación*, *46*, 46–55. http://www.dof.gob.mx/nota_detalle.php?codigo=5432507&fecha=08/04/2016
22. El-Husseiny, A., Farouq, R., Farag, H. A., & El Taweel, Y. (2021). Exergy analysis of a turbo expander: Modeling and simulation. *Acta Chimica Slovenica*, *68*(2), 304–312. https://doi.org/10.17344/acsi.2020.6047
23. El Maghraby, M. A., El Moniem, N. A., & Abdelghany, A. (2022). Controlling hydrocarbon dew point and water dew point of natural gas using Aspen HYSYS. *Journal of Engineering and Applied Science*, *69*(1), 1–10. https://doi.org/10.1186/s44147-022-00126-z
24. Elbashir, N. O., El-Halwagi, M. M., Economou, L. G., & Hall, K. R. (2019). *Natural Gas Processing from Midstream to Downstream* (J. Wiley & L. Sons (eds.)).
25. Elehinafe, F. B., Nwizu, C. I., Odunlami, O. B., & Ibukun, F. D. (2022). Natural Gas Flaring in Nigeria, its Effects and Potential Alternatives – A Review.

Journal of Ecological Engineering, *23*(8), 141–151. https://doi.org/10.12911/22998993/149822
26. Escobar, F. H. (2006). Aspectos fundamentales de recobro secundario y terciario. In *Editorial Universidad Surcolombiana*. http://oilproduction.net/files/Libro Fundamentos de Ing de Yacimientos - Fredy Escobar.pdf
27. Feng, B., Du, M., Dennis, T. J., Anthony, K., & Perumal, M. J. (2010). Reduction of energy requirement of CO2 desorption by adding acid into CO2-loaded solvent. *Energy and Fuels*, *24*(1), 213–219. https://doi.org/10.1021/ef900564x
28. Fernandez, L., Bandoni, J. A., Eliceche, A. M., & Brignole, E. A. (1991). Optimization of ethane extraction plants from natural gas containing carbon dioxide. *Gas Separation and Purification*, *5*(4), 229–234. https://doi.org/10.1016/0950-4214(91)80029-5
29. Garmendia, H. (2019). Simulación del proceso de deshidratación de gas natural de la planta: Bajo Alto El Oro-Ecuado Simulation of the natural gas dehydration using TEG from the plant: Bajo Alto El Oro-Ecuador. *Ciencia e Ingeniería*, *40*(3).
30. Getu, M., Mahadzir, S., Long, N. V. D., & Lee, M. (2013). Techno-economic analysis of potential natural gas liquid (NGL) recovery processes under variations of feed compositions. *Chemical Engineering Research and Design*, *91*(7), 1272–1283. https://doi.org/10.1016/j.cherd.2013.01.015
31. Giri, M. S., Akbari, M., & Niasar, M. S.-. (2011). *A Comparative Survey of Modeling Absorption Tower Using Mixed Amines*. *45*(1), 57–70.
32. Hasan, S., A. Mohamed, A., Mostafa, M., & Gamal, M. (2020). Modeling and Simulation of Gas Dehydration Using Cubic Plus Association Equation of State Model. *Journal of Advanced Engineering Trends*, *39*(1), 35–42. https://doi.org/10.21608/jaet.2020.73332
33. Hasib-ur-Rahman, M., Siaj, M., & Larachi, F. (2010). Ionic liquids for CO2 capture-Development and progress. *Chemical Engineering and Processing: Process Intensification*, *49*(4), 313–322. https://doi.org/10.1016/j.cep.2010.03.008
34. Irina, R., & Watanasiri, S. (2015). Acid Gas Cleaning using Amine Solvents: Validation with Experimental and Plant Data. *Aspen Technology Inc*, 2–10. https://www.researchgate.net/profile/Isam_Eldin_Elgailani2/post/Can_any_one_explain_the_sharp_difference_between_absorption_and_scrubbing/attachment/59d649da79197b80779a442a/AS%3A472794933796864%401489734504039/download/11-7678-WP-Amine-Solvents-1215-FINA
35. Jiang, S., Li, Y., Wang, F., Sun, H., Wang, H., & Yao, Z. (2022). A state-of-the-art review of CO2 enhanced oil recovery as a promising technology to achieve carbon neutrality in China. *Environmental Research*, *210*(February), 112986. https://doi.org/10.1016/j.envres.2022.112986
36. Kherbeck, L., & Chebbi, R. (2015). Optimizing ethane recovery in turboexpander processes. *Journal of Industrial and Engineering Chemistry*, *21*, 292–297. https://doi.org/10.1016/j.jiec.2014.02.035
37. Kim, I., Hoff, K. A., & Mejdell, T. (2014). Heat of absorption of CO2 with aqueous solutions of mea: New experimental data. *Energy Procedia*, *63*(1876), 1446–1455. https://doi.org/10.1016/j.egypro.2014.11.154
38. Koh, C. A., Sloan, E. D., Sum, A. K., & Wu, D. T. (2011). Fundamentals and applications of gas hydrates. *Annual Review of Chemical and Biomolecular Engineering*, *2*(July), 237–257. https://doi.org/10.1146/annurev-chembioeng-061010-114152
39. Kolmetz, K. (2020). *Kolmetz Handbook Of Process Equipment Design - Natural Gas Sweetening Systems Selection, Sizing and Troubleshooting* (Issue April). https://www.researchgate.net/profile/Karl-Kolmetz/publication/340134033_Natural_Gas_Sweetening_Systems_Selection_Sizing_and_Troubleshooting_Kolmetz_Handbook_Of_Process_Equipment_Design/links/5e7aaa714585152fc0ec7f11/Natural-Gas-Sweetening-Systems-Selectio
40. Kothandaraman, A. (2010). Carbon Dioxide Capture by Chemical Absorption: A Solvent Comparison Study [Massachusetts Institute of Technology]. In *Massachusetts Institute of Technology* (Vol. 9, Issue 2). https://doi.org/10.3138/cbmh.9.2.159
41. Langé, S., & Pellegrini, L. A. (2016). Energy Analysis of the New Dual-Pressure Low-Temperature Distillation Process for Natural Gas Purification Integrated with Natural Gas Liquids Recovery. *Industrial and Engineering Chemistry Research*, *55*(28), 7742–7767. https://doi.org/10.1021/acs.iecr.6b00626
42. Louli, V., Pappa, G., Boukouvalas, C., Skouras, S., Solbraa, E., Christensen, K. O., & Voutsas, E. (2012). Measurement and prediction of dew point curves of natural gas mixtures. *Fluid Phase Equilibria*, *334*, 1–9. https://doi.org/10.1016/j.fluid.2012.07.028
43. Luyben, W. L. (2013). Control of an extractive distillation system for the separation of CO 2 and ethane in enhanced oil recovery processes. *Industrial and Engineering Chemistry Research*, *52*(31), 10780–10787. https://doi.org/10.1021/ie401602c
44. Maqsood, K., Mullick, A., Ali, A., Kargupta, K., & Ganguly, S. (2014). Cryogenic carbon dioxide separation from natural gas: A review based on conventional and novel emerging technologies. *Reviews in Chemical Engineering*, *30*(5), 453–477. https://doi.org/10.1515/revce-2014-0009
45. Marinov, O. (2015). *Separation and Re-Injection of CO2 in Enhanced Oil Recovery Processes* (Issue January). https://projekter.aau.dk/projekter/files/207

552853/Separation_and_Re_Injection_of_CO2_in_Enhanced_Oil_Recovery_Processes_K10og_1_E14.pdf
46. Martínez, A. (2018). *Estudio sobre el impacto de la actividad petrolera en las regiones productoras de Colombia. Caracterización departamental Santander*. https://www.repository.fedesarrollo.org.co/bitstream/handle/11445/3669/CDF_No_66_Septiembre_2018.pdf?sequence=1&isAllowed=y
47. Mitra, S. (2015). A Technical Report on Gas Sweetening by Amines. *Sr. Process Engineer Petrofac Engineering*, *June*, 1–58. https://www.researchgate.net/profile/Subhasish-Mitra-2/publication/279298133_A_technical_report_on_gas_sweetening_system/links/5591d11608ae47a34910ba2a/A-technical-report-on-gas-sweetening-system.pdf
48. Mokhatab, S., Mak, J. Y., Valappil, J. V, & Wood, D. A. (2019). *Handbook of Liquefied Natural Gas*.
49. Mokhatab, S., & Poe, W. (2012). Handbook of Natural Gas Transmission and Processing. *Handbook of Natural Gas Transmission and Processing*. https://doi.org/10.1016/C2010-0-66115-3
50. Mokheimer, E. M. A., Hamdy, M., Abubakar, Z., Shakeel, M. R., Habib, M. A., & Mahmoud, M. (2019). A comprehensive review of thermal enhanced oil recovery: Techniques evaluation. *Journal of Energy Resources Technology, Transactions of the ASME*, *141*(3). https://doi.org/10.1115/1.4041096
51. Mørch, Nasrifar, K., Bolland, O., Solbraa, E., Fredheim, A. O., & Gjertsen, L. H. (2006). Measurement and modeling of hydrocarbon dew points for five synthetic natural gas mixtures. *Fluid Phase Equilibria*, *239*(2), 138–145. https://doi.org/10.1016/j.fluid.2005.11.010
52. Mores, P., Scenna, N., & Mussati, S. (2012). CO2 capture using monoethanolamine (MEA) aqueous solution: Modeling and optimization of the solvent regeneration and CO2 desorption process. *Energy*, *45*(1), 1042–1058. https://doi.org/10.1016/j.energy.2012.06.038
53. Osborn, T. J., Jones, P. D., Lister, D. H., Morice, C. P., Simpson, I. R., Winn, J. P., Hogan, E., & Harris, I. C. (2021). Land Surface Air Temperature Variations Across the Globe Updated to 2019: The CRUTEM5 Data Set. *Journal of Geophysical Research: Atmospheres*, *126*(2). https://doi.org/10.1029/2019JD032352
54. Petri, Y., Juliza, H., & Humala, N. (2018). Technical and economic analysis use of flare gas into alternative energy as a breakthrough in achieving zero routine flaring. *IOP Conference Series: Earth and Environmental Science*, *126*(1). https://doi.org/10.1088/1755-1315/126/1/012132
55. Poe, W. A., & Mokhatab, S. (2017). *Modeling, Control, and Optimization of Natural Gas Processong Plants*. Elsevier.
56. Rashid, H., Hasan, N., & Mohamad Nor, M. I. (2014). Temperature peak analysis and its effect on absorption column for CO2 capture process at different operating conditions. *Chemical Product and Process Modeling*, *9*(2), 105–115. https://doi.org/10.1515/cppm-2013-0044
57. Rufford, T. E., Smart, S., Watson, G. C. Y., Graham, B. F., Boxall, J., Diniz da Costa, J. C., & May, E. F. (2012). The removal of CO 2 and N 2 from natural gas: A review of conventional and emerging process technologies. *Journal of Petroleum Science and Engineering*, *94–95*, 123–154. https://doi.org/10.1016/j.petrol.2012.06.016
58. Sáchica, J. (2012). *Estudio de prefactibilidad para la recolección de gas de anulares de los pozos de los activos Lisama, Provincia y Llanito de ECOPETROL S.A.* Universidad Industrial de Santander.
59. Swaidan, B. T. (2016). *Optimization of Natural Gas Liquid (NGL) recovery processes* (Vol. 152, Issue 3) [American University of Sharjah]. file:///Users/andreataquez/Downloads/guia-plan-de-mejora-institucional.pdf%0Ahttp://salud.tabasco.gob.mx/content/revista%0Ahttp://www.revistaalad.com/pdfs/Guias_ALAD_11_Nov_2013.pdf%0Ahttp://dx.doi.org/10.15446/revfacmed.v66n3.60060.%0Ahttp://www.cenetec
60. Tristancho, E. (2017). *Evaluación de alternativas para el diseño y simulación de plantas de procesamiento de gas natural con variación en el contenido de gas ácido (H2S Y CO2)* (Vol. 93, Issue I) [Universidad Nacional de Colombia]. https://repositorio.unal.edu.co/bitstream/handle/unal/59909/80076714.2017.pdf?sequence=1&isAllowed=y
61. UPME. (2013). *Determinación de potencialidades de uso de las acciones necesarias para activar el subsector del GLP en Colombia*. https://bdigital.upme.gov.co/bitstream/001/1028/1/upme_021_Cosenit_detrminacion de potencialidades GLP.pdf
62. UPME. (2018). *Escenarios De Oferta De Hidrocarburos Convencionales y no convencionales*. *11*, 1–122. https://bdigital.upme.gov.co/bitstream/handle/001/1340/v.2.pdf?sequence=2&isAllowed=y
63. Van Denderen, M., Ineke, E., & Golombok, M. (2009). CO2 removal from contaminated natural gas mixtures by hydrate formation. *Industrial and Engineering Chemistry Research*, *48*(12), 5802–5807. https://doi.org/10.1021/ie8017065
64. ZareNezhad, B., & Eggeman, T. (2006). Application of Peng-Rabinson equation of state for CO2 freezing prediction of hydrocarbon mixtures at cryogenic conditions of gas plants. *Cryogenics*, *46*(12), 840–845. https://doi.org/10.1016/j.cryogenics.2006.07.010

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Keywords: *adsorption kinetics, activated carbon, impregnation, MEA, fixed bed column.*

GJRE-C Classification: *LCC: TP156.A3*

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I. Introduction

The removal of carbon dioxide (CO_2) is significant for oil and gas industry due to its harmful acidic effects on oil and gas pipelines with no added energy value to natural gas [1]. Because of the increasing indications of CO_2 implication in global warming [2], capturing CO_2 from its emitting sources is becoming a vital topic. Adsorption is offering an effective alternative for CO_2 capturing comparing to other capture technologies [3]. There are many types of gas adsorbents; conventional, like, activated carbons, silica gel, ion-exchange resins, zeolites, and meso-porous silicates, activated alumina, metal oxides, and new like, carbon fibers and metal-organic frameworks. [4]. Adsorbent most important feature is adsorbing capacity [5], besides, good adsorbent should be selective and chemically and mechanically durable [6]. AC is cost-effective and adaptable microporous adsorbent [7] and is considered a superb adsorbent due to its high specific surface area, appropriate pore size distribution, diversity of surface chemistry [8]. It's mostly micropore structure were used extensively in liquids and gases systems. The micropores and mesopores of the AC particles were utilized to accommodate the impregnating molecules, which can be attached chemically (grafting) or physically (impregnation) to the AC particles [9]. Impregnation of AC particles with chemicals improves their natural adsorption capability to adsorb gases [10]. Alkanolamines, such as, monoethanolamine (MEA), diethanolamine (DEA), and methyldiethanolamine (MDEA) are very important absorbents for acidic gases in the field of natural gas sweetening and for mitigation the adversity of these gases on environment [11] and they are extensively used in CO_2 absorption from different gas sources [12]. MEA, which is a primary amine, has been used intensively to capture CO_2 from gas streams and from many various sources due to its fast reaction kinetics with CO_2, low coast and thermal stability, as it is more favorable than other alkanolamines [13] [14]. Because of the effectiveness of liquid amine absorption process researchers were encouraged to utilize amines in their solid state for CO_2 capture [15]. Adsorption kinetics is essential tool used to evaluate the performance of an adsorbent and to understand the mechanism of adsorption [16] and many researches had included kinetics of batch CO_2 adsorption on different adsorbents in their works [17]. They found that the restriction step is the intraparticle diffusion (pore diffusion). On contrary to the findings of this paper where the restrictive step to CO_2 adsorption was the film diffusion. In this research, dynamic adsorption experiments were conducted to investigate the adsorption kinetics of MEA-impregnated AC particles packed in adsorption column to adsorb CO_2 from gas mixture.

II. Materials and Methodology

a) Materials

1. Certified analytical reagent monoethanolamine (MEA), C_2H_7NO, molecular weight 61.

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2. Commercial palm shell AC was purchased from Bravo Green SDN BHD (Sarawak, Malaysia).
3. Gases

a. Mixture of 15% CO_2 with 85% N_2.
b. Pure N_2.

b) Methodology

i. *AC Particles Characterization*

Granulated palm shell AC particles were physically activated by steam. The mostly micropore particles have total Bet surface area of 838 cm^2/g, while the micropore surface area of that total area is 675 cm^2/g and micropore volume is 0.32 cm^3/g.

ii. *AC Beds Perpetration*

A household coffee grinder crushed the AC particles. 710 and 500 μm sieves were employed to characterize the AC particles to the required particle size of 500 μm (particles passing 710 and stopping on 500 μm sieve).

iii. *Impregnation of AC Samples*

Impregnation was carried out by placing 5 g of granular AC in a beaker, 2 g of MEA added to the beaker with 10 g of deionized water as an environmentally friendly medium and to facilitate the impregnation process. The beaker contents were stirred at 500 rpm for 1 hour at room temperature. The final slurry then dried completely in Heraeus Instrument Vacuthermo oven at 70°C under 0.1 bar vacuum pressure (absolute) for 6 hours. Samples of AC particles prepared for CO_2 adsorption separation experiments are, non-impregnated AC particles and MEA-impregnated AC particles.

iv. *Working Breakthrough Time*

Working breakthrough time was utilized as a method to evaluate the performance of AC beds. Breakthrough time can be defined as the time spanning from the beginning of the adsorption experiment to the point when CO_2 molecules start to break through out of the adsorption column, which was monitored by Guardian Plus CO_2 monitor. Data Acquisition Logger was connected to the CO_2 monitor to measure the breakthrough time in minutes.

Experimental setup is presented in another work [18].

v. *Amine-CO_2 Reactions*

Amines remove CO_2 in a two-step process:

1. The gas absorbs by the liquid forming a weak acid.
2. The weak acid reacts with amines as a weak base [19].

The suggested [20] reaction path of primary and secondary unhindered amines with CO_2 is known as the carbamate formation reaction proceeds through the formation of zwitterion, which was recognized as the reaction mechanism [21].

The first step of the reaction is the formation of amine-CO_2 zwitterion as shown in Equation 1a:

$$CO_2 + R_1R_2NH \leftrightarrow R_1R_2N^+HCOO^- \text{ (Zwitterion)} \quad (1a)$$

The second step is the deprotonation of the zwitterion. For liquid amine reaction, the water would act as a base acquiring the proton released by the zwitterions. In the case of solid amine reaction, another amine molecule would acquire the released proton as the maximum theoretical amount of CO_2 reacting with amine would be 0.5 mol CO_2/1 mol N_2 as shown in equation 1. In this step, the zwitterion would be stabilized by producing carbamate as in equation 1b.

$$R_1R_2N^+HCOO^- + R_1R_2NH \leftrightarrow R_1R_2NCOO^- \text{ (Carbamate)} + R_1R_2NH_2^+ \quad (1b)$$

The overall reaction is as in equation 1:

$$CO_2 + 2R_1R_2NH \leftrightarrow R_1R_2NH_2^+ + R_1R_2NCOO^- \quad (1)$$

vi. *Rate and Mechanism of Adsorption*

To investigate the rate of adsorption two equations were explored namely, pseudo first order (SFO) and pseudo second order (PSO) equations. The mechanism of adsorption and the adsorption controlling step was determined by Weber-Morris intraparticle diffusion model.

III. Results and Discussions

a) Impacts of MEA Surface-Modification on AC Particles

MEA molecules occupied the pores of the mostly micropore AC particles and blocked them, reducing significantly the micropore surface area from 675 to 36m^2/g (96%) and micropore volume from 0.32 to 0.02cm^3/g (94%). MEA-blocked AC particles adsorb selectively more CO_2 comparing to non-impregnated AC particles by 172%, as the adsorption capacity increased from 49 to 18 mg/g, respectively.

b) Adsorption Kinetics

i. *Adsorption Rate*

Pseudo first and second order models were investigated to find out which model is predicting the adsorption rate appropriately.

a. *Pseudo First Order Model (SFO)*

Lagergren [22] published his SFO model to describe homogenous adsorption on solid phase as in equation 2. The equation depends on the adsorption capacity of an adsorption bed rather than concentration of adsorbate as in the case of first order model equation and the adsorption rate is related to the availability of adsorption sites [23]. It had been reported that SFO model can be applied adequately for the adsorption kinetics of CO_2 on AC [24].

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (2)$$

The linear form of equation 1 is as in equation 3:

$$ln(q_e - q_t) = ln\, q_e - \frac{k_1}{2.303}\, t \quad (3)$$

Where,

q_e: Adsorption capacity at equilibrium, mg/g.
q_t: Adsorption capacity at any time t, mg/g.
k_1: Pseudo-first order rate constant, 1/min.
t: Time, min.

Figure 1 is a plot of ln (q_e-q_t) against t for the whole adsorption experiment showing that the straight line fitting the experimental results has good value of R^2 equal to 0.9967, which is suggesting that the SFO kinetic model is applicable for this research. The slope of the straight line from equation 3 is ($\frac{k_1}{2.303}$), where the value of the SFO rate (k_1) was found to be 0.00552721/min.

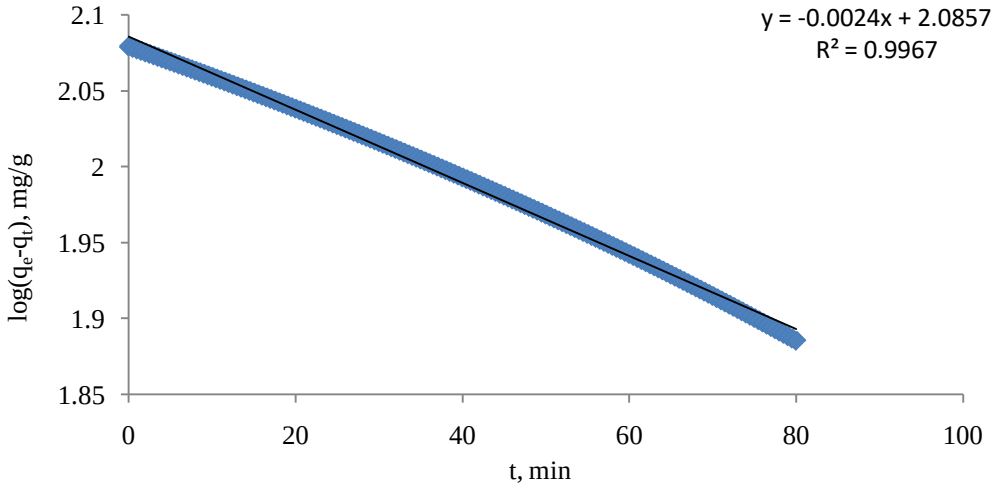

Figure 1: Plot of ln (q_e-q_t) against time

b. *Pseudo Second Order Model (PSO)*

PSO model is usually applied for chemisorption kinetics sorption of liquid solutions [25], the model is in equation 4 and its linear form is as in equation 5:

$$\frac{dq_t}{dt} = k\,(q_e - q_t)^2 \quad (4)$$

$$\frac{t}{q} = \frac{1}{k^2 q_e^2} + \frac{1}{q_e} t \quad (5)$$

The plot of t/q against t for PSO model as in equation 5, didn't yield straight line for the whole experimental data or even for any of its portions on contrary to the straight line of plot ln (q_e-q_t) against t for PFO model, which covers the whole experimental data and suggesting that the adsorption rate here is following PFO model which would be applied to calculate adsorption rate constant (k_1).

ii. *Verification the Rate-Determining Step of the MEA-Impregnated AC Adsorption Bed*

Equation 6 is the intraparticle diffusion equation [26],

$$q_t = k_p t^{\frac{1}{2}} + c \quad (6)$$

Where:

q_t: Amount of adsorbate absorbed at any time, mg g^{-1}.
k_p: Intraparticle diffusion rate constant, mg g^{-1} $min^{-1/2}$.
t: Time, min.
c: Intercept, mg g^{-1}

The multilinearity displayed in Figure 2, the plot of the amount of CO_2 adsorbed (q_t) against the square root of time ($t^{1/2}$) is suggesting that more than one step is taking place. The straight line fitting the curve is not passing through the origin, indicating that the intraparticle diffusion is not the adsorption rate restrictive step [27]. The curve is divided into three zones where the slope of the linear part indicating the rate of adsorption and the rate controlling step is represented by the linear section with lowest slope value [28]. The first zone is the initial zone where the external diffusion of CO_2 molecules through the bulk gas phase is taking place and the slope which is representing the adsorption rate is low. The second zone is the film diffusion where the mass transfer of CO_2 molecules is continuing through the CO_2 film surrounding the AC particles. The slope of the straight line of the second zone is higher than that of the initial zone but lower than that of the third zone due to the resistance exerted by CO_2 gas film, which is indicating that this step combining with the initial zone step are slow and the overall adsorption rate is controlled by mass transfer and film resistances respectively. In the third zone, where the amount of CO_2 molecules adsorbed (q_t)

versus $t^{1/2}$ is displaying a straight line with high slope value indicating that CO_2 molecules intraparticle diffusion step is fast, where CO_2 molecules adsorption is enhanced by the fast CO_2-MEA reaction. The intercept (c) is an indicator of the thickness of the boundary layer surrounding the MEA-impregnated AC particles. Higher values of intercept suggest that the boundary layer is building up as the value of the c in the initial zone is less than that of zone 1, which is in turn less than that of zone 2 deducing that diffusion through the gas film may be considered as the controlling step [29]. CO_2 adsorption in zone 2 is approaching its final stage and the active sites on MEA-impregnated AC particles are not able to adsorb more CO_2 molecules.

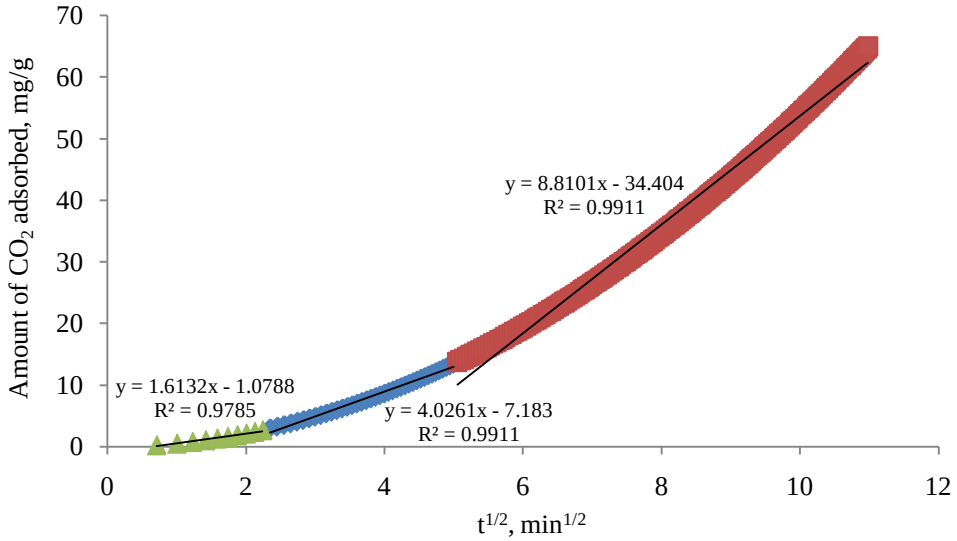

Figure 2: CO_2 Amount adsorbed, mg/g against square root of time, $min^{1/2}$

iii. *Gas Film Diffusion Model*

The transportation of CO_2 molecules from the gas stream bulk to the surface of the AC particles is playing a major role as the analysis of the intraparticle model showed that the mass transfer of CO_2 molecules through the gas film is the limiting step of CO_2 adsorption. To further inspect that gas film is the limiting step in CO_2 molecules adsorption, gas film diffusion model was applied [30], [31] and [32]:

$$\frac{q_t}{q_e} = 1 - e^{k_{fd}\,t} \qquad (7)$$

The linearized form of equation 7 is as in equation 8:

$$\ln(1 - F) = -k_{fd}\,t \qquad (8)$$

Where,

F: Fractional adsorption equilibrium ($F = q_t/q_e$).

k_{fd}: Film diffusion coefficient, min^{-1}.

A plot as in Figure 3 of $-\ln(1 - F)$ vs t with intercept equal to zero and R^2 equal to 0.99 is suggesting that adsorption kinetics is controlled by diffusion through the CO_2 gas film surrounding the AC particles.

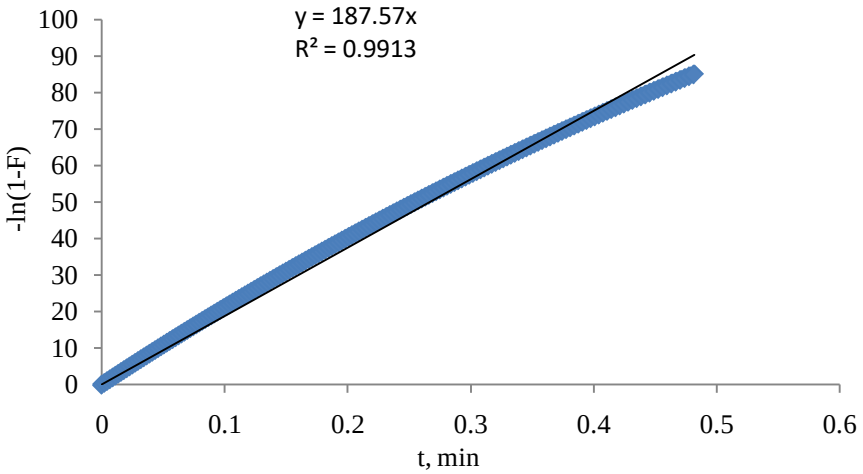

Figure 3: Plot of -ln (F-1) against time

iv. *Avrami (JMAK) Model*

Johnson-Mehl-Avrami-Kolmogorov (JMKA) model, which is called Avrami model too, is expressed inequation 9, [33] and [34]. Avrami equation describes the growth of crystallites with respect to time. In this work Avrami equation is describing the increasing numbers of CO_2 molecules by adsorption inside the AC pores.

$$\alpha = 1 - \exp\left(-k_{Av}\,(t)^n\right) \quad (9)$$

Where, α is adsorption fraction at time t, k_{Av} is the Avrami kinetic constant, and n is a constant which represents the mechanism of particles adsorption (growth).

The linearized form is as in equation 10:

$$\ln(-\ln(1-\alpha)) = n\ln k_{Av} + n\ln t \quad (10)$$

Plotting ln (-ln(1-α)) against ln t as in Figure 4 producing straight line (R^2=0.9991) with intercept equal to $n\ln k_{Av}$ and slope equal to n. If Avrami constant n equal to 1. Furthermore the value of Avrami exponent n, which is $1 \leq n \leq 2$ suggesting one dimensional growth of crystallites and that the growth is homogenous [35], which is agreeing with exponent n in micropore filling method of Dubinin-Astakhov (D-A), equation 11 and its linearized form equation 13. D-A equation is applicable for homogeneous carbonaceous adsorbents with micropore structures [36]. It was found in other study [37] that the value of D-A exponent n for MEA-impregnated beds is showing less heterogeneity and more homogeneity with their exponent n value equal to 2, where the value of exponent n in AC is 3 - 1.5. Moving from 3 to 1.5 the microporous system would be getting more heterogeneous [38] and [39].

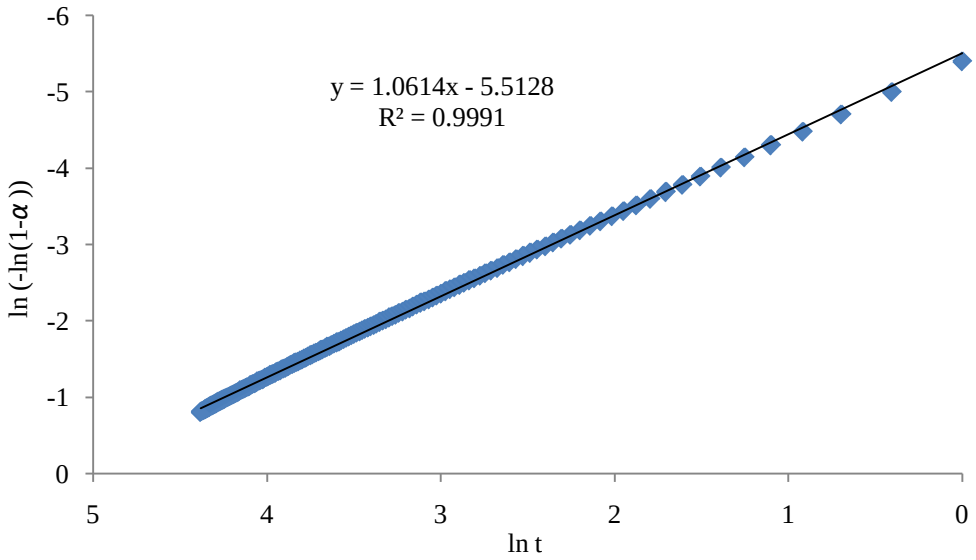

Figure 4: Plot of ln (-ln (1-α)) against ln (t)

c) Mass Balance Mathematical Modeling

Adsorption of CO_2 molecules from feed gas stream containing 15% CO_2 and 85% N_2 was performed in fixed bed packed column of non-impregnated and MEA-impregnated AC beds. Breakthrough time was employed as real time tool to evaluate the efficiency of the adsorption beds. CO_2 monitor was used to display the concentration (%) of the gas stream exiting the adsorption column. Graphs of CO_2 molecules concentration leaving the adsorption column plotted against time were obtained from the data acquisition logger connected to the outlet of the adsorption column.

i. *Mathematical Modeling of MEA-Impregnated 500 µm Adsorption Bed*

To formulate a general mathematical model corresponding to the mainly micropore adsorption mechanism and to cover the two stages mentioned earlier, the following assumptions were made:

1. The system operates under isothermal, isobaric and diabatic conditions.
2. The porosity of the adsorption bed was uniform and constant.
3. The equilibrium of adsorption is a nonlinear isotherm.
4. The velocity distribution is constant across the column diameter.
5. The volumetric flow rate is constant along the column.

Summarizes of the experimental parameters and simulation boundary conditions for the mathematical model validation are in Table 1:

Table 1: Experimental data and simulation boundary conditions

Operating conditions		
Pressure	1 atm	
Temperature	25°C	
Inlet concentration	6.05118E10^{-6} mol/ml	
Inlet volumetric flow rate	10 ml/min	
Adsorption column		
Material	Glass	
Inside diameter	1 cm	
Bed height	9 cm	
Bed weight	5 g	
Bed Volume	7.23 cm^3	
Adsorbent properties		
Bed type	Non-impregnated AC	MEA-impregnated AC
Particles size	500 μm	500 μm
Micropore surface area	675 m^2/g	65 m^2/g
Micropore particle porosity	0.0956 cm^3/g	0.020 cm^3/g
Porosity	0.684	0.620
Bulk density	1.6387 cm^3/g	1.6228 cm^3/g
Bed Volume	7.2285 cm^3	6.2857 cm^3
Pseudo 1st order reaction constant (k)	-	0.004836 1/min

ii. *Mathematical Model of MEA-Impregnated AC Bed*

The mathematical model was based on the CO_2 molecules breaking through the adsorption bed.

The adsorption of CO_2 molecules was declining and more CO_2 molecules were exiting the bed.

The general equation of mass balance with first order chemical reaction for CO_2 in the feed gas:

$$\text{Accumulation} = \text{Input} - \text{Output} + \text{Generation}$$

As the mass balance would be conducted on CO_2 molecules exiting the adsorption bed, the mass balance equation would be:

$$\text{Output} = \text{Input} - \text{Accumulation} + \text{Generation}$$

$$v\frac{dc_o}{dt} = qc_i - qc_{acc} + vk_1c \qquad (14)$$

Where:

K_1: Pseudo first order reaction constant, 1/min.
C_i: Concentration of CO_2 entering the AC bed, mol/ml.
C_o: Concentration of CO_2 exiting the AC bed, mol/ml.
C_{acc}: Concentration of CO_2accumulated in the AC bed, mol/ml.

Equation 14 is an ordinary first order linear differential equation and the final solution would be as in Equation 15.

$$C = C\_i + n\, e\text{^}(-(q\ /\ v - k\_1\ )t) \qquad (15)$$

Initial boundary condition:

At t = 0, C = 0

$n = -C_i$

Then equation 15 would be:

$$C = C\_i - C\_i\ e\text{^}(-(q\ /\ v - k\_1\ )t) \qquad (16)$$

Rearranging equation 16:

$$C = C_i\left(\frac{q/v}{(q/v) - k_1}\right)\left(1 - e^{-((q/v)-k_1)t}\right) \qquad (17)$$

The simulated results were validated by using the experimental results of the MEA-impregnated activated carbon bed. The simulated results were compared with the experimental data. The simulated data demonstrated a reasonable agreement with the experimental data, as the root mean square error (RMSE) calculated was 6.75915E-06. The simulated and experimental data of MEA-impregnated AC beds were plotted in Figure 5.

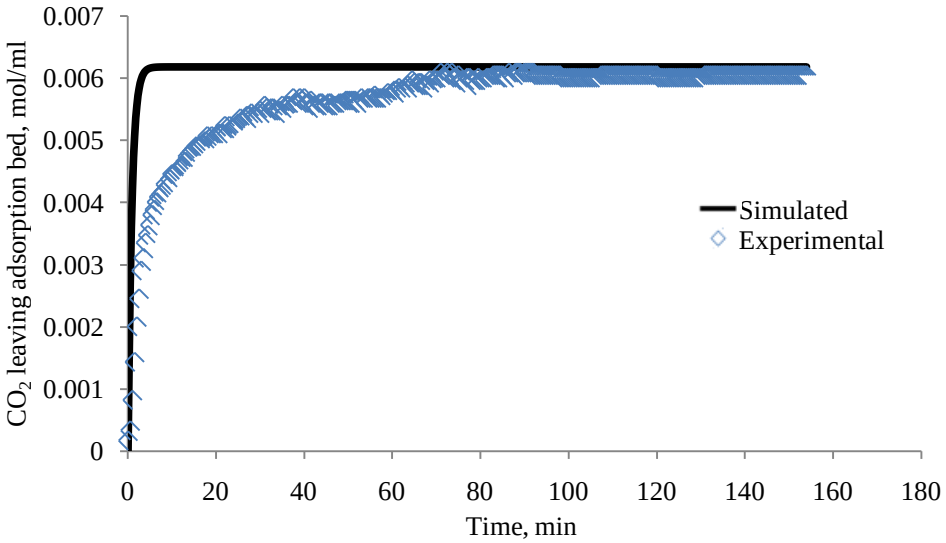

Figure 5: Comparison of CO_2 experimental and simulated breakthrough curves for MEA-impregnated AC bed (Sampled at column outlet)

IV. Conclusions

MEA-impregnated AC particles were used to adsorb CO_2 from gas mixture. Results are showing that AC particles impregnated with MEA adsorb CO_2 molecules in a pseudo first order reaction manner and that the controlling step in this reaction is the mass transfer of CO_2 molecules from through the CO_2 gas film and not the intraparticle diffusion of CO_2 molecules inside the pores of MEA-impregnated AC particles. Due to the homogeneity of the MEA-impregnated activated carbon particles the adsorption of CO_2 molecules follows the Avrami model of homogenous crystallites growth. The mass balance mathematical model showed that the experimental and simulated breakthrough curves have good agreement, as the root mean square error (RMSE) was 5.7678E-09 and 3.88532E-09 for non-impregnated and MEA-impregnated beds respectively, which also proved that the adsorption mechanism of both beds is the same.

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References Références Referencias

1. Rufforda T. E., Smartb S., Watsona G.C.Y., Grahama B. F., Boxalla J., Diniz da Costab J. C., Maya E. F. The removal of CO_2 and N_2 from natural gas: A review of conventional and emerging process technologies. Journal of Petroleum Science and Engineering 2012;94–95:123–54.
2. de_Richtera R. K., Mingb T., Caillola S. Fighting global warming by photocatalytic reduction of CO_2 using giant photocatalytic reactors. Renewable and Sustainable Energy Reviews 2013;19:82–106.
3. Youssef B., Serna-Guerrero R., Sayari A., Adsorption of CO_2 from dry gases on MCM-41 silica at ambient temperature and high pressure. 1: Pure CO_2 adsorption. Chemical Engineering Science 2009;64(17): 3721–28.
4. Li J-R, Ma Y., M. McCarthy C., Sculley J., Yu J., Jeong H-K., Balbuena P. B., Zhou H-C.,. Carbon dioxide capture-related gas adsorption and separation in metal-organic frameworks. Coordination Chemistry Reviews 2011;255(15–16),:1791–823.
5. Knaeble, K. S. Adsorbent selection. Adsorption research Inc., Dublin, Ohio; 2002.
6. Crini G. Recent developments in polysaccharide-based materials used as adsorbents in wastewater treatment. Prog. Polym. Sci 2005;30:38–70.
7. Labus K., Gryglewicz S., Machnikowski J. Granular KOH-activated carbons from coal-based cokes and their CO_2 adsorption capacity. Fuel 2014; 118:9–15.
8. Ozdemira I., Şahina M., Orhanb R., Erdema M., Preparation and characterization of activated carbon from grape stalk by zinc chloride activation. Fuel Processing Technology 2014;123:200-6.
9. Yan W., Tang J., Bian Z., Hu J. and Liu H. Carbon Dioxide Capture by Amine-Impregnated Mesocellular-Foam-Containing Template. Ind. Eng. Chem. Res., 2012;51 (9):3653–62.
10. Ramachandran N., Aboudheir A., Idem R., Tontiwachwuthikul P. Kinetics of the absorption of CO_2 into mixed aqueous loaded solutions of monoethanolamine and methyldiethanolamine. Ind. Eng. Chem. Res. 2006;45:2608-16.
11. Aroua M. K., Daud W.M.A.W., Yin C. Y., Adinata D. Adsorption capacities of carbon dioxide, oxygen, nitrogen and methane on carbon molecular basket

derived from polyethyleneimine impregnation on microporous palm shell activated carbon. Separation and Purification Technology 2008; 62(3):609–13.
12. Yu C-H., Huang C-H., Tan C-S. A Review of CO_2 Capture by Absorption and Adsorption 2012;12: 745–769.
13. Liu Y., Zhang L., Watanasiri S. Representing Vapor-Liquid Equilibrium for an Aqueous MEA-CO_2 System Using the Electrolyte Nonrandom-Two-Liquid Model. Ind. Eng. Chem. Res 1999;38:2080-90.
14. Ma'mun S., Nilsen R., Svendsen H. F., Solubility of Carbon Dioxide in 30 mass % Monoethanolamine and 50 mass % Methyldiethanolamine Solutions. J. Chem. Eng. Data 2005;50 (2):630–634.
15. Sayari, A., Belmabkhout, Y., and Serna-Guerrero, R.. Flue gas treatment via CO2 adsorption. Chemical Engineering Journal 2011;171 (3):760-74.
16. H. Qiu, L. Lv, B-c Pan, Q-j Zhang, Zhang W-M, Zhang Q-X. Critical review in adsorption kinetic models. Journal of Zhejiang University Science A 2009;10:716-24.
17. Sravanthi Loganathan, Mayur Tikmani, Satyannarayana Edubilli, Aakanksha Mishra, Aloke Kumar Ghoshal. CO2 adsorption kinetics on mesoporous silica under wide range of pressure and temperature. Chemical Engineering Journal Volume 256, 15 November 2014, Pages 1–8.
18. Khalil S. H., Aroua M. K., Daud W.M.A.W. Impregnation of commercial palm shell activated carbon with monoethanolamine for adsorbing CO2 from gas mixture. International Conference on Biology, Environment and Chemistry (IPCBEE) 2011;24. IACSIT Press, Singapore.
19. Mondal M. K., Balsora H. K., Varshney P., Progress and trends in CO_2 capture/separation technologies: A review, Energy 2012;46:431–41.
20. Caplow M. Kinetics of carbamate formation and breakdown, J. Am. chem. Soc. 1968;90: 6795-803.
21. Littel R. J., Versteeg G. F., van Swaaij W.P.M, Kinetics of CO_2 with primary and secondary amines in aqueous solutions-1. Zwitterion deprotonation kinetics for DEA and DIPA in aqueous blends of Alkanolamines. Chemical Engineering Science 1992;47:2027-35.
22. Lagergren S. About the theory of so-called adsorption of soluble substance. Kungliga Svenska etenskapakademiens. Handlinger 1898;24:1-39.
23. Loganathan S., Tikmani M., Edubilli S., Mishra A., Ghoshal A. K. CO_2 adsorption kinetics on mesoporous silica under wide range of pressure and temperature. Chemical Engineering Journal 2014;256:1–8.
24. Zhang Z., Zhang W., Chen X., Xia Q., Li Z. Adsorption of CO_2 on zeolite 13X and activated carbon with higher surface area. Sep. Sci. Technol. 2010;45: 710–19.
25. Ho Y. S., McKay G. Sorption of dye from aqueous solution by peat Chem. Eng. J. 1998;70:115–24.
26. Weber Jr W. J., Morris J. C. Kinetics of adsorption on carbon from solution. J. Sanit. Eng. ASCE 1963; 89: 31–59.
27. Cheunga W. H., Szetob Y. S., McKaya G, Intraparticle diffusion processes during acid dye adsorption onto chitosan. Bioresource Technology 2007;98:2897–2904.
28. Cheunga W. H., Szetob Y. S., McKaya G. Intraparticle diffusion processes during acid dye adsorption onto chitosan. Bioresource Technology 2007;98: 2897–2904.
29. Boparai H. K., Joseph M., O'Carroll D. M. Kinetics and thermodynamics of cadmium ion removal by adsorption onto nanozerovalent iron particles. Journal of Hazardous Materials 2011;186:458–65.
30. Boyd G. E., Adamson A. M., Myers L. S. Jr. J Am Chem Soc The exchange adsorption of ions from aqueous solutions by organic zeolites; kinetics 1947;69:2836-48.
31. Gupta S. S., and Bhattacharyya K. G. Adsorption of Ni (II) on clays. Journal of Colloid and Interface Science 2006;295:21–32.
32. Aroua M. K., Leonga S.P.P., Teoa L. Y., Yin C. Y. Wan Mohd Ashri Wan Dauda. Real-time determination of kinetics of adsorption of lead(II) onto palm shell-based activated carbon using ion selective electrode Bioresource Technology 99;20 08:5786–92.
33. Avrami M. Kinetics of Phase Change. I. General Theory. Journal of Chemical Physics 1939;7:1103–12.
34. Elaine C. N. Lopes, Fernanda S. C. dos Anjos, Eunice F. S. Vieira, Antonio R. Cestari. An alternative Avrami equation to evaluate kinetic parameters of the interaction of Hg (II) with thin chitosan membranes. Journal of Colloid and Interface Science 2003;263:542–47.
35. Christian W. The Theory of Phase Transformation in Metals and Alloys. Pergamon Press, Oxford. 1975:20-21.
36. Dubinin M. M. Fundamentals of the theory of adsorption in micropores of carbon adsorbents: characteristics of their adsorption properties and microporous structures. Pure & Appl. Chern. 1989; 61::1841-43.
37. Khalil S. H. Effects on Surface Area, Intake Capacity and Regeneration of Impregnated Palm-Shell Activated Carbon with Monoethanolamide and 2-Amino-2-Methyl1-Propanol Equipped for CO_2 Adsorption. Journal of Earth Science & Climatic Change, 2018, 9:7 DOI: 10.4172/2157-7617.1000 484.
38. Dubinin, M. M. and Stoeckli, H. F. Homogeneous and heterogeneous micropore structures in

carbonaceous adsorbents. J. Colloid Interface Sci. 1980;75: 34-42.
39. Puziy, A. M. Heterogeneity of Synthetic Active Carbons. Langmuir 1995;11:543-44.

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Potential of Rain Water Harvesting and Ground Water Improvement at RVCE

By Pavan Bandakli B R & M Lokeshwari
R V College of Engineering

Abstract- Water is a primary resource for the development of any country. Increase of population in urban areas has resulted in failure of typical water supply system to meet the growing demand. Rainfall is the major source of fresh water. To reach the water demand, utilization of rain water by adopting decentralized rain water harvesting approach is need of the hour. The present study area is R V College of Engineering, Mysore road, Bengaluru. Annual rainfall records and the data required for estimation of potential of rain water and runoff coefficients of different catchment surfaces were collected. It was observed from the study that RVCE campus has the potential of collecting 21.49 Million liters of water annually from roof tops of different buildings and 32.72 Million liters of water by runoff from major catchment areas like play grounds, pavements, parks and sites.

Keywords: *rain water harvesting, ground water recharge.*

GJRE-C Classification: *FOR Code: 090499*

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Potential of Rain Water Harvesting and Ground Water Improvement at RVCE

Pavan Bandakli B R [α] & M Lokeshwari [σ]

Abstract- Water is a primary resource for the development of any country. Increase of population in urban areas has resulted in failure of typical water supply system to meet the growing demand. Rainfall is the major source of fresh water. To reach the water demand, utilization of rain water by adopting decentralized rain water harvesting approach is need of the hour. The present study area is R V College of Engineering, Mysore road, Bengaluru. Annual rainfall records and the data required for estimation of potential of rain water and runoff coefficients of different catchment surfaces were collected. It was observed from the study that RVCE campus has the potential of collecting 21.49 Million liters of water annually from roof tops of different buildings and 32.72 Million liters of water by runoff from major catchment areas like play grounds, pavements, parks and sites. The collected water can be used for flushing, gardening purposes, further ground water recharging can be done by artificial recharging techniques. Sustainability in water management can be achieved at RVCE campus by adopting RWH technique.

Keywords: rain water harvesting, ground water recharge.

I. Introduction

2.5% of Earth's water is fresh water out of which 68.9% is of Glaciers and Ice caps, 30.8% is locked up in ground. Only 0.3% is surface water which serves most of life needs [1]. Water is a primary requirement for our daily activities, Safe and readily available water is required for public health, food production, recreational use, drinking and domestic use. Water management is directly relatable to the economic growth of the country, Water availability is one of the primary criteria for setting up of industries which are associated with local and foreign investments. Majorly many parts of North Karnataka are facing water crisis which is also an indirect reason for poor generation of employment opportunities hence many youths are heading towards metropolitan cities like Bengaluru resulted in rapid increase of population failure of typical water supply system to meet the requirement.

According to Composite Water Management Index, August 2019 released by NITI Aayog 5 out of 20 world largest cities are under water stress are in India, Indian urban population is expected to reach 600 million by 2030 with expected demand supply gap of 50Bcm [2].

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In recent years India has experienced weak monsoons resulted in drought conditions at many places. Ground water table is reducing day by day in many parts of the country, Punjab which produces 10% of India's paddy utilizes 80% ground water for paddy irrigation depleting its own ground water resource, 70% of India's thermal power faces water stress by 2030 which contributes 83% of India's energy power generation in 2016, Presently 40% of India's thermal power plants are in water scare regions, 14 of them faced shutdown in 2013-16 due to water scarcity [2].

Recently Indian government introduced ministry of jalshakthi, which launched programs like Jalshakthi abhiyan to encourage and promote water conservation, Rain water harvesting, renovation and rejuvenation of water bodies, bore well structures. Once a drought village Jakhni of Bunderkhand district, Uttar Pradesh is emerged as self-water reliable village by adopting methods like collection and storage of rain water, Restoration of ponds, Grey water usage with no external funding. Sustainable water management has to be incorporated in private and public buildings to overcome the water demand. Decentralized approach has to be adopted in order to achieve this state. Rain water harvesting by roof top water collection and ground water improvement by simple techniques are the easy, suitable and sustainable solutions for the problems associated with water requirement and its management.

II. Rain Water Harvesting and Ground Water Recharge

Rain water is the ultimate and primary source of fresh water. Lakes, ponds, Rivers, Ground water are the secondary sources. Rain water has highest potential to meet the demand of people if public are involved in conservation of rain water in their houses, public building's, Institutions. Rain water harvesting has been carried out from decades from simple harvesting techniques like collection of water through small drums by using normal cloth as a filter medium to modern techniques. Rain water harvesting is defined as collection of rain water from the surface where it falls, either it may be roof top harvesting or open space harvesting. Rain water harvesting potential depends on catchment area, intensity of rainfall. Rain water collected is stored and utilized or the water from open source can be utilized for ground water recharging.

Rain water is collected from roof tops and is filtered to remove dry leaves, waste materials, dirt present on the roof top, the water is taken to storage tank which can be overhead tank, surface tank and overhead tank by using down take pipes. The stored water can be treated and can be used as potable water or can be used for non-potable purposes like irrigation, gardening etc. The stored water can also be used for recharging of ground water by different methods such as recharging through establishment of recharge pits or trenches, constructing artificial recharge wells or by using abandoned or existing bore wells.

III. Study Area

R V College of Engineering is spread over 50.97 acres located at Bengaluru south which receives an average annual rainfall of 877.8 mm [3]. Satellite view of RVCE campus is shown in figure 1 below. The main motto of the institution to achieve sustainability in terms of water, energy and waste management, in road to achieve this the institution has setup rain water harvesting units in three phases across the campus which has collection capacity of 3.6 lakh liters in total, two bore wells are also established for the purpose of ground water recharging, Campus also has Reverse osmosis water treatment and softening plant of 22000 liters capacity and Sewage treatment plant of 50 kld output [4].

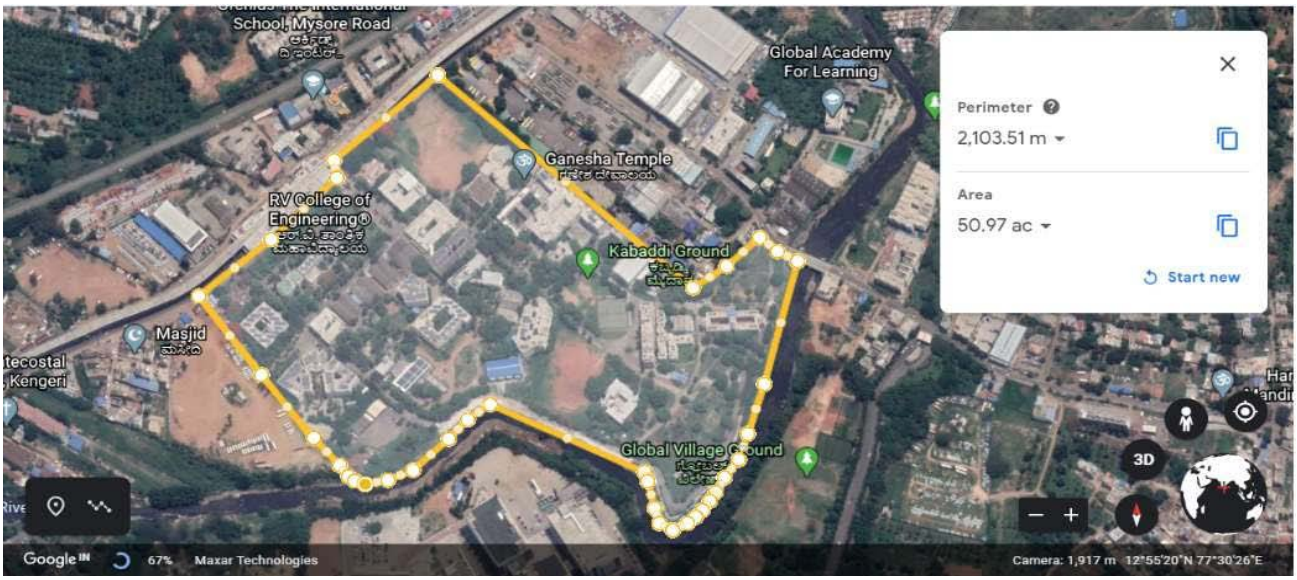

Figure 1: Satellite view of R V College of Engineering (Source: Google Earth®)

IV. Objectives

Present study aims at estimating potential of rain water and runoff which can be collected annually from different roof top area of different buildings located at RVCE.

V. Methodology

1. Obtaining roof top area of different buildings at RVCE campus using Google earth.
2. Collection of rainfall data from India Meteorolgical Department (IMD) website.
3. Runoff co-efficient of different materials are obtained from
4. A building is considered and the monthly/annual water demand and monthly/annual rain water yield from the roof top area is measured and the rain water harvesting tank capacity is determined according to IS 15979: 2008.
5. Similar calculations are extended to other buildings of RVCE to obtain total potential of Rain water.

VI. Estimation of Rain Water Harvesting Capacity

New Cauvery hostel, Male residential hostel for 2nd and 3rd year students is considered to estimate rain water harvesting capacity, Satellite image of new Cauvery hostel is shown in figure 2 below.

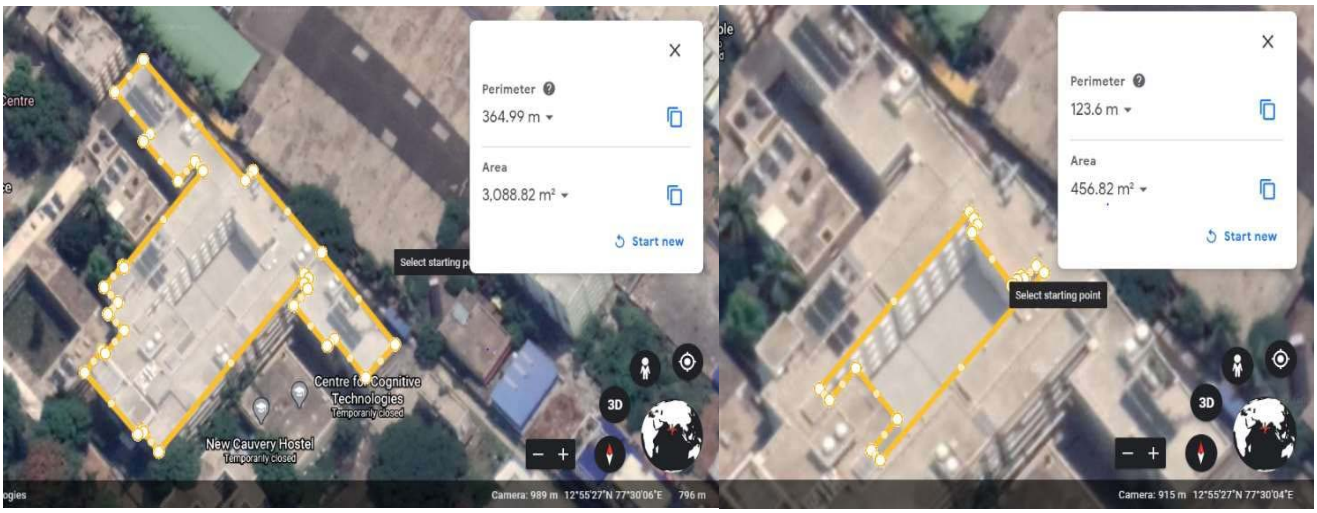

Figure 2: Satellite image of New cauvery hostel (Source: Google Earth®)

Annual rain water yield is given by the formula
Q = A x R x C x F
Where Q = Annual rainwater yield
A = Catchment area in m2
R = Annual precipitation
C = Runoff coefficient of catchment material

Annual rain water yield of Cauvery hostel
Catchment area, A = 2632 m2
Annual precipitation, R = 877.8mm
Runoff coefficient of RCC roof, C = 0.8 [5]
Filter efficiency, considering F = 0.8

Q = A x R x C x F
Q = 2632 x 877.8 x 0.8 x 0.8 = 1478637
liters = 1478.637 m3

Annual water demand of Cauvery hostel for flushing purpose
Number of people residing at New Cauvery hostel = 528
Quantity of water require for flushing per person = 10 liters
Total Quantity of water required monthly = 528 x 10 x 30 = 158400 liters = 158.4 m3
Total Quantity of water required annually = 528 x 10 x 365 = 1927200 liters = 1927.2 m3

a) *Calculation of storage tank size according to monthly demand*

Table 1: Calculation of storage tank size according to monthly demand

Month	Average Rainfall (mm)	Monthly yield(l)	Cumulative yield(l)	Monthly demand(l)	Cumulative demand(l)	Volume stored(l)	Surplus(l)
May	96	161710	161710	158400	158400	3310	3310
June	85.7	144359	306069	158400	316800	0	0
July	100.3	168953	475022	158400	475200	0	10553
August	117.8	198431	673453	158400	633600	39853	40031
September	194.6	327799	1001252	158400	792000	209252	169399
October	154.5	260252	1261504	158400	950400	**311104**	101852
November	43.9	73948	1335452	158400	1108800	226652	0
December	15.8	26614	1362066	158400	1267200	94866	0
January	2.3	3874	1365940	158400	1425600	0	0
February	6.4	10780	1376720	158400	1584000	0	0
March	16	26951	1403671	158400	1742400	0	0
April	44.5	74959	1478630	158400	1900800	0	0
Total	877.8	1478630		1900800			

Table 1 shows the calculation of storage tank size according to monthly demand, Minimum storage required is the difference of maximum volume stored and surplus water left at the end of the year which equals to 311104 liters, Hence, Storage tank of capacity 311.1 m3 is suggested for the hostel with roof top area of 2632 m2 which yields 1478637 liters annually which could meet the demand of flushing purpose with 76.72% water reliability.

VII. Annual Water Yield of Different Buildings at RVCE

Similarly annual water yield from different roof tops of different buildings is calculated by obtaining roof top areas of determined using Google earth and represented in table 2 below, figure 3 represents satellite image of civil department.

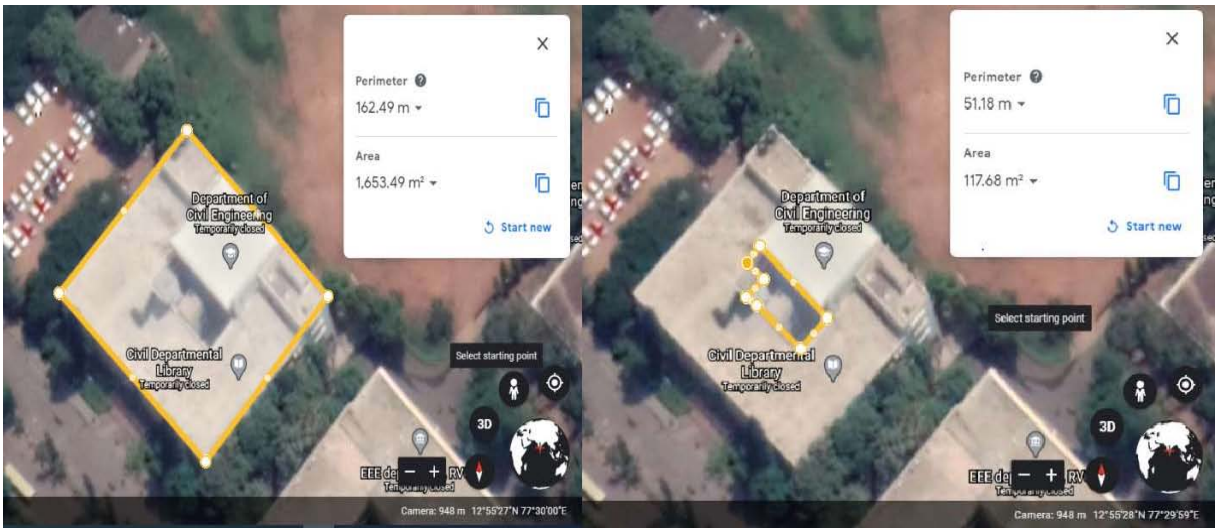

Figure 3: Satellite image of civil department building (Source: Google Earth®)

Table 2: Annual water yield from different roof tops of different buildings of RVCE

Sl. No.	Building name	Area	Annual water yield
1	Department of CV	1535.81	862805.77
2	Department of ME	1431.69	804311.98
3	Department of CSE	1063.36	597387.14
4	Department of EC	1262.1	709037.68
5	Department of EEE	1773.06	996090.92
6	Department of AS and ISE	1911.81	1074039.56
7	Department of BT and EIE	1050.23	590010.81
8	Department of MCA	1596.28	896777.33
9	Department of TE	894.95	502775.75
10	CRC Complex	803.41	451349.31
11	Department of CE	1586.42	891238.06
12	Administrative block	1330.78	747621.55
13	Mechanical PG block	486.43	273272.48
14	Department of IEM	925.75	520078.94
15	Old sports complex	547.44	345990.83
16	New sports complex & Gym center	1239.1	826638.30
17	Food Court	1354.09	855806.54
18	Bank and Post office	153.29	86117.09
19	Aero-space lab	862.21	575204.43
20	Library building	873.11	490506.21
21	Hospital Building	301.61	169442.08
22	Cognitive and Research Block	863.28	484983.78
23	Workshops	3213.01	2143488.935
24	Old cauvery hostel	1251.64	703161.33
25	New cauvery hostel	2632	1478636.54
26	Sir m v hostel	2041.95	1147151.17
27	Chamundi hostel	1159.33	651302.31

28	Dj hostel	1061.77	596493.89
29	Employee's residence	393.74	221199.98
30	Miscellaneous	1265.24	799651.92
	Total annual yield		21492572.62

By harvesting rain water from different buildings of RVCE we can collect 21492572 liters of water annually making RVCE campus self-reliable and self-sustainable in water usage. Collected water can be utilized for flushing, gardening purposes, since the daily requirement of the institution is high adopting RWH techniques is found to be simple and sustainable technique which can be implanted in the campus.

VIII. Estimation of Runoff Potential

Runoff is defined as the ratio of precipitation that makes its way towards rivers or oceans as surface or subsurface flow to the precipitation received. After undergoing infiltration and other loses from the rainfall, to determine potential runoff water that can be collected from different catchment surfaces like playgrounds, parks, pavements etc. present at RVCE campus, figure 4 and figure 5 shown below gives satellite image of cricket ground and site respectively. area of the catchment surfaces are determined using Google earth and represented in table 3, runoff coefficients of different surfaces were collected and annual water yield from runoff is obtained by knowing area and average annual rainfall of the catchment.

Annual water yield, Q is obtained by using the formula

$Q = R \times A \times C$

Where, R is the average annual precipitation

A is the catchment area

C is the runoff coefficient

Runoff coefficient of pavements = 0.7-0.95,

parks = 0.1-0.25,

unimproved areas = 0.1-0.3,

tiles = 0.8-0.9, playgrounds = 0.2-0.35 [5].

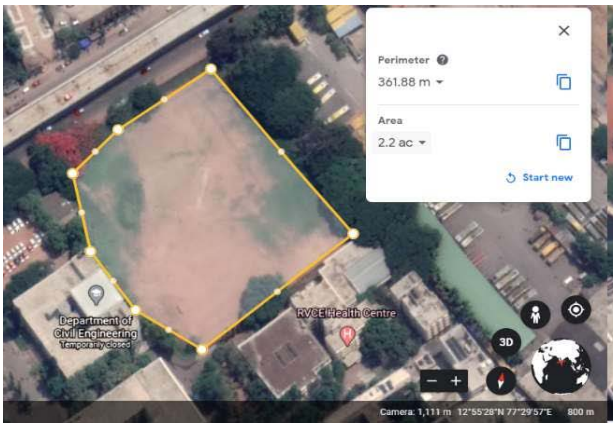

Figure 4: Satellite image of cricket ground (Source: Google Earth®)

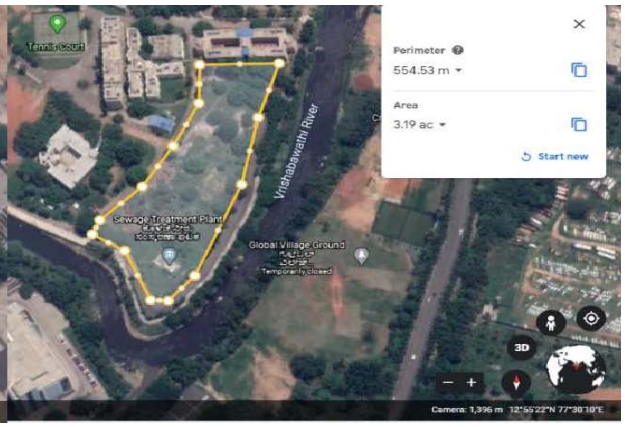

Figure 5: Satellite image of Site behind DJ block (Source: Google Earth®)

Table 3: Estimation of annual runoff potential of RVCE

Sl. No.	Type of catchment	Area (m^2)	Annual water yield(l)
1	Pavements	27913.06	11760975.1
2	Play grounds	20507.54	4950417.62
3	Unimproved areas/ sites	37633.28	8258623.3
4	Parks/greenery	24187.23	4246310.1
5	Brick/tiles/concrete	4996.95	3509058.17
	Total runoff		32725384.29

The runoff water which can be collected from different surfaces such as pavements, parks, sites, playgrounds located at RVCE campus is 32725384.29 liters which can be utilized for recharging of ground water by adopting recharge structures.

IX. Conclusions

The present study concludes that by adopting RWH facility to collect the water from roof tops of all the buildings of RVCE campus, 21.49 Million liters of water can be collected. It is evident that adopting RWH and artificial ground water recharge techniques in all the public buildings can be a solution to water availability and management problems at urban areas.

X. Recommendations

1. Sustainability in water management can be achieved at RVCE by adopting decentralized RWH and Ground water recharge structures.

2. Presently RVCE is collecting 3.6 Million liters of water annually from RWH, by adopting RWH technique to all the roof tops RVCE campus has potential of collecting 21.49 Million liters of water annually from roof tops of different buildings.
3. RVCE has the potential of collecting 32.72 Million liters of water by runoff from major catchment areas like play grounds, pavements, parks and sites, the run-off water collected can be used for improving ground water resources.
4. Open wells can be established near Bus parking, near temple, near DJ hostel and near food court in addition to the existing recharge structures for ground water recharge purpose.
5. Monitoring of existing RWH structures and Recharge structures needs to be done.

References Références Referencias

1. Website of NASA earth observatory,(Source: https://earthobservatory.nasa.gov/features/WeighingWater)
2. Composite water management index, august 2019 by NITI aayog in association with Ministry of Jal Shakti and Ministry of Rural Development.
3. Indian Meteorological Department, Ministry of Earth Sciences, Government of India.
4. Official website of R V College of Engineering, (Source: www.rvce.edu.in)
5. Rain water harvesting in India, 2007 an appraisal by Central pollution control board, Ministry of Environment, Forests and Climate change, Government of India.
6. IS 15797: 2008, Roof top Rainwater harvesting – Guidelines, BIS, New Delhi, India.

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Design and Economic Analysis of a Small Scale Formaldehyde Plant from Flared Gas

By Muesi Zornata Noble, Emmanuel O. Ehirim, Wordu Animia & Jaja Zina

Rivers State University

Abstract- The Simulation of a 10,000 ton/yr capacity Formaldehyde plant from flared gases was performed using Aspen Hysys version 8.8, and the Hysys model of the plant was developed using data from literature. A material and energy balance for the various components of the plant was performed manually and with Hysys for comparison. The design/equipment sizing, Mechanical design, costing and economic evaluation, process control of the functional parameters of the various equipments and finally the full Hysys process flow diagram of the model was performed. The Formaldehyde reactors was simulated to study the effect of process functional parameters such as reactor dimensions, temperature, pressure, The effect of reactor size and number on Formaldehyde output was studied by simulating the plant with a compressor, mixer, conversion reactor, cooler, CSTR, heat exchanger, and storage tank.

Keywords: *design, height, diameter, volume, composition, formaldehyde.*

GJRE-C Classification: *FOR Code: 090499*

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Keywords: design, height, diameter, volume, composition, formaldehyde.

I. Introduction

Formaldehyde is produced in industrial scale from methanol. It uses atmospheric pressure to perform the production. There are steps in formaldehyde production. The first step involves the liquid methanol which vapourized into an air stream while steam was added to the resulting gaseous mixture. Also, the other step involves the gaseous mixture lead over a catalyst bed. The methanol was finally converted to formaldehyde through partial dehydrogenation and partial oxidation. (Alfaree & Adnan, 2016).

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Besides, the report by Welch shows that 10 million of formaldehyde was produced annually and met the demand of the industries as at then, but as population increases, the demand of formaldehyde was increased and the production rate was not able to met industrial scale based on its wide application. (Alzein & Nath, 2018), the process industry would need more of formaldehyde production rate to met world production annually. This increase in population that occurs result to more production of formaldehyde at a later year. In the 2012, the production of formaldehyde amount to 32.5 million tons per year. According to (Sukunya *et al*., 2014), this increase in demand was due to the applications of formaldehyde in chemical synthesis such as resin products. These resins are used for polywood production. Also, formaldehyde solution can destroy bacteria and fungi.

However, the 32.5 million tons per year was a report as at 2012, but we are now in 2019. This has resulted to increase in population of the world as well as the demand for formaldehyde base on its usage in process industries. (Cameroon *et* al., 2019).

Today, many researchers are looking for new areas in which formaldehyde can be applied, technology has increase and new methods are been discovered. (Chauvel & Lefebvre, 2015),The production based on report cannot met the demand today and so more researchers are to go into designing of units operations for the production of formaldehyde to met world demand which as a results of the current population density. Also, more processes for the production of formaldehyde can be added to the existing two processes and hence these calls for more future research to be carried out with a view of which production process gives the most yield with the least cost of production. (Chouldhary *et al*., 2017).

The study of formaldehyde plant calls for new design of reactor that would produce formaldehyde in excess in other to take care of the world's population that requires the uses and applications of formaldehyde. The production of formaldehyde using the silver contact process amounts to 80% of total formaldehyde process. The type of reactor determines the desired productions which depend on feed quality (Antonio *et al*., 2010; Geoffrey *et al*., 2004) and the reactor temperature (Geoffrey *et al*., 2004). The work focus on the type of reactor design would produce formaldehyde in excess as to met the current demand of society today. This is

base on the wide application of formaldehyde. The study require the development of design parameters or sizes of continuous stirred tank, plug flow and batch reactor for the two routes used in producing formaldehyde. The reactor types would be tested in its design to compute and simulate to ascertain which reactor type would be suitable to produce formaldehyde in the required quantity to supply to the needs of the process industry for various applications.

Besides, the various reactor models would be tested with the reaction mechanisms and kinetics for simulations of variables which would be used to ascertain the reactor that best give the highest production. The products from the reactors are fed into absorber to form formaldehyde 37% by mass called formalin or more (Andre *et al*., 2002).

However, the formalin formed at room temperature was not stable and formed paraformaldehyde. The paraformaldehyde formed was high concentration of formaldehyde. But formalin has methanol of 1.14% by mass for more stability in solution and its temperature was more than 313k (Geoffrey *et al*., 2004), the study focuses on the design of reactor types for the production of formaldehyde. This formaldehyde has the formula HCHO and the first series of aliphatic aldehyde which was discovered in 1859. The production of formaldehyde which started during the twentieth century had continued even till date. The study becomes more imperative for industries, engineers and producers who wants to exploits the opportunity to design reactor types for the production of formaldehyde.

Also, the study calls for new design of reactor that would produce formaldehyde in excess in other to take care of the world's population that requires the uses and applications of formaldehyde. (Ghanta *et al*., 2017), the production of formaldehyde using the silver contact process amounts to 80% of total formaldehyde process. The type of reactor determines the desired product which depend on feed quality (Antonio *et al*., 2010; Geoffrey *et al*., 2004), Their work focus on the type of reactor design would produce formaldehyde in excess as to met the current demand of society today. This is base on the wide application of formaldehyde. The study require the development of design parameters or sizes of continuous stirred tank, plug flow and batch reactor for the two routes used in producing formaldehyde. (Ghaza & Mayourian, 2014),The reactor types would be tested in its design to compute and simulate to ascertain which reactor type would be suitable to produce formaldehyde in the required quantity to supply to the needs of the process industry for various applications.

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The production and optimization of formaldehyde can include the streams for air, methanol and water in a suitable composition in a plug flow reactor under certain conditions of temperatures and pressure (Andreasen *et al*., 2003). The purpose of using a plug flow reactor is to get desired product which can be optimized to get best yield of formaldehyde (Antonio *et al*., 2010; Geoffrey *et al*., 2004).

(Lauks *et al*., 2015), on the other hand, when the production of formaldehyde involves the use of silver catalyst, the operation is carried out adiabatically by lagging the system which helps to obtain a selectivity of 90%. (Marton *et al*., 2017), the life of the catalyst is short depending on the impurities in the methanol and the gases at exist that contain considerable amount of hydrogen and water. However, the silver being a metal would have low catalytic activity for the decomposition of methanol even at a very high temperature. (Mazanec *et al*., 2019), the chemisorption of the monoatomic oxygen in the metal brings its activation.

(Meisong, 2015), thermal decomposition of formaldehyde depends on the gas stream, the gas stream is cooled when it passes through the catalyst. The formaldehyde produced is then absorbed in an absorber by water to get pure formaldehyde. Since the gaseous form of formaldehyde is unstable, it is better absorbed in water. (Mohamad, 2016), the products of reaction contains the formaldehyde diluted in water other gases which mainly contains nitrogen. Finally, the commercial and final product is obtain from the absorber of about 55% weight of formaldehyde in water or formalin.

(Mohsenzadeh, 2019), the design and optimization of the reactor for the production of formaldehyde which uses two different routes and each would be considered during the design of the reactor because we want to know which of the route would be best in the production of formaldehyde. Also, the reactors would be batch, continuous stirred tank and plug flow reactor. Each reactor would follow both routes

required for the production of formaldehyde and the optimization of each routes of production and in each of the reactor types. Finally, the physical properties would be presented in tabular form below (Reuss *et al.*, 2003). Jaja *et al*, (2020), Methane is a major component of flared gas as well as natural gas and its composition varies from 70 to 90% in both cases.

II. Materials and Methods

a) Materials

The Materials used in this Research includes:

i. Plant data of flared gas composition obtained from the Port Harcourt Refining Company
ii. Aspen Hysys software version 8.8
iii. Matlab software
iv. Microsoft excel
v. Computer

b) Methods

The methods that will be adopted in this Research includes:

(a) Material Balance
(b) Energy Balance
(c) Equipment Sizing
(d) Mechanical Design
(e) Costing

(a) Material Balance

Material balance are the basics of process design. A material balance taken over the complete process will determine the quantities of raw materials required and products produced. Balances over individual process unit set the process stream flows and compositions. A good understanding of material balance calculations is essential in process design.

Material balances are also useful tools for the study of plant operation and trouble shooting. They can be used to check performance against design; to extend the often limited data from the plant instrumentation; to check instrument calibrations and to locate source of material loss.

The loss of mass associated with the production of energy is significant only in nuclear reactions. Energy and matter are always considered to be separately conserved in chemical reactions.

The general conservation equation for any process can be written as:

$$[Material\ out] = [Matrerial\ in] + [Generation] - [Consumption] - [Accumulation] \quad (1)$$

For steady state process the accumulation term will be zero except in nuclear process, mass is neither generated nor consumed; but if a chemical reaction take place a particular chemical species may be formed or consumed in the process. If there is no chemical reaction the steady state balance reduces to:

$$[\text{Materials in}] = [\text{Materials Out}] \quad (2)$$

(b) Energy Balance

A general *energy balance* equation can be written as:

$$\begin{bmatrix} Rate\ of\ Outflow \\ of\ Energy \end{bmatrix} = \begin{bmatrix} Rate\ of\ Inflow \\ of\ Energy \end{bmatrix} + \begin{bmatrix} Rate\ of\ Generation \\ of\ Energy \end{bmatrix} - \begin{bmatrix} Rate\ of\ Consumption \\ of\ Energy \end{bmatrix} - \begin{bmatrix} Rate\ of\ Accumulation \\ of\ Energy \end{bmatrix} \quad (3)$$

If no chemical reaction occurs

$$\begin{bmatrix} Rate\ of\ Consumption \\ of\ Energy \end{bmatrix} = \begin{bmatrix} Rate\ of\ Generation \\ of\ Energy \end{bmatrix} = 0 \quad (4)$$

Equation (3) becomes

$$\begin{bmatrix} Rate\ of\ Outflow \\ of\ Energy \end{bmatrix} = \begin{bmatrix} Rate\ of\ Inflow \\ of\ Energy \end{bmatrix} - \begin{bmatrix} Rate\ of\ Accumulation \\ of\ Energy \end{bmatrix} \quad (5)$$

If the system is a steady state process

$$\begin{bmatrix} Rate\ of\ Accumulation \\ of\ Energy \end{bmatrix} = 0 \quad (6)$$

Equation (5) becomes

$$\begin{bmatrix} Rate\ of\ Inflow \\ of\ Energy \end{bmatrix} = \begin{bmatrix} Rate\ of\ Outflow \\ of\ Energy \end{bmatrix} \quad (7)$$

Energy flow for each stream shall be computed in terms of Heat Flow using the formula

$$\dot{Q} = \dot{m} C_{p_{mean}} \left(T - T_{ref}\right) \quad (8)$$

Where $Q = Heat\ flow\ rate\ in\ kJ/hr$
$\dot{m} = mass\ flow\ rate\ in\ kg/hr$

$$C_{p_{mean}} = Mean\ Specific\ Heat\ Capacity\ in\ KJ/kg\ ℃$$

$$T = Temperature\ of\ the\ stream\ in\ ℃$$
$$T_{ref} = Reference\ Temperature\ of\ stream\ sometimes\ assumed\ to\ be\ zero$$

(c) Equipment Sizing

The different categories of equipment to be sized in this project includes:

i. Conversion Rector Unit
ii. Continuous Stirred Tank Reactor (CSTR) Unit
iii. Heat Exchange Unit
iv. Storage Tank Unit

(d) Mechanical Design

A vessel must be designed to withstand the maximum pressure to which it is likely to be subjected in operation. For vessels under internal pressure, the design pressure is normally taken as the pressure at which the relief device is set. This will normally be 5 to 10 per cent above the normal working pressure, to avoid spurious operation during minor process upsets. When deciding the design pressure, the hydrostatic pressure in the base of the column should be added to the operating pressure if significant.

Vessels subject to external pressure should be designed to resist the maximum differential pressure that is likely to occur in service. Vessels likely to be subjected to vacuum should be designed for a full negative pressure of 1 bar unless felted with an effective and reliable vacuum breaker.

(e) Cost Estimation and Economic Evaluation

Economic evaluation is very important for the proposed plant. We have to be able to estimate and decide between either native design and for project evaluation. Chemical plants are built to make profit and estimate of the investment is required and the cost of production are needed before the profitability for a project is the sum of the fixed and working capital.

Fixed capital is the total cost of the plant ready to start up. It is the cost paid to the contractors. Working capital is the additional investment needed, over and above the fixed capital to start up the plant and operate it to the point when income is earned. Most of the working capital is recovered from at the end of the project. The full detail of the costing is given in the appendix.

III. Design Simulation (Hysys)

This section represents a process simulation of plant design for the production of Formaldehyde from flared gas. The simulation covers the following equipments/units:

U001	-	Compression unit
U002	-	Mixing unit
U003	-	Conversion Reactor unit
U004	-	Cooling unit
U005	-	CSTR unit
U006	-	Heat Exchanger unit
U007	-	Storage tank unit
S_1 (Stream 1)	-	Flared Gas
S_2 (Stream 2)	-	Compressed Flared Gas
S_3 (Stream 3)	-	Air
S_4 (Stream 4)	-	Mixed Product
S_5 (Stream 5)	-	Vapour product
S_6 (Stream 6)	-	Cooled Vapour
S_7 (Stream 7)	-	Formaldehyde Liquid
S_8 (Stream 8)	-	Vapour Out
S_9 (Stream 9)	-	Formaldehyde Liquid Out
S_{10} (Stream 10)	-	Hot Water Inlet
S_{11} (Stream 11)	-	Cooled Water Outlet
S_{12} (Stream 12)	-	Tank Product

Figure 1 shows the full PFD of the Hysys design Simulation Where formaldehyde from flared gas using the reaction between absorbed methane gas from flared gas and oxygen. The procedure begins with compressing of flared gasses using a compressor. The component of interest being methane is being compressed and mixed with air stream inside a mixer and then sent to a conversion reactor where reaction of methane and oxygen occurs to Formaldehyde, Carbon [iv] oxide and water as products. The overhead products from the conversion reactor is being cooled and sent to a Continuous Stirred Tank Reactor [CSTR] for further reaction and more yield of the formaldehyde.

The product from the CSTR is being sent to the heat exchanger for further hitting to the desired temperature and subsequently sent to the storage tank

for storage. The process was able to convert about 90% of methane and the yield of Formaldehyde is up to 45% making the process very economical to set up a plant for the production process using flared gas and trapping methane as base component of reaction. This is a new innovation in the technology of the production of formaldehyde and a scale up of the plant should be executed in the future.

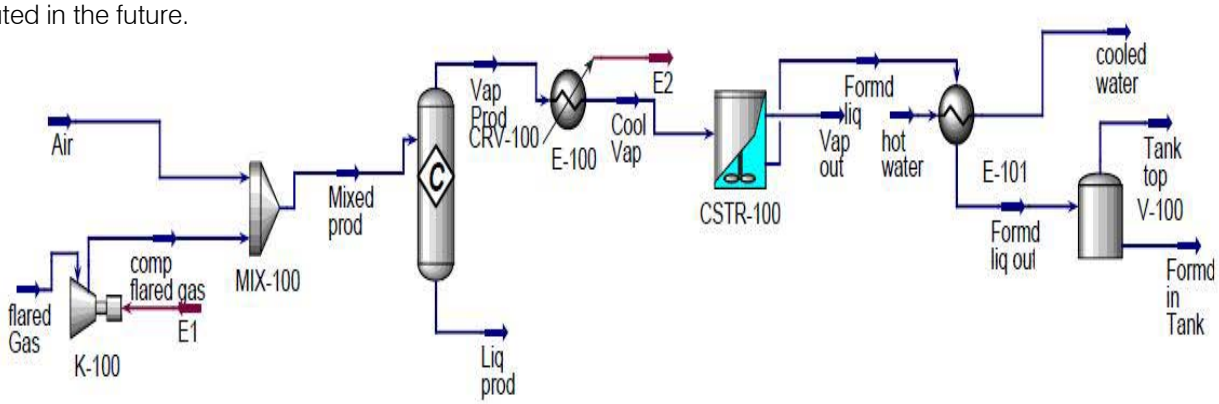

Figure 1: Hysys Simulation PFD

IV. Results and Discussion

a) Material Balance Results

The following results of material balance with manual calculation compared with Hysys simulation is presented in tables below for each unit.

Table 4.1: Comparison of Material Balance Result of Hysys Simulation with Manual Calculation for Compression Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Flared Gas (S_1)			
Mass Flow (kg/hr)	1.23×10^4	1.20×10^4	2.5
Molar Flow (kgmole/hr)	600.50	600.10	0.7
Compressed Flared Gas (S_2)			
Mass Flow (kg/hr)	1.23×10^4	1.20×10^4	2.5
Molar Flow (kgmole/hr)	600.50	600.10	0.7

In Table 4.1 above the mass flow rate of Flared Gas Stream (S_1) for Hysys simulation is 1.2×10^4 kg/hr while that for the manual calculation is 1.23×10^4 kg/hr with a deviation of 2.5%. the molar flow rate for Hysys simulation was found to be 600.10 kgmole/hr while that of manual calculation is 600.50 kgmole/hr with a deviation of 0.7% we also observe that since this unit is a single input, single output stream and applying the principles of conservation of mass, input mass equals output mass, hence the output been Compressed Flared Gas has the same mass and molar flow rates of the input stream which is Flared Gas as well as the same deviation.

Table 4.2: Comparison of Material Balance Result of Hysys Simulation with Manual Calculation for Mixing Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Air (S_3)			
Mass Flow (kg/hr)	1.1×10^4	1×10^4	10
Molar Flow (kgmole/hr)	346.60	346.30	0.9
Flared Gas (S_2)			
Mass Flow (kg/hr)	1.23×10^4	1.20×10^4	2.5
Molar Flow (kgmole/hr)	600.50	600.10	0.7
Mixed Product (S_4)			
Mass Flow (kg/hr)	2.10×10^4	2.20×10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0

In Table 4.2 above the mass flow rate of the Air Stream is 1 x 10^4 kg/hr for Hysys simulation while for manual calculation is found to be 1.1 x 10^4 kg/hr having a deviation of 10%. The molar flow rate for the Hysys simulation is 343.3 kgmole/hr while that of the manual calculation is 343.3 kgmole/hr having a deviation of 0.9%. This Flared Gas stream has been stated in the discussion of Table 4.1, however we are to note that Air stream (S_3) and Flared Gas Stream (S_2) are both input streams respectively which are mixed inside a mixer to produce an outlit stream Mixed Product (S_4) having a mass flow rate of 2.20 x 10^4 kg/hr for Hysys simulation and 2.10 x 10^4 kg/hr for manual calculation with a 4.5%. the molar flow rate of this stream is 947.10 kgmole/hr for Hysys simulation and 947.40 for manual calculation with a deviation of 3%. Applying the principles of conservation of mass to this unit shows that if mass flow rates of the inlet streams are added together the results equals the mass flow rate of the outlet stream which makes our results to be valid for inflow of mass is equal to outflow of mass.

Table 4.3: Comparison of Material Balance Result of Hysys Simulation with Manual Calculation for Conversion Reactor Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Mixed Product (S_4)			
Mass Flow (kg/hr)	2.10 x 10^4	2.20 x 10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0
Vapour Product (S_5)			
Mass Flow (kg/hr)	2.10 x 10^4	2.20 x 10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0
Reaction Extent		24.25	
Fractional Conversion		0.1102	

In Table 4.3 the mass flow rate of the Mixed Product Stream (S_4) for Hysys simulation is 2.20 x 10^4 kg/hr while the manual calculation is 2.10 x 10^4 kg/hr with deviation of 4.5%. The molar flow rate of the Mixed Product Stream (S_4) is 947.10 kgmole/hr for Hysys simulation and 947.40 kgmole/hr for manual calculation with a deviation of 3.0%. We also observe that since this unit is a single input, single Output Stream and applying the principles of conversation of mass, input mass equals output mass, hence the output been Vapour Product (S_5) has same mass and molar flow rates of the Input Stream as well as the same % Deviation. Also the Extent of Reaction for this unit for Hysys simulation is 24.27. The fractional conversion for Hysys simulation is 0.1102 while for manual calculation is 0.1105.

Table 4.4: Comparison of Material Balance Result of Hysys Simulation with Manual Calculation for Cooling Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Vapour Product (S_5)			
Mass Flow (kg/hr)	2.10 x 10^4	2.20 x 10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0
Cooled Vapour (S_6)			
Mass Flow (kg/hr)	2.10 x 10^4	2.20 x 10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0

In Table 4.4 the mass flow rate of the input stream Vapour Product has been stated in the discussion of Table 4.3, this unit contains a single input, single output streams. Hence, the same mass and molar flow rate of the Vapour Product Stream (S_5) is the same for the cooled Vapour Stream (S_6) which is 2.2 x 10^4 kg/hr for Hysys simulation and 2.10 x 10^4 kg/hr for manual calculation. Also the molar flow is 947.10 for Hysys simulation and 947.40 for manual calculation.

Table 4.5: Comparison of Material Balance Result of Hysys Simulation with Manual Calculation for CSTR Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Cooled Vapour (S_6)			
Mass Flow (kg/hr)	2.10 x 10^4	2.20 x 10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0
Formaldehyde Liquid (S_7)			
Mass Flow (kg/hr)	888.5	888.7	0.2
Molar Flow (kgmole/hr)	45.04	45.03	0.3

Vapour Out (S_8)			
Mass Flow (kg/hr)	2.12×10^4	2.111×10^4	0.4
Molar Flow (kgmole/hr)	903.2	902.1	0.1

In Table 4.5 the mass flow rate of cooled vapour stream (S_6) is 2.20×10^4 kg/hr for Hysys simulation and 2.10×10^4 kg/hr for manual calculation with a deviation of 4.5%. The molar flow rate for Hysys simulation is 947.10 kgmole/hr and for manual calculation 947.40 kgmole/hr with a deviation of 3.0%. The mass flow rate of Formaldehyde Liquid stream for Hysys simulation and manual calculation are 888.7 kg/hr and 888.5 kg/hr respectively having a deviation of 0.2%. While the molar flow rate are 45.03 kgmole/hr and 45.04 kgmole/hr having a deviation of 0.3%. The mass and molar flow rate of the Vapour Out Stream for Hysys simulation and manual calculation are 2.111×10^4 kg/hr and 2.12×10^4 kg/hr having a deviation of 0.4% while molar flow rate are 902.1 kgmole/hr and 903.12 kgmole/hr having deviation of 0.1%.

Table 4.6: Comparison of Material Balance Result of Hysys Simulation with Manual Calculation for Heat Exchanger Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Formaldehyde Liquid (S_7)			
Mass Flow (kg/hr)	888.5	888.7	0.2
Molar Flow (kgmole/hr)	45.04	45.03	0.3
Formaldehyde Liquid Out (S_9)			
Mass Flow (kg/hr)	888.5	888.7	0.2
Molar Flow (kgmole/hr)	45.04	45.03	0.3
Hot Water Inlet (S_{10})			
Mass Flow (kg/hr)	900.20	900	0.2
Molar Flow (kgmole/hr)	50.00	49.96	0.1
Cooled Water Outlet (S_{11})			
Mass Flow (kg/hr)	900.20	900	0.2
Molar Flow (kgmole/hr)	50.00	49.96	0.1

In Table 4.6 Formaldehyde Liquid Stream has the same mass and molar flow rate as Formaldehyde Liquid Out. While Hot Water Inlet Stream has the same mass and molar flow rate as Cooled Water Out. This is expected for the design of the Heat Exchanger.

b) Energy Balance Results

The following results of energy balance with manual calculation compared with Hysys simulation is presented in tables below for each unit.

Table 4.7: Comparison of Energy Balance Result of Hysys Simulation with Manual Calculation for Compression Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Flared Gas (S_1)			
Temperature (℃)	25	25	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-4.682e7	-4.686e7	4.7
(E1)			
Temperature (℃)	-	-	
Pressure (kpa)	-	-	
Heat Flow (kJ/hr)	3.421e5	3.427e5	1.4
Compressed Gas (S_2)			
Temperature (℃)	38.84	38.84	0.0
Pressure (kpa)	120	120	0.0
Heat Flow (kJ/hr)	-4.6479e7	-4.6478e7	1.3

In Table 4.7 above the heat flow of Stream (S_1) and Stream (E1) when added equals the heat flow of stream (S_2) and this is in line with the principles of **Conservation of Energy** for a steady state process with chemical reaction occurring.

Table 4.8: Comparison of Energy Balance Result of Hysys Simulation with Manual Calculation for Mixing Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Compressed Gas (S_2)			
Temperature (℃)	38.84	38.84	0.0

Pressure (kpa)	120	120	0.0
Heat Flow (kJ/hr)	-4.6478e7	-4.6474e7	5.4
Air (S_1)			
Temperature (℃)	25	25	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	0	0	0.0
Mixed Product (S_4)			
Temperature (℃)	34.84	34.84	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-4.6478e7	-4.6474e7	5.4

In Table 4.8 it is observed that the heat flow of the air stream is zero because the temperature of this stream equals its reference temperature hence no heat flow. Also the heat flow of Compressed Gas Stream (S_2) and Mixed Stream (S_4) are equal.

Table 4.9: Comparison of Energy Balance Result of Hysys Simulation with Manual Calculation for Conversion Reactor Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Mixed Product (S_4)			
Temperature (℃)	34.84	34.84	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-4.6478e7	-4.6474e7	5.4
Vapour Product (S_5)			
Temperature (℃)	34.84	34.84	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-4.6478e7	-4.6474e7	5.4

In Table 4.9 above the flow of Mixed Stream (S_4) and Vapour Product Stream (S_5) are equal since it is a Single Input, Single Output Stream and also in with the principles of conservation of energy.

Table 4.10: Comparison of Energy Balance Result of Hysys Simulation with Manual Calculation for Cooling Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Vapour Product (S_5)			
Temperature (℃)	34.84	34.84	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-4.6478e7	-4.6478e7	5.4
(E_2)			
Temperature (℃)	-	-	
Pressure (kpa)	-	-	
Heat Flow (kJ/hr)	2.636e7	2.636e7	0.0
Cooled Vapour (S_6)			
Temperature (℃)	800	800	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-7.283e7	-7.285e7	2.4

In table 4.10 the sum of the Heat Flow of Stream E2 and cooled Vapour Stream equals that of Vapour Product Stream (S_5) which is line with the principles of conservation of energy.

Table 4.11: Comparison of Energy Balance Result of Hysys Simulation with Manual Calculation for CSTR Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Cooled Vapour (S_6)			
Temperature (℃)	800	800	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-7.283e7	-7.285e7	2.4
Formaldehyde Liquid (S_7)			

Temperature (℃)	80	80	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-1.169e7	-1.167e7	3.0
Vapour Out (S_8)			
Temperature (℃)	800	800	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-6.114e7	-6.116e7	12.5

In Table 4.11 the sum of the heat flow Formaldehyde Liquid Stream (S_7) and Hot Water Inlet Stream (S_{10}) equals to the sum of the heat flow of Formaldehyde Liquid Out Stream (S_9) and cooled Water Stream (S_{11}) which is in line with the principles of conservation of energy which states that inflow of energy is equal to outflow of energy provided that the system is a steady state process and no chemical reaction occurs.

Table 4.12: Comparison of Energy Balance Result of Hysys Simulation with Manual Calculation for Heat Exchanger Unit

Streams	Manual calc.	Hysys Simulation	% Deviation
Formaldehyde Liquid (S_7)			
Temperature (℃)	80	80	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-1.169e7	-1.167e7	3.0
Formaldehyde Liquid Out (S_9)			
Temperature (℃)	120	120	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-1.154e7	-1.156e7	3.6
Hot Water Inlet (S_{10})			
Temperature (℃)	200	200	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-1.160e7	-1.162e7	3.2
Cooled Water Outlet (S_{11})			
Temperature (℃)	195	195	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-1.175e7	-1.174e7	1.4

In Table 4.12 the design parameters such as Column Height, Column Diameter, Cross-sectional Area, Volume, Space time, Space Velocity, Thickness and Corrosion Allowance was compared with Hysys simulation and Manual calculation and the maximum deviation was found to be 3.2%.

b) Design /Sizing Results

The equipment design and sizing of each equipment of the plant is presented in the table below, for manual calculation compared to Hysys Simulation.

Table 4.13: Comparison of Sizing/Design Results of Hysys Simulation with Manual Calculations for Conversion Reactor Unit

Design/Sizing Item	Hysys Simulation	Manual Calculation	% Deviation
Flow Type			
Materials of Construction	Stainless steel	Stainless steel	
Column Height	3.86	3.84	2.4
Column Diameter	2.57	2.54	5.3
Cross Sectional Area	5.18	5.17	5.6
Volume	20	21	4.8
Space Time	0.43	0.42	2.3
Space Velocity	2.32	2.34	6.3
Thickness	18.63	18.65	3.1
Corrosion allowance	2.00	2.00	0.00

In Table 4.13 the design parameters such as Column Height, Column Diameter, Cross-sectional Area, Volume, Space time, Space Velocity, Thickness and Corrosion Allowance was compared with Hysys simulation and Manual calculation and the maximum deviation was found to be 6.3%.

Table 4.14: Comparison of Sizing/Design Results of Hysys Simulation with Manual Calculations for CSTR Unit

Design/Sizing Item	Hysys Simulation	Manual Calculation	% Deviation
Flow Type			
Materials of Construction	Stainless steel	Stainless steel	
Column Height (m)	5.54	5.56	0.36
Column Diameter(m)	3.72	3.71	1.40
Cross Sectional Area(m^2)	10.80	10.79	1.30
Volume(m^3)	60.02	60.00	3.30
Space Time(hr)	0.74	0.75	1.33
Space Velocity(hr^{-1})	1.35	1.33	6.06
Thickness(mm)	21.60	21.59	1.67
Corrosion allowance(mm)	2.00	2.00	0.00

In Table 4.14 the design parameters such as Column Height, Column Diameter, Cross-sectional Area, Volume, Space time, Space Velocity, Thickness and Corrosion Allowance was compared with Hysys simulation and Manual calculation and the maximum deviation was found to be 6.06%.

Table 4.15: Comparison of Sizing/Design Results of Hysys Simulation with Manual Calculations for Heat Exchanger Unit

Design/Sizing Item	Hysys Simulation	Manual Calculation	% Deviation
Equipment Name	Shell and tube heat exchanger	Shell and tube heat exchanger	
Objective.	Cooling the reactor effluent	Cooling the reactor effluent	
Equipment Number	U-007	U-007	
Designer	MUESI NOBLE PG.2017/02618	MUESI NOBLE PG.2017/02618	
Type	Split ring floating head (two shell four tubes)	Split ring floating head (two shell four tubes)	
Utility	Brackish Water	Brackish Water	
Insulation	Foam Glass	Foam Glass	
Heat load Q (kw)	945	947	0.0
Heat transfer Area (m^2)	53.4	53.5	0.2
LMTD (°C)	32	32.1	0.2
U (W/m^2K)	640	640.3	0.1
Inlet temperature) °C)	80	80	0.0
Shell Diameter (mm)	476	476	0.0
Shell coefficient W/m^2C	**1516**	**1516.4**	0.2
Outlet temperature (°C)	40	40	0.0
Baffle spacing (25% cut)	95.2	95.2	0.0
Shell material	Carbon steel	Carbon steel	
Inlet temperature (°C)	25	25	0.0
Tube Diameter (mm od/id)	20/16	20/16	0.0
Tube length (m)	4.83	4.83	0.0
Pitch type	Triangular	Triangular	
Outlet temperature (°C)	40	40	0.0
Number of Tubes	172	172.2	0.0
Tube material	Carbon alloy	Carbon alloy	
Pitch	25mm	25mm	0.0

In Table 4.15 Heat Exchanger Design Parameter was compared between Hysys simulation and manual calculation and the maximum deviation was found to be 0.2%

V. Sensitivity Analysis

The functional parameters such as length of Reactor, Diameter, Space time, Space velocity were studied to see how they change with conversion and are presented in figures – to

a) Length of Reactor with Conversion

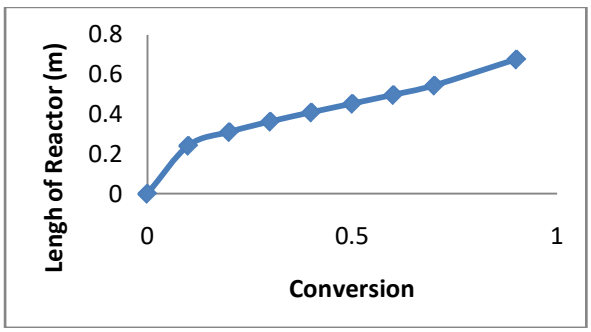

Figure 1: Profile Reactor versus Conversion

Figure 1 demonstrates the profile variation of length of the reactor varying with conversion. The results in the profile gives an increase of the length of reactors value with conversion increase. The length of reactor values increased from 0 m to 0.76m due to increase in conversion from 0 to 0.9. the increase in length resulted to increase in volume of the reactor and decrease in the rate of reaction values. The volume of the reactor is a function of length and rate of reaction.

b) Diameter of Reactor with Conversion

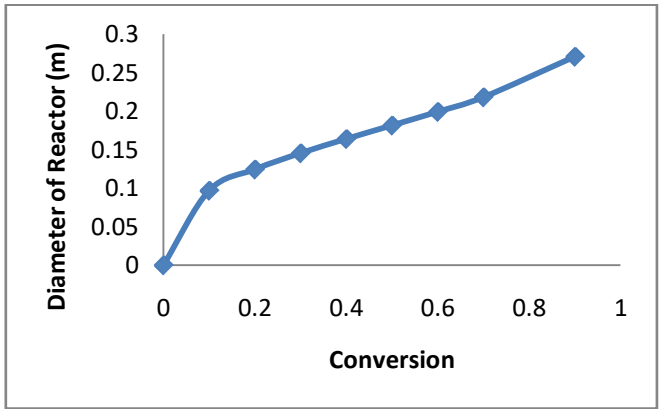

Figure 2: Plot of Diameter of Reactor versus Conversion

Similarly, figure 2 demonstrates the variation of the diameter the variation of the diameter of the reactor for the production of formaldehyde with conversion. The relationship is such that the length increases with increase in conversion and results to values such that when D=0, X_A=0 and D=0.27m, X_A=0.9. since the volume of reactor increases, the length and diameter of the reactor too increases to achieved the production of ethylene oxide and proper sizing of the reactor.

c) Space Time with Conversion

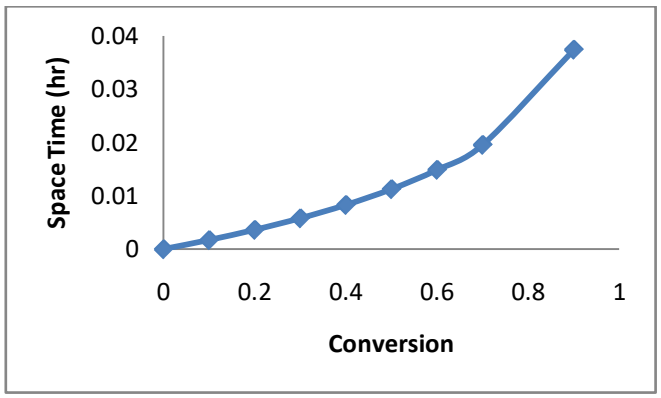

Figure 3: Profile of Space Time of the Reactor versus Conversion

Figure 3 depicts the variation of space time of reactor varying with conversion. The profile of the space time is exponentially increasing with conversion starting from 05-0.035hr when X_A=0-0.9 respectively. Space time is defined as the time taken for one reactor feed volume converted to product. From the results, the space time values are very small meaning the reaction is a fast one. Increasing the space time values, leads to increase in the value of the reactor and higher yields of the product formed.

d) Space Velocity with Conversion

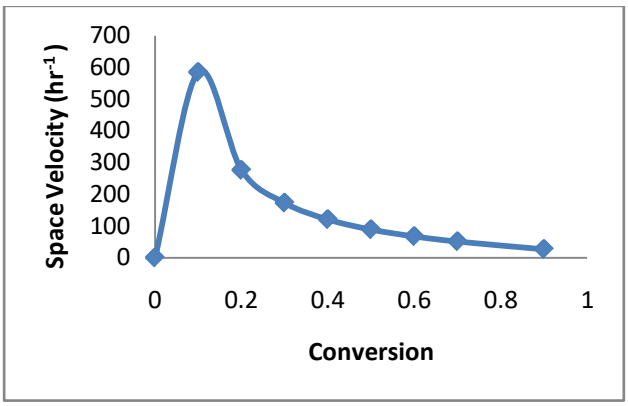

Figure 4: Graph of Space Velocity versus Conversion

Figure 4 shows the graph of space velocity varying with conversion. The universe of space time gives the space velocity's values. The space velocity's values are higher and increases from 0-600hr^{-1} when conversion increases too from 0-0.1 and then drops exponentially from 600-10hr^{-1} when conversion increases from 0.1-0.9.The space velocity should be reduced to achieve higher yield at lower cost as shown from the profile plot.

e) Volume of Reactor with Conversion

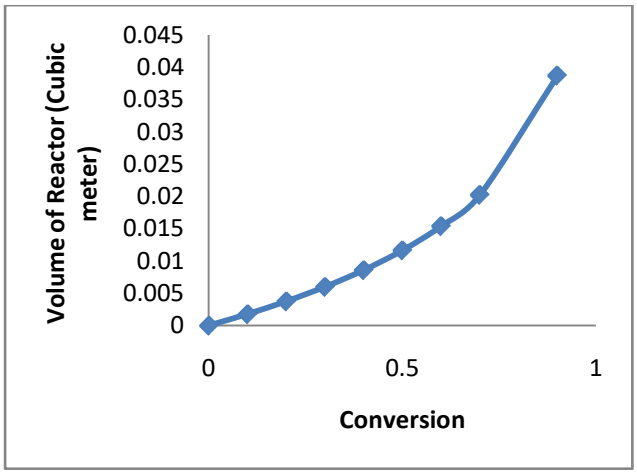

Figure 5: Variation of Volume of Plug Flow Reactor versus Conversion

Figure 5 depicts the variation of volume of plug flow reactor for formaldehyde production from methane and oxygen. The volume increases exponentially from 0m^3 to 0.038m^3 as conversion too increases from 0-0.9. The increase in volume is achieved as a result of decrease in the rate values.

VI. Conclusion

The design of a 10,000 ton/yr Formaldehyde plant has been executed. The design considered first the material balance of the plant using the principles of conservation of mass which states that for steady state process the inflow of mass equals the outflow of mass, hence the mass balance of each unit/equipment was extensively evaluated, the principles of conservation of energy which states that outflow of energy equals inflow of energy for a steady state process was applied to evaluate the flow of energy for each stream. The design also considered other aspect such as equipment sizing/design specification, mechanical design, costing and economic evaluation, instrumentation and process control, layout, safety and environmental consideration and finally Hysys design simulation. Comparison of the material balance results between manual calculation and Aspen Hysys simulation and the highest difference was 0.8% for the energy balance result the difference between the manual calculation and Aspen Hysys simulation was 0.5% for the sizing results, the highest difference between the manual calculation and Aspen Hysys simulation was 0.3%.

Mechanical design to determine the thickness of vessels to withstand pressure was also considered as we as adding corrosion allowance. A detailed cost estimation and economic evaluation was analyzed to determine the profitability of the plant before setting up and it is given in the appendix.

References Références Referencias

1. Andreasen, C., Van-Veen, O.H., & Martin M.(2002). Mechanistic Studies on the Oxidative Dehydrogenation of Methanol Over Polycrystalline Silver Using the Temporal-Analysis-of-Products Approach. *Journal of Catalysis,* 210, 53-66.
2. Antonio-Carlos, P.F., & Rubens M.F. (2010). Hybrid Training Approach for Artificial Neural Networks Using Genetic Algorithms for Rate of Reaction Estimation: Application to Industrial Methanol Oxidation to Formaldehyde on Silver Catalyst, *Chemical Engineering Journal,* 157, 501-508.
3. Geoffrey, I.N., Waterhouse, G.A. Bowmaker, K., & James B. M. (2004). Mechanism and active sites for the partial oxidation of methanol to formaldehyde over an electrolytes silver catalyst, *Applied catalysis A*, 265, 85-101.
4. Geoffrey, I.N., Waterhouse, G. A., Bowmaker, K., & James B. M. (2004). Influence of Catalyst Morphology on the performance of electrolytic silver catalysts for the partial oxidation of methanol to formaldehyde, *Applied catalysis B,* 266, 257-273.
5. Alfares, H. K., & Adnan, M.A. (2016, July 7). An Optimization Model for Investment in Ethylene Derivatives. Retrieved from https://www.Research gate.net.
6. Alzein, Z., & Nath, R. (2018, January 4). Ethylene plant optimization: Automation and Control. Retrieved from https://www.Researchgate.net.
7. Cameroon, G., Le, L., Levine, J., &Nagulapalli, N. (2019, April 14). Process Design for the Production of Ethylene from Ethanol. Retrieved from https:// www.Researchgate.net.
8. Chauvel, A., & Lefebvre, G. (2015). Petrochemical Process: Technical and Economic Characteristic. Paris: Editions Technip.
9. Choudhary, V., Mondal, K.C., & Mulla, S. A. (2017). Non-Catalytic Pyrolysis of Ethane to Ethylene in the presence of CO_2 with/without limited O_2. *Journal of Chemical Science, 118* (3), 261-267.
10. Ghanta, M., Fahey, A., Subramaniam, D. B. (2017). Environmental Impacts of Ethylene Production from Diverse Feedstock and Energy Sources. *Applied Petrochemical Resources,* 4(1),167-179.
11. Ghaza, E., C., &Mayourian, J. (2014). *Ethylene Production Plant Design: Process Evaluation and Design II.* U.S.A: Mc Graw Hill.
12. Gujarathi, A., M., Patle, D. S., Agarwal, P., Karemore, A. L. & Babu, B. V. (2020). Simulation and Analysis of Ethane. *Cracking Processes, 45(1)*, 1-9.
13. Lauks, U. E., Vas Binder, R. J., Valkenburg, P. J & Van Leeuwen, C. (2015). *On-line Optimization of an Ethylene Plant.* Germany: OMV Deutschland GmbH.
14. Marton, S (2017) Renewable Ethylene*: A Review of Options for Renewable steam cracker Feedstocks.* (unpublished Master's Thesis), Chalmers University of Technology, Sweden: Gothenburg.
15. Mazanec, T. J., Yuschak, T & Long, R (2019). *Ethylene Production Via Ethane Oxidation in Microchannle Reactors*. (unpublished Master's Thesis), Velocity Inc. USA, Plain City, Ohio.
16. Meisong, Y. B. (2015). *Simulation and Optimization of an Ethylene Plant*. (unpublished Master's Thesis), University of California, California.
17. Mohamad A. F. (2016). *Practical Engineering guidelines for processing plants*. New Age International Publishers: New Delhi.
18. Mohsenzadeh, A., Zamani, A &Taherzadeh, M. J. (2019). Bio-Ethylene Production from Ethanol: A review and Techno-economical evaluation. *Chemical and Biological Engineering Reviews, 4* (2), 1-18.
19. Jaja, Z., Akpa, J.G. and Dagde, K.K. (2020) Optimization of Crude Distillation Unit Case Study of the Port Harcourt Refining Company. *Advances in Chemical Engineering and Science*, 10, 123-134.

Appendix

Unit operation

Name	Equipment Cost [USD]	Installed Cost [USD]	Equipment Weight [LBS]	Installed Weight [LBS]	Utility Cost [USD/HR]
CSTR-100	43900	174300	3200	15911	0
E-100	23500	121600	2700	11110	17.982
K-10	835600	1034500	12900	40584	8.67225
E-101	7700	48500	270	4478	0
V-100	23800	83300	7000	23244	0
CRV-100	0	0	0	0	0
MIX-100	0	0	0	0	0

Summary

Name	Summary
Total Capital Cost [USD]	4890900
Total Operating Cost [USD/Year]	1917740
Total Raw Materials Cost [USD/Year]	0
Total Product Sales [USD/Year]	0
Total Utilities Cost [USD/Year]	261300
Desired Rate of Return [Percent/Year]	20
P.O.Period [Year]	0
Equipment Cost [USD]	934500
Total Installed Cost [USD]	1462200

Utilities

Name	Fluid	Rate	Rate Units	Cost per Hour	Cost Units
Electricity		152.598	KW	11.826345	USD/H
Cooling Water	Water	0.14985	MMGAL/H	17.982	USD/H

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Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

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

Manuscript Style Instruction (Optional)

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

Structure and Format of Manuscript

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

A research paper must include:

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

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

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

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

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

Format Structure

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

All manuscripts submitted to Global Journals should include:

Title

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

Author details

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

Abstract

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

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

Keywords

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

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

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

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

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

Numerical Methods

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

Abbreviations

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

Formulas and equations

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

Tables, Figures, and Figure Legends

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

Figures

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

Preparation of Eletronic Figures for Publication

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

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

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

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

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

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

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

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

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

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Informal Guidelines of Research Paper Writing

Key points to remember:

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

Final points:

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

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

The discussion section:

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

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

General style:

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

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

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

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

Title page:

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

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

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

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

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

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

Approach:

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

Introduction:

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

The following approach can create a valuable beginning:

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

Approach:

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

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

Procedures (methods and materials):

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

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

Materials:

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

Methods:

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

Approach:

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

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

What to keep away from:

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

Results:

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

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

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

Content:

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

What to stay away from:

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

Approach:

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

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

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

Figures and tables:

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

Discussion:

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

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

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

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

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

Approach:

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.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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