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CHEMICAL ENGINEERING



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Ultrafiltration Membrane Modified by Mussel-Inspired Method and the effect on Protein Solution Filtration

By Jéssica Vardanegaa, Mariane Carolina Pronera, Monique Juna Lopes Leitea, Angélica Lorenzettia, Ingrid Ramalho Marquesa & Marco Di Luccioaa

University of Santa Catarina

Abstract- Ultrafiltration is a well established process in the food industry, especially in the dairy sector to isolate and concentrate whey proteins. However, the ultrafiltration has the disadvantage of fouling that causes reduction in permeate flux, and increasing operational costs. So, the use of antifouling strategies is of scientific and industrial interest. Among the studied strategies, the modification of the membrane surface by the mussel-inspired method stands out for its simplicity, versatility and stability. The mussel-inspired method is based on the code position of dopamine (DA) and hydrophilic polymers on the membrane surface. In this context, this study evaluates the performance of an ultrafiltration membrane modified (50 kDa) through immersion in a solution containing 2mg mL⁻¹ of DA e different concentrations (2, 4 and 16 mg mL⁻¹) of polyvinylpyrrolidone (PVP). The modified and control membranes were submitted to water and protein filtration tests and characterized by contact angle.

Keywords: *membrane surface modification, musselinspired method, dopamine, polyvinylpyrrolidone, fouling, protein.*

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Ultrafiltration Membrane Modified by Mussel-Inspired Method and the effect on Protein Solution Filtration

Jéssica Vardanegaa ^α, Mariane Carolina Pronera ^α, Monique Juna Lopes Leitea ^ρ, Angélica Lorenzettia ^ω, Ingrid Ramalho Marquesa [¥] & Marco Di Luccioaa [§]

Abstract- Ultrafiltration is a well established process in the food industry, especially in the dairy sector to isolate and concentrate whey proteins. However, the ultrafiltration has the disadvantage of fouling that causes reduction in permeate flux, and increasing operational costs. So, the use of antifouling strategies is of scientific and industrial interest. Among the studied strategies, the modification of the membrane surface by the mussel-inspired method stands out for its simplicity, versatility and stability. The mussel-inspired method is based on the code position of dopamine (DA) and hydrophilic polymers on the membrane surface. In this context, this study evaluates the performance of an ultrafiltration membrane modified (50 kDa) through immersion in a solution containing 2mg mL⁻¹ of DA e different concentrations (2, 4 and 16 mg mL⁻¹) of polyvinylpyrrolidone (PVP). The modified and control membranes were submitted to water and protein filtration tests and characterized by contact angle. The results showed that the modified membrane with 16 mg mL⁻¹ of PVP concentration presented the best results of hydraulic permeability, contact angle and permeate flux in the filtration of protein solution. This study indicate that the ultrafiltration membrane modification with DA and PVP increases hydrophilic degree and improves the protein solution filtration.

Keywords: membrane surface modification, mussel-inspired method, dopamine, polyvinylpyrrolidone, fouling, protein.

I. INTRODUCTION

Among the membrane separation processes (MSP), ultrafiltration (UF) is highlighted in the dairy industry, in the milk filtration, cheese production and in the recovery and concentration of whey proteins (Brans *et al.*, 2004; Daufin *et al.*, 2001). However, ultrafiltration has disadvantages due to the solute interaction (such as proteins) with the membrane surface causing an accumulation of these molecules on its surface, known as fouling, which leads to a reduction in permeate flux reflecting the decrease in performance and the increase in the number of cleanings (Brans *et al.*, 2004; Makardij *et al.*, 1999).

To reduce the effects of fouling, techniques based on physical and chemical methods are suggested. In this context, physical methods, such as plasma, are not very effective, as they are not stable and, chemicals methods, such as grafting, often require the use of toxic chemical reagents (Cheng *et al.*, 2012; W. Xu *et al.*, 2017). Thus, the mussel-inspired method (MI) was presented as a solution, due to its simplicity, versatility and stability, based on the deposition of dopamine (DA) on the membrane surface, which polymerizes in certain conditions and forms polydopamine (PDA). The PDA is able to adhere to the membrane surface and also to undergo reactions with other polymers giving specific properties (Cheng *et al.*, 2012; H. C. Yang *et al.*, 2016). The fact that the PDA has free functional groups for the aggregation of other polymers opens up a range of possibilities for carrying out promising studies. However, there are few studies on the codeposition of DA with hydrophilic polymers in ultrafiltration membranes (Lv *et al.*, 2015; Y. C. Xu *et al.*, 2016; Q. Yang *et al.*, 2019) and studies on ultrafiltration membrane modification with DA and polyvinyl pyrrolidone (PVP) have not been found.

In view of the above, this study proposes to modify UF membrane surface by the muslin-inspired method, with the objective of increasing the degree of hydrophilicity and improving the permeate flux of protein solution. For this purpose, 50 kDa UF membranes were modified by the muslin-inspired method by codeposition of DA and different concentrations of PVP. The effects of the modification were evaluated for the degree of hydrophilicity and performance in the filtration of protein solution of bovine serum albumin (BSA).

II. MATERIAL AND METHODS

a) Material

To carry out the work, the UH050 membrane was acquired by Microdyn-Nadir (Germany). UH050 is a polymeric ultrafiltration membrane, made of polyethersulfone (PES) and molar weight cut-off (MWCO) equal to 50 kDa.

Ethanol P.A. (99%, Synth) was used to condition the commercial membrane prior to modification. The membrane remained immersed in ethanol for 2 h, rinsed

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with ultrapure water and immersed in ultrapure water for 12 h. This procedure was performed to remove possible preservatives and fill the membrane pores with water. The DA and PVP solution for modification was prepared with dopamine hydrochloride (DA), PVP (Mw = 40,000 Da) and Tris (hydroxymethyl) aminomethane (Tris), purchased from Sigma-Aldrich (Brazil). As a model protein solution, bovine serum albumin (BSA) with a concentration of 2.5 g L⁻¹ and pH 6.5 was used and. BSA was acquired at Sigma-Aldrich (Brazil), with purity greater than 96% and a molar mass of 66 kDa. The cleaning procedures of the membrane after filtration of the model protein solution was used ultrapure water (physical cleaning) and sodium hydroxide (NaOH) 0.02% (pH 10, chemical cleaning, Lafan).

b) Methods

i. Membranes Modification

PVP was dissolved in 50 ml of Tris buffer solution (pH 8.5 and 5.0 mM) in concentrations 2, 4 and 16 mg mL⁻¹ and the DA was added with a fixed concentration of 2mg.mL⁻¹. The PVP and DA solution was placed on the petri dish together with the conditioned membrane and stirred in an orbital shaker (TECNAL TE-420) at 50 rpm and 23±2 °C for 2 hours. After completing the deposition time, the membrane was rinsed with ultrapure water to remove excess solution that did not adhere to its surface and then stored in ultrapure water. The concentration of the DA and PVP solution and the reaction time were based on previous tests by the research group. The modification procedure was performed in duplicate.

ii. Experimental apparatus

Permeation tests and fouling tests were carried out at room temperature (23±2 °C), with the modified and control membrane. The permeations were made in a pressurized cell on a stainless steel, laboratory scale, with a volumetric capacity of 500 mL and a filter area of 9.6 cm², in the dead-end configuration. The pressure in the system was made by the injection of nitrogen in the upper part of the controlled cell through a manual manometer. The system was depressurized using a regulating valve. Figure 1 show the filtration system used.

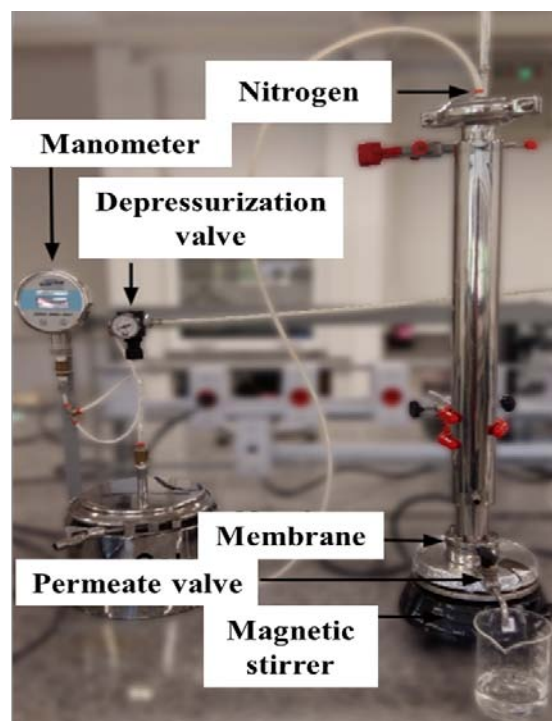


Figure 1: Image of the experimental apparatus used in the filtration tests.

iii. Contact angle

The contact angle measurements were made in a RAMÉ - HART goniometer (model 250-FI), using the sessile drop method at the Analysis Center of the Department of Chemical Engineering and Food Engineering at the Federal University of Santa Catarina (UFSC).

iv. Hydraulic permeance

First, the control and modified membranes were compacted at 5 bar. After the compaction time, three collections of permeate flux were made for 1 minute at pressures 4, 3, 2, and 1 bar. At each pressure change there was an interval of 10 minutes for system stabilization. The data of permeate volume (L_p , L) and data as the membrane area (A_m , m²) and the collection time, t (h), it was possible to calculate the permeate flux, J (L h⁻¹ m⁻²) given by Equation 1.

$$J = L_P / (t \times A_m) \quad (1)$$

Thus, a graph of permeate flux versus pressure was generated. The angular coefficient obtained by linearizing the data corresponds to the hydraulic permeance of the membrane. The tests were performed in duplicate

v. Filtration tests

The filtration tests with BSA solution were performed with the control membrane and with the modified membrane that showed better hydraulic permeability. The cell was filled with 100 ml of BSA solution (2.5 g L⁻¹ and pH 6.5), closed and pressurized to 4 bar. For the filtration tests the pressure was kept

constant and aliquots of permeate were collected for 1 minute in an interval of 15 minutes totaling 2 hours of filtration. Permeation was carried out under stirring. At the end of the process, an aliquot of the retained and permeate was collected to determine the protein concentration by the Bradford method (Bradford, 1976), and then the membrane retention (R) was calculated by Equation (2).

$$R (\%) = (1 - P/R_{et}) \times 100 \quad (2)$$

Where, P is the protein concentration in the permeate (g L⁻¹) and R is the protein concentration in the retained (g L⁻¹). The tests were performed in duplicate.

After filtration tests, physical and chemical cleaning procedures were carried out on the membranes in order to recover their initial permeability. Physical cleaning was carried out by adding 100 mL of ultrapure water to the cell, without pressure and under agitation for 10 minutes. Chemical cleaning was carried out with 100 mL of sodium hydroxide solution 0.02% (pH 10) for 30 minutes, without pressure and under agitation. At the end of the 30 minutes, after removing the sodium hydroxide solution, 100 mL of ultrapure water was added under stirring for 5 minutes to remove the remaining excess alkaline solution.

After each cleaning procedure, water filtration tests were performed to assess the recovery of hydraulic permeance (R_f, %) calculated by Equation (3)

$$R_f (\%) = (P_f/P_i) \times 100 \quad (3)$$

Where, P_i is the initial hydraulic permeance (L h⁻¹ m⁻² bar⁻¹) and P_f is the hydraulic permeance obtained after cleaning procedures (L h⁻¹ m⁻² bar⁻¹).

III. RESULTS AND DISCUSSION

a) Membrane modification

The membranes were modified by codeposition in a single step of DA and PVP with different concentrations (2.0: 2.0; 2.0: 4.0 and 2.0: 16.0 mg mL⁻¹) and deposition time of 2 h. The deposition time of 2 h was chosen based on the study carried out by the researchers group from Membrane Processes Laboratory (LABSEM) of the Federal University of Santa Catarina (UFSC), in the modification of PES membranes with PDA and polyethyleneimine presented in the work of Marques (2017) and Proner *et al.* (2020). Proner *et al.* (2020) observed a drop in hydraulic permeance in long deposition times (24h) due to the formation of PDA/PEI aggregates on the membrane surface, which leads to obstruction the pores of the membrane. Similar results were presented by Jiang *et al.* (2013), polypropylene (PP) membrane modified with DA/PVP. For Marques (2017), among the tested times of 2, 4 and 6 h, the membrane with the best hydraulic permeance was the deposition time of 2 h.

The concentration of dopamine was fixed at 2 mg mL⁻¹ because higher concentrations of dopamine interfere in the membrane permeability. According to Kasemset *et al.* (2013), increasing the concentration of dopamine generates a thicker coating of PDA, interfering in the water permeate flux for UF membranes that have smaller pore diameters compared to MF membranes.

Figure 2 shows images of the modified and control membrane. Through a visual analysis, it can be seen that the PES commercial polymeric membrane (UH050) showed a homogeneous color throughout its surface indicating that the modification occurred uniformly. In addition, it can be observed that the modified membrane, regardless of the concentration of solution used, after 2 h of modification, presented a darker color than the control. Comparing between the modified ones, it is possible to notice a slight difference, the membrane with the highest PVP concentration (16mg mL⁻¹) presented a slightly lighter color than the one with the lowest concentration (2 mg mL⁻¹).



Figure 2: UH050 control and modified membranes with concentrations of DA/PVP of 2:2; 2:4; 2:16 mg mL⁻¹ and deposition time of 2h.

All membranes were evaluated for their hydrophilicity degree and hydraulic permeance. The control and modified membranes that performed best were evaluated with a fouling test, which comprises the initial hydraulic permeance, membrane retention, permeate flux of the protein solution and recovery of the hydraulic permeance after cleaning procedures.

b) Hydrophilicity degree and hydraulic permeance

i. Contact angle

In order to determine the hydrophilicity degree of the membrane, the angle of contact with ultrapure water was measured for the control and modified membranes. The results obtained are shown in Table 1.

Table 1: Contact angle for the UH050 control and modified membrane with DA:PVP concentrations of 2:2; 2:4; 2:16 mg mL⁻¹ and deposition time of 2h.

DA:PVP concentration (mg mL ⁻¹)	Contact angle (°)
Control	71,2±0,2
2:2	59,6±0,4
2:4	58,1±0,8
2:16	53,4±0,3

According to the results (Table 1), the control membrane had a contact angle greater than 70°. Membranes modified with 2:2; 2:4; 2:16 mg mL⁻¹ of DA:PVP showed a reduction in the contact angle of 16, 18 and 25%, respectively, when compared to the control membrane. This reduction in the contact angle indicates an increase in the hydrophilicity degree of the membranes, resulting from the deposition of DA and PVP, which present in their structure groups of catechol and amine, conferring hydrophilic characteristics, which can lead to greater resistance the adhesion of hydrophobic components on the membrane surface and the increase in its wettability (affinity with water). Figure 3 shows the images of the drops obtained in the contact angle test of the UH050 control and modified membrane.

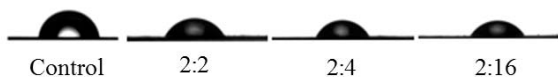


Figure 3: Image of water droplets on the UH050 control and modified membrane, with concentrations of DA:PVP of 2:2; 2:4; 2:16 mg mL⁻¹ and deposition time of 2h.

The only study of codeposition of DA/PVP in a commercial membrane present in the literature is by Jiang *et al.* (2013), who also showed results of reducing the contact angle after modifying the MF membrane of PP with DA/PVP and deposition time of 24 h. Proner *et al.* (2020), presented similar results in the modification of PES commercial polymeric membrane of ultrafiltration by codeposition of DA/PEI, showing a reduction in the contact angle of 25% in the modified membranes with higher concentration of PEI in relation to the control membrane. Marques (2017) modified the PES ultrafiltration membrane with codeposition of DA/PEI, showed a 30% reduction in the angle of contact with the modified membrane with a concentration of 2:16 mg mL⁻¹ compared to the control and 2 h of deposition.

Thus, the modification of the PES UF membrane with higher concentrations of PVP showed a tendency to reduce the contact angle, which indicates an increase in its hydrophilicity, probably due to the presence of hydrophilic groups deposited on its surface.

ii. Hydraulic permeance

To evaluate the performance of PES membranes modified with different concentrations of DA/PVP water permeation tests were performed. The results obtained can be seen in Figure 4.

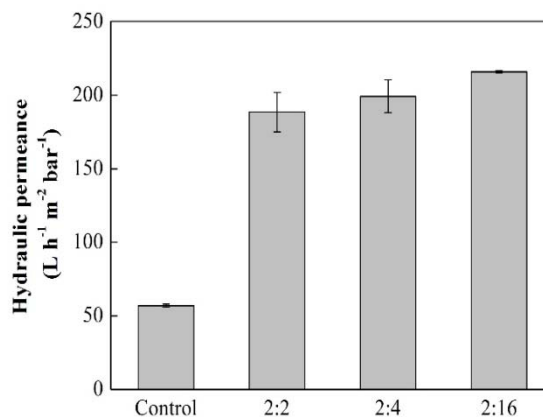


Figure 4: Initial hydraulic permeance of UH050 control and modified membranes with concentrations of 2:2; 2:4 and 2:16 mg mL⁻¹ of DA / PVP and deposition time of 2 hours.

The control membrane showed hydraulic permeance of 56.85 L h⁻¹ m⁻² bar⁻¹, 70% less than the hydraulic permeance of the modified membrane at 2:2 mg mL⁻¹ DA/PVP. Among the modified membranes, the modified membrane with 2:16 mg mL⁻¹ of DA/PVP showed the best results of hydraulic permeance (215.85 L h⁻¹ m⁻² bar⁻¹), 279% larger than the control membrane.

Therefore, the modified membrane with the concentration of 2 mg mL⁻¹ of DA and 16 mg mL⁻¹ of PVP showed the best results of hydraulic permeance, which reveals an increase in hydrophilicity in comparison to the control membrane. This change may have occurred because PVP is a hydrophilic polymer and strong hydrogen receptor. Thus, the PDA/PVP codeposition forms a hydrophilic coating on the membrane surface, improving its hydrophilicity which can reflect on the performance of the filtrations.

Due to the membrane modified with the concentration 2:16 mg mL⁻¹ of DA/PVP having presented the best performance, it was chosen to perform the permeation tests with the protein solution.

c) Protein solution filtration performance

The permeation of the BSA protein solution with a concentration of 2.5 g L⁻¹ and the cleaning procedures were performed, the results can be seen in Figure 5.

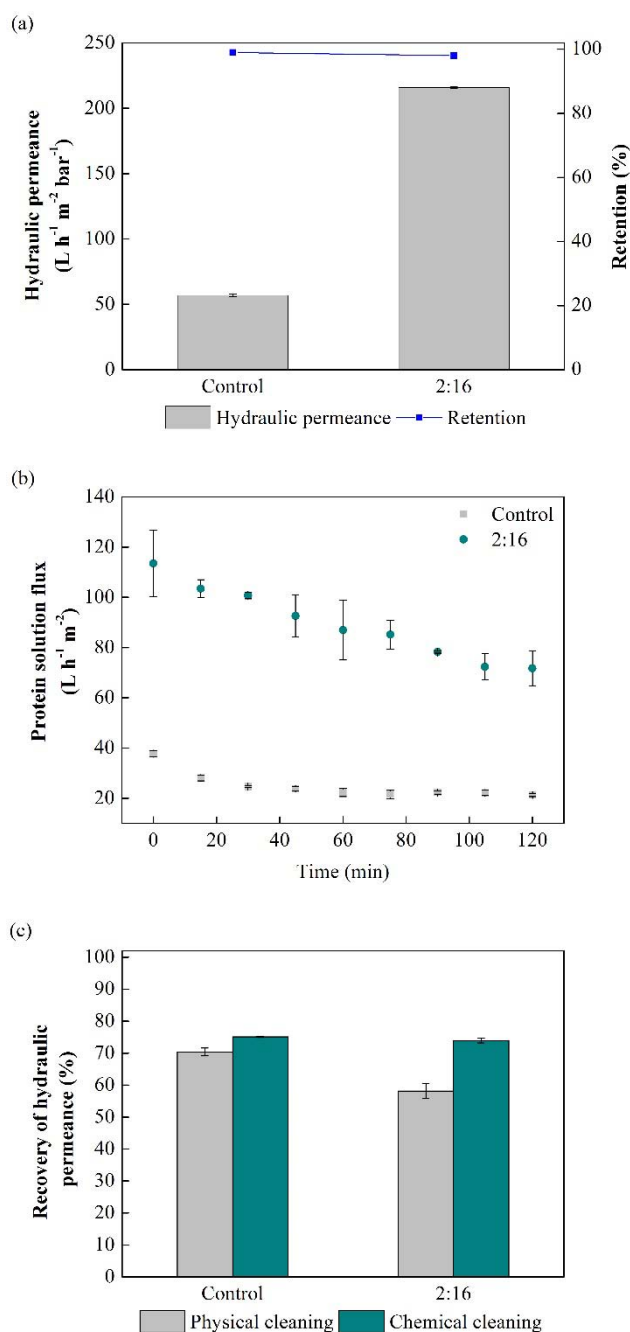


Figure 5: Performance of the control and modified UH050 membrane with concentrations of 2:2; 2:4 and 2:16 mg mL⁻¹ of DA/PVP and deposition time of 2 h in the BSA protein solution filtration with concentration of 2.5 mg mL⁻¹ g. (a) Initial hydraulic permeance and protein retention, (b) permeate flux curve of the protein solution and, (c) recovery of hydraulic permeance after physical and chemical cleaning procedure.

Figure 5a shows the results obtained from initial hydraulic permeance and retention of the control and modified UH050 membrane. The control membrane showed a hydraulic permeance of 56.85 L h⁻¹ m⁻² bar⁻² and the modified membrane showed a hydraulic

permeance of 215.5 L h⁻¹ m⁻² bar⁻¹, four times larger than the control membrane. As shown in Figure 4, the PDA/PVP film formed on the membrane surface generates a hydrophilic character that facilitates the absorption of water on the surface, reducing the resistance to mass transfer, reflecting in the increase in the permeate flux.

The retention for the ultrafiltration membrane with MWCo of 50 kDa was approximately 99% and the modified membrane was 98%. After the modification, the membranes maintained retention of BSA molecules. Naturally it was expected, since the membrane has lower MWCO than the molecules of the BSA protein solution, and also it is an indication that the modification did not alter the membrane selectivity.

The results obtained by filtering the BSA protein solutions are shown in Figure 5b. It is possible to observe that the initial protein solution flux from the modified membrane was 113.50 L h⁻¹ m⁻², 200% greater than the control membrane flux. In addition, the results show that the first 20 minutes of filtration the control and modified membrane presented a permeate flux decay due to the adhesion of protein solution molecules on the membrane surface, and at the end of the 2 h of filtration the modified membrane showed flux of 71.72 L h⁻¹ m⁻², 240% greater than the control membrane.

This result indicates that the modified membrane presented a significant increase, not only in hydraulic permeability, but also in the BSA protein solution flux. The evaluation of the permeate flux in the protein solution filtration carried out by Jiang *et al.* (2013) showed good results. The PP MF membrane modified by DA/PVP increased the permeate flux in 220% in relation to the control membrane. According to the author, after the modification the water molecules were able to absorb on the membrane surface, reducing the resistance to mass transfer reflecting the increase in the permeate flux.

After the filtration tests with the protein solution and the physical and chemical cleaning, the hydraulic permeance of the control and modified control membranes were evaluated and the results shown in Figure 5c. The recovery of hydraulic permeance for the control membrane after physical cleaning was 70% and, for chemical cleaning 75%. For the membrane modified the recovery was 58% for physical cleaning and 74% for chemical cleaning.

Although the PVP modification led to an increase in the permeate flux, the recovery of hydraulic permeability was similar to the control membrane. Marques (2017), obtained a similar result, according to the author such behavior may reflect the change in the surface charges of the membrane after modification, because when depositing components rich in amine (DA/PVP) there is a tendency to increase charges positive on the surface (Lv *et al.*, 2015; Y. C. Xu *et al.*,

2016), and since the protein solution is usually negatively charged does not reflect in improving the recovery of hydraulic permeance. However, in the filtration performance the change in the zeta potential of the membrane surface was probably less representative in terms of increasing the hydrophilicity degree, since the permeate flux increased considerably, the affinity for water increased in order to reduce resistance to mass transfer and intensify the permeate flux.

Thus, due to the results obtained for hydraulic permeance and contact angle of the ultrafiltration membrane modified by the DA/PVP codeposition are promising for application in filtration processes in the industry. In addition, the membrane modified at a concentration of 2:16 mg mL⁻¹ of DA/PVP, due to its greater hydraulic permeability, smaller contact angle and excellent improvement in the permeate flux in the filtration of protein solution is interesting for application in protein solution process industries.

IV. CONCLUSIONS

The modification of the ultrafiltration membrane through the codeposition of DA and PVP resulted in a membrane with greater hydrophilic character, excellent performance in protein solution filtration, being a promising strategy in the production of membranes with anti-fouling properties. The results obtained showed that with a higher concentration of PVP (16 mg mL⁻¹) in the modification membrane there is an excellent improvement in the permeate flux of protein solution, 200% greater than the control.

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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].

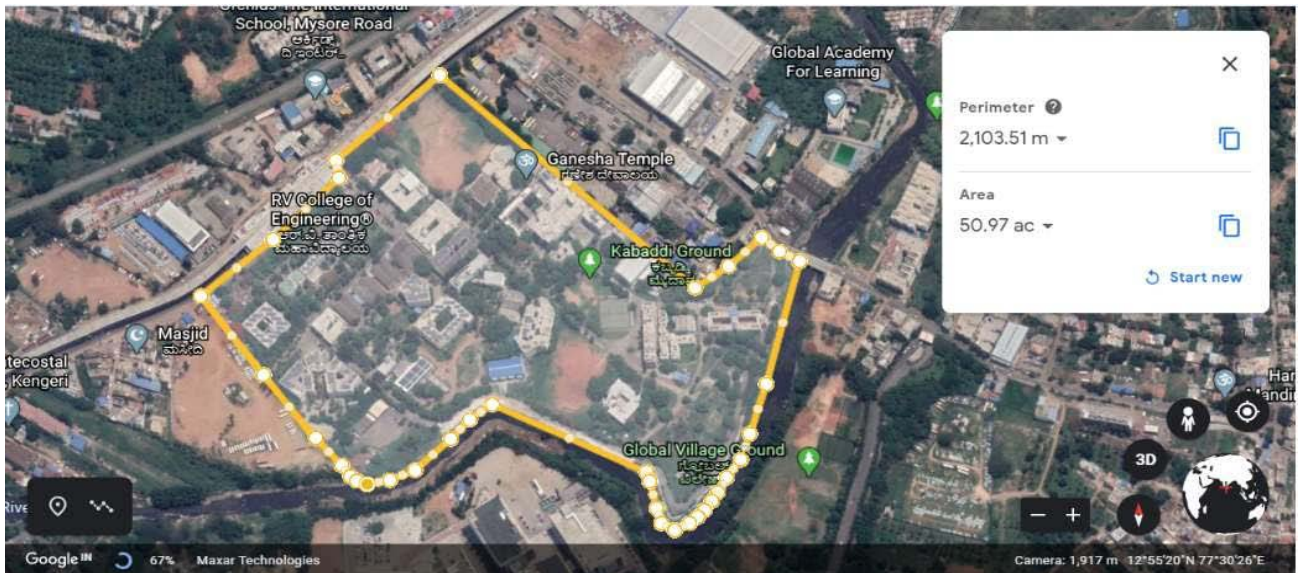


Figure 1: Satellite view of R V College of Engineering (Source: Google Earth®)

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 Meteorological 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.

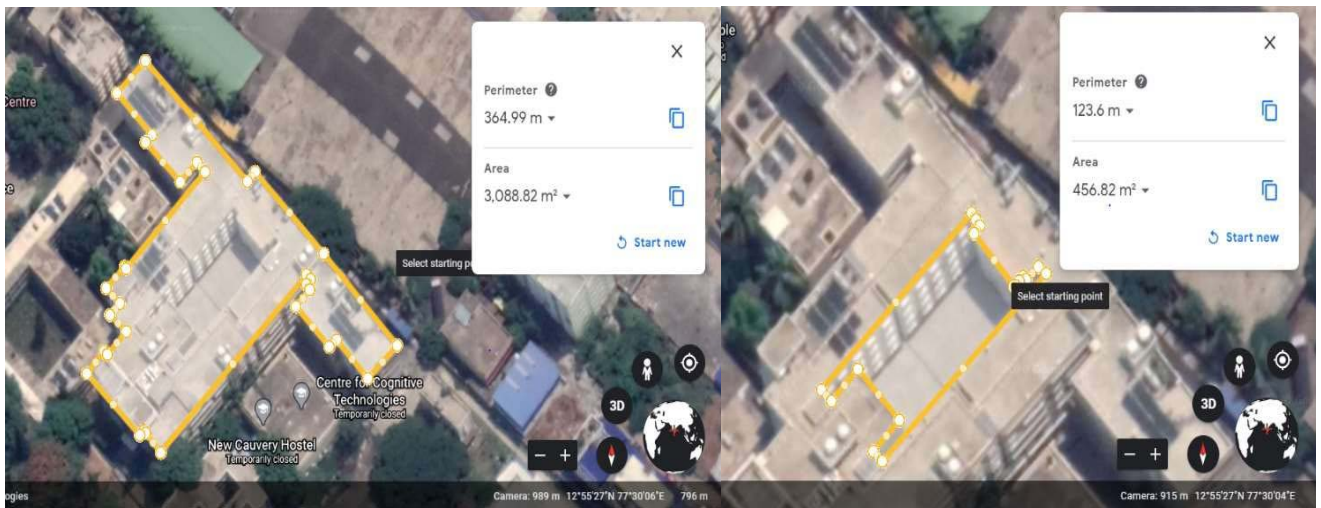


Figure 2: Satellite image of New cauvery hostel (Source: Google Earth®)

Annual rain water yield is given by the formula

$$Q = A \times R \times C \times F$$

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

$$Q = A \times R \times C \times F$$

$$Q = 2632 \times 877.8 \times 0.8 \times 0.8 = 1478637$$

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.

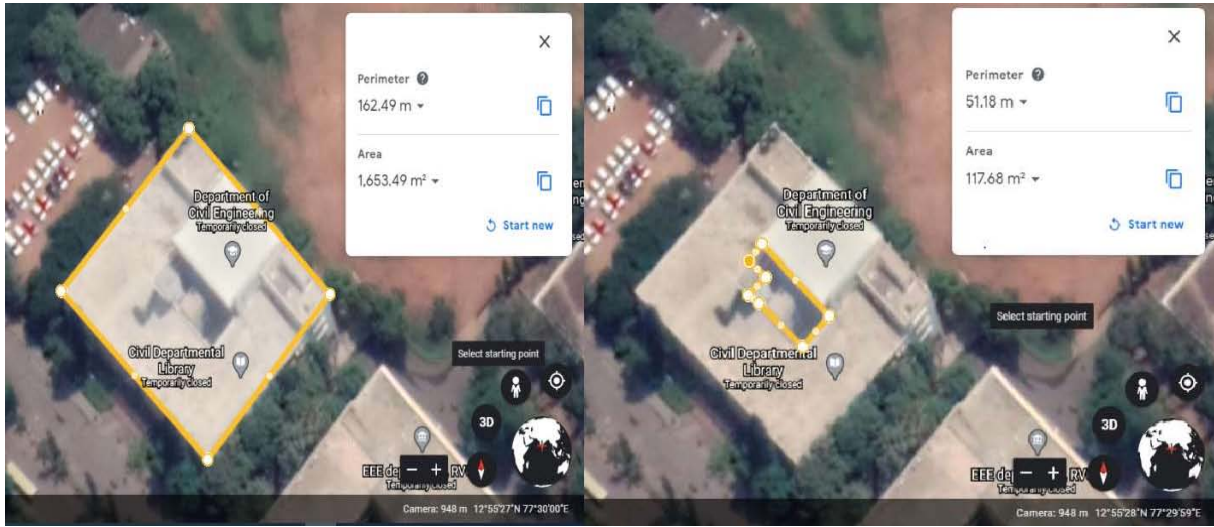


Figure 3: Satellite image of civil department building (Source: Google Earth®)

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].

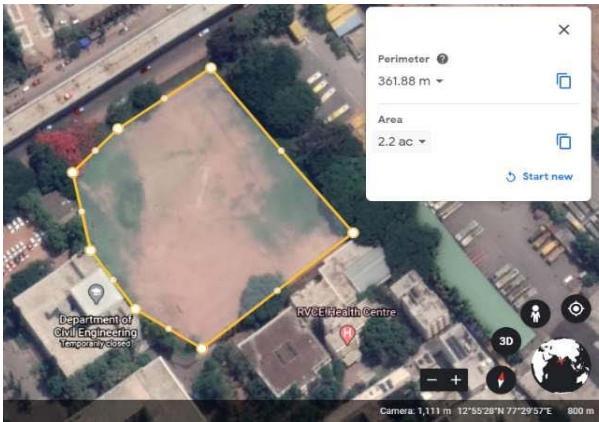


Figure 4: Satellite image of cricket ground (Source: Google Earth®)



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.

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Evaluation of Transformer Grade Oil from Coconut Seed Waste

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Keywords: coconut oil, extraction, physico-chemical, thermodynamic and kinetic properties, modeling, extraction.

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Otaraku, Ipeghan J. ^α & Okwonna, Obumneme O ^α

Abstract- This study evaluated the extraction process of transformer grade oil from coconut seed waste using a Soxhlet extractor in a batch process. The thermodynamic and kinetic properties of the process were evaluated while a comparison was drawn for the experimental and predicted yields at temperatures of 80, 75, and 70 °C. The mass transfer model gave good fit with the experimental data with R² values above 0.99. The extraction process performed at 80 °C had the highest R² value and the least error and χ^2 , values while the model best describes the process at this temperature. Effective diffusivities (D_{eff}) were obtained as $2.6058 \times 10^{-3} \text{cm}^2\text{-s}^{-1}$, $2.6257 \times 10^{-3} \text{cm}^2\text{-s}^{-1}$, and $2.6257 \times 10^{-3} \text{cm}^2\text{-s}^{-1}$ at temperatures of 80, 75, and 70 °C respectively. Enthalpy (ΔH°) of 34.82Jmol^{-1} indicates the endothermic nature of the extraction process and the energy requirement whereas entropy (ΔS°) of $104.09 \text{Jmol}^{-1}\text{K}$ describes the process as irreversible.

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I. INTRODUCTION

Coconut oil is vegetable oil derived from the kernel of *Cocos nucifera* Linn. It can be extracted either by mechanical pressing or with solid-liquid extraction using solvent (Sriti *et al.*, 2011; Amin *et al.*, 2010). According to Amin *et al.* (2010) and Liauw *et al.* (2008), extraction using solvent gives a higher yield and less turbid oil. Oil obtained from this process can be used as edible oil, production of cosmetics and biodiesel among many other industrial uses.

Whereas coconut oil has been used mainly for edible and cosmetic purposes, transformers have traditionally used mineral oils and synthetic esters for insulation purposes. Such oils serve the dual purpose of temperature regulation (cooling) and insulation in these transformers (Rouabeh *et al.*, 2019; Muhamad and Razali, 2016). As an insulating medium, the oil fills the pores in fibrous insulation as well as the gaps between the coil conductors, windings and tanks, thereby increasing the dielectric strength of insulation. Also, these transformers generate an enormous amount of heat in the winding process which is transmitted by the oil to the radiators by convection; oil from the radiators

in-turn cools the winding. Other important properties of transformer oils include: dielectric strength, flash point, pour point, viscosity, specific gravity etc (Mahanta and Laskar, 2017; Tante and Al-Liddawi, 2014). The oil demand of these transformers, in terms of quality, is relative to their rating.

Works on the kinetics of the oil extraction process include: Sulaiman *et al.* (2013), Saxena *et al.* (2011), Perez *et al.* (2011), Topallar and Geçgel (2010), Amarni and Kadi (2010), Sayyar *et al.* (2009), Liauw *et al.* (2008), Meziare *et al.* (2008), Mani *et al.* (2007), Kumoro and Hassan (2006), among others. Kinetic study of solid-liquid extraction depends on the nature of the oil and solvent, temperature of the process, particle size, reaction time and the ratio of the solid to the solvent (Sayyar *et al.* 2009).

There is a need to seek an alternative to these commercial-grade transformer oils based on considerations for cost, environmental factors and other physicochemical properties. However, to qualify as good grade transformer oil, the aforementioned properties have to be considered. Understanding the extraction process of this grade of oil obtained from coconut also implies having an adequate knowledge of the kinetics of the process, evaluation of the intra-particle mass transfer and the thermodynamic data parameter estimation. This study, therefore, seeks to evaluate these parameters for the extraction of transformer-grade oil from coconut seed.

II. MATERIALS AND METHODS

a) Materials

The thirteen (13) coconut seeds used in this study were purchased from a local market at Choba, Rivers state (4°47'21" N, 6°59'55"E) Nigeria. Equipment used include: manual blender, mantle heater, water bath, round bottom flasks, marked tape, filter paper, Soxhlet extractor, thermostat and beaker. Reagents used were obtained as pure grade namely: n-hexane (95 %w/w) and phosphoric acid (85 %w/w) supplied by Analar and distilled water.

b) Method

This work involved the following processes: sample pre-treatment, oil extraction and purification, physico-chemical property analysis, kinetic and thermodynamic data parameter estimation and analysis.

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These processes were carried out using the American Society for Testing and Materials (ASTM) procedures under the laboratory conditions.

c) *Sample Preparation & Pre-treatment*

The pretreatment process for the coconut oil extraction involved the removal of the coconut shell, shredding, washing and drying of the coconut seed. The drying was done using an oven drier operated at a temperature of 70°C for 3 days. The dried seed were further crushed using a blender so as to improve its surface area to ensure good contact of the particles with the solvent. The coconut particles were then stored in clean dry containers.

d) *Extraction Process*

The extraction process was conducted using a 1000 ml capacity laboratory soxhlet extractor. Heating of the solvent was done using a heating mantle while the cold water circulating was controlled by water bath. The crushed coconut seed (copra) was weighed, wrapped in a filter paper and placed inside the thimble of the soxhlet extractor while the extraction liquid (n-hexane) was placed inside a reservoir (round bottom flask) for about half its volume. On application of heat from the heating mantle, the liquid vapourized and further condensed in the condenser before coming in contact with the wrapped sample inside the thimble of soxhlet extractor to extract components of solid sample.

The oil was extracted into the extraction compartment through the thimble into the siphon tube and emptied into the reservoir tank. The content of the thimble was exposed to fresh liquid extractant (n-hexane) from the condenser and the cycle repeated during which the solvent boiled off from the miscella. The extraction process was conducted at varying time (1 to 8 hrs) and temperature (70 – 80 °C).

The solvent was recovered through a distillation process after equilibrium had been reached, so as to separate the solvent from the extract (miscella) using a Liebig condenser. Based on boiling point difference, the solvent was distilled off and recovered in a flask while the oil was left behind in the reservoir (round bottom flask) as the residue.

The oil yield from the coconut was determined by the correlation of Equation 1.

$$\text{Yield}(\%) = \frac{\text{mass of oil extracted}}{\text{mass of coconut sample}} \times 100 \quad (1)$$

e) *Oil Refining and Purification*

The extracted oil was refined through degumming, bleaching, and de-odourization processes.

- i. *Degumming*: This was done by adding 0.03% phosphoric acid (H_3PO_4) inside the oil and the mixture heated at a temperature of 90 °C for 10 mins using a Jenway hotplate with a magnetic

stirrer (model 1000) after which the phospholipids were removed after settling.

- ii. *Bleaching*: The degummed oil was bleached using bleaching earth (Tonsil 267FF) at temperature of 120 °C over 1 hr period. Filtration of the degummed oil was done using Whatmann filter paper after which the filtered sample was further heated to a temperature of 130 °C for 90 mins.
- iii. *Deodourization*: The bleached oil was deodourized by heating it at a temperature of 180 °C for 10 minutes in a water bath.

f) *Physico-Chemical Property Analyses*

i. *Moisture Content Analysis*

A clean 250cm³ beaker was dried and weighed after which 5ml of coconut oil was added into it, and the setup re-weighed. The sample was heated for 5 mins in a microwave oven at 60 °C to evaporate as much water as possible and re-weighed after evaporation. It was thereafter placed in a desiccator for cooling and re-weighed. This moisture content was obtained as a ratio of the weight of the oil samples before and after heating using Equation 2.

$$\text{Moisture Content}(\%) = \frac{W_i - W_f}{W_f} * 100 \quad (2)$$

ii. *Flash Point*

Using the Pensky-Marten's closed test cup method and a 0 to 400 °C thermometer, the flash point of the oil was evaluated. Following standard laboratory procedures, the oil samples were placed in the well or barrel of the tester and a thermometer inserted into the cup to monitor the temperature of the setup which was heated at temperature intervals of 10 °C. The fumes released from the oil were tested with a lighted match stick and the temperature at which the fumes support the flame for about 2 seconds was determined as the flash point.

iii. *Pour Point*

The pour point test was carried out in the laboratory using ice bath, test tubes and a negative thermometer. The apparatus was set up in such a way that the test tubes containing the oil samples were stuck in the ice bath with the flow characteristics monitored periodically at temperature intervals of 3°C. The temperature at which the oil sample starts to coagulate was determined as pour point. (1)

iv. *Density*

This test was carried out on the oil samples using a known weight of a 50 ml volume density bottle from where the oil density was derived through calculation.

v. *Viscosity*

This was carried out using the NDJ-5S digital Rotary viscometer and the DBK minimag stirrer/heater. The oil samples were placed in the beaker on a heater

and the piston of the viscometer placed inside the beaker. Readings were taken from the viscometer over the range of 45-60 °C. Temperature was monitored using a thermometer placed at the side of the beaker and the viscometer.

vi. *Dielectric Strength*

To evaluate this, 50 g of the extracted oil samples were placed in two 500 ml constant fixed volume beakers which were then placed in an SW19 model of Foster transformer (serial no 91ZA925) manufactured in London. Current was passed through the oil samples until the circuit breaker unit went off indicating the stoppage of current. The voltage at which this occurred indicates the voltage dielectric strength. This process was repeated for three more times while noting the results at each stage.

g) *Kinetic and Thermodynamic Data Parameter Estimation*

i. *Kinetic Model Development*

A kinetic model of the process was developed for the oil extraction process with the assumption that its rate is controlled by the mass transfer of the oil from the crushed coconut particles (solute) to the liquid (solvent) in accordance with the works of Saxena *et al.* (2011) and Amin *et al.* (2010).

Using the correlation of Liauw *et al.* (2008) the mass transfer rate can be expressed as follows:

$$\frac{dW_A}{dt} = KA(C_{Ai} - C_A) \quad (4)$$

Where

$\frac{dW_A}{dt}$ = mass transfer rate of the coconut oil (g/s)

A = surface area of the mass transfer process (m²)

K = mass transfer coefficient (ms)

C_{Ai} = initial (equilibrium) concentration of coconut particles in the solvent (g/m³)

C_A = concentration of coconut particles in the solvent at time, t (g/m³)

Also, since the extraction was conducted in a batch process, the volume was constant throughout the experiment hence Equation 3 becomes

$$\frac{dW_A}{dt} = K \frac{A}{V} (W_{Ai} - W_A) \quad (4)$$

Where:

V = volume (m³)

$$\alpha = \frac{A}{V} \quad (5)$$

$$\frac{dW_A}{dt} = K\alpha(W_{Ai} - W_A) \quad (6)$$

$$\frac{dW_A}{(W_{Ai} - W_A)} = K\alpha dt \quad (7)$$

$$\int_0^{W_A} \frac{dW_A}{(W_{Ai} - W_A)} = \int_0^t K\alpha dt \quad (8)$$

$$W_{Ai} - W_A = U \quad (9)$$

$$\frac{dU}{dW_A} = -1 \quad (10)$$

$$dW_A = -dU \quad (11)$$

$$-\ln(W_{Ai} - W_A) \Big|_0^{W_A} = K\alpha t \Big|_0^t \quad (12)$$

$$\ln(W_{Ai} - W_A) - \ln(W_{Ai} - 0) = -K\alpha t \quad (13)$$

$$\ln\left(\frac{W_{Ai} - W_A}{W_{Ai}}\right) = -K\alpha t \quad (14)$$

Taking the natural log of both sides

$$\left(\frac{W_{Ai} - W_A}{W_{Ai}}\right) = e^{-k\alpha t} \quad (15)$$

$$1 - \frac{W_A}{W_{Ai}} = e^{-k\alpha t} \quad (16)$$

$$\frac{W_A}{W_{Ai}} = 1 - e^{-k\alpha t} \quad (17)$$

The model for the determination of the mass of coconut oil at any given time is Equation 18

$$W_A = W_{Ai}(1 - e^{-K\alpha t}) \quad (18)$$

Expressing this in terms of Yield (Y)

$$Y_A = Y_{Ai}(1 - e^{-K\alpha t}) \quad (19)$$

Where

Y_A = yield of coconut oil at time t (g)

Y_{Ai} = yield of coconut oil at equilibrium (g)

$K\alpha$ = volumetric mass transfer coefficient

t = time (s)

The non-linear regression analyses of the kinetic model were done using Microsoft Office Excel Solver (2007). The regression analysis was performed to estimate the model parameters. The coefficient of determination (R^2), root mean square error ($RMSE$), the reduced chi-square (χ^2), and standard error of the estimate (SEE) were used as the primary criteria to assess the goodness of the fit of the models to the experimental data. Moreover, the coefficient of determination (R^2) serves as a measure of the closeness of the relation to linearity, whereas the $RMSE$, χ^2 , and SEE shows the deviation between the predicted and experimental values. Hence, the best model exhibits the highest R^2 , whereas the $RMSE$, χ^2 and SEE approaches to zero. The statistical parameters were calculated using the following equations:

$$R^2 = 1 - \frac{\sum_{i=1}^n (Y_{A \text{ pre},i} - Y_{A \text{ exp},i})^2}{\sum_{i=1}^n (Y_{A \text{ exp},i} - Y_{A \text{ exp},i \text{ mean}})^2} \quad (20)$$

$$RMSE = \sqrt{\left[\frac{\sum_{i=1}^n (Y_{A\ pre,i} - Y_{A\ exp,i})^2}{n} \right]} \quad (21)$$

$$\chi^2 = \frac{\sum_{i=1}^n (Y_{A\ pre,i} - Y_{A\ exp,i})^2}{n-z} \quad (22)$$

$$SEE = \sqrt{\left[\frac{\sum_{i=1}^n (Y_{A\ pre,i} - Y_{A\ exp,i})^2}{n-z} \right]} \quad (23)$$

Where

$Y_{A\ exp,i}$ = the i^{th} experimental yield ratio

$Y_{A\ pre,i}$ = the i^{th} predicted yield ratio

$Y_{A\ exp\ mean}$ = the mean value of the experimental yield ratio

n = the number of experimental data points

z = the number of constants in the model.

The scatter plot was equally used to assess the appropriateness of the extraction model at different temperatures. This was obtained by plotting the errors (ε_i) against the i^{th} experimental yield ratio ($Y_{exp,i}$) from the correlation:

$$\varepsilon_i = Y_{A\ exp,i} - Y_{A\ pre,i} \quad (24)$$

ii. Intra-particle mass transfer

The intra-particle mass transfer for the oil extraction process was evaluated with the Thiele modulus with the assumption that this process was neither controlled nor limited by internal diffusion. To determine the Thiele modulus, the effective diffusivity (D_{eff}) was evaluated using Fick's 2nd law from the slope of the plot of the Yield vs Time using the correlation presented by Pinelo *et al.* (2006) as shown in Equation 25

$$\ln Y = \ln \left(\frac{6}{\pi^2} \right) \frac{\pi D_{eff}}{r^2} t \quad (25)$$

Where:

Y = yield of oil (g)

r = radius of coconut particle (mm)

D_{eff} = effective diffusivity (m^2s)

t = time (s)

From the plot of $\ln Y$ vs t , the slope and intercept were given by Equations 26 and 27 respectively.

$$slope = -\frac{\pi D_{eff}}{r^2} \quad (26)$$

$$Intercept = \ln \left(\frac{6}{\pi^2} \right) \quad (27)$$

The effective diffusivity value obtained from the slope was used to evaluate the intra-particle mass transfer during the oil extraction process using the Thiele modulus as expressed by Equation 28

$$\phi = \frac{dp}{6} \left(\frac{k\rho}{D_{eff}} \right) 0.5 \quad (28)$$

Where: ϕ = intra-particle mass transfer, dp = diameter of the catalyst particle (mm), k = extraction rate (s^{-1}), ρ = density of the coconut oil.

iii. Thermodynamic data parameter estimation

At each experiment, the change in equilibrium constant (K_{eq}) was determined using the linear form of the Van't Hoff equation shown in Equation 29 from where thermodynamic parameters of enthalpy change (ΔH), entropy change (ΔS), and Free energy (ΔG) were also evaluated.

$$\ln K_{eq} = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} \quad (29)$$

Plot of $\ln K_{eq}$ vs $1/T$ is effective in estimating the change in enthalpy, total energy, and entropy or amount of disorder of a chemical reaction (Scott, 2016).

Where: K_{eq} = equilibrium constant for the oil yield at different temperatures, R = ideal gas constant, ΔH° = standard enthalpy change of the extraction process (KJ/mol), ΔS° = standard entropy change of the system (KJ/mol)

$$slope = -\frac{\Delta H^\circ}{R} \quad (30)$$

$$intercept = \frac{\Delta S^\circ}{R} \quad (31)$$

$$K_{eq} = \frac{Y_t}{Y_u} \quad (32)$$

Where: Y_t = the yield percent of extraction oil at Temperature (T); Y_u = the yield percent of unextracted oil in the coconut.

$$\Delta G^0 = \Delta H^0 - T\Delta S^0 \quad (33)$$

Where ΔG^0 = Free Energy

III. RESULTS AND DISCUSSION

a) Effect of Temperature and Time on Yield of Coconut Oil

The Plots of experimental and predicted yields of Coconut oil at 80, 75 and 70°C respectively are shown in Figures 1 to 3:

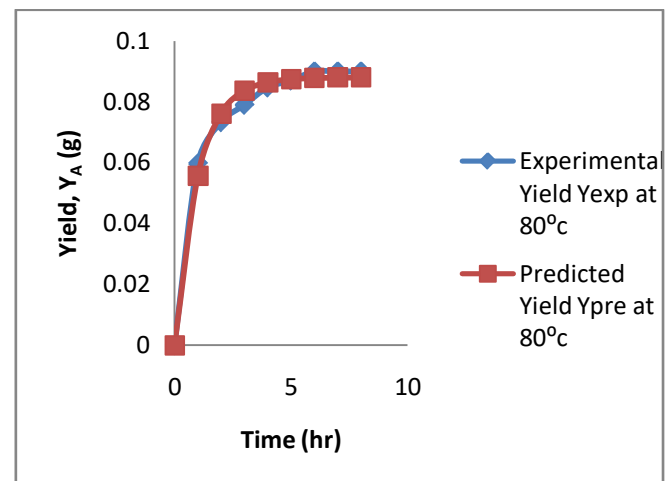


Figure 1: Yield of Coconut Oil vs Time at 80 °C

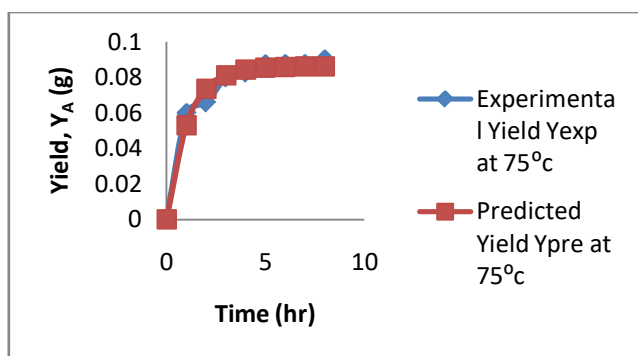


Figure 2: Yield of Coconut Oil vs Time at 75 °C

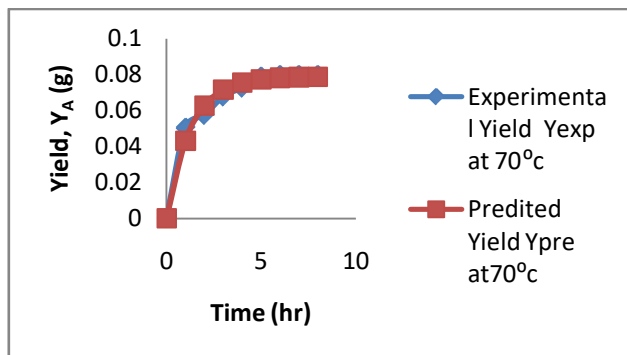


Figure 3: Yield of Coconut Oil vs Time at 70 °C

Similar yield pattern was observed for the oil extraction process carried out at the 3 different temperature conditions. Increase in extraction time also gave a corresponding increase in yield of oil under experimental conditions although the yield became constant after 7 hours. This same pattern was observed for the predicted yield with slight increment observed after 7 hours for extractions done at 70 and 75 °C. Generally, increase in temperature resulted in increased yield during the extraction process. Sulaiman *et al.* (2013), Eikani *et al.* (2012) and Meziane and Kadi (2008) reported temperature to have a direct relationship with oil diffusion rate and an inverse relationship with the oil viscosity. The mass transfer coefficient of the extraction process also increases with temperature thus affecting diffusion. According to Sulaiman *et al.* (2013), Amarni and Kadi (2010), and Sayyar *et al.* (2009), choice of solvent affects the oil yield hence the 15% increase in yield observed using hexane solvent. Moreover, Sulaiman *et al.* (2013) also reported an inverse relationship between yield and surface area. The rapid yield rate at the beginning of the process gradually declined in the course of the process as the copra was exposed to more of the fresh solvent. Hence as the free oil on the surface of the copra was being solubilized, the extraction rate increased accordingly. This finding corroborates with the work of Aryee and Simpson (2009). Low concentration of oil in the solvent was observed whereas the mass transfer gave rise to rapid diffusion of oil from the copra to the solvent. The oil yield

remained constant even on extension of extraction time as soon as the maximum amount of extractable oil was reached.

b) Physicochemical Properties of Coconut Oil

Table 1: Properties of Coconut Oil and Mineral Oil

Properties	Crude Coconut Oil	Refined Coconut Oil	Mineral Oil
Moisture content (mg/kg)	3.47	0.89	1.5
Flash point (°C)	224	203	154
Pour point (°C)	16.5	13	-40
Density (kgdm ⁻³)	0.95	0.94	0.91
Viscosity@60°C	26	24	22
Dielectric strength (KV)	25.6	39	50

Note: These values are a mean of 3 determinations.

Tanteh and Al-Liddawi (2014) reported that properties such as moisture content, flash point, pour point, density, viscosity and dielectric strength affect the efficiency of transformer oil. Muhamad and Razali (2016) reported an adverse effect of moisture content on the properties of transformer oil which could also affect its performance. Solid insulation and a risk of paper insulation breakdown are some of the likely consequences of moisture content in transformer oil (Swanson *et al.*, 2018; Hamrick, 2009). Temperature has been reported to also affect the moisture content of transformer oil. Transformer oil (mineral oil) is obtained from fractions of crude (petroleum) and so is more volatile with little water content compared to coconut oil which contains unsaturated acids that can easily absorb moisture. The moisture content for the mineral oil was obtained as 1.5 mg/kg, whereas the moisture content for crude and refined coconut oil was 3.47 and 0.89 mg/kg respectively. Low moisture content observed of the refined coconut oil indicates its enhanced insulating property compared to that of the mineral oil. Previous report (Muhamad and Razali, 2016) have highlighted the adverse effect of moisture content on the dielectric properties of transformer oil, in addition to other such similar effect on paper insulation of the core and the winding of transformer. However, low moisture content alone does not disqualify the coconut oil sample as good alternatives to mineral oil since the moisture content can be reduced by heating to enhance insulating property of oil sample.

Rouabeh *et al.* (2019) as well as Biermann and Metzger (2007) showed that a relationship exists between moisture content, ageing time, and dielectric strength of transformer oil. The moisture content obtained in this study corroborates the work of Muhamad and Razali (2016) whereas Mahanta and Laskar (2017) reported similar values for mineral oil and 100 mg/kg as the value for moisture content from vegetable oil.

Crude coconut oil had a flash point of 224 °C which was higher than the 203 °C and 154 °C reported for refined oil and mineral oil respectively. This value for the refined oil was moderate because low value obtained for the mineral oil grade shows its ease to ignite and hence a limitation to its usability. The flash point values obtained in this work are less than what was reported by Muhamad and Razali (2016). However these values corroborate the work of Abeysundara *et al.* (2001) for coconut oil and these values are above the value of 154 °C for standard oil (IEC 296). The low flash point of the mineral oil has been attributed to its exposure to more volatile substances which burn faster at lower temperatures. High flash point values are desirable to aid cooling property thereby reducing the risk of explosion during operation of transformer. Furthermore, El-refaie *et al.* (2009) reported that flash point changes with the duration of use of the transformer because of age and temperature of operation. High temperatures could lead to the production of hydrocarbons with lower molecular weight causing a reduction in the flash point values of the transformer oil. Based on flash point consideration, all samples considered in this study are good candidates for transformer oil.

The nature and type of bonds between carbon chains of the fatty acids affect the pour point of the transformer oil obtained from the edible seeds such as coconut oil (Biermann and Metzger, 2007). Pour point of unsaturated acid is usually very low compared to pour point of saturated acids (Bremmer and Plansker, 2008; Franco *et al.*, 2007 and Bassim *et al.*, 2003). The pour point values obtained from this study using the ASTM D97 corroborated the findings of Biermann and Metzger (2007). The refined coconut oil gave a better pour point value than that of the crude coconut oil. Pour point affects the insulating property of the oil when the transformer is used in cold weather conditions. It is important to keep this value as low as possible so as not to disrupt the cooling operation of the transformer by convection. The transformer, while in operation, generates heat which result in a rise in the temperature of the oil and this is fundamental in pour point consideration (Biermann and Metzger, 2007). The standard pour point for transformer oil is -40 °C, although there is a tendency that coconut oil can solidify if the power supply is disconnected for a long time due to its higher pour point which could lead to a failure of the transformer (Abeysundara *et al.*, 2001). However, unsaturated fatty acids in the transformer oil contain double bonds and this could pose a challenge when it is subjected to heavy electromagnetic fields (Mcshane *et al.* 2003). There is a possibility that double bonds may break due to polarization. This work therefore posits that refined coconut oil is far better than crude coconut oil based on its pour point value.

The refined coconut oil and crude coconut oil had a density of 0.94 kgdm⁻³ and 0.95 kgdm⁻³ respectively which are both high when compared to mineral oil whose value is 0.895 kgdm⁻³. Moreover, Abeysundara *et al.* (2001) reported the effect of density on the flow and convection of transformer oil. Hence the lower the density, the more efficient the oil and although 0.94 kgdm⁻³ reported in this work is higher than the 0.91 kgdm⁻³ reported by Abeysundara *et al.* (2001) for coconut oil, it corroborates the standard reported by Biermann and Metzger (2007) for environmentally friendly fluids. El-refaie *et al.* (2009) reported the effect of time of operation on the specific gravity of transformer oil.

A similar effect has also been reported for the oil viscosity by Muhamad and Razali (2016). Viscosity of the oil affects its cooling property, because the cooling of a transformer is mainly governed by convection, so it is important to have a low viscosity to facilitate convection. Hence, the lower the viscosity of the oil, the more effective it is at cooling. Increase in temperature reduces viscosity while the viscosity of the crude and refined coconut oil decreased with increasing temperature. It is possible that the desired range of viscosity could be reached at some elevated temperature. At the highest temperature tested in the laboratory (45 - 60 °C), viscosities of crude coconut oil and refined coconut oil were 26 and 24 respectively. Abeysundara *et al.* (2001) did not ascertain any effect of oil viscosity on the dielectric strength of the transformer oils obtained from similar sources because of the nature of the bonds between their molecules.

In this study, the dielectric strength was obtained as 25.6 KV for crude coconut oil while upon refinement and purification, it improved significantly to 39KV. The dielectric strength of the crude coconut oil shows that it can be used as insulating liquids in low medium voltage transformers having a capacity range of 69 to 288KV which require minimum dielectric breakdown voltage of between 20 to 30KV. This phenomenon can be explained by the degree of unsaturation of the coconut oil sample whereas the refined coconut oil can be used in high medium voltage transformers having a capacity of 35KV and above in agreement with the work of Bhumiwat *et al.* (2010).

c) Kinetics of the Oil Extraction Process

The results of the model and statistical parameters which was used to access the goodness of fit of the kinetic model to the experimental data at various temperatures are shown in Table 2:

Table 2: Model and Statistical Parameters of the Kinetic Model

Temperature (°C)	Model parameters		Statistical Parameters			
	Y_i	$K\alpha$	R^2	RMSE	χ^2	SEE
80	0.08801	0.99952	0.999998	0.000318	1.35E-07	0.000367
75	0.08624	0.95469	0.999951	0.001414	2.6667E-06	0.001633
70	0.07877	0.79496	0.999987	0.000636	5.4E-07	0.000735

Where $n = 8$ and $z = 2$

All the temperatures considered gave very high R^2 and low error values thus showing the suitability of the kinetic model in describing the extraction process under these conditions. The predicted aligned closely to the experimental values. Furthermore, the extraction

process performed at 80 °C had the highest R^2 value and the least RMSE, χ^2 , and SEE values closest to zero and hence the model best describes the process at this temperature.

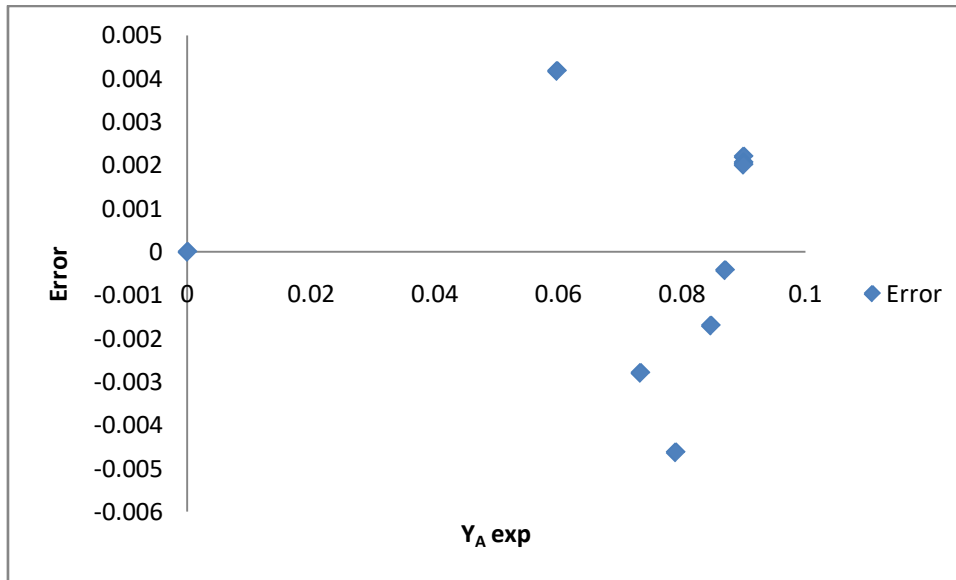


Figure 4: Error plot at 80 °C temperature

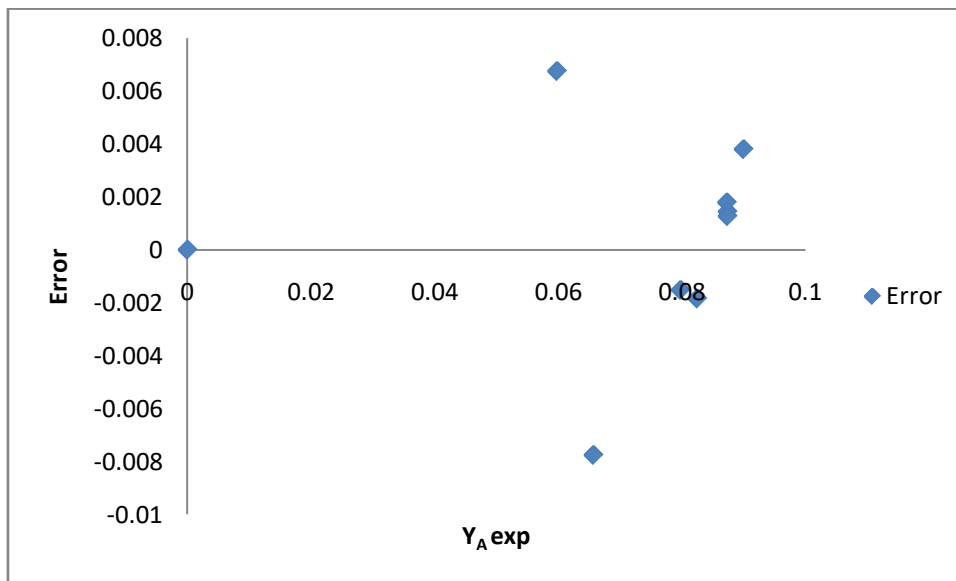


Figure 5: Error plot at 75 °C temperature



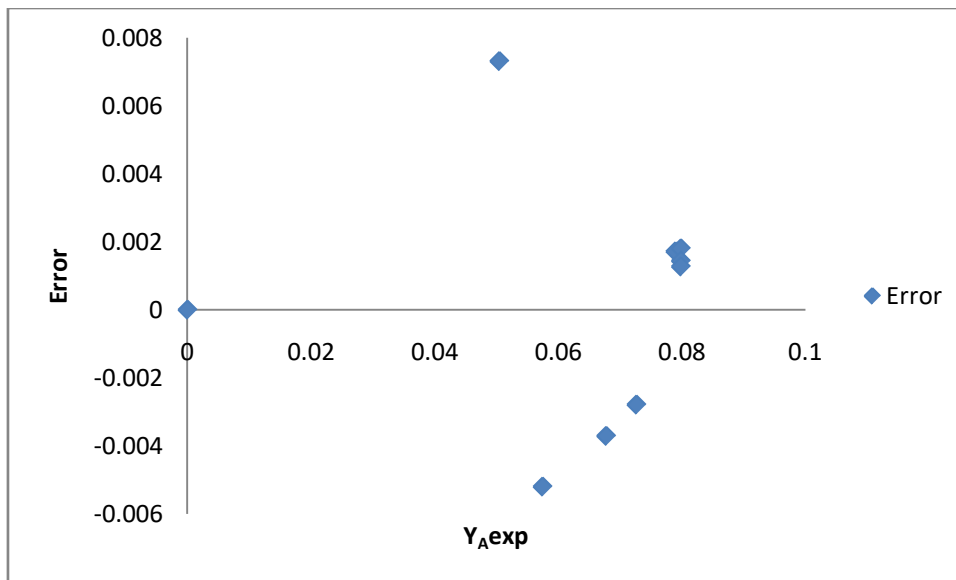


Figure 6: Error plot at 70 °C temperature

The scatter plots (Figures 4 to 6) show that $\varepsilon = \pm 0.02$ which indicate the closeness of the experimental values to the population mean at these temperature conditions. These plots further show the appropriateness of the extraction model to predict the oil yield at these temperatures.

d) Intra Particle Mass Transfer

Thiele modulus was used to investigate the mass transfer within the particle. To determine the value

of Thiele modulus, effective diffusivity (D_{eff}), m^2s^{-1} was calculated. The Ficks second law was used to determine effective diffusivity by assuming the D_{eff} constant with the yield (Y) at time (t) for initial yield of the oil. Evaluation of effective diffusivity was done using the correlation of Pinelo *et al.* (2006) and shown in Figures 7 to 9.

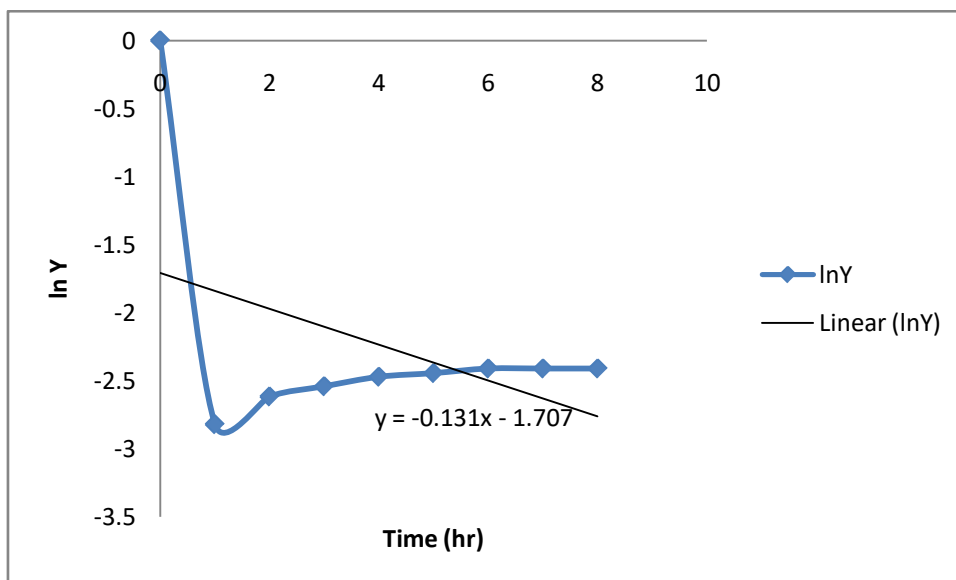


Figure 7: Plot of ln Y vs Time (hr) for extraction at 80 °C

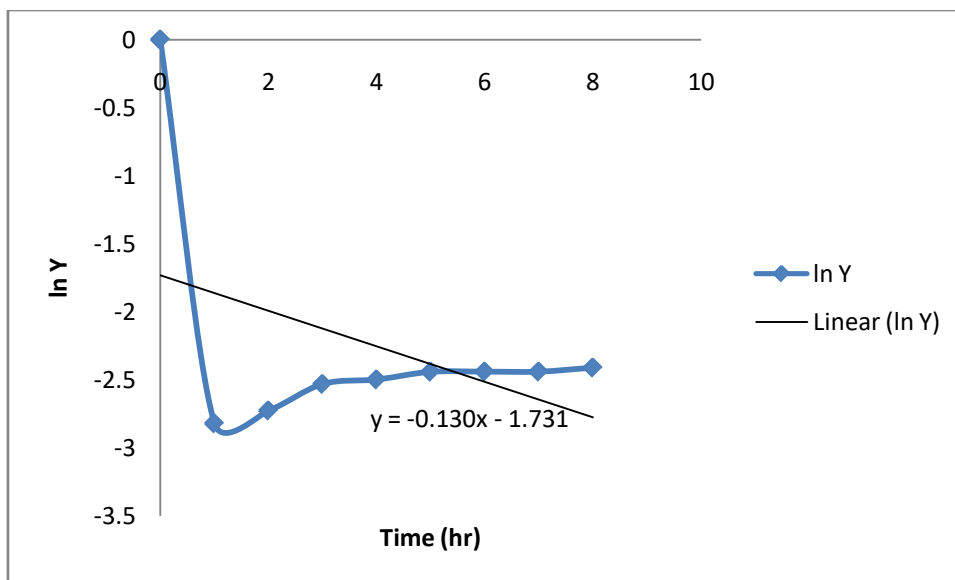


Figure 8: Plot of ln Y vs Time (hr) for extraction at 75 °C

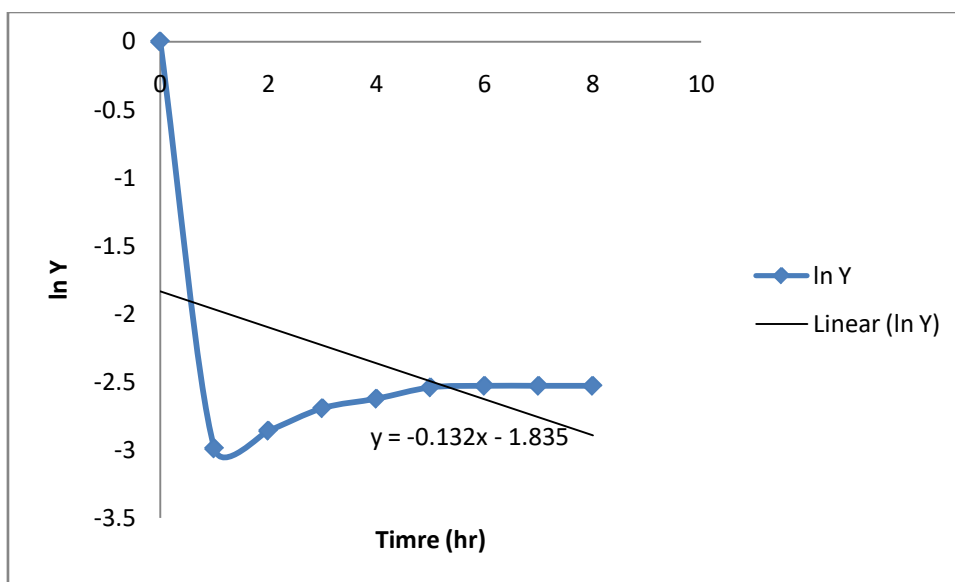


Figure 9: Plot of ln Y vs Time (hr) for extraction at 70 °C

The density of the oil and the average particle size were found to be 0.94g/cm^3 and 0.5cm respectively. Substituting values for the slope and particle radius, the effective diffusivity (D_{eff}) were obtained as $2.6058 \times 10^{-3}\text{cm}^2\text{-s}^{-1}$, $2.6257 \times 10^{-3}\text{cm}^2\text{-s}^{-1}$, and $2.6257 \times 10^{-3}\text{cm}^2\text{-s}^{-1}$ at temperatures of 80, 75, and 70 °C respectively. Furthermore, substituting values of the extraction rate (K) and density (ρ) of the coconut oil, particle diameter of the crushed coconut (chopra) as well as the effective diffusivity into the correlation of Giri and Sharma (2000) the Thiele modulus ϕ was obtained as 2.1751, 2.0909 and 1.8039 at temperatures of 80, 75, and 70 °C respectively, therefore, showing a corresponding decrease with temperature. Low value of the Thiele modulus indicates that surface reaction controls the process and the good diffusive property of

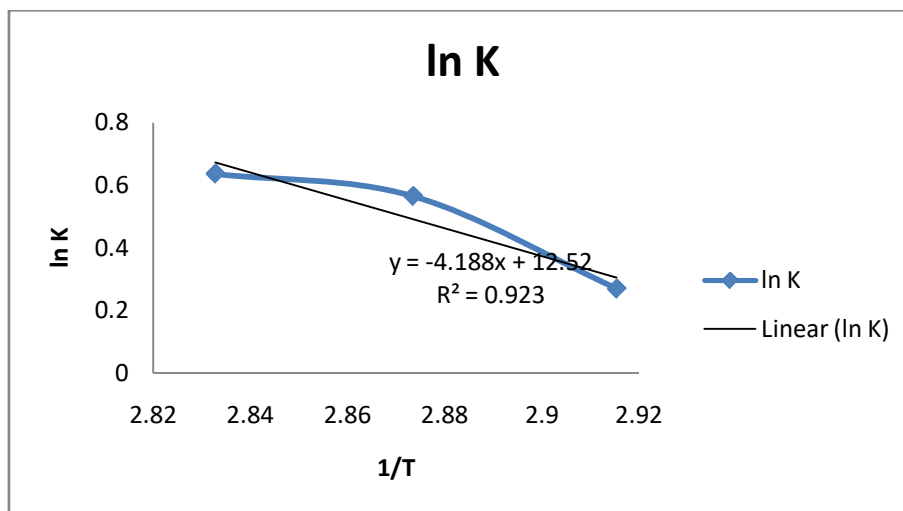
the solvent (Scott, 2006). According to Giri and Sharma (2000), limited surface reaction decreases the rate of internal mass transfer diffusion. However, results obtained from this study shows that the system was not affected by the mass transfer within the particle, because of the small value of the Thiele modulus which was less than 3. Giri and Sharma (2000) reported that the Thiele modulus values of Coal were 0.1057 and 0.016 at particle sizes of 0.1275mm and 0.016mm respectively.

e) Thermodynamic Parameter Estimation

The values of the thermodynamic parameters were obtained as shown in Table 3.

Table 3: Thermodynamic Parameters of the Coconut Oil Extraction Process

Temperature (K)	Thermodynamic Properties			
	K_{eq}	ΔG° (J/mol)	ΔH° (J/mol)	ΔS° (J/molK)
353	1.89	-36709		
348	1.76	-36188.5	34.82	104.09
343	1.31	-35668.1		

Figure 10: Plot of $\ln K_{eq}$ vs $1/T$

The plot of $\ln K_{eq}$ vs $1/T$ (Figure 10) was used to determine the value of the Thermodynamic parameters for the extraction process. Enthalpy value for this process was obtained as 34.82 Jmol^{-1} which is comparable to the value obtained for other agricultural products such as melon, rubber seed and olive cake oil (Meziane and Kadi, 2008; Attah and Ibemesi, 1990). Also, Topallar and Geçgel (2010) reported an enthalpy value of 112 KJmol^{-1} ; these values are within the acceptable range of $30 - 135 \text{ Jmol}^{-1}$ for these oils. Positive enthalpy change indicates the endothermic nature of the extraction process and the energy required to achieve this process in agreement with the works of Amin *et al.* (2010) and Topallar and Geçgel (2010).

Furthermore, the mixture contained grounded coconut (copra) in hexane which implies an increase in entropy of the mixture due to the oil molecules extraction. The entropy value which was obtained as $104.09 \text{ Jmol}^{-1}\text{K}$ describes the process as irreversible and hence corroborates the findings of Saxena *et al.* (2011), Topallar and Geçgel (2010), as well as Meziane and Kadi (2008).

The Gibbs free energy values of -36709 , -36188.5 , $-35668.1 \text{ Jmol}^{-1}$ were obtained at temperatures of 353 , 348 , 343K respectively. Negative value of the Gibbs free energy indicates that the process is spontaneous which shows that the energy required to break the solute-solvent and solvent-solvent interaction are more than the energy released in solute-solvent

interaction; hence, the reaction proceeds in the forward direction. The Gibbs free energy values obtained in this work were also less than the range of $0.23 - 1.25 \text{ kJmol}^{-1}$ and $33.31 - 39.57 \text{ Jmol}^{-1}$ reported by Sulaiman *et al.* (2013) for 1.2 , 0.7 and 0.5 mm of particle size respectively.

IV. CONCLUSION

The extraction process using the soxhlet extractor gave good yield of the oil from coconut seed. For all the temperature conditions, a similar pattern was observed for the experimental and predicted yields of the oil. The density and viscosity of the oil were comparable to that of the commercial grade mineral oil whereas the flash point and dielectric strength were indicative of the cooling and insulating capacity of the oil. The kinetic model gave good fit with the experimental data with R^2 above 0.99 and the process was best described at 80°C . Effective diffusivity (D_{eff}) were obtained as $2.6058 \times 10^{-3} \text{ cm}^2\text{-s}^{-1}$, $2.6257 \times 10^{-3} \text{ cm}^2\text{-s}^{-1}$, and $2.6257 \times 10^{-3} \text{ cm}^2\text{-s}^{-1}$ at temperatures of 80 , 75 , and 70°C respectively. ΔH° of 34.82 Jmol^{-1} indicates the endothermic nature of the extraction process and the energy required to achieve this process whereas ΔS° which was obtained as $104.09 \text{ Jmol}^{-1}\text{K}$ describes the process as irreversible. These findings show the suitability of the extracted oil as good transformer grade oil.

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

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

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

Muesi Zornata Noble ^α, Emmanuel O. Ehirim ^σ, Wordu Animia ^ρ & Jaja Zina ^ω

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. The results of the material and energy balance of the various components of the plant performed manually and with Hysys showed a maximum deviation of 0.8%. The design and sizing results of various functional parameters of the reactor in terms of Volume, Diameter, Height, Spacetime, SpaceVelocity, and Volume flowrate respectively were: 45m³, 3.368m, 5.052m, 1.8892hr, 0.5293/hr, 23.82m³/hr. The design and sizing results of the heat exchanger in terms of Heat load, Heat transfer area, log mean temperature difference (LMTD), Overall heat transfer coefficient, tube length, number of tubes, pitch were: 69.94KW, 60.32m², 49.79°C, 23.29W/m²K, 4.83m, 160, 50mm. The effect of reactor size and number showed that At 90% conversion the following output results were obtained for formaldehyde product in terms of mass flow rate, molar flow rate, composition (mole fraction), and yield: 479.53kg/hr, 0.79kgmole/hr, 0.0541, and 0.8988 respectively.

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).

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 meet industrial scale based on its wide application. (Alzein & Nath, 2018), the process industry would need more of formaldehyde production rate to meet 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 meet the demand today and so more researchers are to go into designing of units operations for the production of formaldehyde to meet 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 meet the current demand of society today. This is

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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.

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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

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

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:

$$\left[\frac{\text{Rate of Outflow}}{\text{of Energy}} \right] = \left[\frac{\text{Rate of Inflow}}{\text{of Energy}} \right] + \left[\frac{\text{Rate of Generation}}{\text{of Energy}} \right] - \left[\frac{\text{Rate of Consumption}}{\text{of Energy}} \right] - \left[\frac{\text{Rate of Accumulation}}{\text{of Energy}} \right] \quad (3)$$

If no chemical reaction occurs

$$\left[\frac{\text{Rate of Consumption}}{\text{of Energy}} \right] = \left[\frac{\text{Rate of Generation}}{\text{of Energy}} \right] = 0 \quad (4)$$

Equation (3) becomes

$$\left[\frac{\text{Rate of Outflow}}{\text{of Energy}} \right] = \left[\frac{\text{Rate of Inflow}}{\text{of Energy}} \right] - \left[\frac{\text{Rate of Accumulation}}{\text{of Energy}} \right] \quad (5)$$

If the system is a steady state process

$$\left[\frac{\text{Rate of Accumulation}}{\text{of Energy}} \right] = 0 \quad (6)$$

Equation (5) becomes

$$\left[\frac{\text{Rate of Inflow}}{\text{of Energy}} \right] = \left[\frac{\text{Rate of Outflow}}{\text{of Energy}} \right] \quad (7)$$

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

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

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

(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:

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

(b) Energy Balance

A general energy balance equation can be written as:

$$C_{p_{mean}} = \text{Mean Specific Heat Capacity in KJ/kg } ^\circ\text{C}$$

T = Temperature of the stream in $^\circ\text{C}$

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 Reactor 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.

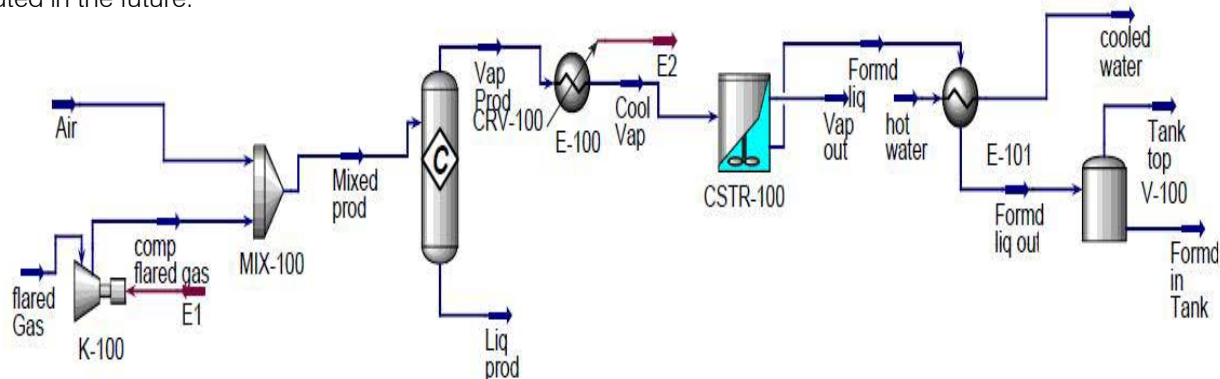


Figure 1: Hysys Simulation PFD

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 1×10^4 kg/hr for Hysys simulation while for manual calculation is found to be 1.1×10^4 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 outlet stream Mixed Product (S_4) having a

mass flow rate of 2.20×10^4 kg/hr for Hysys simulation and 2.10×10^4 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)	2.10×10^4	2.20×10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0
Vapour Product (S_5)			
Mass Flow (kg/hr)	2.10×10^4	2.20×10^4	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 2.20×10^4 kg/hr while the manual calculation is 2.10×10^4 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)	2.10×10^4	2.20×10^4	4.5
Molar Flow (kgmole/hr)	947.40	947.10	3.0
Cooled Vapour (S_6)			
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 4.4 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 2.2×10^4 kg/hr for Hysys simulation and 2.10×10^4 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)	2.10×10^4	2.20×10^4	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 x 10 ⁴	2.111 x 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 (S₈) is 2.20 x 10⁴ kg/hr for Hysys simulation and 2.10 x 10⁴ 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 x 10⁴ kg/hr and 2.12 x 10⁴ 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 (°C)	25	25	0.0
Pressure (kpa)	101.3	101.3	0.0
Heat Flow (kJ/hr)	-4.682e7	-4.686e7	4.7
(E1)			
Temperature (°C)	-	-	
Pressure (kpa)	-	-	
Heat Flow (kJ/hr)	3.421e5	3.427e5	1.4
Compressed Gas (S ₂)			
Temperature (°C)	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 (S₁) and Stream (E1) when added equals the heat flow of stream (S₂) 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 (°C)	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 (°C)	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 (°C)	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 (S₂) and Mixed Stream (S₄) 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 (°C)	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 (°C)	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 (S₄) and Vapour Product Stream (S₅) 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 (°C)	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 (°C)	-	-	-
Pressure (kpa)	-	-	-
Heat Flow (kJ/hr)	2.636e7	2.636e7	0.0
Cooled Vapour (S ₆)			
Temperature (°C)	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 (S₅) 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 (°C)	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 (°C)	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 (°C)	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 (S₇) and Hot Water Inlet Stream (S₁₀) equals to the sum of the heat flow of Formaldehyde Liquid Out Stream (S₉) and cooled Water Stream (S₁₁) 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 (°C)	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 (°C)	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 (°C)	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 (°C)	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			
Type	MUESI NOBLE PG.2017/02618 Split ring floating head (two shell four tubes)	MUESI NOBLE PG.2017/02618 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 (m²)	53.4	53.5	0.2
LMTD (°C)	32	32.1	0.2
U (W/m²K)	640	640.3	0.1
Inlet temperature (°C)	80	80	0.0
Shell Diameter (mm)	476	476	0.0
Shell coefficient W/m ² C	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

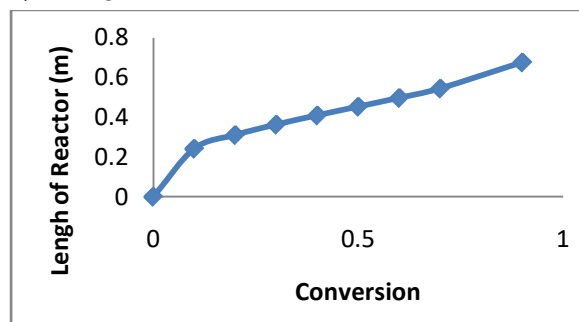


Figure 1: Profile Reactor versus Conversion

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

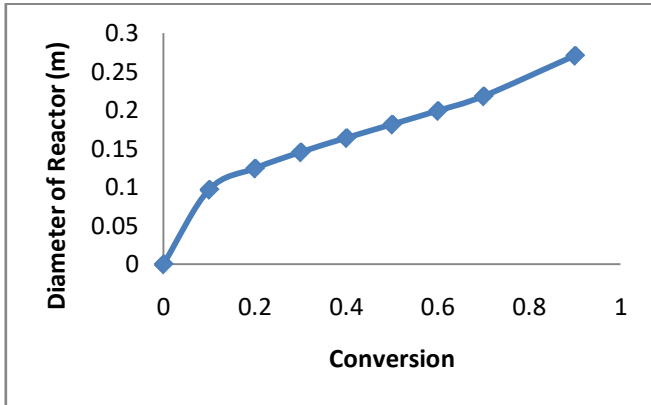


Figure 2: Plot of Diameter of Reactor versus Conversion

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

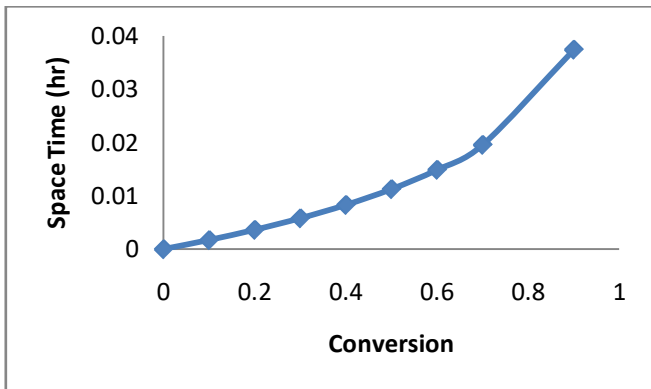


Figure 3: Profile of Space Time of the Reactor versus Conversion

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 0-0.035hr 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

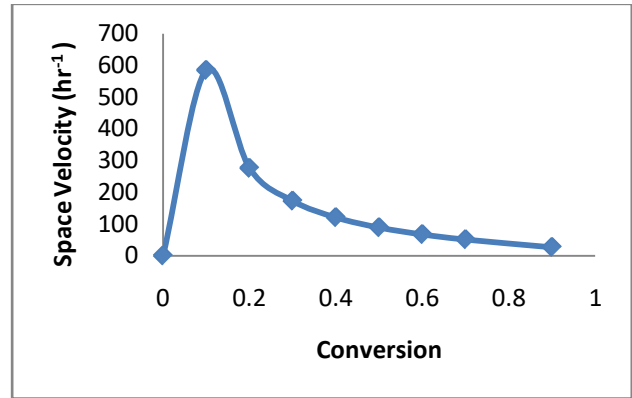


Figure 4: Graph of Space Velocity versus Conversion

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

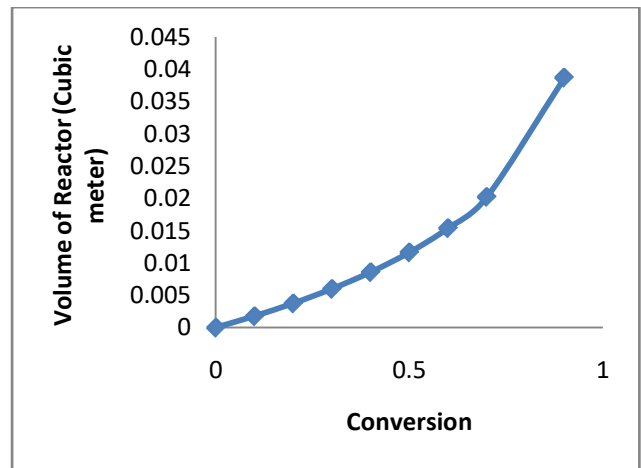


Figure 5: Variation of Volume of Plug Flow Reactor versus Conversion

Figure 5 depicts the variation of volume of plug flow reactor for formaldehyde production from methane and oxygen. The volume increases exponentially from 0m³ to 0.038m³ 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.

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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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Early View



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Assessment of Water Quality and Power Consumption in Small Size Reverse Osmosis Water Treatment Units

By Khan Md. Rabbani Rasha & Quazi Hamidul Bari

Khulna University of Engineering and Technology

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Keywords: reverse osmosis, water quality, power consumption, removal efficiency, maintenance.

GJRE-C Classification: FOR Code: 090499



Strictly as per the compliance and regulations of:



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1. INTRODUCTION

Reverse osmosis is a pressure-controlled process that is used to clean and desalinate water. It's a membrane separation mechanism that recovers water to a point greater than the osmotic pressure of the solution from a pressurized saline solution. The process of reverse osmosis is used effectively to remove salt and to reduce organic and inorganic components [1]. This process is used primarily for drinking water treatment, wastewater reuse, water desalination, industrial wastewater treatment, oil field water treatment, marine desalination, and various water treatment plants.

The total cost of water is estimated by the addition of capital costs to the operating costs [2]. As materials improved and costs decreased, the use of membrane desalination increased. Today, reverse osmosis membranes are the leading technology for new desalination installations, using tailored pre-treatment

and membrane system design to apply them to a variety of salt water resources [3]. The use of membrane processes for treating and reusing wastewater is expanding rapidly. Reverse osmosis (RO) membrane processes effectively remove organic, inorganic, and biological constituents [4]. RO systems extract contaminants from water like nitrates, chemicals, chlorides, toxins, pharmaceuticals, arsenic and much more. A RO carbon filter system will also eliminate chlorine and hardness [5]. These treatment systems have some moving or replaceable components, which is why cleaning and servicing is very simple.

Filtration of reverse osmosis provides water which is better than bottled. It is also cost-effective when compared with water quality. Due to its relatively low energy consumption, reverse osmosis is an increasingly common desalination method [6]. This technology has been shown to be useful in treating a wide range of effluents from the chemical, textile, pulp and paper, petroleum and petrochemical industries, food, tanning and metal finishing industries, although it has very strict requirements for the concentration of suspended solids, fibers and oily components [7]. In the pharmaceutical, fiber, petrochemical, electrochemical, food paper and tanning sectors, RO membranes can be used to produce high quality water and to recycle wastewater effluents [8].

In a typical coastal reverse osmosis plant, in the proposed approach, 3 to 10 kWh of electrical energy is required to produce one cubic meter of freshwater, since only the product water needs to be pumped to the surface, the specific energy consumption can be reduced to 2.46 kWh [9]. A huge amount of energy is needed to let the water through the RO membranes in seawater desalination. Brackish water RO desalination typically involves fewer energy around the same recovery than seawater desalination because of low salinity [10]. Setting up an energy recovery system can lower energy consumption from 6– 8 kWh / m³ to 4–5 kWh / m³, which might be further reduced to 2 kWh / m³. RO systems powered by gas / steam turbines have generally lower costs (0.43\$/m³), and brine staging units can boost water recovery and lessen specific power consumption [11]. The amount of freshwater that can be extracted is therefore reduced to as little as 25% to 45% for seawater but as high as 90% for brackish water. A

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25% increase in energy prices will drive up the cost of produced water by 11% at these levels [12].

Reverse osmosis is an effective technology for removing arsenic that has been proven through bench and pilot scale studies according to a report prepared for the US-EPA. Arsenic is very effectively removed by RO in the generally high oxidation states of (V). Practical processes can be developed with RO to remove all major arsenic species from water with further attention to removing the weakly acidic arsenic species in waters by operating RO at sufficiently high pH made possible by the newer antiscalants [13]. More than 15,000 desalination plants are in operation around the world today, and about 50 percent of these are RO plants. The Middle East holds about 50% of the world's production capacity (and 2.9% of the world's population), and has forged ahead as the leader in large-scale desalination of seawater. In 2005, Israel opened the largest RO desalination plant in the world with a capacity of 330,000m³/day or 100 million m³/year [14]. In 2005, the United Arab Emirates (UAE) opened its desalination plant in Fujairah, combining MSF and RO technology to produce 454,000m³/day of freshwater [15].

Countries in North Africa and the Middle East, such as Algeria, Tunisia, and Jordan, have minimal freshwater supplies and studied utilizing desalination of both brackish and coastal waters. The world's largest RO desalination plant for brackish water was completed in 2006 in Wadi Ma'in, Jordan, operating at 129,000m³/day, with a maximum capacity of over 150,000m³/day [16]. Algeria plans to increase the number of plants from 10 to 43 by 2019, with an output goal of 2 million m³/day; in 2007, production started at Algeria's capital city, Algiers, with the largest RO desalination plant in Africa (200,000 m³/day). Countries in South America, such as Chile, have recently set up massive desalination plants and Australia is dealing with a water crisis with modern RO projects from Sydney to the Gold Coast [17]. The desalination plant site should be carefully selected and especially for forward planning for possible future expansions should be away from residential areas. The main cause of emissions is the noise pollution, visual pollution, depletion in outdoor fishing and bathing sites, leakage of pollutants into the water, the brine drainage and forms of disposal methods used. The RO membranes, however, are susceptible to fouling and scaling and as such need to be regularly cleaned with chemicals that may be toxic to receiving waters [18].

Khulna is the commercial and port city of Bangladesh, situated in South West Bangladesh. At present, the Khulna water supply network relies entirely on the source of groundwater. In the Khulna area, drinking water availability is not viable due to high salinity and iron. Clean water supplies are minimal at the KUET campus and the amount of available water is not adequate as needed. The quantity of safe drinking water

needs to grow as the total population of KUET rises each year. Salinity is the major issue here. The main problem at KUET campus is salinity. The gross dissolved solid is, however, very small. Using the water treatment method Reverse Osmosis will easily remove these issues. The selected RO filters for this study are installed in Planning and Engineering Building, IDM, Civil Engineering Department and Amar Ekushey Hall. This research aims to differentiate the parameters of water quality from four chosen outlets and to establish the physical and chemical characteristics of the treated water. Water was obtained on a weekly basis and pH, color, conductivity, turbidity, chlorides, total coliform, fecal coliform, dissolved oxygen, total solids, total dissolved solids, hardness, total chlorine. Monthly data on power consumption and water production is gathered to determine the power consumption whether it is cost-effective or not. In addition, this study aims to monitor RO filter maintenance and a questionnaire was carried out at Amar Ekushey Hall among students about the water quality and service of RO water system at their residential hall. Several investigations were carried out.

II. RESEARCH METHODS

a) Study Area

For this research Khulna University of Engineering & Technology (KUET) was chosen as the study area. It is located at Teligati and has a total area of 101 hectares. It is located about 15 km north of Khulna's main city. Khulna, the Teligati area in particular, is suffering from acute water scarcity due to unplanned urbanization and increased salinity in both surface and groundwater. To solve the problem, an effective water treatment system is needed.

Reverse osmosis filter is used in almost all buildings in KUET. Since the other water sources are scarce, the plant with Reverse Osmosis plays a very important role. The filtered water is used only for purposes in drinking water. Since this is a complete setup, there is no need for a distribution network to deliver potable water handled by RO water treatment plant. Four KUET campus reverse osmosis units have been chosen for monitoring one is situated in New Academic Building outside the IDM (Institute of Disaster Management), one is installed in the Department of Civil Engineering, one is installed in the Amar Ekushey Hall and another one is the Planning and Engineering Building. Figure 1 show the locations of the selected RO units.

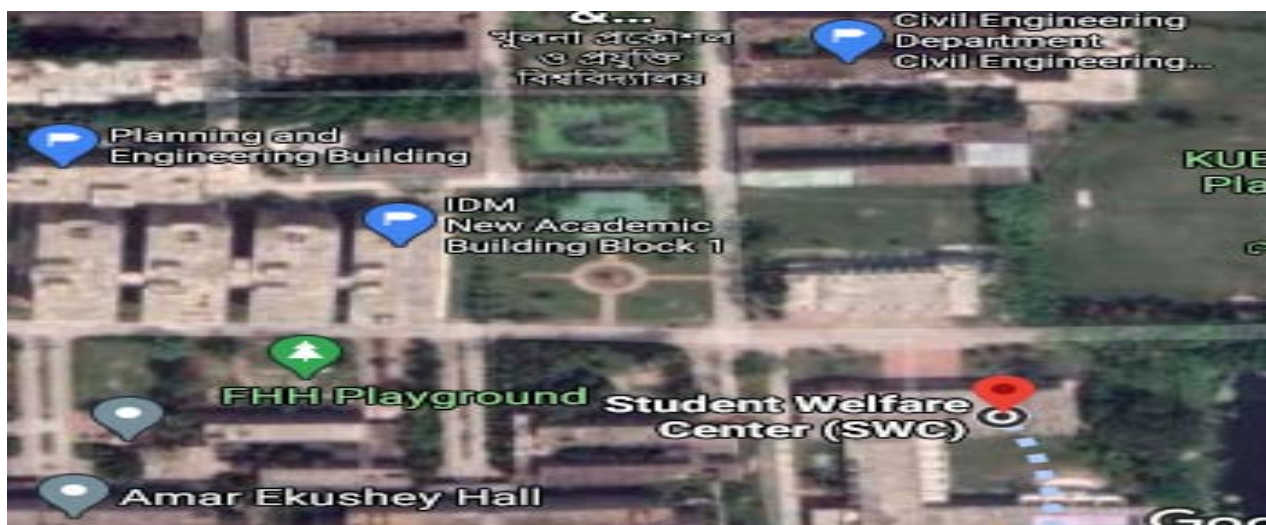


Figure 1: Locations RO water treatment units

b) Sample Collection

The bottle was washed several times with distilled water before collecting water samples. The bottles were then air dried or sun dried. After that the bottles were prepared for collecting water sample. Water samples were obtained each week for testing the water quality of the raw and treated water. Twenty water samples were collected for each location for this study spanning a year. They were obtained from the feed water from the selected four locations. The performance of RO filter had to be contrasted with both treated and feed water.

c) Water Quality Parameter Test

KUET is found in a region influenced by salinity. Each week, water samples from this field have been obtained from identified KUET campus locations. Next, Laboratory check calculated the consistency of Sample Air. The results of the tests were correlated with normal Bangladesh and WHO. The following tests were performed using normal methods to determine KUET Campus water quality parameters-pH it was measured with pH meter model no sension 2 (HACH). Color- A spectrophotometer, model DR 2700 was used for color testing. Electrical conductivity- Conductivity was measured by a conductivity meter. Turbidity- Turbidity was measured with a turbidity meter. Chlorides- The chloride of the sample was determined by titration with a standard silver nitrate solution in the presence of an AgNO_3 indicator. Hardness- Hardness was determined by titration with a standard EDTA solution with the help of standard buffer solution (to raise pH of water) and Eriochrome Black T dye. Dissolved oxygen- DO meter was used for measuring dissolved oxygen. Data was taken with a DO sensor. Total chlorine- Total chlorine was measured with a spectrophotometer, model DR 2700. Standard methods were conducted to determine TC, FC, TS and TDS.

d) Water Quality Index

To recognize and analyse the water quality of all the water samples, the WQI was used. WQI is characterized as a relative influence and significance of various water quality parameters on the quality of water. First, each of the parameters was given a weighting level (w_i) according to its relative contribution and importance according to the predicated weightage given to each water quality parameter by World Health Organization (WHO). For each sample, a comparison study was conducted against the value calculated from lab testing results with the desired limit specified by WHO for each parameter, and weightage was assigned to each parameter based on self-analysis of results and comparison to WHO's predicted weightage.

Second, using the equation below, the relative weightage (W_i) of each water quality parameter was calculated:

$$W_i = \sum_{i=1}^n w_i$$

$$q_i = (C_i/S_i) * 100$$

Where n denotes the number of parameters considered in the WQI calculation, and w_i denotes the weightage calculated or assigned to each parameter [5-6]. In the third step, a quality rating value (q_i) for each water quality parameter was calculated by dividing the parameter's known concentration in each water sample after analysis by the standard permissible concentration specified in WHO, and multiplying by 100.

C_i is the concentration of each water quality parameter in each water sample, and S_i is the concentration stated according to WHO [21]. The sub-index (SI_i) for each water quality parameter is then calculated using the equation below to calculate WQI:

$$SI_i = W_i * q_i$$

$$WQI = \sum_{i=1}^n SI_i$$

Third and the last step were to compute WQI (WQI = 200–300); Water unsuitable for drinking (WQI ≥ 300)[22].

values are classified into five categories:
Excellent water (WQI ≤ 50); Good water (WQI = 50–100); Poor water (WQI = 100–200); Very poor water

Table 1: Parameters, weight factors w_i and W_i values

Parameter	w_i	$W_i = w_i/\sum w_i$	WHO Standard
pH	4	.08	6.5-8.5
EC	4	.08	400
Turbidity	3	.06	5
Chloride	5	.10	250
TS	4	.08	1200
TDS	4	.08	600-900
Hardness	5	.10	180
Color	3	.06	15
DO	3	.06	6.5
TC	4	.08	0
FC	4	.08	0
Total Chlorine	4	.08	4
$\sum w_i = 47$			

e) Power and Water Consumption

In the Engineering Building an electricity meter was built to measure the amount of electrical energy used by the Reverse Osmosis filter. It reported weekly power consumption (in kWh). A piezometer was mounted at the brine tank to calculate the daily water outputs. A half inch pipe with T-joint was installed. All data were gathered, and tests were regularly tested in the laboratory.

III. RESULTS AND ANALYSIS

a) General Water Quality Characteristics

From the eighty samples collected from the selected four locations tested were carried out for both raw water and treated water. The statistical values such as the maximum, minimum, average, standard deviation and variance were calculated to get an understanding of the water quality of the raw water. From table 1 we can

see that conductivity, chlorides (salinity), total solids, total dissolved solids and hardness of raw water surpassed the permissible limit for drinking water according to WHO standards. Standard deviation value stipulates how much the parameter is deviated from the average value. Total dissolved solids have the highest standard deviation meaning that TDS values are spread out from the average. Total chlorine has the least standard deviation indicating it is closely near to the average value. The term variance refers to a statistical measurement of the spread between numbers in a data set. A large variance indicates that numbers in the set are far from the mean and far from each other. A small variance, on the other hand, indicates the opposite. Here we can see that conductivity has the highest variance of 72071.41 and total chlorine has the lowest variance of 0.000169.

Table 2: Statistical values of raw water quality parameters of the study area

Parameter	Maximum	Minimum	Average	Std. Deviation	Variance	WHO Standard
pH	8.20	6.42	7.15	0.279899	0.529055	6.5-8.5
EC(μ s/cm)	2030	1143	1508.25	268.4613	72071.41	400
Turbidity (NTU)	3.57	1.67	2.29	0.339099	0.114988	5
Cl(mg/L)	750	385	559.36	99.09198	9819.221	250
TS (mg/L)	1780	1080	1461.46	130.4244	17010.52	1200
TDS (mg/L)	1700	920	1380.38	176.3526	31100.26	600-900
Hardness (mg/L)	245.56	166.28	202.96	13.04427	170.1530	180
Color (Pt.Co)	52	0	9.75	18.73387	350.9578	15
DO (mg/L)	8.2	6.2	7.30	0.664989	0.442210	6.5

TC (Nos./100mL)	10	0	2.5	2.5	6.25	0
FC (Nos./100mL)	5	0	0.5	1.788854	3.2	0
Total Chlorine (mg/L)	0.35	0	.03	0.013017	0.000169	4

For this study the along with the raw supplied water of the area the treated reverse osmosis water was also tested to see the removal efficiency and the compare the water quality values before and after going through the reverse osmosis treatment. From table 2 we can see that conductivity has the highest standard deviation of and Total coliform (TC) and Fecal Coliform (FC) has the lowest standard deviation. Also, Total Solids (TS) has the highest variance and TC and FC has the lowest variance among the treated water quality parameters. Another significant thing we can see that is after going through the reverse osmosis treatment the water quality parameters such as conductivity, chlorides

(salinity), TS, TDS and hardness values is well within the acceptable limit of drinking water according to WHO standard, which wasn't the case for the raw water. The removal efficiency is above 90 percent for conductivity, chloride, TS, TDS, color, TC, FC and total chlorine which enables the values to be good enough for drinking. After the reverse osmosis treatment, the hardness value becomes well within the WHO drinking standard, but its removal efficiency is much lower at 57.71 percent than the other water quality parameters. But the value of turbidity is well within the permissible limit for drinking but its removal efficiency is very low at 22.50 percent.

Table 3: Statistical values of treated water quality parameters of the study area

Parameter	Maximum	Minimum	Average	Std. Deviation	Variance	Removal Efficiency (%)	WHO Standard
pH	8.15	6.10	6.28	0.379682	0.144158		6.5-8.5
EC (μ s/cm)	331	80	148.25	59.10229	3493.081	91.30	400
Turbidity (NTU)	2.25	1.36	1.90	0.284327	0.080842	22.50	5
Cl ⁻ (mg/L)	105	33	56.21	18.16184	329.8526	90.13	250
TS (mg/L)	320	80	129.85	58.00626	3364.726	90.15	1200
TDS (mg/L)	280	50	95.36	49.82271	2482.302	93.08	600-900
Hardness (mg/L)	106.68	65.15	85.32	10.04610	100.9243	57.71	180
Color (Pt.Co)	36	0	6.25	14.43123	208.2605	96.54	15
DO (mg/L)	8.1	6.4	7.42	0.493003	0.243052		6.5
TC (Nos./100mL)	3	0	1	0	0	97.72	0
FC (Nos./100mL)	0	0	0	0	0	99.65	0
Total Chlorine (mg/L)	0.3	0	0	0.1	0.01	99.25	4

In table 1, table 2 and table 3 all the values of the permissible limit were inducted according to the WHO guideline but dissolved oxygen has no fixed guideline according to WHO. So, to calculate the water quality index the value considered for dissolved oxygen was 6.5 because the range of values of dissolved oxygen good for warm water was 6.5-9.5. Again, there is no removal efficiency for the value of pH and dissolved oxygen, the reason being these two water quality parameters have no such contribution to the overall water quality of drinking standards. They have a certain range of values that are considered adequate in drinking

water but no permissible limit that can't be exceeded. That's the reason the removal efficiency is not calculated or considered for the values of pH and dissolved oxygen.

b) Water Quality Index Calculation

Selected water quality parameters were tested at four different locations in KUET. The selected filters are RO unit 1 (Planning and Engineering building), RO unit 2 (IDM), RO unit 3 (Civil Engineering department), RO unit 4 (Amar Ekushey Hall). The samples were tested for raw water and treated water to understand the water quality index and category of water.

Table 4: Sample location, Water quality index value and category of water for raw water

Sample Location	Water Quality Index Value	Category of Water
RO Unit 1	124.84	Poor Water
RO Unit 2	128.42	Poor Water
RO Unit 3	122.38	Poor Water
RO Unit 4	131.26	Poor Water

Table 5: Sample location, Water quality index value and category of water for treated water

Sample Location	Water Quality Index Value	Category of Water
RO Unit 1	28.8	Excellent Water
RO Unit 2	29.1	Excellent Water
RO Unit 3	28.2	Excellent Water
RO Unit 4	29.7	Excellent Water

Water quality index (WQI) is an important indicator of the overall water quality of drinking water. It can be seen from table 4 that for raw water the range of water quality index is 124-132 summarizing the category of drinking water to be poor. From table 5 it is seen that for the reverse osmosis treated water the water quality index is in the range of 28-30, it indicates that the treated water is excellent in category. So, the value of the water quality index falls drastically after going through the reverse osmosis water treatment units. The supplied raw water from all four locations had poor-quality water but after the reverse osmosis water treatment the purified water from all the locations became inducted in the excellent water category.

c) *Power Consumption and Water Production of RO unit (Planning and Engineering Building)*

To observe how much electricity is consumed and its cost, an electricity meter was set with an RO filter. The meter reading, power consumption and water production data are shown in Table 6. Ten months data was collected here. By subtracting the meter reading, power consumption was determined. Power consumption of RO units depends on the water demand or water production.

Table 6: Meter reading, power consumption and water production of RO unit (Planning and Engineering Building)

Date	Meter reading	Power consumption (kWh)	Water production (liter)
7/4/2019	60.5		
14/4/2019	63.2	2.7	274
28/4/2019	64.5	1.3	93
30/5/2019	70.1	5.6	568
23/6/2019	74.1	4	400
30/6/2019	75.9	1.8	180
10/7/2019	78.1	2.2	214
17/7/2019	79.7	1.6	161
24/7/2019	81.7	2	174
31/7/2019	83.4	1.7	172
7/8/2019	85	1.6	161
14/8/2019	86.9	1.9	182
21/8/2019	89.3	2.4	246
30/8/2019	91.3	2	193
8/9/2019	93.1	1.8	172
15/9/2019	95	1.9	181
22/9/2019	97.3	2.3	228
30/9/2019	99.4	2.1	206
6/10/2019	101.3	1.9	171
13/10/2019	105.5	4.2	426
20/10/2019	108.2	2.7	218
30/10/2019	110.3	2.1	206
17/11/2019	113.5	3.2	328
30/11/2019	116.2	2.7	294
3/12/2019	117.5	1.3	131

16/12/2019	119.7	2.2	217
22/12/2019	121.2	1.5	125
29/12/2019	123.6	2.4	241
5/1/2020	125.7	2.1	184
12/1/2020	127.2	1.5	143
19/1/2020	129.3	2.1	211
30/1/2020	131	1.7	175
2/2/2020	132.6	1.6	105
16/2/2020	135.2	2.8	219
23/2/2020	138.6	3.2	314
1/3/2020	141	2.4	226

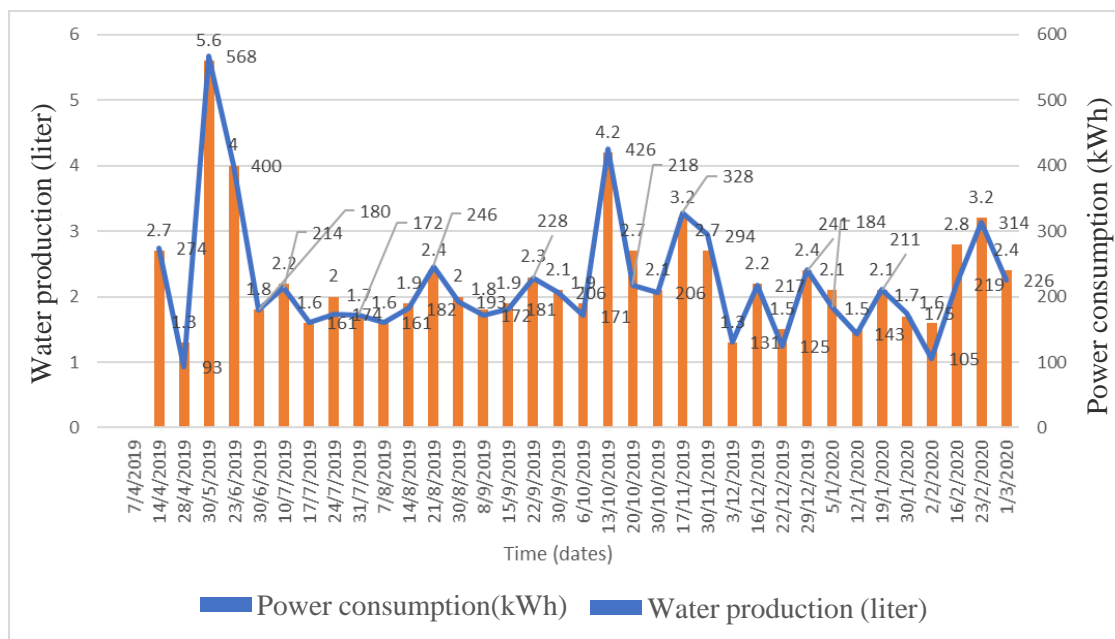


Figure 2: Power consumption and water production of RO unit (Planning and Engineering Building)

From figure it is observed that, power consumption and water production increase with time as water demand.

BDT) is calculated according to BERC (Bangladesh Energy regulatory Commission). According to BERC-

d) Cost of RO Water Treatment

From the power consumption, cost of water production per month is determined. The cost (taka

Table 7: New rates of household users according to BERC

Price of Slab	Per unit cost
0 to 50 unit	Tk. 3.50
0 to 75 unit	Tk. 4
76 to 200 units	Tk. 5.45
201 to 300 units	Tk. 5.70
301 to 400 units	Tk. 6.02
401 to 500 units	Tk. 9.30
Above 600 units	Tk. 10.70

As the power consumption per month is less than 50 units (1kWh= 1 Unit), per unit cost 3.5 Tk is taken. Per month power consumption, water consumption and cost are shown in the table 8 (1\$= 85Tk.).

The cost of electricity and the water production values will give a better understanding of the overall cost and effectiveness according to its cost.

Table 8: Per month data of power consumption, water production and monthly cost

Month	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Power consumption (kWh)	4	5.6	5.8	7.5	7.9	8.1	10.9	5.9	7.5	7.4	8.1
Water production (liter)	367	568	580	721	782	787	1021	602	734	703	864
Cost (tk.)	14	19.6	20.3	26.2	27.6	28.3	38.1	20.6	25.1	25.8	28.3

From figure 3, it is observed that the maximum water production per month of RO is 1021 liter in the planning and engineering building RO filter. The monthly

cost does not exceed 40 tk. Hence, using an RO filter is economic as compared to its effectiveness. Per cubic meter cost of water production by RO 27 tk.

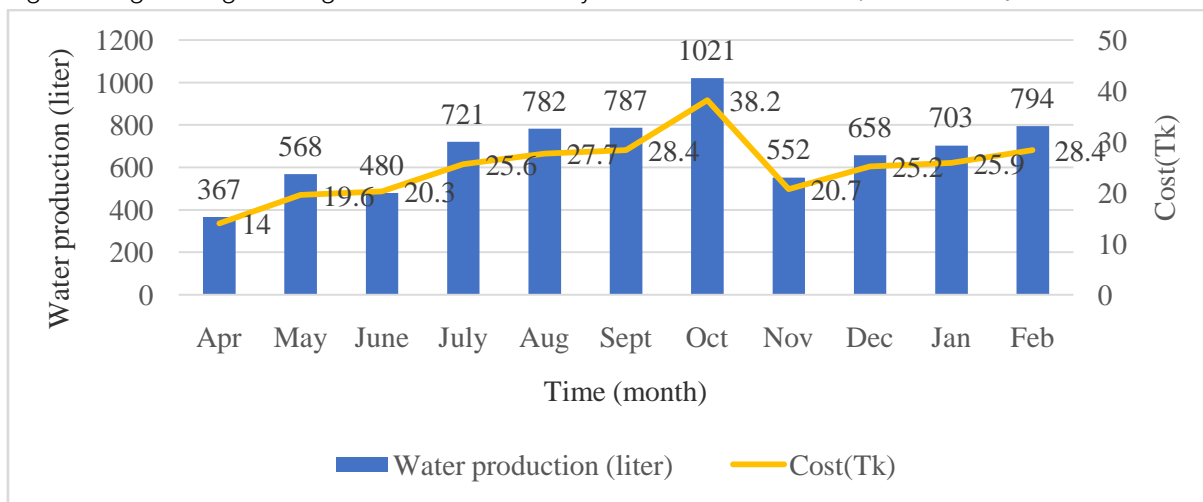


Figure 3: Water production and monthly cost data from April, 2019 to February, 2020

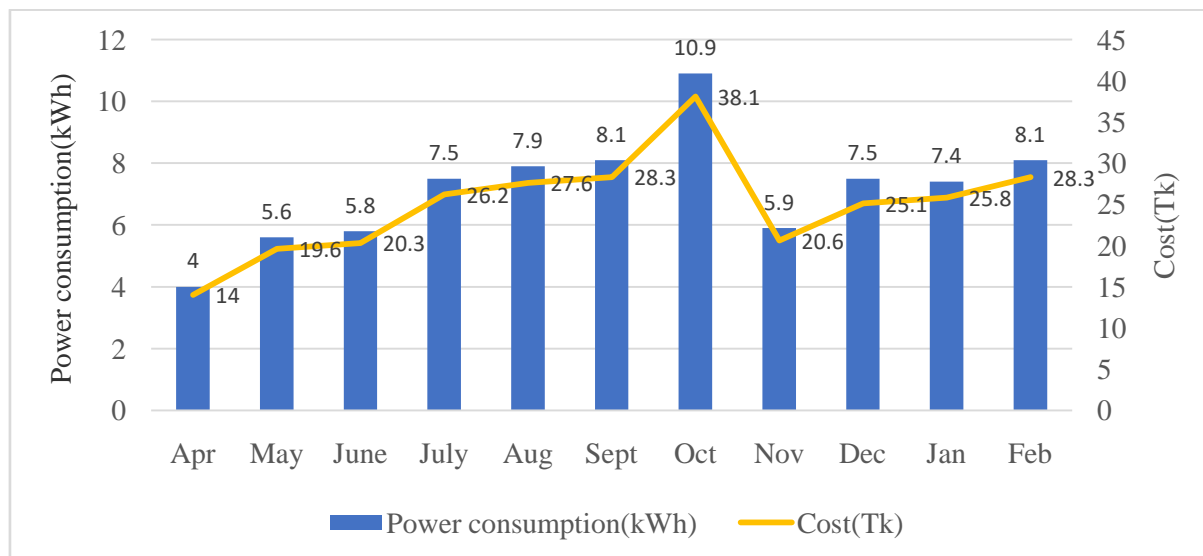


Figure 4: Power consumption and monthly cost data from April, 2019 to February, 2020

e) Maintenance of RO Water Treatment Plant

It's been nearly two years since the Reverse Osmosis (RO) units were installed at Engineering Building, IDM, Civil Engineering department and Amar Ekushey hall. At this time, no obstructions or problems

have occurred. Different works and methods were observed that have preserved the function of the RO water treatment system. A person is always involved in the maintenance and monitoring of RO units. The sediment filter and carbon filter need to be changed

after 6-12 months. Though it depends on the quality of source water. Sediment Filter is designed to remove sediment and dirt from the water so your carbon filter and RO membrane doesn't get clogged prematurely.

Every water system might have different amounts of sediment in the input water so there is no fixed amount of time that is the same for every system. Water from Sediment Filter is passed through the carbon filter (also known as the Activated Carbon Filter), which removes chlorine and other organic contaminants. Carbon filters also filter out the bad odour and unpleasant taste from the water. As the water of KUET campus area enriched with high salinity, a large amount of total dissolved solid and hardness sediment filter and carbon filter was changed within 3 months. If you take good care of the sediment and carbon filters, and replace them at the required intervals then RO membrane only needs to be changed after purification of 6000-7000 litres of water. The RO membrane may die early or last longer depending on the TDS of input water. The replacement of RO membrane will be based on the consumption of water, quality of input water and efficiency of sediment filter and carbon filter. Typically, RO Membranes last for about 2-3 years. Your RO

membrane may die earlier if you have really hard water or if you never flush the membrane. In the RO system of planning and Engineering building that we observed it produced nearly 7800 litres of water from April 2019 to February 2020. So, because of the high salinity and hardness of raw water along with producing huge amounts of water the RO membrane was changed within a year to maintain the quality and production of the RO water treatment system.

f) Flavour Profile Assessment

A short questionnaire survey was done among the people who use reverse osmosis treated water in the four selected RO filters. Among the 250 people who participated in the survey most were from Amar Ekushey Hall because it is the most frequent use of any other filter and has the greatest number of users who use it daily for drinking purposes. Different questions were asked to them from their knowledge of the RO filters to their overall satisfaction about the quality of the treated water. We all know apart from being tested in a lab the most usual way for the general people to judge a sample of water is through the initial color, taste and smell of the water.

Table 9: Rating of opinion about the RO treated water

Comment on RO treated water	Water quality Rating
Very Satisfied	5
Satisfied	4
Neutral	3
Dissatisfied	2
Very dissatisfied	1

So, their opinion was that their preference of the attributes that most enables them to make their decision about their treated drinking water and their assessment of the color, taste and smell of the RO filter water. From table 9 we can see that people's opinion about the treated drinking water was given an option of being very satisfied to very satisfied and a rating was given to them according to the opinion from very satisfied was assigned rating of 5 to very dissatisfied was assigned to a rating of 1.

From figure 5 we can clearly assume that most of the consumers of treated water have a preference towards taste of the water most that means before judging a water sample their taste of water has a more profound impact on the overall quality assessment of the drinking water and according to the surveyed people color has the least impact on their assessment of a good quality drinking water.

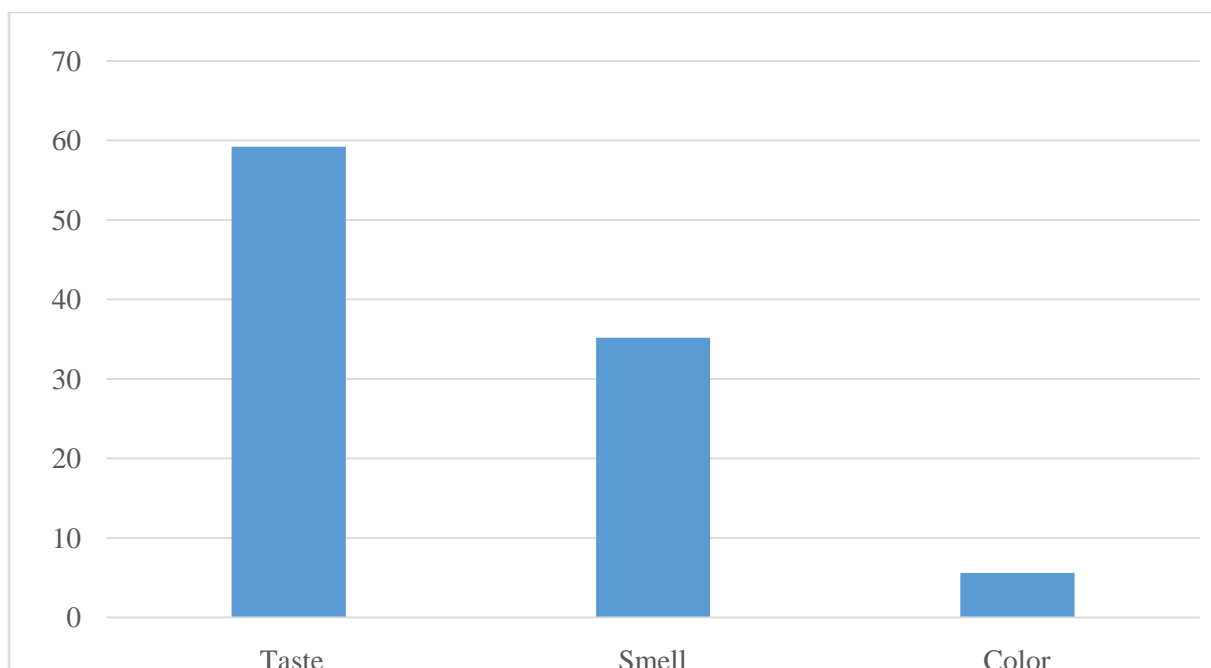


Figure 5: Percentage of people's preference about water quality features

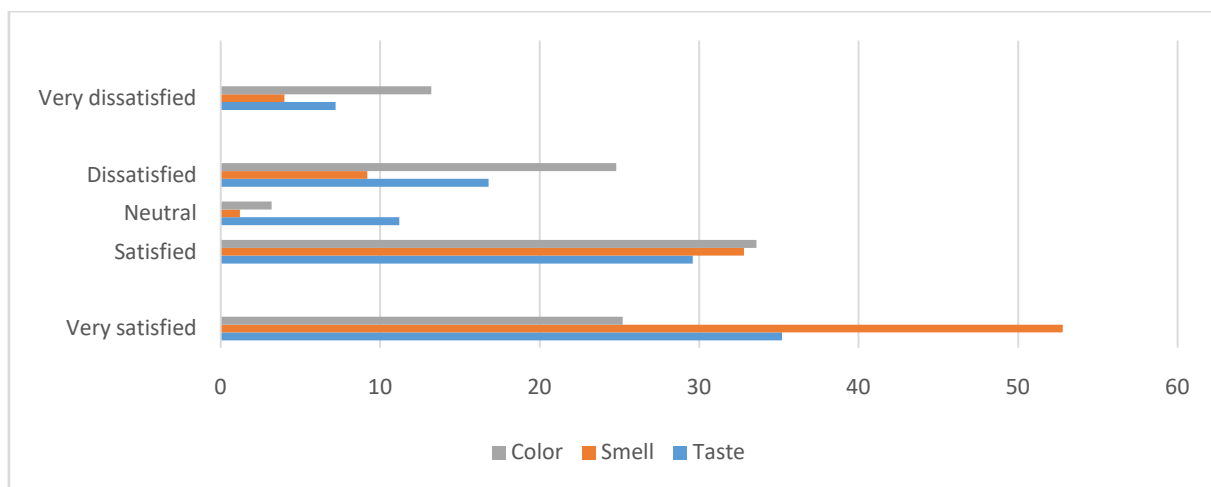


Figure 6: Rating of water quality features

From figure 6 we can see that very few people about 7.2% of people are very dissatisfied and given a rating of 1 with the taste of RO treated water and 35.2% of people are very satisfied and have given a rating of 5 for the taste of the drinking water. As for the smell 52.8% of people have given a rating of 5 and about 1.2% of the people are neutral giving a rating of 3 as they think the smell is not too bad or too good for their liking. For color 33.6% of people are satisfied and given a rating of 4 and 24.8% of people are dissatisfied with the color of treated water giving a rating of 2.

IV. CONCLUSIONS

For understanding the water quality of the raw water and treated water different parameters were tested and the electricity usage and water consumption per month were also monitored and calculated.

Maintenance of the RO water treatment system was also observed for the continuing to maintain quality of treated water and functioning fully. pH value is acceptable ranges in both cases (treated and raw water) according to WHO. Salinity of raw water exceeds the acceptable limit. It can be easily used for residual purposes but without treatment it is not suitable for drinking. RO filtering removes a significant amount of chlorides. It can be seen that the chloride value is high for the raw water but it reduces significantly after treatment. From table 2 it can be seen that the removal efficiency of RO water treatment system is very high, more than 90 percent for most of the parameters that have been tested. Only turbidity is not reduced by that much, accounting for only about 22% and hardness is moderately reduced to nearly 58 percent. DO is quite good. The amount of total dissolved solid is very high (940-1450 mg/L) and

sometimes is in unacceptable range (>1200 mg/L). TDS value of treated water is almost below the allowable range (50-150 mg/L) which is not harmful though. Total chlorine is pretty much non present in treated water. The raw supplied water had a water quality index of about in range of 120-135 in all four selected RO Units which attributes to being categorized as poor water. But after being purified the treated water had a water quality index about in range between 25-30 which makes the treated water on the RO units as excellent water. Almost a one-year study shows that the water production of RO filters is gradually increasing which indicates the demand is increasing. In April to July water production varies from 367-721 liter and in October to December it is 552-1021 liter. Though installation cost of RO filter is high, apparently 10,500-19,000tk BDT, per month water production cost is very low. The monthly cost does not exceed 40 Tk. Per cubic meter cost of water production by RO is 27Tk. The maintenance of this filter isn't so complicated. It doesn't need any training or study to operate this. Also, changing the sediment filter or carbon filter is easy. Sediment filter and carbon filter required to be changed within 2.5-4 months. From the survey about the quality features of the RO treated water it was found that the consumers find the taste of the water most important ahead of smell and color. Along with that the people consuming RO treated water are overall quite content with the quality of the drinking water.

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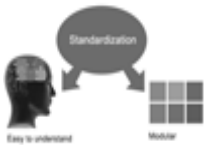
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Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

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

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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.

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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.

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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.

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

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

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

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

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

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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.



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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:

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

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- 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.
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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.

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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.

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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:

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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:

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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.

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BY GLOBAL JOURNALS

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Topics	Grades		
	A-B	C-D	E-F
<i>Abstract</i>	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
<i>Introduction</i>	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
<i>Methods and Procedures</i>	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
<i>Result</i>	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
<i>Discussion</i>	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
<i>References</i>	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring



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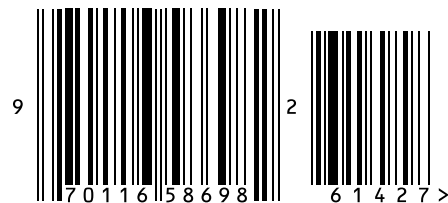


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