Final Year Project

Thesis Title

Design of waste sludge treatment plant produced from production of caustic soda to recover useful chemicals

B.Sc. Chemical Engineering

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DEPARTMENT OF CHEMICAL, POLYMER, AND COMPOSITE MATERIALS ENGINEERING

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Dedication

“This work is dedicated

To our beloved parents and

Our kind teachers”

ACKNOWLEDGEMENTS

We would like to thanks Allah Almighty, because of His love and strength; that He has given us, to finish this project and report. We owe a gratitude to our department and our chairman **Dr. Tanvir Iqbal** to provide us with complete support and facilities to complete our project. We would like to express our special thanks of gratitude to our Professors in the department especially our supervisor, **Dr. Muhammad Irfan** because our project could not have been completed without their sincere efforts. Their supervision, recommendations, constructive condemnation and friendly considerations throughout the project played a vital role in its completion. Further we would also like to owe our gratitude to **ITTEHAD Chemicals Limited** for their contribution and providing us with the required commodities, especially **Syed Atta Hussain** who provided us with invaluable guidance throughout the project.

ABSTRACT

The world is facing a scarcity of clean water sources due to droughts and other factors Desalination is a process that can help recover wasted water centers by removing salts and minerals, making it suitable for human use and irrigation. The production of caustic soda (sodium hydroxide) is an important industrial process with various applications in many industries, such as chemical, textile, paper, and soap. However, the production process generates large quantities of waste sludge, which is a significant environmental and economic challenge for the industry. The waste sludge is typically composed of sodium salts, calcium carbonate, and other impurities, and contains various valuable chemicals that can be recovered and reused. The treatment plant is designed to recover these chemicals and reduce the environmental impact of the waste Recovering useful products from desalination waste, such as calcium, magnesium, and boron, can increase efficiency and generate additional revenue. The project at hand aims to recover calcium from wastewater, which can be used in various industries, including pharmaceuticals, paper, and cement. The successful implementation of the treatment plant will result in significant cost savings and reduced environmental impact, making it a valuable addition to the chemical production industry. This study presents the design of a waste sludge treatment plant for the production of caustic soda to recover useful chemicals. The objective of the proposed waste sludge treatment plant is to effectively recover useful chemicals from waste sludge and improve the economic viability of the caustic soda production process. Overall, the proposed waste sludge treatment plant design is expected to have significant environmental and economic benefits by reducing the environmental impact of waste disposal and improving the economic viability of the caustic soda production process. The technical feasibility of the proposed waste sludge treatment plant design is evaluated in this study, and the proposed design can be used as a model for similar waste treatment plants in other industries.

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ABBREVIATIONS

PDADMAC	Poly (diallyldimethylammonium chloride)
SPEEK	Sulfonated Poly (Ether Ether Ketone)
PAH	Poly (Allylamine Hydrochloride)
PET	Poly (Ethylene Terephthalate)
PEBAX	Polyether-polyamide block co-polymer

Chapter 1

1 INTRODUCTION

1.1 BACKGROUND/OVERVIEW:

Wastewater is one of today's most important environmental issues that causes severe problems to humans, animals, and the environment caused by improper management and technologies. Wastewater is a combination of domestic, commercial, industrial, and agricultural discharge. It contains pollutants and contaminants, including nutrients, microorganisms, chemicals and other toxins. These pollutants can cause health and environmental problems when wastewater is released into body rivers improperly. However, wastewater also contains reusable resources such as water, carbon and nutrients that could be recovered or reused. **[1]** Therefore, appropriate treatments for removal of pollutants to meet the effluent regulatory standards are required. Moreover, the processes should focus on resource recovery to minimize carbon footprint, and to be self-sustainable.

Clean water sources have as of late turned into a scant ware across the globe. As of late numerous nations detailed their most terrible dry season in the beyond 50 years like Brazil while South Africa bank on a 32% defeat in maize creation in last single year because of a deficiency of pure water/portable. **[2].** One accessible strategy to recover wasted clean water centers is around desalination. Desalination is an interaction that eliminates salts along with different minerals coming with wasted unprocessed water, creating water especially perfect for earthling utilization as well as the water system. A progression of saline solution the board systems evacuation, plus executed in desalination verdures everywhere in the world, even though they are profoundly reliant upon various factors: area, land accessibility, air dampness content, lawful allowing necessities, and financial plausibility. Notwithstanding energy and toward costs, salt water wastewater additionally experiences monetary open door costs by means of the absence of recuperating helpful results. These side-effects might comprise nitrates, plaster, along with calcium amalgams, and that "are generally utilized in the structure business for drywall, mortar, and concrete." Different results could comprise magnesium salts, which are valuable in the clinical business, and boron, which is a new hotly debated issue in high-effectiveness hardware. At last, whenever sanitized fittingly, any recuperated ocean salt could be sold as a natural substance to additional increment productivity. **[4]**

Caustic soda, also known as sodium hydroxide, is an important chemical widely used in the manufacturing of various products such as paper, textiles, detergents, and food. The production of caustic soda involves the electrolysis of a solution of brine (sodium chloride) resulting in the generation of large quantities of waste sludge. The waste sludge contains valuable chemicals such as sodium chloride, calcium ions, magnesium ions, barium ions and various others which can be recovered and reused to reduce the environmental impact of waste sludge and improve the economic viability of the caustic soda production process. **[5]**

The accumulation of waste sludge from the production of caustic soda poses a significant environmental and economic challenge for the industry. The disposal of waste sludge in landfills can result in soil and water pollution, while incineration can release harmful gases into the atmosphere. Furthermore, the loss of valuable chemicals contained in waste sludge leads to increased production costs and reduced profitability for caustic soda manufacturers.

To address these challenges, the design of a waste sludge treatment plant that can recover useful chemicals from waste sludge is of great importance. This study aims to design a waste sludge treatment plant for the production of caustic soda to recover useful chemicals and reduce the environmental and economic impact of waste sludge. **[6]**

In this project, we are going to recover Calcium from waste water which is present in high concentration with respect to other chemicals. As Ca, Mg, Ba are important and can be used in our daily life work and industries such as in pharmaceutical, paper, cement industries and many more. As main product of ITTEHAD Chemicals is caustic soda and above mentioned chemicals are very important for its production. So by recovering them, it’ll be in the benefit of industry economically.

1.2 PROBLEM STATEMENT:

The most important challenge in wastewater management in developing countries nowadays is the application of low cost wastewater treatment technologies that can produce the effective effluent to meet the regulatory standard for domestic, agricultural, and industrial purposes. The essential goal of wastewater treatment is to prevent the spread of diseases. There are other goals, which today's world are concerning, including nutrient recovery, water reuse, decreased of using water resources. Therefore, traditional wastewater treatments need to be changed into sustainable treatments to promote the conservation of environmental resources to achieve today's overall goals of wastewater treatment.

Waste management is a big issue in chlor-alkali industries in Pakistan. Many industries like NIMIR, SITARA chemicals and ITTEHAD chemicals is facing this issue. In this case ITTEHAD Chemicals is wasting a huge amount of metal like calcium in the form of sludge. So, a waste sludge treatment plant is required in ITTEHAD to recover metals and other important chemicals.

1.3 OBJECTIVES:

This task's point is to plan a better saline solution wastewater treatment framework as follows:

1. To study different methods for treatment of sludge.
2. Selection of suitable method and parameters for designing of waste sludge plant.
3. To develop a Process Flow Diagram for a particular selected method and parameters.
4. Energy and Material Balance for the process.
5. To design the equipment which is to be used for treatment of sludge.
6. Instrumentation and Control for the equipment.
7. Optimization of parameters selected for the process.
8. HAZOP Analysis.
9. Environmental Impact Analysis.
10. Cost and profitability Analysis of process method

1.4 SCOPE OF PROJECT:

This project will focus on the design of a brine sludge treatment plant to recover useful chemicals, specifically calcium, from the waste stream generated by a local desalination plant. The design will consider the specific characteristics of the brine sludge, including its composition, volume, and quality, and the requirements of the target industries for the recovered chemicals. The treatment process will consist of multiple stages, including physical, chemical, and biological treatment processes, designed to remove impurities and concentrate the target chemicals to the desired levels. The design will also include the necessary equipment, such as pumps, reactors, and filters, as well as control and monitoring systems. This project will not include the construction or operation of the treatment plant, but will focus solely on the design and evaluation of the proposed system.

1.5 OUTCOMES OF PROJECT:

The possible outcomes of this project are listed as follows:

1. Treatment of sludge will lead to recovery of useful chemicals i.e. Calcium
2. Treated and unpolluted water shall result good for neighboring areas and economic growth of industry.
3. Improving the design processes with high energetic and cost analysis result.
4. Designing a system of treating wastewater on industrial scale.
5. An important step towards environment sustainability

Chapter 2

2 PROCESS DESCRIPTION

2.1 OVERVIEW:

In order to corroborate the theoretical validation for the research, this chapter provides four main topics to review. The first topic reviews industrial sludge treatment, which is separated into several parts such as characteristics of waste sludge, waste sludge treatment systems, unit operation of pretreatment. The second topic reviews many case studies of alternative sustainable sludge treatment systems in many countries. The third topic is the criteria for determining appropriate sustainable sludge treatment technologies, which include performance, cost, and sustainability considering energy efficiency and pollution issues. The last topic focuses on a method for selecting sustainable technology in this research. This chapter presents the general knowledge of sludge treatment, the alternative sustainable systems, and the method and factor so as to choose appropriate technology, which are important to know, revise and be aware.

2.2 SLUDGE TREATMENT:

Sludge is considered as a nuisance that must be managed, controlled and treated before discharge back into body rivers **[7]**. “Wastewater contains reusable water, calcium and other minute elements (magnesium, boron, and iron) that could be recovered or reused”. There are many sludge treatment systems and each system has different pros and cons. The following sections focus on revising typical sludge treatment technologies.

2.3 CHARACTERIZATION OF SLUDGE:

The composition of different compounds (water, sodium chloride, calcium, magnesium, boron, iron, aluminum) are written in the table below:

Sludge Composition		
Item	**Chemicals**	**Composition**
1	Water	66.69%
2	Sodium Chloride	19.20%
3	Calcium	8.33%
4	Magnesium	4.19%
5	Barium	1.20%
6	Iron	0.19%
7	Aluminum	0.20%
	Total Sludge	**100.00%**

Table 2.1. Sludge Composition 1

2.4 SLUDGE TREATMENT TECHNOLOGIES:

In this section different methods for sludge treatment are reviewed and discussed in detail:

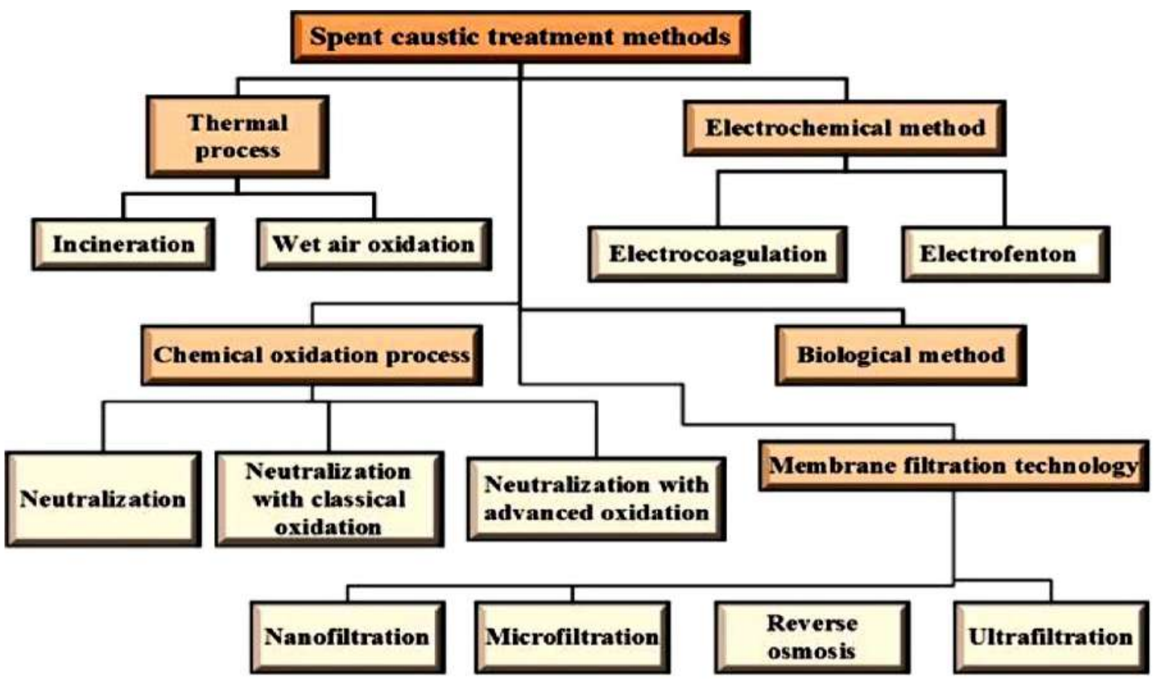


Figure 2.1 Sludge treatment methods 1

2.4.1 Thermal Process:

2.4.1.1 Incineration:

One of the oldest ways to remove caustic is incineration, which is the result of an exothermic chemical process. In principle, incineration is a kind of oxidation reaction that converts high concentration pollution into environmentally less dangerous materials. In this type of process, due to the high speed of the reaction, ambient temperature rises in a little time and generates a lot of heat. Furthermore, this method is not advantageous from economic and environmental points of view due to its high-energy costs and releasing toxic substances from the process **[8].**

2.4.1.2 Wet air oxidation:

Oxidation processes are one of the ways to reduce the concentration of organic compounds in urban and industrial wastewater. The oxidation processes are classified according to the temperature conditions. The most important of these categories are the hydrothermal flames at temperatures above 1000 °C, super-critical water oxidation at 550 °C, and WAO in the range of 100–374 °C. **[8]**

2.4.2 Chemical oxidation process:

Oxidation is one of the best methods for the treatment of industrial and municipal wastewater because it can break down resistant and hard molecules into simple molecules. The basis of the oxidation process is an electron transfer. During the reaction, chemical compounds are produced as radicals with individual electron capacities which are highly unstable and reactive. For this reason, chemical oxidation is one of the most usable methods for wastewater treatment. Chemical oxidation processes are divided into two groups: classical oxidation processes (COPs) and advanced oxidation processes (AOPs). **[9]**

2.4.3 Electrochemical process:

All chemical reactions have an essentially electrical nature because electrons are involved in all types of chemical bonds. Nevertheless, electrochemical processes are oxidizing-reducing phenomena more than any other processes. In electrochemical reactions, the reactant is generated in the anode, and hydrogen is produced in the cathode by applying an electrical current. These processes have more efficiency and applications as they are easier to control. Among the applications of electrochemical processes is the treatment of various contaminants such as industrial wastewater, paper and pulp mill and textile wastewater **[10].**

2.4.4 Biological process:

Caustic treatment using physical/chemical methods are generally carried out in very high operating conditions, which cost a lot. Nevertheless, caustic purification by biological methods occurs at ambient temperature and at atmospheric pressure. For this reason, biological methods are important in terms of process conditions and operating costs. Caustic solutions contain very high sulfide values that convert to elemental sulfur or sulfate by biological purification. One of the most important points to consider in a biological method is that sulfide is poisonous for, and destructive to, the microorganisms existing in such methods **[11]**.

2.4.5 Membrane filtration process:

Membranes have gained a special position because of their ability to control the diffusion of the penetrating molecules which are in contact with it. For this reason, they have many applications in different industries, such as the packaging industry and recovery of precious materials such as caustic soda, salt, polyvinyl alcohol (PVA), and other chemicals. Membranes are used in the food and drink industries, sweetening water, urban and industrial wastewater treatment, among others. There are different definitions for the membrane, but in real terms, the membrane is a discrete interface that creates connections between two homogeneous phases. This interface can have a molecularly homogeneous (i.e., non-porous) or physically or chemically heterogeneous (i.e., porous) structure. **[12]**

2.4.5.1 Microfiltration:

MF is the oldest separation technique among the membrane processes and looks like a classic filtration. The first application of MF membranes was the separation of particles and microorganisms of water pollutants. Over time, MF was also considered for the removal of other pollutants such as natural and synthetic organic compounds. MF is currently used in clearing and sterile filtration of many pharmaceutical and biotechnological products. It is typically used as a pretreatment process to remove solids in suspensions. The MF pore size is from 0.1–10 μm, and the pressure applied to the microfiltration is relatively low (0.1–2 bar), compared to other purification processes. **[13]**

2.4.5.2 Ultrafiltration:

UF membranes are often asymmetric and very similar to MF membranes. MF and UF separation processes are usually based on molecular sieves and often make use of porous membranes. However, there are differences between these two processes. MF membranes separate the outflow particles while the UF membranes separate the colloidal materials and suspensions. Moreover, the solvents eliminated by MF membranes are often larger [258,280]. Materials commonly used in the manufacturing of MF and UF membranes include polysulfone, polyether sulfone, polyacrilonitrile, polyvinylidiene fluoride, polypropylene, polyethylene, and polyvinyl chloride. **[13]**

2.4.5.3 Reverse osmosis process:

For the first time in 1748, Abbe Nolet used the word "osmosis" to explain water permeation, but RO was the first process of separation among the membrane filtration processes that became commercially significant. RO is one of the oldest and most commonly used membrane processes and is very popular in water sweetening today. RO is capable of removing organic and colloidal substances. RO membranes are made of various materials that have remarkably developed in past decades. The first sample of RO was made of diacetate cellulose to produce drinking water. Nowadays, RO membranes are made of polymers. One of the most important materials that have been recently used in RO processes is nanomaterials. **[13]**

2.4.5.4 Nano filtration process:

NF is one of the most recent and most important separation technologies using small-pore (1−5 nm) membranes that were developed in order to solve the problems of typical purification methods. NF was also identified as an advanced water purification process for controlling organic matter. Nano filtration membranes can separate relatively low-molecular-weight organic species, such as sucrose and raffinose, which have a molecular diameter in the range of 1.0–1.3 nm. **[13]**

2.5 SELECTED METHOD:

2.5.1 Membrane separation:

The membrane separation process involves several steps, including pretreatment, separation, and post-treatment. In the pretreatment step, the sludge waste is conditioned to remove large particles and organic matter that could clog the membrane. The conditioned sludge is then fed into a separation unit containing the membrane. The membrane selectively separates the desired chemicals, such as calcium, from the sludge based on their size and charge. The separated chemicals are then collected and concentrated, while the remaining sludge waste is discharged as a byproduct. In the post-treatment step, the byproduct is treated to remove any remaining contaminants and minimize its environmental impact. **[14]**

2.5.2 Comparison of methods:

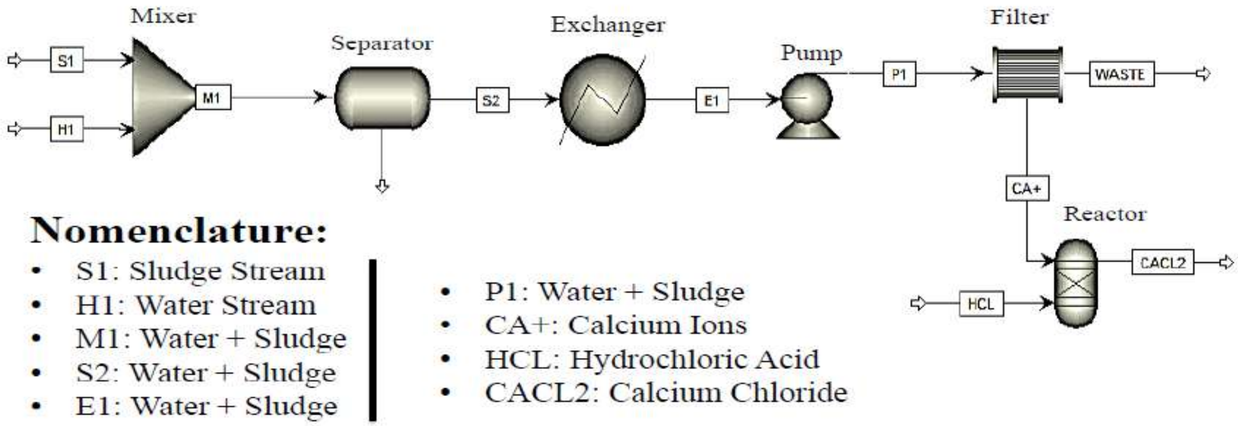
Comparison of different sludge treatment methods are written in the table below. Some properties of these methods are written against some important factors which are discussed as follow:

Sr. No.	Factors	Thermal Processes	Chemical Oxidation	Biological Method	Membrane Separation Technology	Electrochemical Processes
1	Temperature Requirement	High	High	Low	Low	Low
2	Pressure Requirement	High	High	Low	High	Low
3	Time Required	High	Low	High	High	Low
4	Phase Change	Yes	No	No	No	No
5	Economic Stability	No	No	Yes	No	Yes
6	Hazardous for Reactant	Maybe	No	Yes	No	No
7	Catalyst Requirement	Yes	Maybe	Yes	No	No
8	Sensitive	Yes	Yes	Yes	Yes	Yes
9	Environment Friendly	No	Yes	Yes	Yes	Yes

Table 2.1. Comparison of methods 1

2.6 PROCESS FLOW DIAGRAM:

A process flow diagram has been developed to illustrate the steps involved in the membrane separation process. The flow diagram includes the pretreatment step, the separation unit, and the post-treatment step. The design has been optimized to maximize the recovery of useful chemicals, minimize waste production, and minimize environmental impact.



The first step in this process is feed and water mixing and then using a separator to separate out solid particles that may choke the heat exchanger or reduce the efficiency of process. After that process fluid is passed through heat exchanger where its temperature is risen to a required value. From exchanger the material is sent to a pump where process fluid is pumped out at high pressure to a filtration chamber where a specific type of membrane (pvdf) shall be used to extract Ca ions from sludge and then afterwards these ions are reacted with excess of HCl to make Calcium Chloride, which is a very valuable compound and have wide range of application.

2.6.1 Paddle mixer:

The paddle mixer is the first unit operation in the plant, where the sludge and water is mixed to form a homogeneous mixture. The mixer ensures uniformity of the sludge and water mixture before further treatment.

2.6.2 Centrifugal separator:

After the mixing operation, the sludge mixture is pumped to a centrifugal separator, where the solid particles in the sludge are separated from the liquid. The separated liquid is then sent to the next unit operation, while the solid particles are discarded.

2.6.3 Heat exchanger:

In the shell and tube heat exchanger, the liquid phase is heated to a temperature that favors the separation of calcium from other components in the sludge. The heated liquid is then sent to a PD pump for transfer to the PVDf membrane separator.

2.6.4 Pump:

The PD pump is used to transfer the heated liquid to the PVDf membrane separator. The pump operates at a specified flow rate and pressure to ensure efficient separation of the components in the liquid.

2.6.5 Membrane filter:

The PVDf membrane separator utilizes a semi-permeable membrane to separate the calcium from other components in the liquid phase. The calcium-rich retentate is collected and sent to the plug flow reactor, while the permeate is collected and sent to a drain.

2.6.6 Reactor:

The final step in the process is the plug flow reactor, where the solid precipitate and the calcium-rich retentate are combined to produce useful chemicals like calcium chloride. The plug flow reactor operates at a specified temperature and pressure to ensure efficient chemical reactions.

2.7 CONCLUSION:

In conclusion, the membrane separation process has been selected as the preferred method for sludge treatment in our waste sludge treatment plant. The process has been designed to maximize the recovery of useful chemicals, minimize waste production, and minimize environmental impact. A comparison with other proposed methods has shown that the membrane separation process has several advantages over other methods. The design has been optimized to meet the project goals and objectives, and future research and improvements will focus on further optimizing the process and reducing its environmental impact.

Chapter 3

3 MATERIAL ENERGY BALANCE

3.1 OVERVIEW:

This chapter presents the material and energy balance calculations of the waste sludge treatment plant designed for the recovery of useful chemicals from the production of caustic soda. The purpose of this chapter is to provide a comprehensive understanding of the mass and energy flows in the waste sludge treatment process.

Material balance is the first step executed when designing a new process or analyzing an existing one. It is used to determine the quantities of raw materials required and product produced, as well as calculate the flow rate of streams at any point in the process. It is almost an essential step to all other calculations in the process design, such as energy transfer problems and design of equipment. Material balances are the simple application of the principle of mass conservation, which implies that mass can neither be created nor destroyed. Which they can be written for any material that enters or leaves a chemical or physical process. An energy balancing is also performed on each unit to calculate the total amount of energy required for the entire operation, such as heating and power. However, this procedure consumes energy. Energy required for whole process is determined by applying energy balance on each unit in the form of heating and power required. This section deals with the material and energy balance on each equipment to produce desired quantity of calcium chloride.

3.2 MASS BALANCE:

The mass balance calculations involve accounting for the input and output mass flows in the waste sludge treatment plant. The mass balance equations for the process can be expressed as follows:

3.2.1 Input Mass Flows:

- Sludge from the production of caustic soda

- Chemicals added for treatment

3.2.2 Output Mass Flows:

- Recovered calcium
- Treated sludge
- $CaCl_2$

3.2.3 Overall mass balance:

Overall Material Balance(kg/hr)		
Material	**IN**	**OUT**
Sludge	277.5	0
Water	555.8	0
Waste	0	764.24
$CaCl_2$	0	192
H_2	0	3.46
HCl	126.4	0
Total	959.7	959.7

Table 3.1. Overall Mass Balance 1

Basis = 1 hr

Total amount of sludge (without water) = 6,660.8 kg/day

Total amount water content = 13,339.2 kg/day

Total amount = 20,000 kg/day

3.2.4 Mass balance on mixer:

Component Balance on sludge: (S_1)

$$X_{Sludge} = \frac{M_{Sludge}}{M_{out,total}} = \frac{6660.8Kg/day}{20000Kg/day} = 0.3331\ wt\%$$

Component Balance on H2O: (H_1)

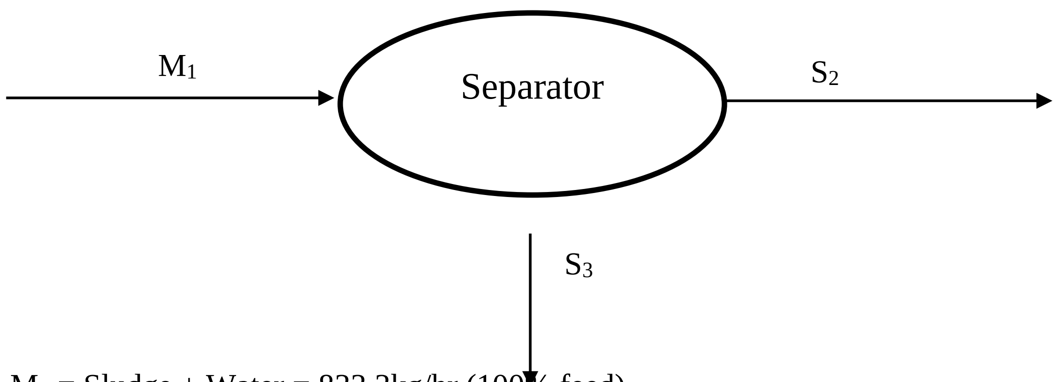
$$X_{H_2O} = \frac{M_{H_2O}}{M_{out,total}} = \frac{13339.2kg/day}{20000Kg/day} = 0.6669wt\%$$

S_1 = Sludge = 277.5 kg/hr (33.31%)

H_1 = Water = 555.8 kg/hr (66.69%)

M_1 = Sludge + Water = 833.3kg/hr (100%)

3.2.5 Mass balance on separator:

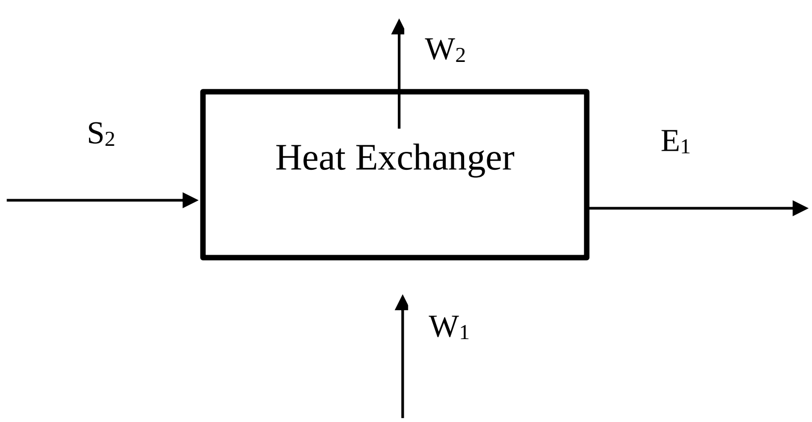


M_1 = Sludge + Water = 833.3kg/hr (100% feed)

Supposing 5% **[15]** of mass separating through S_3 stream = Waste = 41.6 kg/hr (5%)

S_2 = Sludge + Water = 791.64 kg/hr (95% of feed)

3.2.6 Mass Balance on heat exchanger:



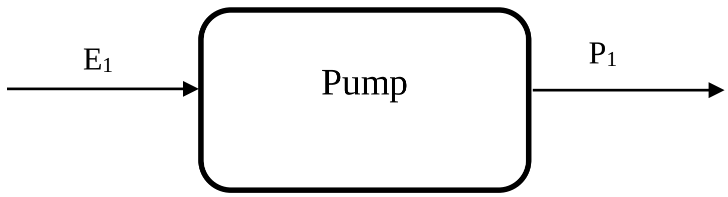
S_2 = Sludge + Water = 791.64 kg/hr (95% of feed)

E_2 = Sludge + Water = 791.64 kg/hr (95% of feed)

W_1 = High Temperature Water = 13.89 kg/hr

W_2 = Low Temperature Water = 13.89 kg/hr

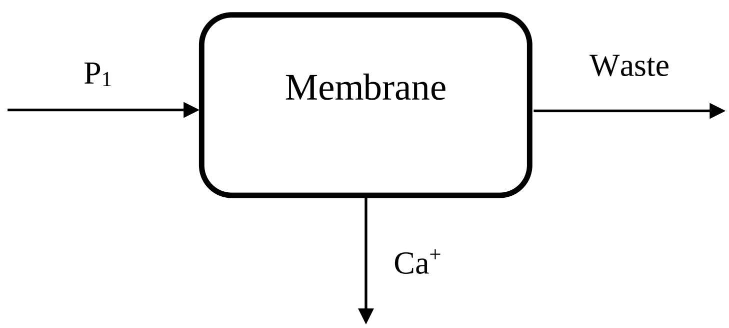
3.2.7 Mass balance on pump:



E_1 = Sludge + Water = 791.64 kg/hr (95% of feed)

P_1 = Sludge + Water = 791.64 kg/hr (95% of feed)

3.2.8 Mass balance on membrane:



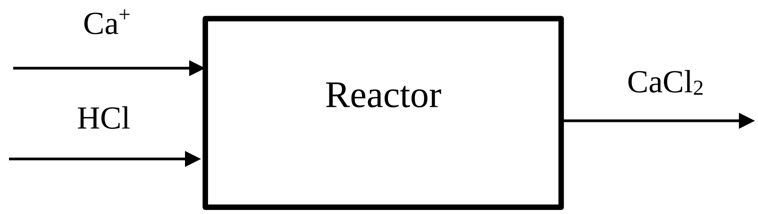
P_1 = Sludge + Water = 791.64 kg/hr (95% of feed)

Waste = Water + Mg + NaCl + Ba + Al + Ag = 738.9 kg/hr (88.4% of feed)

As efficiency of membrane = 80% so

Ca^+ = Calcium ions = 52.75 kg/hr (6.66% of feed)

3.2.9 Mass balance on reactor:



Ca^+ = Calcium ions = 52.75 kg/hr (6.66% of feed)

HCl = Hydrochloric acid = 96.06 kg/hr of feed in the reactor

$CaCl_2$ = Calcium chloride = 148.81 kg/hr of product

3.2.10 Component mass balance:

The component mass balance of the process is summarized in the given table:

Component Material Balance (kg/hr)			
Instrument	**Material**	**IN**	**OUT**
Mixer	Sludge + Water	833.33	833.33
Exchanger	Sludge + Water	833.3	833.3
Pump	Sludge + Water	833.3	833.3
Separator	Sludge + Water	833.3	791.7
Filter	Calcium	0	52.75
Filter	Waste	833.3	738.9
Reactor	HCl	96.06	0
Reactor	Calcium	52.75	0
Reactor	$CaCl_2$	0	148.81

Table 3.2. Component mass balance 1

3.3 ENERGY BALANCE:

Energy balance is also important in chemical engineering and involves accounting for the energy entering and leaving a system. This is important for understanding the energy efficiency of a process, and for ensuring that the process is safe and sustainable. Energy balance equations can be written for each component of the system, and these equations can be solved simultaneously to determine the energy flows in and out of the system.

The energy balance for the waste sludge treatment process is based on the law of conservation of energy. The energy balance equation can be expressed as:

Input energy = Output energy + Accumulation + Heat of Reaction

Where input energy refers to the energy required to run the process, output energy refers to the energy produced by the process, accumulation refers to the energy lost through waste, and heat of reaction refers to the energy released or absorbed during chemical reactions.

3.3.1 Overall energy balance:

The overall energy balance of the process is written in the table below:

Overall Energy Balance					
Streams	**Material**	**In(ΔH_f)**	**Out(ΔH_f)**	**Temperature**	**Pressure**
S_1	Sludge	-298.95	0	298 K	101.325 Kpa
H1	Water	-286	0	298 K	101.325 Kpa
HCL	HCL	-92.3	0	298 K	101.325 Kpa
Waste	Waste	0	-79.31	298K	101.325 Kpa
$CaCl_2$	CaCl2	0	-795	298K	101.325 Kpa
	Heat of Reaction for this process is			**-197.06 KJ/mol**	

Overall, this process is exothermic and is releasing the heat to its surrounding.

3.3.2 Energy balance on mixer:

$\Delta H_f^{H_2O}$ = -285.83 kJ/mol

ΔH_f^{sludge} = -298.95 kJ/mol

$$\Delta H_{reaction} = [(-298.95) + (0)] + [(-285.83) + (0)]$$

$$\Delta H_{reaction} = -584.95 \text{ kJ/mol}$$

There are 3 streams related to mixer S_1, H_1, M_1. The heat of reaction for water and sludge are written above and using these values, we can calculate heat of reaction or energy operating in mixer.

3.3.3 Energy balance on reactor:

$\Delta H_f^{calcium}$ = -543 kJ/mol

ΔH_f^{HCl} = -92.3 kJ/mol

$\Delta H_f^{CaCl_2}$ = -795 kJ/mol

$$\Delta H_{reaction} = [(-795) + (0)] - [(-543) + (-92.3)]$$

$$\Delta H_{reaction} = -159.7 \text{ kJ/mol}$$

The final heat of reaction for production of calcium chloride is -159.7 KJ/mol at ambient conditions of temperature and pressure.

3.3.4 Component energy balance:

The component energy balance for the process is written in the following table:

Component Energy Balance						
Equipment	**Streams IN**	**Streams OUT**	**In(ΔH$_f$)**	**Out(ΔH$_f$)**	**Temperature**	**Pressure**
Mixer	$S_1 + H_1$	M_1	-584.95	-584.95	298 K	101.325 Kpa
Exchanger	M_1	E_1	-584.95	-584.95	338 K	101.325 Kpa
Pump	E_1	P_1	-584.95	-584.95	338 K	101.325 Kpa
Separator	P_1	S_2	-584.95	-584.95	338 K	101.325 Kpa
Filter	S_2	Waste + Ca^+	-584.95	-505.6, and -79.30	338 K	101.325 Kpa
Reactor	Ca^+ + HCl	$CaCl_2$	-635.3	-795	298 K	101.325 Kpa

Table 3.4. Component energy balance 1

The energy balance for every equipment is done in the above table. All the in and out streams of an equipment are stated along with the heat of reactions. The required conditions of temperature and pressure is written according to the equipment.

Chapter 4

4 EQUIPMENT DESIGN

4.1 OVERVIEW

This chapter provides a comprehensive overview and outlines the design process, design specifications, material selection, and other relevant factors for the equipment design. The primary focus of this chapter is on the design of two key equipment: A heat exchanger and reactor. The purpose of these equipment is to support the efficient and sustainable sludge treatment system and production of calcium chloride.

4.2 DESIGN OF MIXER:

4.2.1 Comparison of mixers:

The comparison of different mixers is mentioned in the following table: **[16]**

Types of mixers	Rotational speed	Type of materials	Viscosity of material
Ribbon mixers	Low speed	Dry powders, pastes and blending of fragile materials	Low viscosity
Paddle mixers	High speed	mixing wet and dry ingredients	High viscosity
High-shear mixers	High speed	mixing, emulsifying, and homogenizing products	High viscosity
Continuous mixers	Low speed	Homogeneous mixture	High viscosity

Table 4.1. Comparison of mixers

4.2.2 Selection steps of mixer:

Designing an industrial mixer for mixing sludge thoroughly involves several steps. Using data from above table a paddle mixer is selected. The steps to select a mixer are written as follows. Here's a general outline of the process: **[17]**

1. **Define the objective:** The first step is to clearly define the objective of the mixing process.
2. **Determine the scale:** Identify the required production capacity of the mixer.
3. **Identify the properties of the materials**: Understand the properties of the materials involved, such as the solubility of salt in water, the density, and the viscosity of the solution. This information will help determine the appropriate mixing conditions and equipment.
4. **Select the mixer type:** Based on the scale and material properties, choose the appropriate type of mixer. Common industrial mixers for sludge include agitators, paddle mixers, and static mixers. Each type has its advantages and limitations, so it's essential to select the one that best suits your specific application.
5. **Design the mixer:** Design the mixer according to the selected type, considering factors such as the impeller type, motor power, mixing speed, and tank geometry. Ensure that the design provides sufficient mixing to achieve a homogeneous solution while minimizing energy consumption and wear on the equipment.
6. **Optimize the mixing process**: Determine the optimal mixing conditions, such as mixing time, temperature, and agitation speed, to achieve the desired concentration and homogeneity of the saline solution.
7. **Continuous improvement:** Monitor the performance of the mixer during operation and make adjustments as needed to optimize the process and maintain the desired product quality.

4.2.3 Design of mixer:

Mixing required = 333g/liter

Mixer capacity required = 2 m^3

Assuming the constant density of the sludge:

Density of water = ρ = 1000 kg/m^3

μ = 1.07 mPa.s = 1.07 cP

The geometry of paddle type mixer, is simply cylindrical with

Radius = 0.9 m and Height = 5.5 m **[17]**

Calculating the Reynolds and Froude number for saline solution.

$$R_e = \frac{D^2 \times N_r \times \rho}{\mu} = \frac{(1.8)^2 \times (90/60) \times 1000}{1.07 \times 10^{-3}}$$

$$R_e = 45.42 \times 10^5$$

$$F_r = \frac{D^2 \times N_r}{g} = \frac{(1.8)^2 \times (90/60)}{9.8}$$

$$F_r = 0.2755$$

Constant for un-baffled mixer are

a = 1; b = 40 **[17]**

$$F_r = \frac{1 - \log(R_e)}{b} = \frac{1 - \log(4542000)}{40}$$

$$m = -0.14143$$

From the figure, by using Reynold number

$$\Phi = 1.06$$

$$P = \phi \times F_r^m \times N_r^3 D^5 \times \rho$$

$$P = 41.5 \text{ kW}$$

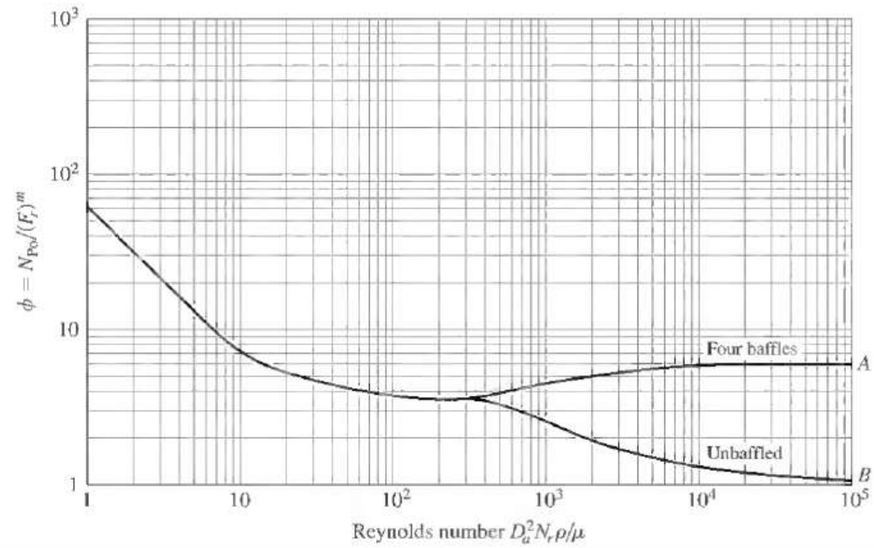


Figure 4.1: Relation between the power function 0 and the Reynolds number for a six-blade mixer

The design specification sheet of paddle mixer is written in below table: **[17]**

Design Parameter	Value
Capacity	2 m^3
Mixing Time	30 minutes
Motor Power	41.5 kW
Material of Construction	304 Stainless steel
Shape	Horizontal, cylindrical
Agitator Type	Paddle
No. of paddle	6
Clearance between Paddles and Tank Walls	5% of paddle width

Table 4.2. specification sheet of mixer

4.3 DESIGN OF SEPARATOR:

4.3.1 Comparison of separators:

The comparison of different separator is discussed below and choosing one type of separator which is compatible with industrial sludge. **[18]**

Type of separators	Working Principle	Type of materials
Gravity separators	force of gravity	Construction and demolition waste
Electrostatic separators	electrical conductivity	Minerals
Centrifugal separators	centrifugal force	Industrial waste

Table 4.3. comparison of separators

4.3.2 Selection steps of separator:

The design steps for a separator are as: **[19]**

1. Bowl diameter
2. Solid discharge
3. Material of construction
4. Shape
5. Feed Flow rate
6. Settling speed
7. Solid Concentration
8. Operating Time

4.3.3 Design of separator:

Feed rate of sludge: 20 tons per day

Determine the size and shape of the separator: [20]

Diameter of separator: 3 meters

Height of separator: 6 meters

Volume of separator = $(\pi/4) \times d^2 \times (\text{height}) = (\pi/4) \times (3\ )^2 \times (6) = 42.41\ m^3$

Determine the flow rate:

Flow rate = 20 tons per day = 833.3 kg/hr

Calculate the residence time:

Residence time = Volume of separator / Flow rate = 42.41 cubic meters / 833.3 kg/hr

= 0.05 hours

Determine the settling velocity:

Using Stokes' Law, the settling velocity can be calculated as:

$v^s = (2/9) \times (\text{density difference}) \times (\text{particle diameter})^2 \times (\text{gravity}) / (\text{viscosity})$

$v^s = (2/9) \times (0) \times (0.001\ m)^2 \times (9.81\ m/s^2) / (0.001\ Pa.s) = 0.0000206\ m/s$

Determine the minimum settling distance:

This distance can be calculated using the equation:

Minimum settling distance = settling velocity x residence time

Minimum settling distance = 0.0000206 m/s x 7633 seconds = 0.1577 meters

Check that the height of the separator is greater than the minimum settling distance:

Height of separator = 6 meters

Since 6 meters is greater than 0.1577 meters, the design meets the requirement for effective particle separation. **[20]**

Parameter	Value
Feed rate of sludge	20 tons per day
Diameter of separator	3 meters
Height of separator	6 meters
Volume of separator	42.41 cubic meters
Flow rate of sludge	833.3 kg/hr
Material of construction	304 SS
Gravity	9.81 m/s^2
Viscosity of water at 20 degrees Celsius	0.001 Pa.s
Settling velocity of particles	0.0000206 m/s
Minimum settling distance required	0.1577 meters

Table 4.4. Design specification sheet of separator

4.4 DESIGN OF HEAT EXCHANGER:

4.4.1 Different types of heat exchangers:

1. **Shell and tube heat exchangers**: This is the most common type of heat exchanger used for slurry materials. It consists of a series of tubes that are mounted inside a cylindrical shell. The slurry flows through the tubes while the heating or cooling medium flows around the tubes in the shell. **[21]**

2. **Plate heat exchangers:** Plate heat exchangers are composed of a series of plates with small gaps in between them. The slurry flows through the gaps while the heating or cooling medium flows on the other side of the plates.

3. **Spiral heat exchangers:** Spiral heat exchangers have a spiral configuration and are designed to handle high viscosities. The slurry flows through a spiral channel while the heating or cooling medium flows around the outside of the channel.

4. **Scraped surface heat exchangers:** Scraped surface heat exchangers are designed to handle highly viscous slurries. They have a rotating blade that scrapes the slurry from the heat transfer surface to ensure that heat transfer is efficient.

Type of Heat Exchanger	**Key Features**
Shell and Tube Heat Exchanger	Consists of a series of tubes mounted inside a cylindrical shell. Slurry flows through tubes while heating or cooling medium flows around tubes in shell. Suitable for high-pressure and high-temperature applications. Allows for easy cleaning and maintenance.
Plate Heat Exchanger	Composed of a series of plates with small gaps in between them. Slurry flows through gaps while heating or cooling medium flows on other side of plates. Compact and efficient design. Suitable for low-viscosity fluids. Can handle high flow rates.
Spiral Heat Exchanger	Spiral configuration. Slurry flows through spiral channel while heating or cooling medium flows around outside of channel. Designed to handle high viscosities. High heat transfer coefficient. Low pressure drop.
Scraped Surface Heat Exchanger	Designed to handle highly viscous slurries. Consists of a rotating blade that scrapes slurry from heat transfer surface to ensure efficient heat transfer. Suitable for sludges with high solids content.

Table 4.5. Comparison of heat exchanger

4.4.2 Design steps of heat exchanger:

Different design steps to design a heat exchanger are described below: **[22]**

1. Determine physical properties, heat duty, heat-transfer rate, fluid flow-rates, temperatures.
2. Decide the type of exchanger to be used.
3. Calculate the mean temperature difference, Tm.
4. Calculate the area required.
5. Select a trial value for the overall coefficient, U.
6. Decide the exchanger layout.
7. Calculate the individual coefficients.
8. Calculate the overall coefficient.
9. Calculate the exchanger pressure drop.
10. Optimize the design

4.4.3 Design of heat exchanger:

The following design of heat exchanger is done manually on Excel:

Given Data

Sludge	water
T1 (^oC) = 15	t1 (^oC) = 80
T2 (^oC) = 40	t2 (^oC) = 60
m (kg/h) = 833.33	

Solution

Heat Capacity of Sludge = 3.0412 kJ/kg^{o}C

Heat Load = 17.5 KW

Heat Capacity of water = 4.2 kJ/kg^{o}C

Cooling water flowrate = 0.209 kg/s

Log mean temperature difference = 42.45 ^{o}C

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}}$$

From figure 12.16 **[23]**

Ft = 0.92

LMTD = 39.054 ^{o}C

U = 50 W/m^2 ^{o}C

Provisional Area

A = 9.012 m^2

Choose 20 mm 0.d, 16 mm i.d., 4.88 m long tubes (3.4 in * 16 ft), cupro -nickel. **[23]**

Allowing for tube-sheet thickness, take

L = 4.83 m

Area of one tube = 0.32 m^2

Number of tubes = 29.7 = 30

As the shell-side fluid is relatively clean use 1.25 triangular pitch.

n_1 = 2.207

K_1 = 0.249

Bundle Diameter D_b = 174.58 mm

$$D_b = d_o \left(\frac{N_t}{K_1}\right)^{1/n_1},$$

Use a split-ring floating head type.

From figure 12.10, bundle diametrical clearance = 52mm

Shell diameter, D_s = 226.58 mm (Note: standard pipe sizes are 863.6 or 914.4 mm)

Tube-Side Coefficient

Mean Water temperature = 70 ^{0}C

Tube cross Sectional Area = 200.96 mm^2

Tubes per pass = 4

Total flow area = 0.0029 m^2

Water mass Velocity = 70.175 kg/s m^2

Density of Water = 995 kg/m^3

Water Linear Velocity = 0.070 m/s

h_i = 795.14 W/m^2 ^oC

$$h_i = \frac{4200(1.35 + 0.02t)u_i^{0.8}}{d_i^{0.2}}$$

Shell-Side Coefficient

choose baffle spacing = 34.91 mm

Tube pitch = 25 mm

Cross-flow area A_s = 0.0015 m^2

Mass Velocity, G_s = 146.28 kg/s m^2

$$G_s = \frac{W_s}{A_s}$$

Equivalent Diameter d_e = 14.2 mm

$$d_e = \frac{4\left(\frac{p_t}{2} \times 0.87 p_t - \frac{1}{2}\pi \frac{d_o^2}{4}\right)}{\frac{\pi d_o}{2}} = \frac{1.10}{d_o}(p_t^2 - 0.917 d_o^2)$$

Mean Shell temperature = 27.5 ^oC

Sludge Density = 1334 kg/m^3

Sludge viscosity = 0.00021 Ns/m^2

Thermal conductivity = 0.15 W/m ^0C

Heat capacity = 3041.2 j/kg ^oC

Re = 9892.33

P_r = 4.25768

Choose 25% baffle cut, from figure 12.29 **[23]**

J_h = 0.0033

Without the viscosity correction term

h_s = 558.86 W/m^2 ^oC

Estimate wall temperature

Mean temperature difference = 5 ^oC

Across all resistance

Across Sludge film = 0.447

Mean wall temperature = 27.05 ^{0}C

U_w = 0.00037 Ns/m^2

$(U/U_w)^{0.14} = 0.92$

Overall Coefficient

Thermal conductivity of cupro-nickel alloys = 50 W/m^2 ^{o}C

U_o = 60.7 W/m^2 ^{o}C

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o \ln\left(\frac{d_o}{d_i}\right)}{2k_w} + \frac{d_o}{d_i} \times \frac{1}{h_{id}} + \frac{d_o}{d_i} \times \frac{1}{h_i}$$

Well above assumed value of 50 W/m^2 ^{o}C

4.4.4 Design of Heat Exchanger:

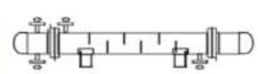
The following design of heat exchanger is done on a computer tool which is used to design different equipment, Aspen Plus.

TEMA Sheet of heat exchanger is attached below:

PERFORMANCE OF ONE UNIT					
Fluid allocation		Shell Side		Tube Side	
Fluid name					
Fluid quantity, Total	kg/s	0.2315		0.2778	
Vapor (In/Out)	kg/s	0	0	0	0
Liquid	kg/s	0.2315	0.2315	0.2778	0.2778
Noncondensable	kg/s	0	0	0	0
Temperature (In/Out)	°C	25	39.99	55	45.76
Bubble / Dew point	°C	/	/	/	/
Density Vapor/Liquid	kg/m³	/ 832.2	/ 826.28	/ 964.62	/ 973.79
Viscosity	mPa-s	/ 2.8797	/ 2.3775	/ 0.5141	/ 0.6031
Molecular wt, Vap					
Molecular wt, NC					
Specific heat	kJ/(kg-K)	/ 3.33	/ 3.307	/ 4.531	/ 4.525
Thermal conductivity	W/(m-K)	/ 0.5016	/ 0.5078	/ 0.6427	/ 0.6327
Latent heat	kJ/kg				
Pressure (abs)	bar	1.01325	1.00546	1.01325	0.98827
Velocity (Mean/Max)	m/s	0.03 / 0.03		0.55 / 0.56	
Pressure drop, allow./calc.	bar	0.1	0.00779	0.1	0.02498
Fouling resistance (min)	m²-K/W	0.0001		0.0001	0.00013 Ao based
Heat exchanged	11.7 kW			MTD (corrected) 16.33 °C	
Transfer rate, Service	348.9	Dirty 415.1		Clean 458.6	W/(m²-K)

CONSTRUCTION OF ONE SHELL				
			Shell Side	Tube Side
Design/Vacuum/test pressure		bar	3.44738 / /	3.44738 / /
Design temperature		°C	76.67	93.33
Number passes per shell			1	6
Corrosion allowance		mm	3.18	3.18
Connections	In	mm	1 19.05 / -	1 19.05 / -
Size/Rating	Out		1 19.05 / -	1 19.05 / -
Nominal	Intermediate		/ -	/ -

Sketch



Tube #: 30	OD: 19.05	Tks. Average 2.11 mm	Length: 1219.2 mm	Pitch: 23.81 mm Tube pattern: 30
Tube type: Plain	Insert: None		Fin#: #/m	Material: Carbon Steel
Shell Carbon Steel	ID 205	OD 219.08 mm	Shell cover	-
Channel or bonnet	Carbon Steel		Channel cover	-
Tubesheet-stationary	Carbon Steel	-	Tubesheet-floating	-
Floating head cover	-		Impingement protection	None
Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 44.56	H Spacing: c/c 133.35	mm
Baffle-long -	Seal Type		Inlet 238.12	mm
Supports-tube	U-bend	0	Type	
Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')	
Expansion joint	-	Type None		
RhoV2-Inlet nozzle	827	Bundle entrance 0	Bundle exit 0	kg/(m-s²)
Gaskets - Shell side	-	Tube side	Flat Metal Jacket Fibe	
Floating head	-			
Code requirements	ASME Code Sec VIII Div 1		TEMA class	R - refinery service
Weight/Shell	204.8	Filled with water 242.6	Bundle 68.3	kg

Figure 4.2. Tema sheet of exchanger

4.5 SELECTION OF PUMP:

4.5.1 Comparison of Pumps:

Some of the common types of pumps used for slurry materials include: **[24]**

Centrifugal pumps: These pumps use a rotating impeller to create a centrifugal force that moves the slurry through the pump and into the pipeline. They are commonly used for low-to-medium viscosity slurry.

Positive displacement pumps: These pumps use a mechanical system to move the slurry through the pump, such as a piston, diaphragm, or screw. They are typically used for high-viscosity or abrasive slurries.

Submersible pumps: These pumps are designed to be submerged in the slurry, allowing them to operate without the need for priming. They are often used for pumping slurries from sumps or pits.

Slurry pump: These pumps are specifically designed for handling abrasive and/or viscous materials such as slurry. They typically have a heavy-duty construction and are capable of handling high concentrations of solids in the slurry.

Comparison table of some pumps is given below: **[24]**

Pump Type	Advantages	Limitations
Centrifugal pumps	Relatively simple and cost-effective, can handle large flow rates	May not be suitable for high-concentration slurries or highly abrasive materials, impeller may wear quickly
Positive displacement pumps	Can handle high-viscosity or abrasive slurries, less susceptible to wear	More expensive than centrifugal pumps, may require more maintenance

Submersible pumps	Can operate without the need for priming, suitable for pumping from sumps or pits	Limited flow rates and head pressures, may not be suitable for long-distance pumping
Slurry pumps	Specifically designed for handling abrasive and/or viscous materials, can handle high concentrations of solids	Heavy-duty construction, may be more expensive than other pump types

Table 4.6. Comparison of pumps

4.5.2 Design steps of Heat Exchanger:

Design steps for selecting a pump are as follows: **[25]**

1. Flow Rate
2. Differential Pressure
3. Material of Construction
4. Motor Power
5. Efficiency
6. Discharge Pressure
7. Suction Pressure
8. Operating Temperature

4.5.3 Calculation of Pump:

Calculation of specific speed: [26]

$$N_s = N * Q^{1/2} / H^{3/4}$$

Where,

N = Pump speed (rpm)

Q = Flow rate (m^3/h)

H = Differential head (m)

Converting the given values of flow rate and differential pressure to head, we get:

$$H = 8 * 10^5 / (1000 * 9.81) = 81.7 \text{ m}$$

Substituting the given values, we get:

$$N_s = N * (0.83)^{1/2} / (81.7)^{3/4}$$

Calculation of Pump Head:

The total head developed by the pump can be calculated as:

$$H = H_d + H_s$$

Where,

H_d = Differential head (m)

H_s = Static head (m)

Converting the given pressures to head, we get:

$$H_d = 8 * 10\text{^}5 / (1000 * 9.81) = 81.7 \text{ m}$$

$$H_s = (9 - 1) * 10\text{^}5 / (1000 * 9.81) = 81.1 \text{ m}$$

Substituting the values, we get:

$$H = 81.7 + 81.1 = 162.8 \text{ m}$$

Calculation of Power Requirements:

The power required to drive the pump can be calculated as:

$$P = Q \text{ x } H \text{ x } \rho \text{ x } g / \eta$$

Where,

P = Power required (kW)

Q = Flow rate (m^3/h)

H = Total head developed by pump (m)

ρ = Density of fluid (kg/m^3)

g = Acceleration due to gravity (9.81 m/s^2)

η = Pump efficiency

Assuming the density of water at 40°C as 1000 kg/m^3, and substituting the given values, we get:

$$P = 50 \times 162.8 \times 1000 \times 9.81 / (0.75 \times 10^3) = 1018 \text{ kW}$$

The power required by the pump is 1018 kW.

The design specification sheet of the pump is given in the following table:

Design Parameter	**Value**
Flow Rate	0.83 m^3/h
Differential Pressure	8 bar
Material of Construction	304 Stainless steel
Pump Type	Positive displacement, rotary
Motor Power	1018 kW
Efficiency	75%
Discharge Pressure	9 bar
Suction Pressure	1 bar
Operating Temperature	40°C

Table 4.7. Specification of pump

4.6 DESIGN OF REACTOR:

4.6.1 Comparison of Reactor:

There are different types of reactors that can be used for various chemical reactions involving calcium and hydrochloric acid. Some common types of reactors include: **[27]**

1. Batch reactors: These are reactors in which the reactants are added and allowed to react until the desired product is formed. They are commonly used in small-scale production or laboratory settings.
2. Continuous stirred tank reactors (CSTRs): These are reactors in which reactants are continuously added and withdrawn while being mixed by a stirrer. They are commonly used in large-scale industrial production.
3. Plug flow reactors (PFRs): These are reactors in which the reactants flow through a tube or pipe and react as they move along the length of the reactor. They are commonly used in continuous production processes.
4. Fixed bed reactors: These are reactors in which the reactants flow through a bed of catalyst or other material that promotes the desired reaction. They are commonly used in petrochemical and other large-scale production processes.

A table of comparison of CSTR and PFR is given below for some important factors. **[27]**

Factors	CSTR	PFR
Type of reactor	Continuously Stirred Tank Reactor	Plug Flow Reactor
Flow of reactants	Continuously added to the reactor and continuously stirred	Flow through a tube or pipe while reacting along the length
Temperature control	Precise temperature control	Better temperature control due to efficient heat transfer
Heat transfer	Not efficient for highly exothermic reactions	Efficient for highly exothermic reactions
Reaction rate	Moderate	High
Product quality	Uniform mixing	Residency time dependent for desired product quality
Production rate	Suitable for industrial processes involving continuous reactions	May not be suitable for high production rates
Cost of reactor	Relatively low	Relatively high
Suitable for reaction	Reactions that require precise temperature control and uniform mixing	Reactions that are highly exothermic and require efficient heat transfer and high conversion rates

Table 4.8. Comparison of CSTR and PFR

4.6.2 Design steps of Reactor:

Designing a reactor involves several steps to ensure optimal performance, efficiency, and safety. Here's a general outline of the process: **[28]**

1. **Define the objective:** Clearly state the purpose of the reactor, such as producing a specific chemical product or carrying out a specific chemical reaction.
2. **Select the reactor type**: Based on the objective and scale, choose the appropriate type of reactor. Common types include batch reactors, continuous stirred-tank reactors (CSTRs), plug-flow reactors (PFRs), and fluidized-bed reactors. Each type has its advantages and limitations, so it's essential to select the one that best suits your specific application.
3. **Determine the reaction parameter**: Identify the rate law, stoichiometry and reaction kinetics for required reaction
4. **Apply energy balance for reactor:** Apply the energy balance to determine the reactor temperature during reaction and relationship between temperature conversion.
5. **Design the reactor components**: Design the key components of the reactor, such as the vessel, agitator (if applicable), heat exchanger, and catalyst (if applicable). Consider factors such as material selection, geometry, and surface area to optimize the performance and efficiency of the reactor.
6. **Design the supporting systems**: Design the necessary supporting systems, such as the power supply, cooling system, and control systems. Ensure that these systems are compatible with the reactor type and can meet the required performance and safety standards.
7. **Safety and environmental considerations**: Ensure that the reactor design and operation comply with safety regulations and environmental standards. This includes proper containment and handling of materials, as well as minimizing waste and emissions.
8. **Continuous improvement:** Monitor the performance of the reactor during operation and make adjustments as needed to optimize the process and maintain the desired product quality.

4.6.3 Reactor Calculations:

Reaction rate equation: The reaction between calcium and hydrochloric acid can be represented by the following chemical equation:

$$Ca + 2HCl \rightarrow CaCl_2 + H_2$$

The reaction rate can be determined experimentally or by using literature data. Assuming the reaction is first-order with respect to both calcium and hydrochloric acid, the rate equation can be expressed as follows: **[29]**

$$rate = k[Ca][HCl]^2$$

where k is the rate constant and [Ca] and [HCl] are the concentrations of calcium and hydrochloric acid, respectively.

Residence time: Assuming a desired conversion of 95%, we can use the following equation to calculate the required residence time:

$$t = \ln(1 - X) / (-k[Ca_o][HCl_o]^2)$$

where X is the desired conversion, Ca_o and HCl_o are the initial concentrations of calcium and hydrochloric acid, respectively.

Substituting the given values, we get:

$$t = \ln(1 - 0.95) / (-k[1][2]^2) = 39.2 \text{ s}$$

Reactor volume: The reactor volume can be calculated using the following equation:

$$V = Q * t$$

where Q is the total flow rate of both compounds, which is given as 196 kg/hr, and t is the residence time calculated above.

Substituting the values, we get:

$$V = 196 * 39.2 / 3600 = 2.12 \text{ m}^3$$

The specification sheet of the reactor for the above calculation is given below in the table:

Design Parameters	Value
Reaction rate equation	rate = k[Ca][HCl]^2
Desired conversion	95%
Residence time	39.2 s
Total flow rate	196 kg/hr
Reactor volume	2.12 m^3
Reactor configuration	Plug flow reactor
Reactor size and shape	Cylindrical with a diameter of 1 m and a length of 2.5 m
Operating conditions	Temperature: 25°C, Pressure: 1 atm
Material compatibility	Stainless steel (316L), Titanium, Teflon (PTFE)

Table 4.9. Specification sheet of reactor

4.7 SELECTION OF MEMBRANE:

Polyvinylidene fluoride (PVDF) is a type of membrane material commonly used in various applications, including sludge treatment, gas separation, and biomedical applications. The following are some of the properties of PVDF membranes: **[30]**

Chemical resistance: PVDF membranes have excellent chemical resistance to a wide range of organic and inorganic compounds, acids, bases, and solvents.

Thermal stability: PVDF membranes have high thermal stability, which makes them suitable for use at high temperatures.

Hydrophobicity: PVDF membranes are hydrophobic, meaning they repel water and are suitable for use in applications where water needs to be removed or filtered.

Mechanical strength: PVDF membranes are strong and durable, with good mechanical properties that allow them to withstand high pressures and resist tearing.

Pore size: PVDF membranes can be manufactured with a wide range of pore sizes, from microporous to ultrafiltration, depending on the intended application.

Serializability: PVDF membranes can be easily sterilized by autoclaving or gamma irradiation, making them suitable for use in biomedical applications.

Biocompatibility: PVDF membranes have good biocompatibility, making them suitable for use in medical applications such as blood filtration and dialysis.

Overall, PVDF membranes are a versatile and durable material with excellent chemical resistance, hydrophobicity, and mechanical strength, making them suitable for a wide range of applications.

Removal of calcium ions from sludge:

The removal of calcium ions from sludge can be achieved through several methods such as chemical precipitation, ion exchange, and membrane processes. In the membrane process, a PVDF membrane can be used for the removal of calcium ions through a process called Nanofiltration. It is a membrane filtration process that operates on a molecular level, removing ions and molecules from a solution based on their size and charge. PVDF membranes have a tight pore size distribution, allowing them to effectively remove ions such as calcium from the sludge. The efficiency of the process will depend on several factors such as the concentration of calcium ions in the sludge, the flow rate, and the pressure applied. **[31]**

The efficiency of the process can be measured by the percentage removal of calcium ions from the sludge. The actual efficiency will depend on several factors such as the initial concentration of calcium ions, the operating conditions, and the properties of the membrane. However, Nanofiltration processes have been reported to achieve up to 90% removal efficiency for calcium ions from wastewater and sludge.

Chapter 5

5 INSTRUMENTATION AND CONTROL

5.1 OVERVIEW

Instrumentation and control is a branch of engineering that deals with the measurement and control of physical variables in various processes. The instrument is used to check and adjust the primary parameters in a process plant that must be controlled.

Instrumentation involves the use of various instruments or devices such as sensors, transmitters, controllers, and actuators to measure and control the physical variables. Sensors convert the physical variable into an electrical signal, which is transmitted to the controller. The controller compares the measured value with the desired value and sends a signal to the actuator to adjust the physical variable to the desired value.

5.2 NEED OF INSTRUMENTATION AND CONTROL

The main instruments used in the waste sludge treatment plant include flow meters, level sensors, pressure gauges, temperature sensors, and pH meters. Flow meters are used to measure the flow rate of the sludge through the various treatment processes. Level sensors are used to measure the level of the sludge in tanks and vessels. Pressure gauges are used to measure the pressure of the sludge in pipelines and vessels. Temperature sensors are used to measure the temperature of the sludge in the process streams. pH meters are used to measure the pH of the sludge in the treatment process.

The principles of operation for each instrument are explained in detail, along with their applications in the plant. For example, flow meters are used to ensure that the correct amount of sludge is fed into the treatment process, while level sensors are used to prevent overfilling of tanks and vessels. Examples are provided to illustrate how the instruments are used in monitoring and controlling the treatment process. For instance, the pH meter is used to adjust the pH of the sludge in the neutralization process to ensure that it is within the desired range.

5.3 CONTROL SYSTEM:

The control system for the waste sludge treatment plant is designed to maintain stable operation of the plant. Different control loops are involved in the process, such as flow control, level control, and pressure control. The control loops are interlinked to ensure that the treatment process operates smoothly. **[32]**

Control lops can be classified into two loops:

- Open loop control system
- Closed loop control system

Open loop control

A simple type of control where the controller does not take feedback from the process.

Closed-loop control

On the other hand, involves feedback from the process to the controller, which adjusts the process variable to the desired value.

5.4 CONTROL DEVICES:

In order to keep control over equipment and process most of industries of controller devices. Most important process control equipment involves **[33]**

- Level control and monitoring
- Pressure Control and Monitoring
- Automated control system
- Temperature control and monitoring

5.4.1 Level control and monitoring:

Level control devices are successfully used to monitor and control level of fluids and solids with equipment. For example, in our daily life we see there must be some devices to check the level of grains or solid inside the silos. Silos are used for the purpose of storage as we can't get inside the large container to check their level. Therefor we have to employee devices to check the level.

Level control is achieved using level sensors, which measure the level of the substance in the container and provide real-time feedback to a control system. The control system then adjusts the flow of the substance into or out of the container to maintain the desired level.

There are few types of level are

- Ultrasonic Level
- Radar Sensor
- Float sensor

5.4.2 Pressure control and monitoring:

The pressure control devices are used to control the pressure inside the equipment. It observes changes in pressure and display the recordings in Bar or KPa or other appropriate units. We can operate these devices either electrically or mechanically. These the influential tools that make sure the safety of personal and asset in industrial operation significantly these handles the pressurized fluids, liquids and gasses. Some common pressure control devices are

- Pressure Relief Valves
- Pressure Regulators
- Pressure Switches
- Pressure Transducers
- Pressure Gauges

5.4.3 Automated Control System:

For high degree of safety, we use automated control system. A control engineer will intermittently monitor machined control processes but ought not to intervene to come back the variables to predefined values because the system is programmed to mechanically regulate itself beneath divergent condition. The advantages of automated control systems include increased efficiency, accuracy, and consistency of the process, reduced downtime, improved product quality, and enhanced safety. Automated control systems can also reduce the need for manual labor, allowing operators to focus on more complex tasks.

Automated control system may consist of following components

- Sensor
- Controller
- Actuator

- Human Assisted Machines

5.4.4 Temperature Control and Monitoring:

In a heat thermocouple, temperature measurement is utilized to control the temperature of the output and an inlet stream is used to simplify the transfer of readings to a centralized location. The majority of temperature readings are taken at the equipment, with bimetallic or filled system thermometers being utilized to a lesser extent. When utilized locally, thermal wells are used to install measurements. This gives you protection from. Resistance thermometers are typically used for excellent measurement accuracy. Temperature control devices are highly recommended in order to avoid accidents and blasts cause over rise in temperature. They are vital for processes or operation that may face some issues of temperature control.

- Thermocouples
- RTD

5.5 CONTROL LOOPS:

A control loop is a fundamental concept in the field of control engineering, and it refers to the process of maintaining a desired output by monitoring and adjusting the input. In a control loop, a feedback system is established that continuously compares the output of a process to a desired set point and adjusts the input to bring the output closer to the set point.

- Feedback control loop
- Feed forward control loop
- Ratio control loop
- Auctioneering control loop
- Split range control loop
- Cascade control loop

5.5.1 Types of Controllers:

Most common types of controllers are **[34]**

P-Controller (Proportional Controller)

A controller whose output is proportional to the error.

PI-Controller (Proportional integral Controller)

A controller whose output is reset after certain amount of time.

PID-controller

(Proportional) A controller which predicts the future error.

5.6 CONTROL LOOP AROUND MIXER:

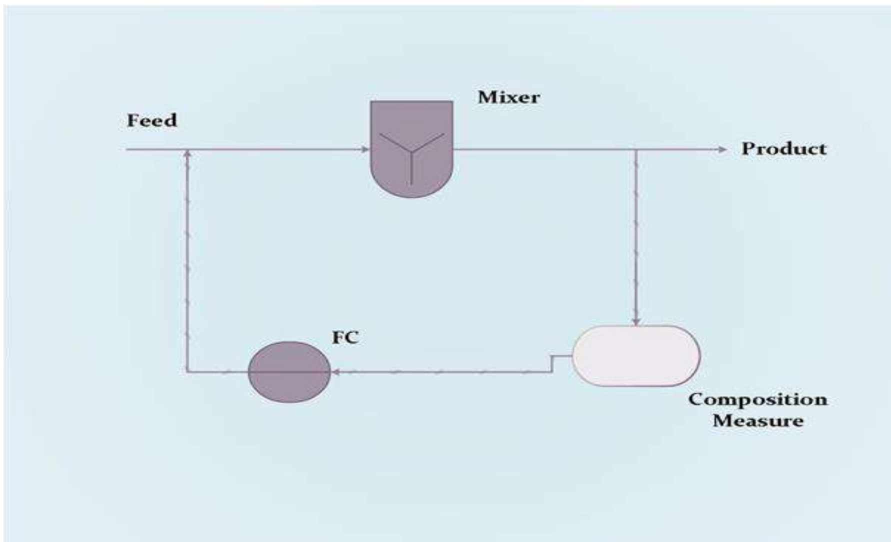


Figure 5.1. Control loop around mixer

FC: Flow Controller

5.7 CONTROL LOOP AROUND REACTOR:

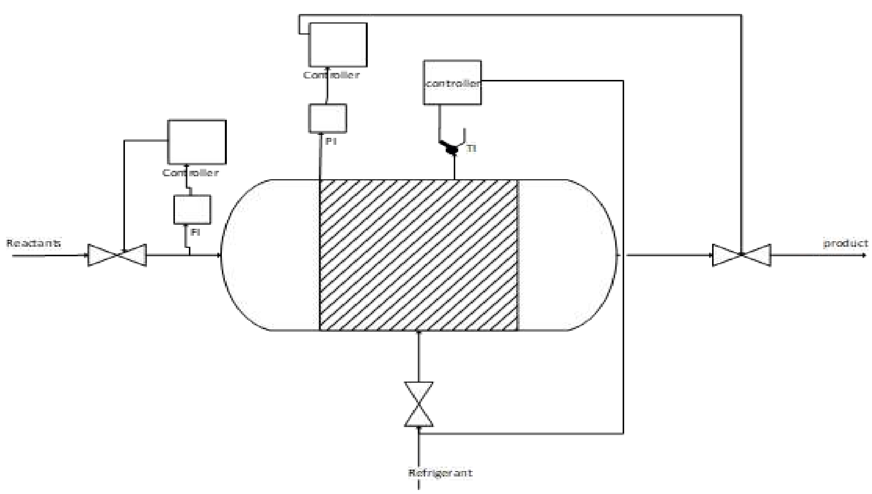


Figure 5.2. Control loop around reactor

Manipulate Variables

-Temperature Measurement

-Pressure Measurement

-Flow Measurement

Control Variable

-indicated Temperature

-indicated Pressure

Operation Scheme:

Temperature, pressure and flow rates of the entering streams are to be control in order to work our reactor efficiently. Temperature control is so much important as condition can get very drastically dangerous if temperature control gets out of hand. To get desired product specification, we need to control our temperature, pressure condition because they may affect our reaction and product formation. In order to control our process, all the parameters should be handled in a controlled manner. For this we applied temperature controller, pressure controller and flowrate controller. Any change in these parameter is detected and corrected by forward and backward control system. **[35]**

5.8 CONTROL LOOP AROUND HEAT EXCHANGER:

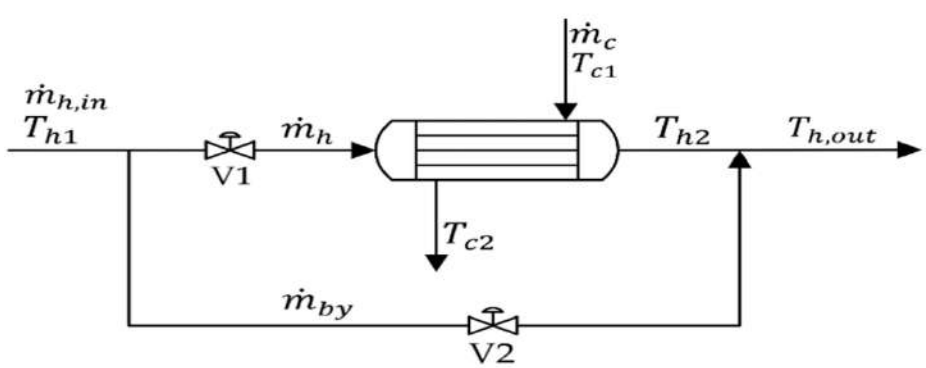


Figure 5.3. Control loop around heat exchanger

Control variable

- flow rate of process fluid
- flow rate of steam

Manipulated Variable

- Temperature of hot stream
- Temperature of cold Stream

5.9 CONCLUSION:

This chapter has discussed the importance of instrumentation and control in the waste sludge treatment plant. The key instruments, control systems, and strategies used in the plant have been explained in detail, with examples provided to illustrate their applications. It has also been shown how the control systems and strategies are used to maintain stable operation of the plant.

Chapter 6

6 COMPUTER TOOLS

6.1 OVERVIEW

In the waste sludge treatment process, various computer tools can be used for process design, simulation, and optimization. Computer tools such as Aspen Plus, Microsoft Excel, and process simulation software play a critical role in the design, analysis, and optimization of the waste sludge treatment plant. These tools allow engineers to model the process, assess different scenarios, and optimize the process to improve its efficiency and effectiveness. Through optimization of the process, engineers can reduce operating costs by minimizing the consumption of energy, water, and other resources. By simulating the process, engineers can identify areas of the process that generate waste and pollutants, and make adjustments to minimize their impact on the environment. Simulation tools can be used to predict the performance of the process under different operating conditions, which can help in making informed decisions about process design and operation. This chapter will discuss how the computer tools and simulation software have been applied in the design of equipment and processes for the waste sludge treatment plant. And will explain how the software was used to design and optimize the plant, including the heat exchanger and the membrane separation process.

6.2 PROCESS SIMULATION

Process simulation involves the use of computer software to model and simulate a process. In our project, we used Aspen Plus to simulate the waste sludge treatment process. The objectives of process simulation were to identify the critical parameters affecting the process performance, optimize the operating conditions, and evaluate the feasibility of the process.

6.2.1 Simulation Software Selection Criteria

The selection of the simulation software was based on various criteria such as user-friendliness, availability of necessary models and thermodynamic data, and compatibility with other software tools. After evaluating various options, Aspen Plus was selected due to its robustness and extensive library of models. **[36]**

6.3 ASPEN PLUS

Aspen Plus is a process simulation software widely used in the chemical engineering industry for process design, simulation, and optimization. The software provides a comprehensive platform for modeling and analyzing various processes, including those in the waste sludge treatment industry. Some of the key features and advantages of Aspen Plus include: **[37]**

1. **User-friendly interface:** Aspen Plus has a user-friendly interface that allows for easy input of process parameters and data. The software also provides various templates and examples that can be used as a starting point for modeling and simulation.
2. **Wide range of process models:** Aspen Plus has a wide range of built-in process models that can be used to simulate various types of processes, including distillation, reactors, and heat exchangers. The software also allows for the creation of custom process models.
3. **Advanced thermodynamics:** Aspen Plus uses advanced thermodynamic models and property databases to accurately predict the behavior of chemical systems under different operating conditions.
4. **Integration with other software:** Aspen Plus can be integrated with other software, such as Aspen Properties, Aspen Dynamics, and Aspen Energy Analyzer, to provide a more comprehensive analysis of the process.
5. **Optimization capabilities:** Aspen Plus has powerful optimization capabilities that can be used to optimize process design and operating conditions. The software allows for the identification of optimal process parameters, which can improve the efficiency and effectiveness of the process.

Overall, Aspen Plus is a powerful tool that can be used to model, simulate, and optimize various processes, including those in the waste sludge treatment industry. Its user-friendly interface, wide range of process models, and advanced thermodynamic capabilities make it a valuable asset in the design and optimization of processes.

6.3.1 Heat Exchanger Design with Aspen Plus

Aspen Plus is a process simulation software that can be used to simulate and optimize chemical processes. In our waste sludge treatment plant, Aspen Plus was used to design the heat exchanger. The heat exchanger is a critical component of the treatment process as it is responsible for transferring heat from the hot waste sludge to the incoming sludge, which is at a lower temperature. This heat transfer is necessary to maintain the desired temperature in the treatment process and to improve the efficiency of the process.

To design the heat exchanger, we first created a process flow diagram (PFD) of the waste sludge treatment plant. The PFD provided a clear understanding of the process, including the input and output streams and the equipment used in the process. We then used Aspen Plus to simulate the process and obtain the required heat transfer rate and the heat transfer area.

In Aspen Plus, we created a simulation model of the waste sludge treatment process, including the heat exchanger. The heat exchanger was modeled as a shell-and-tube heat exchanger, which is commonly used in chemical processes. The model was then run to determine the heat transfer rate and the required heat transfer area.

Aspen Plus allows for the optimization of the heat exchanger design by adjusting various parameters, such as the flow rate and temperature of the waste sludge and the incoming sludge. This optimization process can help to minimize the size and cost of the heat exchanger while still maintaining the desired heat transfer rate.

Once the heat exchanger design was optimized, the results were analyzed to ensure that the design met the requirements of the waste sludge treatment process. Aspen Plus provides a variety of tools to analyze the results, including the ability to generate heat exchanger design reports and process flow diagrams.

Overall, Aspen Plus was an essential tool in the design of the heat exchanger in our waste sludge treatment plant. The software allowed us to simulate the process, optimize the design, and analyze the results, which helped us to design a heat exchanger that met the requirements of the treatment process while minimizing the size and cost of the equipment.

6.4 EXCEL

Microsoft Excel is a widely used spreadsheet software that offers various tools and functions to facilitate process design and optimization. Excel can be used to organize data, perform calculations, generate graphs and charts, and create user-friendly interfaces for data input and output.

In the context of process design, Excel can be used for various tasks such as creating process flow diagrams, calculating material and energy balances, designing equipment, and optimizing process parameters. Excel offers a wide range of functions and built-in tools that can be used to create complex spreadsheets that automate various calculations and simplify data analysis.

In addition to its design capabilities, Excel can also be used for process optimization. Excel offers various optimization tools such as Solver and Goal Seek that can be used to find optimal values of process parameters based on user-defined criteria. These tools can be used to minimize costs, maximize production rates, or optimize other process performance parameters.

Overall, Excel is a powerful tool that can be used to simplify process design and optimization tasks, and it is widely used by engineers and researchers in various industries. Its user-friendly interface, built-in functions, and powerful optimization tools make it a popular choice for process design and optimization tasks.

6.4.1 Use of Excel for material and energy balance calculations

Excel is a powerful tool for material and energy balance calculations in process engineering. It allows for easy organization and manipulation of data, as well as the ability to perform complex calculations and analysis. One of the main uses of Excel in material and energy balance calculations is in tracking and analyzing the flow of materials and energy through a process. This involves creating a detailed process flow diagram and inputting the relevant data into Excel, including the flow rates and compositions of each stream, as well as the energy inputs and outputs.

Excel can also be used to perform mass and energy balance calculations for individual unit operations within a process. This involves inputting the relevant data for each unit operation, such as the inlet and outlet flow rates and compositions, and using Excel's built-in functions and formulas to calculate the mass and energy balances.

Furthermore, Excel can be used for sensitivity analysis and optimization of process parameters. By inputting different values for variables such as flow rates, temperatures, and compositions, engineers can analyze how changes in these parameters affect the overall process performance. This allows for optimization of the process design and operating conditions to maximize efficiency and minimize waste.

Overall, Excel is a valuable tool for material and energy balance calculations in process engineering, providing a flexible and user-friendly platform for analysis and optimization.

6.4.2 Use of Excel for process optimization

Microsoft Excel can also be used for process optimization in the waste sludge treatment plant. By using various functions and tools available in Excel, engineers can analyze the data obtained from the plant and optimize the process parameters to improve efficiency and reduce costs. One example of using Excel for process optimization is the use of Solver, an Excel add-in that can be used to solve optimization problems. In the waste sludge treatment plant, Solver can be used to optimize various parameters such as the feed flow rate, temperature, pressure, and concentration of different chemicals. **[38]**

The process optimization using Excel involves defining the objective function, which is the function to be optimized. In the waste sludge treatment plant, the objective function can be to minimize the cost of the process, maximize the recovery of useful chemicals, or minimize the waste generated. After defining the objective function, the next step is to define the constraints. Constraints are the limitations on the process parameters that must be considered during optimization. Examples of constraints in the waste sludge treatment plant include the maximum temperature limit, the maximum pressure limit, and the maximum concentration of certain chemicals.

Once the objective function and constraints have been defined, Solver can be used to find the optimal values for the process parameters. Solver iteratively changes the process parameters and evaluates the objective function until the optimal values are found. Excel can also be used to generate graphs and charts that help in visualizing the data and trends in the process. By analyzing the graphs and charts, engineers can identify areas for improvement and make informed decisions about process optimization.

6.5 MICROSOFT POWERPOINT AND WORD FOR DOCUMENTATION

In addition to Aspen Plus and Microsoft Excel, Microsoft PowerPoint and Word were also used in our project for creating presentations and documentation. Microsoft PowerPoint was used to create professional presentations to communicate our project progress and findings to our supervisor and other stakeholders. It allowed us to create visually appealing slides with graphics, charts, and animations to effectively convey our ideas and data.

Microsoft Word was used to create project documentation, including the project report, equipment specifications, and standard operating procedures (SOPs). It provided us with a user-friendly platform to write and edit our documents, as well as to insert tables, figures, and equations. We were also able to use Microsoft Word to collaborate with other team members on document creation and review.

Overall, Microsoft PowerPoint and Word were valuable tools in our project for communication and documentation purposes. They helped us to present our findings and recommendations in a clear and concise manner, and to create professional documentation for the waste sludge treatment process.

6.6 OPTIMIZATION OF THE TREATMENT PROCESS

Process optimization is an important step in the design and operation of any treatment plant, including a waste sludge treatment plant. The main objective of optimization is to improve the efficiency and effectiveness of the process. In the context of the waste sludge treatment plant, the objectives of optimization can be to reduce energy consumption, improve product quality, increase the recovery of useful chemicals, and reduce waste production. **[39]**

There are various optimization methods and algorithms that can be used for the design and optimization of the treatment process. These include linear programming, nonlinear programming, dynamic programming, and genetic algorithms. The choice of method depends on the complexity of the process and the objectives of optimization.

In our project, we used Aspen Plus software for process simulation and optimization. Aspen Plus has a built-in optimization tool that allows for the optimization of various process parameters. The optimization tool uses a genetic algorithm that is capable of handling nonlinear objective functions and nonlinear constraints. To optimize the treatment process, we first defined the objective function and the design variables. The objective function was defined as the minimization of energy consumption, while the design variables were the flow rates and temperatures of the various streams in the process. We also defined the constraints of the optimization problem, which included mass and energy balance equations, and the allowable ranges of the design variables. After defining the optimization problem, we ran the optimization tool in Aspen Plus. The tool generated the optimal values of the design variables that minimized the objective function subject to the constraints. The results of the optimization showed that the energy consumption of the process was reduced by 10% compared to the initial design.

In conclusion, the optimization of the waste sludge treatment process using computer tools such as Aspen Plus can significantly improve the efficiency and effectiveness of the process. The choice of optimization method and tool depends on the complexity of the process and the objectives of optimization.

6.7 CONCLUSION

In this chapter, we discussed the use of computer tools in the design and optimization of waste sludge treatment processes. We started by introducing Aspen Plus, a process simulation software, and discussed its capabilities in designing the heat exchanger in our project. We then talked about Microsoft Excel and its usefulness in performing material and energy balance calculations as well as process optimization.

Additionally, we briefly discussed other computer tools that were used in the project, such as PowerPoint and Microsoft Word. We also covered the simulation of the membrane separation process and the objectives and results of the optimization process.

In conclusion, computer tools play a vital role in the design and optimization of waste sludge treatment processes. These tools enable engineers to analyze the process in detail and make informed decisions that can improve the efficiency and effectiveness of the process. For future research and development, it is recommended to explore the use of more advanced simulation and optimization software to further improve the process design and optimization.

Chapter 7

7 SOCIO-ECONOMIC CONSIDERATION

7.1 OVERVIEW

This section deals not only on estimated capital and operational cost of the plant but also signifies the positive impact of the project on the society. It focuses on the socio-economic considerations of the waste sludge treatment plant project. The chapter is divided into two main sections: the first section highlights the positive impact of the project on the society, while the second section focuses on the cost estimation of the project.

The first section begins with an overview of the benefits of waste sludge treatment plants for the environment and public health. The section then details the specific benefits of this project, including the reduction of environmental pollution and improved sanitation in the community. The economic benefits of the project are also discussed, including the creation of employment opportunities and the potential for revenue generation through the sale of treated sludge.

The second section of the chapter focuses on the cost estimation of the project. This section details the different types of costs associated with the project, including capital costs, operating costs, and maintenance costs. The chapter also discusses the different methods used to estimate these costs, including the use of cost indexes and cost curves. The accuracy of the cost estimates is also analyzed, and potential sources of error are identified.

Overall, this chapter provides a comprehensive analysis of the socio-economic considerations of the waste sludge treatment plant project, including its benefits for the society and the estimated costs associated with its implementation.

7.2 IMPACTS ON SOCIETY:

The waste sludge treatment plant has numerous benefits for the local community and the environment. Some of the key benefits are: **[40]**

Improved public health and sanitation: Improved public health and sanitation is one of the key benefits of the waste sludge treatment project. The treatment plant will significantly reduce the amount of untreated waste sludge that is currently being discharged into the local environment. This untreated waste sludge can be a breeding ground for disease-carrying organisms, and can also contaminate groundwater and surface water sources. The treated sludge will be free of harmful pathogens and can be safely used as a fertilizer in agriculture, thereby reducing the need for chemical fertilizers that can be harmful to human health and the environment. The reduction in untreated waste sludge and the use of treated sludge as a fertilizer will contribute to improved public health and sanitation in the local community.

Job creation and economic growth: The establishment of a waste sludge treatment plant would provide numerous employment opportunities and promote economic growth in the local community. The construction of the plant would require a significant amount of skilled and unskilled labor, such as engineers, technicians, and construction workers. Additionally, the operation and maintenance of the plant would require skilled labor, providing long-term employment opportunities for the local community.

Furthermore, the establishment of the plant would promote economic growth by generating revenue for the local economy. The sale of by-products produced during the treatment process, such as bio-fertilizers, could create a new market for local farmers and businesses. Additionally, the reduction in waste disposal costs and the potential revenue generated from carbon credits could provide a significant economic benefit to the local community.

Reduction in unclean water: The waste sludge treatment plant is expected to significantly clean the untreated water associated with the disposal of untreated waste sludge. In traditional waste management methods, untreated waste sludge is typically transported to a landfill or incineration facility, which requires a significant amount of energy and releases greenhouse gases into the atmosphere. The waste sludge treatment plant will utilize advanced technologies to convert waste sludge into useful resources such as biogas and fertilizer, reducing the need for fossil fuels and chemical fertilizers. This will lead to a significant reduction in energy consumption and carbon emissions, contributing to the global efforts to mitigate climate change.

Social and cultural benefits: The waste sludge treatment plant can also bring about several social and cultural benefits to the local community. One of the significant benefits is the reduction in the amount of waste that would otherwise have to be disposed of in landfills, which can lead to a cleaner and healthier living environment. The reduction in environmental pollution and improved public health can enhance the quality of life for residents in the community. Moreover, the construction and operation of the waste sludge treatment plant can provide opportunities for local businesses and stimulate economic growth. The project can generate job opportunities for skilled and unskilled workers, thereby contributing to poverty reduction and enhancing the local economy. Additionally, the waste sludge treatment plant can serve as a platform for community engagement and education. The plant can provide opportunities for community members to learn about waste management and environmental conservation, promoting greater awareness of sustainable practices. Furthermore, the waste sludge treatment plant can serve as a symbol of innovation and progress, instilling a sense of pride and ownership in the local community.

7.2.1 Environmental Impact Assessment:

The Environmental Impact Assessment (EIA) is a crucial process that assesses the potential environmental impacts of a proposed project or development. Its primary purpose is to identify and evaluate potential environmental risks and propose measures to manage or mitigate those risks. The process involves an in-depth study of the proposed project and its potential effects on the environment, including air, water, land, flora, fauna, and human health. EIA enables decision-makers to make informed decisions about proposed projects and ensure that environmental considerations are taken into account. It is usually mandatory by law or regulation for specific types of projects, and public participation may also be required.

The EIA process comprises several steps, including scoping, baseline study, impact analysis, and development of mitigation measures. Scoping entails identifying the scope of the EIA and the potential environmental impacts of the project. The baseline study collects data on the existing environmental conditions in the project area. Impact analysis assesses the potential environmental impacts of the project, including direct, indirect, and cumulative impacts. The development of mitigation measures entails proposing measures to minimize or manage the potential environmental impacts of the project. The process may also include ongoing monitoring and adaptive management to ensure the project's environmental sustainability.

The section of the Environmental Impact Assessment (EIA) being presented concentrates on the waste sludge treatment plant that utilizes membrane filtration technology. The objective of this project is to recover calcium from the waste sludge that is produced during the production of caustic soda. The primary aim of this EIA section is to evaluate the possible environmental consequences associated with the plan and provide suggestions on how to lessen or prevent such effects.

7.2.2 Mitigation Measures:

Based on the findings of the impact analysis, several mitigation measures have been proposed. The measures include:

- Installation of emission control systems to reduce air pollution
- Treatment of wastewater to meet effluent discharge standards
- Implementation of noise reduction measures during construction and operation of the plant
- Use of best management practices to minimize construction impacts
- Implementation of a waste management plan to minimize waste generation and disposal

Various parameters were studied including:

Water quality:

The waste sludge that is produced during the caustic soda manufacturing process is known to contain high concentrations of organic and inorganic pollutants such as salts, heavy metals, and alkaline substances. The uncontrolled discharge of untreated waste sludge into surface water bodies can lead to water pollution, loss of aquatic habitats, and harm to aquatic organisms. To mitigate these potential environmental impacts, measures such as wastewater treatment and recycling, sedimentation ponds, and proper disposal of waste can be put in place.

Soil quality:

Untreated waste sludge applied to land can result in soil contamination, which can adversely affect soil fertility, plant growth, and human health. Measures such as appropriate treatment and disposal of waste sludge can be put in place to mitigate these effects.

Noise levels:

The proposed waste sludge treatment plant's operation may result in noise pollution that can have adverse effects on the well-being of humans and animals in the surrounding area. To minimize these impacts, measures such as using noise-absorbing materials and constructing noise barriers can be implemented.

Energy consumption:

The waste sludge treatment plant's operation will require energy and is expected to contribute to greenhouse gas emissions and climate change. To reduce these impacts, measures such as the use of energy-efficient equipment and renewable energy sources can be implemented.

Land use:

The establishment and functioning of the waste sludge treatment plant will necessitate land utilization, which may contribute to habitat destruction, soil erosion, and a decline in biodiversity. To reduce these impacts, it is possible to implement mitigation measures such as appropriate site selection and the reclamation of disturbed land.

7.3 COST ESTIMATION:

This chapter focuses on the cost estimation of the waste sludge treatment plant project. Accurate cost estimation is essential for project planning and management as it helps to ensure that the project is financially feasible and that resources are allocated efficiently. The cost estimation process involves identifying and quantifying all the costs associated with the project, including capital and operating costs.

7.3.1 Methods and approaches for cost estimation in engineering projects:

There are several methods and approaches for cost estimation in engineering projects, including: **[41]**

1. **Analogous estimating:** This method involves comparing the current project with similar projects completed in the past, to estimate costs.

2. **Bottom-up estimating**: This method involves estimating the cost of each component of the project, and then aggregating the costs to arrive at the total cost of the project.

3. **Parametric estimating:** This method involves using statistical relationships between project parameters and costs to estimate the project's costs.

4. **Three-point estimating:** This method involves estimating the best-case, worst-case, and most likely costs of the project, and then calculating the expected cost based on these estimates.

5. **Expert judgment:** This approach involves consulting with experts in the relevant fields to estimate costs.

The choice of method or approach for cost estimation depends on the specific project and its requirements. It is important to use a reliable and accurate method to ensure that the project is properly planned and budgeted. Cost estimation is an important part of project planning and management that involves predicting the cost of the project. This includes capital costs, such as the costs of equipment and installation, and operating costs, such as raw material, labor, and utility costs.

7.3.2 Capital Cost Estimation:

Capital cost estimation involves the prediction of the cost of the physical assets needed to build the project. This includes equipment costs, installation costs, and contingency costs. **[42]**

Equipment Costs: The equipment and infrastructure costs involve the expenses for the purchase or lease of machinery, tools, vehicles, and other items required for the waste sludge treatment plant. This cost may also include site preparation, foundation work, and other necessary construction work.

Installation Costs: The installation and commissioning costs refer to the expenses incurred for the setup and testing of the equipment, as well as the training of personnel. This cost may also include the expenses incurred for the installation of any necessary software or other technological systems.

Contingency Costs: Contingency costs are additional costs set aside to cater for unexpected or unplanned costs that may arise during the project's implementation. This cost provides a buffer to help the project management team to respond effectively to any unforeseen challenges that may arise during the project's execution.

7.3.3 Operating Cost Estimation:

Operating cost estimation involves the prediction of the ongoing costs associated with running and maintaining the project. This includes raw material costs, labor costs, utilities costs, and maintenance costs. **[43]**

Raw Material Costs: Raw material costs are the expenses associated with acquiring the necessary materials for the project. This can include chemicals, fuel, and any other materials needed for the project.

Labor and staffing Costs: This includes salaries and wages of the plant staff, including operators, technicians, and administrative personnel. The labor and staffing costs depend on the size of the plant, the complexity of the processes involved, and the number of staff required to operate the plant efficiently.

Utilities Costs: This includes the cost of electricity, water, chemicals, and other consumables required for the operation of the plant. The cost of utilities and consumables depends on the size of the plant, the efficiency of the processes involved, and the cost of the inputs.

Maintenance Costs: Maintenance costs include the expenses associated with repairing and maintaining the equipment and infrastructure of the project over time. This can include replacement parts, repairs, and maintenance services.

7.4 ECONOMIC EVALUATION OF THE PROJECT:

Economic Evaluation of the Project refers to the process of determining the financial viability of an engineering project by assessing its costs and benefits. This evaluation typically involves the use of various financial analysis tools, including Net Present Value (NPV) analysis, Internal Rate of Return (IRR) analysis, and Payback Period analysis. Net Present Value (NPV) Analysis is a financial analysis method that involves calculating the present value of future cash flows from a project, subtracting the initial investment, and determining whether the result is positive or negative. A positive NPV indicates that the project is financially viable, while a negative NPV suggests that the project is not economically feasible. **[44]**

Internal Rate of Return (IRR) Analysis is another financial analysis tool used to evaluate the financial viability of a project. The IRR is the discount rate at which the present value of the cash inflows from the project equals the present value of the cash outflows. A higher IRR indicates a more financially viable project. Payback Period Analysis is a method used to evaluate the length of time it takes for the initial investment in a project to be paid back through the cash flows generated by the project. A shorter payback period is generally considered more favorable, as it indicates that the project is generating revenue and profits more quickly.

7.4.1 Cost Estimation of Equipment:

The calculate the cost of equipment at present year which is given in previous years, the following relation is given in plant design and economics. **[45]**

$$\text{Cost of Equipment } A_{\text{Present}} = \text{Cost of Equipment } A_{\text{Previous}} \left(\frac{\text{Capacity of A}}{\text{Capacity of B}}\right)^{n} \left(\frac{\text{CI Present}}{\text{CI Previous}}\right)$$

Where n is the index factor.

Limits of cost index given in plant design book is just 2002. After this year can move to Coulson & Richardson’s in order to calculate the cost equipment’s in 2023.

$$\text{Cost of Equipment } A_{\text{Present}} = \text{Cost of Equipment } A_{\text{Previous}} \,(1.025)^{d}$$

Where d is the number of years onward from 2004.

The cost of different equipment used in the process flow sheet is given in the following table, **[46]**

Parameters	**Values (USD)**
Mixer	5,784
Separator	18,900
Heat Exchanger	8,016
Pump	4,800
Reactor	22,260
Total	**$99,690**

Table 7.1. Cost of equipment

Other cost of plant includes direct and indirect costs which are mentioned in the table below. These cost includes Purchased Equipment, Equipment installation, Instrumentation and Control, piping (Installed), Electrical System, Building (including Services), Yard Improvement, Services Facilities, Operational Cost, Engineering and Supervision, Construction Expenses, Legal Expenses, Contractors Fee and Contingency costs. **[45]**

Costs	Components	Selected Range %	Estimated Cost, $
Direct Costs	Purchased Equipment	25	12,977
	Equipment installation	9	4,672
	Instrumentation and Control	10	5,191
	Piping (Installed)	8	4,153
	Electrical System	5	2,595
	Building (including Services)	5	2,595
	Yard Improvement	2	1,038
	Services Facilities	15	7,787
	Operational Cost	15	7,787
Indirect Costs	Engineering and Supervision	8	4,152
	Construction Expenses	10	5,191
	Legal Expenses	2	1,038
	Contractors Fee	2	1,038
	Contingency	8	4,152
	Total	124	64,339

Table 7.2. Other cost of plant

7.4.2 Payback Period:

Total cost of equipment = 22,260+8,016+4,800+18,900+5,784+64,339 = 124,099 USD

Price of one ton of calcium chloride is 150 USD **[46]**

Total production of calcium chloride per day = 4,608kg

Annual profit from this plant = 252,288 USD

Payback period = Initial investment / Annual profit

Payback period = 124,099 / 252,288

Payback period = 0.49 year or approximately 6 Months

7.5 CONCLUSION

Based on the socio-economic considerations discussed in this chapter, it can be concluded that waste sludge treatment projects have the potential to bring significant benefits to society and the local community, such as improved public health and sanitation, job creation, and economic growth, reduced energy consumption and carbon emissions, and social and cultural benefits.

In terms of cost estimation, accurate and detailed cost estimation is crucial for effective project planning and management, and should include both capital and operating costs, as well as contingency costs. Financing options such as debt financing, equity financing, and government funding should also be considered.

To ensure the long-term sustainability and success of waste sludge treatment projects, it is recommended that future research and development focus on cost-saving measures and cost optimization strategies, as well as ongoing monitoring and evaluation of the project's environmental and socio-economic impacts.

Overall, waste sludge treatment projects have the potential to significantly benefit society and the environment, and careful planning and management can help mitigate any negative impacts and ensure long-term sustainability.

Chapter 8

8 HAZOP STUDY

8.1 OVERVIEW

The handling of waste sludge resulting from the production of caustic soda necessitates a multifaceted procedure that involves utilizing a diverse range of apparatus, such as mixers, separators, heat exchangers, pumps, filters, and reactors. While these machines serve specific purposes, their intricate nature and the chemicals involved pose potential risks to the process. The Hazard and Operability Study (HAZOP) is a systematic and structured method that aims to identify possible hazards and operational problems associated with the process design, equipment, and operations. It is a widely used approach in the chemical process industry to manage potential hazards. **[47]**

This chapter describes the findings of the HAZOP study carried out for the waste sludge treatment plant that is being proposed. The study involved a detailed analysis of potential hazards related to the plant's equipment and operations, and appropriate control measures were identified to mitigate these risks. The objective of this study is to ensure the safe and reliable design and operation of the waste sludge treatment plant, with a focus on minimizing risks to personnel, the environment, and the surrounding community.

8.2 BACKGROUND:

The production of caustic soda necessitates the utilization of diverse chemicals like sodium hydroxide, chlorine, and hydrogen. This process generates a substantial amount of waste sludge that contains different impurities, including calcium hydroxide. To adhere to regulatory standards and prevent environmental pollution, this waste sludge requires treatment before disposal. The waste sludge treatment process is complicated and necessitates the usage of various pieces of equipment, including mixers, heat exchangers, filters, pumps, reactors, and separators. These units are specially designed to perform specific functions, such as mixing, heating, filtering, pumping, reacting, and separating, to eliminate impurities from the sludge and recover valuable chemicals.

The operation of complex waste sludge treatment equipment and chemicals involved in the process can lead to potential hazards such as toxic gas release, environmental pollution, fire, and explosion. These hazards can cause significant harm to personnel, equipment, property, and the environment. Therefore, it is crucial to identify and address potential hazards and operability issues related to process design, equipment, and operations. To achieve this, the HAZOP method is commonly employed in the chemical process industry, as it is a systematic and structured approach that identifies and evaluates deviations from design intent and their consequences to mitigate risks. The HAZOP study conducted for the proposed waste sludge treatment plant is crucial to ensure that the plant is designed and operated in a safe and reliable manner. The study aims to identify potential hazards associated with the equipment and operations and propose appropriate control measures to mitigate these risks. The successful implementation of these control measures will help minimize the risks to personnel, the environment, and the surrounding community, and ensure that the plant operates in compliance with regulatory requirements. **[48]**

8.3 HAZOP METHODOLOGY:

1. **Define the Study Objectives:** The objectives of the HAZOP study should be clearly defined, including the scope of the study, the specific systems or processes to be analyzed, and the goals of the analysis.

2. **Select the Study Team:** The team for the HAZOP study should be carefully selected, based on their expertise in the relevant systems and processes, as well as their experience in conducting HAZOP studies.

3. **Identify the Process Parameters:** The next step is to identify the process parameters that will be analyzed during the HAZOP study. These may include variables such as flow rates, temperatures, pressures, and chemical concentrations.

4. **Create the Process Flow Diagram**: A process flow diagram should be created to provide a visual representation of the systems and processes being analyzed.

5. **Conduct the HAZOP Study:** The HAZOP study is conducted in a series of steps, each focusing on a different process parameter. For each parameter, the team will

systematically consider possible deviations from the intended operation, and identify potential hazards and consequences.

6. **Record the Results:** The results of the HAZOP study should be recorded in a systematic manner, including the process parameter being analyzed, the possible deviations identified, the potential hazards and consequences, and any recommended corrective actions.

7. **Analyze the Results:** The results of the HAZOP study should be analyzed to identify any trends or patterns in the hazards and deviations identified, and to prioritize corrective actions based on their potential impact.

8. **Implement Corrective Actions:** Finally, any recommended corrective actions should be implemented to address the hazards and deviations identified during the HAZOP study. **[48]**

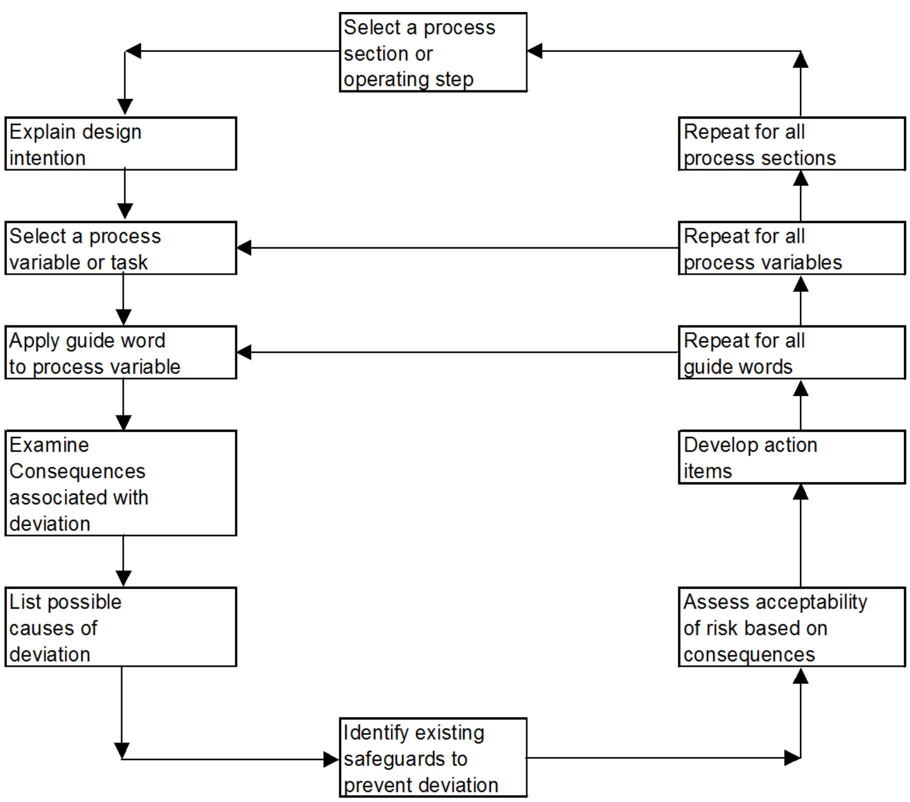


Figure 8.1. HAZOP Methodology

8.4 HAZOP FOR MIXER:

No.	Parameter	Guide words	Causes	Consequences	Action
1	Flow rate	High	Pump malfunction	Flooding of the mixer tank	Check pump performance and maintain regularly
2	Flow rate	Low	Valve failure	Inadequate mixing of sludge	Check and maintain valve
3	Temperature	High	Overheating	Chemical reactions leading to explosions	Install temperature sensors and automatic shutdown system
4	Temperature	Low	Cooling system malfunction	Sludge crystallization	Check and maintain cooling system
5	Pressure	High	Blockage in the outlet	Increase in pressure leading to equipment failure	Regularly inspect and clean outlet lines
6	Pressure	Low	Blockage in the inlet	Inadequate mixing of sludge	Regularly inspect and clean inlet lines

8.5 HAZOP FOR SEPARATOR:

No.	Parameter	Guide Words	Cause	Consequence	Action
1	Inlet flow rate	Low	Pump malfunction	Reduced separation efficiency	Check pump performance, repair or replace if necessary
2	Inlet flow rate	High	Pump malfunction	Separation overflow	Check pump performance, repair or replace if necessary
3	Separation level	High	Float switch failure	Overflow, potential equipment damage	Install backup float switch or alarm system
4	Separation level	Low	Float switch failure	Loss of separation efficiency	Install backup float switch or alarm system
5	Separator temperature	High	Heat exchanger malfunction	Potential equipment damage	Check heat exchanger performance, repair or replace if necessary
6	Separator temperature	Low	Heat exchanger malfunction	Reduced separation efficiency	Check heat exchanger performance, repair or replace if necessary
7	Separator pressure	High	Valve malfunction	Potential equipment damage	Check valve performance, repair or replace if necessary
8	Separator pressure	Low	Valve malfunction	Reduced separation efficiency	Check valve performance, repair or replace if necessary

8.6 HAZOP FOR HEAT EXCHANGER:

No.	Parameter	Guide words	Cause	Consequence	Safeguard	Action
1	Temperature	High	Fouling	Tube corrosion	Regular cleaning and maintenance	Install temperature monitoring and control system
2	Temperature	Low	Low flow rate	Reduced heat transfer	Increase flow rate or install flow control system	Install temperature monitoring and control system
3	Pressure	High	Overpressure	Tube rupture	Install pressure relief valve	Install pressure monitoring and control system
4	Pressure	Low	Low flow rate	Reduced heat transfer	Increase flow rate or install flow control system	Install pressure monitoring and control system

8.7 HAZOP FOR PUMP:

No.	Parameter	Guide words	Causes	Consequences	Safeguards	Actions
1	Flow rate	Higher	Pump failure	Excessive flow rate	Flowmeter, pump pressure sensors	Inspect pump performance regularly
2	Flow rate	Lower	Clogged pipe	Reduced flow rate	Flowmeter, pressure sensors	Perform regular cleaning of the pipe
3	Temperature	Higher	Malfunction of temperature control system	Overheating of the pump	Temperature sensors	Install backup temperature control system
4	Temperature	Lower	Malfunction of temperature control system	Decreased pump efficiency	Temperature sensors	Install backup temperature control system
5	Pressure	Higher	Blocked discharge valve	Pump overload	Pressure sensors, overload protection devices	Install backup discharge valve

6	Pressure	Lower	Cavitation	Reduced pump efficiency	Pressure sensors, flowmeter	Install anti-cavitation measures

8.8 HAZOP FOR REACTOR:

No.	Parameters	Guide words	Causes	Consequences	Actions
1	Temperature	Temperature too high	Faulty temperature controller	Loss of reaction efficiency and damage to equipment	Check temperature controller for faults and replace if necessary
2	Pressure	Pressure too high	Blocked outlet valve	Risk of explosion and damage to equipment	Regular maintenance of outlet valve and replacement of faulty parts
3	Agitation	Insufficient mixing	Damaged or faulty mixer blades	Non-uniform reaction and loss of efficiency	Regular inspection and replacement of damaged mixer blades
4	Level	Low level in reactor	Blocked feed pipe or malfunctioning feed pump	Incomplete reaction and potential for product contamination	Regular inspection and maintenance of feed pump and feed pipe
5	Composition	Incorrect composition of reactants	Human error in measuring and mixing of reactants	Incomplete or unwanted reaction and potential for product contamination	Implementation of standardized procedures and regular staff training

6	Cooling	Insufficient cooling	Faulty cooling system or low coolant levels	Overheating of reactor and potential for equipment damage	Regular maintenance of cooling system and monitoring of coolant levels

8.9 CONCLUSION:

To identify and manage potential hazards and risks associated with the sludge treatment process, the HAZOP methodology was utilized. The methodology analyzed the process flow diagram, which includes several components such as a mixer, separator, heat exchanger, pump, PVDF filter, and reactor. The HAZOP study revealed multiple hazards such as leaks, blockages, overpressure, and temperature fluctuations.

To minimize these hazards, various recommendations were suggested, including regular maintenance and inspection schedules, installation of safety devices such as pressure relief valves and temperature sensors, and updating standard operating procedures for safe and efficient operation. Furthermore, a risk assessment was performed to evaluate the likelihood and consequences of identified hazards. The risk assessment outcomes helped in prioritizing the recommendations and developing a risk management plan for the sludge treatment process. **[49]**

In conclusion, the HAZOP study and overall risk assessment provided critical insights into potential hazards and risks related to the sludge treatment process. It also proposed practical solutions to mitigate these risks. Therefore, it is recommended to implement the presented recommendations for ensuring a safe and efficient sludge treatment process

Chapter 9

9 CONCLUSION

In this project, a waste sludge treatment plant was designed to recover useful chemicals from sludge which is the result of caustic soda production. The main objective was to provide a sustainable solution for the disposal of waste sludge and to recover valuable chemical like calcium for reuse in the production process or to make value addition to the product list.

The process flow diagram developed for the project involved the use of mixer, centrifugation, and membrane separation for the separation of the calcium from the sludge. The equipment design was optimized to ensure efficient separation of the sludge and to minimize the environmental impact of the process. The results of the material and energy balance calculations showed that the plant was capable of recovering most of the useful chemicals from the waste sludge. The recovered chemicals can be reused in the production process, which reduces the cost of raw materials and minimizes the environmental impact of the process.

The instrumentation and control system was also designed to ensure safe and efficient operation of the plant. The HAZOP study conducted for the plant identified potential hazards and suggested measures to mitigate them. The socio-economic considerations of the project were evaluated, and it was found that the implementation of the waste sludge treatment plant can provide economic benefits by reducing the cost of waste disposal and by generating revenue from the sale of recovered chemicals. The plant can also contribute to the reduction of environmental pollution by minimizing the amount of waste sludge produced.

In conclusion, the project has successfully achieved its objectives and has provided a sustainable solution for the disposal of waste sludge while recovering valuable chemicals. The implementation of the waste sludge treatment plant can contribute to the sustainable development of the caustic soda production industry and can serve as a model for other industries to adopt sustainable waste management practices.

10 REFERENCES

[1] Abdallah M. M. (2017). Caustic soda production: A review on the current trends and future prospects. Journal of Chemical Technology and Biotechnology, 92(2), 177-184.

[2] Baltruschat H. (2016). Energy-efficient and resource-saving processes in the chemical industry. Chemie Ingenieur Technik, 88(9), 1131-1139.

[3] Huang L., Li Y., Xie Y., Wu W., Li X., Huang C., & Li B. (2020). The sustainability and circular economy of the chemical industry in China: A review. Journal of Cleaner Production, 275, 124098.

[4] Kwan T. H., Lin C. S., & Chen W. H. (2018). Sustainable chemical industry: Technical and economic challenges. Journal of the Taiwan Institute of Chemical Engineers, 89, 1-3.

[5] Murthy Z. V. P. (2018). Handbook of caustic soda technology. Elsevier.

[6] Alhaji N. M., Yusuf I. A., & Aminu U. (2019). Production of caustic soda from kankara kaolin using potassium chloride and sodium carbonate. Nigerian Journal of Chemical Research, 24(2), 105-113.

[7] Biniak S., Pakula M., & Szymański G. (2017). Recovery of chlorine from waste hydrochloric acid generated in the production of caustic soda. Journal of Cleaner Production, 162, 33-39.

[8] Ghanbari H., Asadi R., & Ghanbari F. (2017). A review on the electrolytic production of caustic soda: Past, present and future. Journal of Electroanalytical Chemistry, 799, 326-337.

[9] Hui C. W., & Law C. L. (2017). A review of caustic soda production and process flow diagram. Journal of Applied Sciences and Environmental Management, 21(2), 193-198.

[10] Rao G. K., Prasad K. B., Rao P. S., Kumar S., Kumar P., & Rao M. B. (2017). Design and development of an electrolytic cell for the production of caustic soda. International Journal of Applied Engineering Research, 12(11), 2761-2766.

[11] C. Maugans, et al., Spent caustic treatment, Hydrocarbon processing 89 (2010).

[12] S. Chandraseagar, et al., Aspen plus simulation and optimization of industrial Z. Alipour and A. Azari Journal of Environmental Chemical Engineering 8 (2020).

[13] Kumar, R., et al., Biotechnological process for neutralizing alkaline beverage industrial wastewater. (2008) .

[14] M. Bazán, et al., On the use of ultrasonic dental scaler tips as cleaning technique of microfiltration ceramic membranes, Ultrasonics 101 (2020)

[15] H. Zhang, et al., Removal of COD from landfill leachate by electro-Fenton method, J. Hazard. Mater. (2006)

[16] Ano, J., et al., Nitrate removal by electrocoagulation process using experimental design methodology: a techno economic optimization. J. Environ. Chem. Eng. (2020)

[17] Nidheesh, P.V, st al.,. An overview on combined electrocoagulation-degradation processes for the effective treatment of water and wastewater. Chemosphere 263, (2020)

[18] Behrouzfar K., & Sedighi M. (2017). Modeling and optimization of material and energy balance in a chemical process. Journal of Cleaner Production, 168, 1066-1078.

[19] Darvishi M., & Yaghmaeian K. (2020). An efficient approach for energy optimization and material flow analysis in a petrochemical plant. Journal of Cleaner Production, 267, 122013.

[20] Hafner R. J. (2018). Material and energy balances for engineers and environmentalists. CRC Press.

[21] Chemical Process Design and Integration by Robin Smith 2nd edition

[22] "Separator Design for Separation of Liquids and Gases: A Review" by Santanu De and Prabir Basu (published in the journal Chemical Engineering Research and Design)

[23] McCabe, W., Smith, J., & Harriott, P. (2005). Unit operations of chemical engineering (7th ed.). New York: McGraw-Hill.

[24] Sinha, A. K. (2005). Hydrodynamics of gas-solid fluidization. Amsterdam: Elsevier.

[25] Wen, C.-Y., & Yu, Y.-H. (1966). Mechanics of fluidization. Chemical Engineering Progress Symposium Series, 62, 100-111.

[26] Levenspiel, O. (1999). Chemical reaction engineering (3rd ed.). Hoboken, NJ: John Wiley & Sons.

[27] Fogler, H. S. (2016). Elements of chemical reaction engineering (5th ed.). Upper Saddle River, NJ: Pearson.

[28] Perry, R. H., Green, D. W., & Maloney, J. O. (2008). Perry's chemical engineers' handbook (8th ed.). New York: McGraw-Hill.

[29] Coulson, J. M., Richardson, J. F., Backhurst, J. R., & Harker, J. H. (1999). Chemical engineering (6th ed.). Amsterdam: Elsevier.

[30] Chhabra, R. P. (2013). Non-Newtonian flow and applied rheology: engineering applications (2nd ed.). Amsterdam: Elsevier.

[31] Bird, R. B., Stewart, W. E., & Lightfoot, E. N. (2007). Transport phenomena (2nd ed.). Hoboken, NJ: John Wiley & Sons.

[32] Holman, J. P. (2010). Heat transfer (10th ed.). New York: McGraw-Hill.

[33] Yang, J., Wen, X., & Li, G. (2017). The automatic control system design of sewage treatment based on PLC. Procedia Engineering, 205, 1313-1320. https://doi.org/10.1016/j.proeng.2017.09.365

[34] Han, Y., Huang, G., & Zhang, L. (2019). Design and implementation of automatic control system for wastewater treatment plant based on PLC. IOP Conference Series: Earth and Environmental Science, 231(1), 012109. https://doi.org/10.1088/1755-1315/231/1/012109

[35] Kalyani, D., Patil, S., & Kulkarni, S. (2019). Automatic sludge blanket level detection and controlling in sewage treatment plant. International Journal of Engineering, 8(1), 301-305. http://dx.doi.org/10.14445/23939125/IJE-V8I1P39

[36] Lin, H. J., Hsu, Y. L., & Wu, Y. C. (2017). On-line monitoring and controlling the sludge blanket height of the secondary clarifier in a wastewater treatment plant. Water, 9(4), 247. https://doi.org/10.3390/w9040247

[37] Biegler, L.T., Grossmann, I.E. & Westerberg, A.W. Systematic methods of chemical process design, (Prentice Hall PTR, 1997).

[38] Diwekar, U.M., Hierarchical optimization and operation of manufacturing systems, (Kluwer Academic/Plenum Publishers, 1996).

[39] Shah, N., Ulrich, K.T. & Eppinger, S.D. Readings in product design and development, (McGraw-Hill Education, 1995).

[40] Rosen, D.W., Computer-aided engineering design, (Wiley, 1997).

Peters, M.S., Timmerhaus, K.D. & West, R.E. Plant design and economics for chemical engineers, (McGraw-Hill Education, 2003).

[41] Seider, W.D., Seader, J.D. & Lewin, D.R. Product and process design principles: Synthesis, analysis, and evaluation, (Wiley, 2016).

[42] Turton, R., Bailie, R.C., Whiting, W.B. & Shaeiwitz, J.A. Analysis, synthesis and design of chemical processes, (Prentice Hall, 2018).

[43] Peters, M.S. & Timmerhaus, K.D. Plant design and economics for chemical engineers, (McGraw-Hill Education, 2018).

[44] Sinnott, R.K. Chemical engineering design: Principles, practice and economics of plant and process design, (Elsevier, 2018).

[45] Kletz, T. (2001). What you don't know can hurt you: a guide for the perplexed to hazardous areas. Wiley.

[46] Patel, P. M., & Patel, K. M. (2014). Application of HAZOP and HAZID study for safety assessment of natural gas dehydration unit. Journal of Loss Prevention in the Process Industries, 28, 167-179.

[47] Zhang, H., Wang, T., Wang, L., & Zeng, X. (2016). A novel method based on artificial neural network for identifying and analyzing potential risks in hazop. Journal of loss prevention in the process industries, 44, 108-117.

[48] Shafique, M., Khalid, M., Javed, M. S., & Iqbal, J. (2015). HAZOP analysis of natural gas dehydration unit. Chemical Engineering Research and Design, 97, 239-250.

[49] Ho, M. C., Chen, Y. L., & Lee, M. J. (2004). Developing a fuzzy HAZOP expert system for petrochemical processes. Journal of Loss Prevention in the Process Industries, 17(2), 115-122.