STUDY OF OPERATION AND MAINTENANCE OF WASTEWATER TREATMENT PLANT

By

Muhammad Izaan Khan

Ameer Moavia

Muhammad Jahangir Sarfraz

School of Chemical and Materials Engineering
National University of Sciences and Technology
2021

STUDY OF OPERATION AND MAINTENANCE OF WASTEWATER TREATMENT PLANT

By

Leader - 00000237894 Muhammad Izaan Khan
Member 1 - 00000217575 Ameer Moavia
Member 2 - 00000219679 Muhammad Jahangir Sarfraz

A THESIS
Submitted to
National University of Sciences and Technology
in partial fulfilment of the requirements
for the degree of

B.E. CHEMICAL ENGINEERING

School of Chemical and Materials Engineering (SCME)

National University of Sciences and Technology (NUST)

June, 2021

CERTIFICATE

This is to certify that work in this thesis has been completed by Mr. Muhammad Izaan Khan, Mr. Jahangir Sarfraz and Mr. Ameer Moavia under the supervision of Dr. Salman Raza Naqvi (UG Coordinator) at School of Chemical and Materials Engineering (SCME), National University of Sciences and Technology, H-12, Islamabad, Pakistan.

Supervisor:

Dr. Salman Raza Naqvi
Department of Chemical Engineering
School of Chemical and Materials Engineering
National University of Sciences and Technology

Submitted Through:

HOD ------------------------------------
Dr. Erum Pervaiz
Department of Chemical Engineering
School of Chemical and Materials Engineering
National University of Sciences and Technology

Principal/Dean ------------------------------------
Prof. Dr. Amir Azam Khan
School of Chemical and Materials Engineering
National University of Sciences and Technology

DEDICATION
TO

OUR PARENTS

Without whom none of this would have been possible and for their support throughout our lives.

AND TEACHERS

For inspiring us and supporting us throughout the entirety of this project.

ACKNOWLEDGEMENTS

First of all, we bow before Allah Almighty to thank for His countless blessings and rewards who gave us the strength and ability to complete the thesis.

It is a pleasure and a deep sense of indebtedness that we acknowledge the valuable help of our respected supervisor who has enriched the text by their generous contribution and patronage. We express our cordial gratitude to our supervisor, **Dr. Salman Raza Naqvi** for his encouragement, guidance, enthusiastic support, constructive suggestions and ever helping supervision.

We are also thankful to **Mr. Abdul Majid** for being a constant support in our project.

We are thankful to our Industrial supervisor **Mr. Nawaz Saqui**, maintenance engineer, Kohinoor Textile Mills Ltd, Pakistan for being an ideal mentor and inspiring us and being there for us in each problem we encountered during our project.

We are thankful to the **Kohinoor Textile Mills Ltd, Pakistan** for reducing the student-industry gap, giving us industrial exposure, and giving us a chance to apply our knowledge and learning in practical industry problems and situations.

We are also thankful to our parents, without their assistance and encouragement; it was not possible to complete the project successfully.

ABSTRACT

A wastewater treatment plant is a facility in which a combination of various processes (e.g., physical, chemical, and biological) are used to treat industrial wastewater and remove pollutants. Textile wastewater usually consists of chlorides, sulphates, dyes, bleaching agents, suspended solids, and organic & inorganic impurities. We aspire to come up with a highly feasible solution to the major problem that majority of the industries are encountering i.e., treatment of the wastewater which the industry is producing. Conventionally, this process consists of a series of membranes and chemical treatments and is an energy intensive process. Hence, to cope up with this, we have planned on introducing a more efficient method that uses the uprising technology of Hydrodynamic Cavitation (HC) that minimizes the steps involved in the treatment process, thus lowering the energy consumption, and providing a much better output. The industry assigned to us is Kohinoor Textile Mills Ltd and we'll be utilizing a Hydrodynamic Cavitator to breakdown impurities and suspended solids within the wastewater on the principle of creating high and low-pressure zones caused by variation in the orifice diameter of the piping instrumentation. We aim to achieve a certain amount of purity of the treated water which can either be utilized for domestic purposes or for use in agricultural fields.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Cpmin: Minimum Pressure Coefficient at nozzle throat

A: Area

C: Cost

^{o}C: Degree centigrade

D: Diameter

F: Flow Rate

g: Acceleration due to gravity

H: Height

J: Joule

L: Length

Mol: Mole

P: Power

Q: Energy Flow rate

t: time

V: Volume

W: Width

C_P: Specific Heat Capacity at Constant Pressure

T: Temperature

V: Volumetric Flow Rate

σ: Cavitation Number

CHAPTER 1

INTRODUCTION

1.1 About Kohinoor Textile Mills Ltd

With approximately 1800 people and $110 million in sales, Kohinoor Mills is one of Pakistan's largest and leading textile companies. We deliver over 70 million meters of world-class grey, white, and colored fabrics to major fashion designers and retailers around the world from our 90-acre state-of-the-art facility in Lahore. Weaving, Dyeing, and Finishing are the three main and major businesses of the company. Spinning is the process of making yarn from natural and synthetic fibers. The Weaving phase is responsible for the creation of greige fabric and Kohinoor weaving Mills was declared as a company limited by SECP (Shares with securities and Exchange Commission of Pakistan) under the consideration of Companies Act.1984(At present it is known as Companies Act 2017). On December 21,1987, SECP issued all the certificates and documents related to incorporation of the company. The company was also manifested as a public limited company on Pakistan Stock Exchange. Having the symbol as KML, it’s shares are bartered under the textile composite sector. SECP's automation in 2006 resulted in the replacement of all old registration numbers with a company's New Customized Identification Number. When considering the nature of the Company's operations, the word "weaving" in the company's name did not properly represent the scope as indicated in the Memorandum and Articles of Association. The Processing & Home Textile section works with greige cloth to create printed and colored textiles. Kohinoor dyeing was established in 2002 when a heroic and strategic decision was taken the company to go up with the textile value chain and to compete with the processing mills situated in Europe where the production costs were becoming economically less efficient. At now, Kohinoor Dyeing is the market leader in the section of cotton stretch fabrics for the fashion sector after 15 years of operation. It designed innovative textiles and hand-feel textures in its R&D lab, allowing it to become major suppliers for worldwide brands such as Zara, Levi's, Ralf Lauren, American Eagle, and Next. Every month, the division uses cutting-edge European machinery from Bennenger and Monforts to manufacture 4 million meters of colored, white, and print fabrics.

1.2 Products Manufactured.

Kohinoor textile mills are known for a variety of products they produce. One of their innovative ones being the special fibre CVC yarn, a blend of CVC with Bright and Lyocell fibres. Their other commonly sold products include; Kitchen textiles, curtains, bed ware, dyed and printed fabrics, Griege fabrics, blended and cotton yarn respectively.

1.3 Problem Statement

Textile industry makes use of tons of water for their daily processing, but the problem they have to encounter is it's treatment after usage. As the processed water is contaminated with impurities such as SMBS (Sodium meta bisulfate), a dyeing agent and $HClO3$, Hydrogen chlorate, a bleaching agent, it cannot be flushed directly into the ocean. Hence, for it's treatment, the industry was previously utilizing a membrane separation process that required frequent replacement and a vast equipments, with an efficiency of only 40%.. Therefore, we were asked to improvise an approach that would treat their wastewater cheaply and much more efficiently.

1.4 Background

There is a specific threshold value for the amount of chloride and sulphate ions in the industrial water and that is 390 ppm and 250 ppm respectively. If this threshold value exceeds then we cannot let the wastewater be dumped or drained in the municipal channels and neither can the water be used for agricultural or domestic purposes at homes. Apart from this, there are certain dissolved and saturated solids which need to be removed from the wastewater, and when coupled with other organic and inorganic impurities, they can prove to be fatal, if consumed.

1.5 Issue

The contaminated water due to the dyeing agent and the bleaching agent used during the process, cannot be dumped directly into an ocean as it would majorly affect marine life, and is unacceptable for domestic use. Flushing of this water into oceans will not only affect marine life but also the neighbouring villages that lie alongside the and use it's running water for their domestic purposes. Furthermore, dumping it in a landfill will cause the land to become barren and incapable of being cultivated.

1.6 Possible Solutions

In order to solve the issue, hydrodynamic cavitator can be introduced into the current operating system. It is a pressure vessel that decomposes and breaks down impurities in it using variation in pressure as the principle. With the installation of this equipment, there will be no need for membranes to filter the effluent or any sort of coagulant/ flocculant (chemical dosing) for the impurities to form clusters. Because this pressure vessel has the tendency to remove almost any type of impurity present in the effluent stream.

1.7 Hydrodynamic Cavitator

A large number of industries are using mechanical draft cooling towers. Mechanical draft cooling towers are famous due to their compactness and brilliant performance in transferring heat. Mechanical draft is famous due to their high effectiveness, light weight and reasonable price.

Although they are used by industries for many years, this technology and its manufacturing is limited to few companies in some developed nations.

Mechanical draft towers use fans, driven by electric motors to produce the flow of air. The tower is called an induced draft if a fan is installed in the air exit at the top of the tower. The tower is called force draft if a fan is installed in the air entry at the bottom of the tower. The flow is counter flow hot water enters from the top and air from the bottom in between there is a packing where there is a direct contact between two fluids and they exchange heat. Cold water leaves from the bottom and hot air from the top.

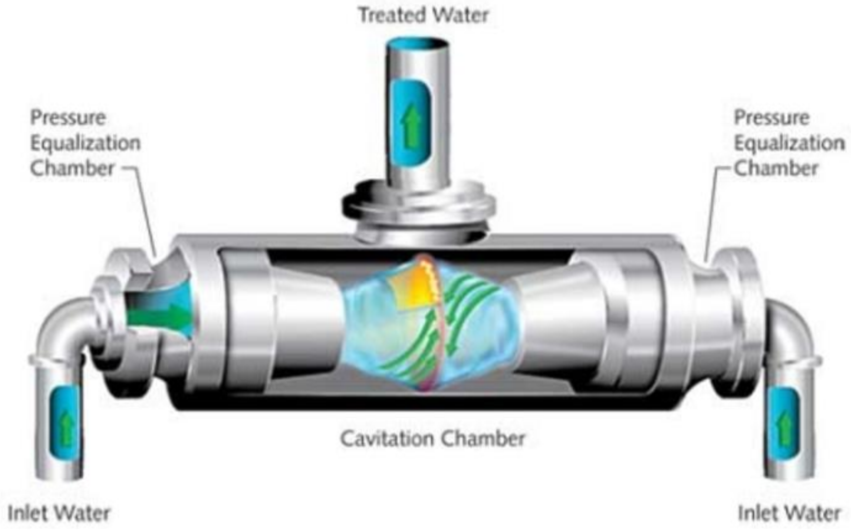


Figure 1. Hydrodynamic Cavitator

1.7.1 Why Hydrodynamic Cavitator?

- A hydrodynamic cavitator cleans water comparable to water being processed by three to four sets of membranes ()microfiltration, ultrafiltration, nanofiltration and Reverse Osmosis).
- Bioreactor is no longer required after it’s installment as impurities are dealt with and decomposed by introducing pressure variations.
- No chlorination is needed to make water acceptable for drinking and domestic purposes.
- A single Hydrodynamic Cavitator replaces other major equipment installed and requires no frequent replacing, hence lowering down plant capital and operating cost, and in turn enhancing production rate and plant efficiency.
- The efficiency of the plant goes up-to 90% after it’s installment.

How does it work?

The working principle of Hydrodynamic Cavitor involves variation in pressure within fluid flow induced by an orifice plate placed at the inlet or a nozzle provided inside of the cavitator. The sudden reduction in pressure causes cavities to be produced as the pressure drops below the vapor pressure of fluid, and downstream to the nozzle, as the pressure suddenly recovers by an increase in cross-sectional area, the cavities, or so-called bubbles produced, begin to burst. The impurities captured or residing within the bubbles decompose, lowering down the water’s Chemical Oxygen demand (COD) and Biological Oxygen demand (BOD) making it suitable for domestic and drinking purposes.

1.8 Other types of cavitation

Following are some other types of cavitation

- Acoustic
- Optic and Particle

1.8.1 Acoustic Cavitation

The production and collapse of bubbles in a liquid after irradiation by powerful ultrasound is known as acoustic cavitation. The speed of the bubble collapsing in the liquid can sometimes approach the sound velocity. As a result, this process in which the collapse of the bubble takes place becomes a quasi-adiabatic process. Inside a bubble, the temperature and pressure rise to thousands of Kelvin and thousands of bars, respectively.As a consequence, inside a bubble, water vapour and oxygen, if both of them are present, disintegrate, and oxidants including OH, O, and H2O2 are formed.This process is known as sonochemical reactions.The pulsating active bubbles are actually nonlinear intrinsically.Subsequently, the encompassing bubble radius in sonochemical process is generally smaller than the direct linear radius's range. There are actually two further types in acoustic cavitation;transient and stable cavitation.There are two brief definitions for transient and stable cavitation. One is defined in terms of its shape stability of the air bubbles. and the other is by the movement of bubbles in light outflow or synthetic reactions.Acoustic cavitation advances nucleation of particles and improves mass exchange.

1.8.2 Optic and Particle

Optic and particle cavitation happens when an intense energy is stored on a fluid. Optic cavitation happens when a fluid is irradiated with light of focused energy, for example, enormous beats of a Q-exchanged ruby laser. In optic cavitation, photons are used to damage and penetrate the liquid surface. Under these conditions, breakdown of the fluid happens and air pockets are formed that can be seen by a fast turning mirror camera. In this sort of cavitation, when the charged particle travels through the fluid, it leaves an ionization trail for a small part of a second. Some of the energy from these particles goes into a couple of quick electrons, which release about 1000 eV of energy in a little volume to produce a drastic amount of heat. In the event that the fluid has been superheated due to expansion while heating. Now bubbling occurs and this will bring about the arrangement of multiple minute cavities. Both optic and particle cavitations are to a great extent used to study motion of bubbles and their responses for an individual cavity and its collapse, as well as the interactions among numerous bubbling cavities under a controlled temperature and pressure.

CHAPTER 2

LITERATURE REVIEW

2.1 Process Description:

Textile sectors play an important role in one of the world's major environmental pollution problems,due to the release of undesirable dye effluents.Dyes used in colouring the cloths comprises contaminants in varying concentrations in textile wastewater. As a result, environmental legislation frequently asks textile factories to clean these effluents before transferring them into receiving watercourses. Textile industries are categorised according to the type of fabric they produce, which comprises cellulosic materials derived from plants (e.g., cotton, rayon, and linen), protein fabrics derived from animals (e.g., wool, silk, and mohair), and synthetic fabrics derived artificially (e.g. nylon, polyester and acrylic). Dry and wet processes are being used in textile factories to produce fibre.The wet process consumes a large amount of potable water and releases potentially polluted wastewater. Sizing, de-sizing, sourcing, bleaching, mercerising, dyeing, printing, and finishing techniques are all part of this process.The dyeing process is a critical step in the textile manufacturing process. The colour is introduced to the fibres at this stage, and various chemicals may be utilized to enhance the adsorption phenomenon between the colour and the fibres. When the finalised product is completed after the completion of finishing process , some of the dyes and chemicals get added to the textile industry pollutants.In addition to their unappealing appearance and health consequences after breakdown, these dyes and chemicals may pollute nearby soil, sediment, and surface water, posing a major global environmental pollution conundrum. Textile effluent treatment is mandatory for the protection of the ecosystem and also allows for subsequent recycling of the treated effluent to be utilised for irrigation purposes .So, to overcome this Global environmental challenge posed by the discharge of textile industry's wastewater,a highly efficient purification technique like hydrodynamic cavitation can play a significant role in this scenario.

Initially, the impurities are pumped to the API Separator in which components of effluent are separated based on differences in specific gravity. Oxygen is utilized by microorganisms in the aeration tank to cope with the BOD. A stream of lime is introduced that reacts with the exit stream from aeration tank, according to the following reaction,

- $Na_2SO_4 + Ca(OH)_2 + 2H_2O \Rightarrow CaSO_4.2H_2O + 2NaOH$

while sodium hydroxide is reacted with HCl, forming sodium chloride and water.

- $NaOH + HCl \Rightarrow NaCl + H_2O$

Gypsum, sodium chloride and other unreacted species are taken out as sludge.

Impurities are then pumped to the Hydrodynamic Cavitator, which works on the principle of pressure changes caused by the variation in diameter of the pipe at the inlet, or by using an orifice. At this point Cavitation begins with the formation of vapour cavities (bubbles or voids) when liquid enters the low-pressure region, and these cavities eventually reach their maximum size under isothermal expansion circumstances. An instant adiabatic collapse occurs during the subsequent compression cycle, leading to the formation of a supercritical state characterized by high local temperature and pressure, referred to as a hotspot. The chemical and physical changes needed for the process happen as a consequence of the high temperatures and pressures that are generated within those hot spots.Cavitation in a liquid medium can be developed by either varying the flow of a fluid flowing, known as hydrodynamic cavitation (HC), or by moving ultrasonic waves through the liquid, called as acoustic cavitation. Other modes of creating cavitation,such as optic and particle cavitation,are generally used for single-bubble cavitation, which cannot be adjusted to cause any physical or chemical variations in bulk solution. When compared to Acoustic cavitation, Hydrodynamic Cavitation produces mostly low-intensity cavity collapse, but it develops more cavities due to its geometrical configuration. Hydrodynamic Cavitator is designed to induce both stable and transient cavitation, which are primarily determined by the geometry of a cavitating device. Better cavitation results can be obtained by producing both sorts of cavitation in a controlled way. AC has been thoroughly researched (different frequencies ranges, varying power, and continuous and pulse mode) for its implementation in various chemical and physical operations such as nanoparticle synthesis, emulsion polymerization, chemical synthesis using oxidation reaction, extraction and leaching, nano emulsification and wastewater treatment over the last two decades.

2.2 HC Induced Effects:

Dynamic cavity oscillations are characterized by a sudden pressure and velocity variations, and as the cavity implodes, specific physical and chemical likely caused in its vicinity, resulting in the required transformations. The required transformation is also controlled by the type of cavity implosion. Mahulkar and Pandit (2010) distinguished between two types of cavity collapse which are: symmetric and asymmetric. Because of the existence of an interface at the boundary or another particle/bubble surface close to the vibrating cavity, the cavity may continue to stay spherical until the bursting point, or it may become nonspherical.

Under spherical collapse, i.e. symmetric collapse, which is considered necessary for chemical transformations, the creation of reactive free radicals and the thermal pyrolysis of organic molecules are extremely beneficial. Nonspherical collapse, or asymmetric collapse, on the other hand, generates high-velocity liquid jets and intense turbulence, both of which are useful for physical transformation.Even though both symmetric and asymmetric collapse absorb the same energy from pressure fluctuations, the energy is given in different ways, either as in a way of strong turbulence or as an extreme pressure and temperature's conditions. The symmetric collapse is useful in applications incorporating chemical changes, particularly oxidation reactions. Chemical transformations are primarily triggered by the generation of reactive and free radicals in the substrate molecules and, secondarily, by the thermal disintegration of larger molecules into the smaller molecules in the existence of a local hot spot. One basic example is; the generation of extremely reactive hydroxyl radicals (OH) as a result of water molecule breakdown under cavitating circumstances.Such hydroxyl radicals possess the greatest oxidation potential and are capable of oxidising particularly large organic compounds. The chemical variations take place in two ways: first, the trapped molecules inside the imploding cavity undergo thermal breakdown during the collapse, and second, the produced free radicals strike the targeted molecules at the cavity-liquid boundary and in the bulk liquid, thus oxidising them.

2.3 Importance of Treatment and Control:

Dependability, productivity, and cost of any industry depend on it’s cooling water system. Monitoring corrosion and various parameters is necessary to provide the best possible Total Cost of Operation. Different treatment methods can be used to ensure that we have the minimum TCO. Monitoring is also a vital aspect of this control. It is used so we can see how well our treatment is working, and how we can tune our parameters to get the best possible cost to benefit ratio.

2.4 Treatment Programs:

The success of developing and implementing the wastewater treatment plant depends on the below mentioned factors:

- Combination of chemical treatment and autonomous system control programs.

- Employees, including operators, supervisors, engineers, and managers – must understand the value of the cooling water system in relation to production and must be committed to maintain and control the program.
- Monitoring and control must be continuous and must utilize the proper techniques, equipment, and supplies.
- A complete system approach combining these aspects will optimize Total cost of operation.

2.5 Reasons for handing over this project:

- Constant and costly maintenance of membranes and clarifiers which require continuous supply chemical dosing such as coagulating and flocculating agents.
- Treating effluent would result in an output that goes hand in hand with our requirements.
- Effluent from the industry cannot be disposed directly into the landfill sites or municipal drains.
- Devise an efficient and cost-effective methodology for treating the industrial wastewater.

2.6 Our Mission

We aspire to reduce the number of membranes being utilized in the Wastewater treatment process. As these membranes choked with time, reducing plant efficiency and were required to be changed regularly. Hence, we modified the water treatment process that consists of a centrifugal pump to supply water at a certain height to induce pressure drop and in turn create cavities in the water stream. Then in the hydrodynamic cavitator, impurities get trapped in these cavities and the bubbles comprising those trapped impurities burst at a stage of pressure recovery and due to this bursting phenomenon and sudden pressure variations taking place inside the cavitator, temperature and pressure rises to 800K and 1.5bar, which is more than enough to kill viruses, bacteria and to decompose other toxic inorganic impurities into harmless compounds.

The main concern while incorporating a Hydrodynamic Cavitator in our plant was the material it needed to be built with to withstand immense temperature and Pressure Variations inside. To resolve this, we have planned to construct it with Stainless Steel (SS), a material widely available and able to withstand high temperatures and Pressures. Moreover, we further plan to build it with 2-3 sets of identical cylindrical vessels, joined together, (instead of just one) with spaces in between, to allow for expansion or contraction of the material due to significant pressure and temperature variations. Lastly, a Pressure safety valve will also be fitted on the top of the cavitator that will automatically open in case pressure reading goes beyond control. We aim at making this treated effluent useful for domestic purposes which poses no harm even if it is used for agricultural fields and drinking as well.

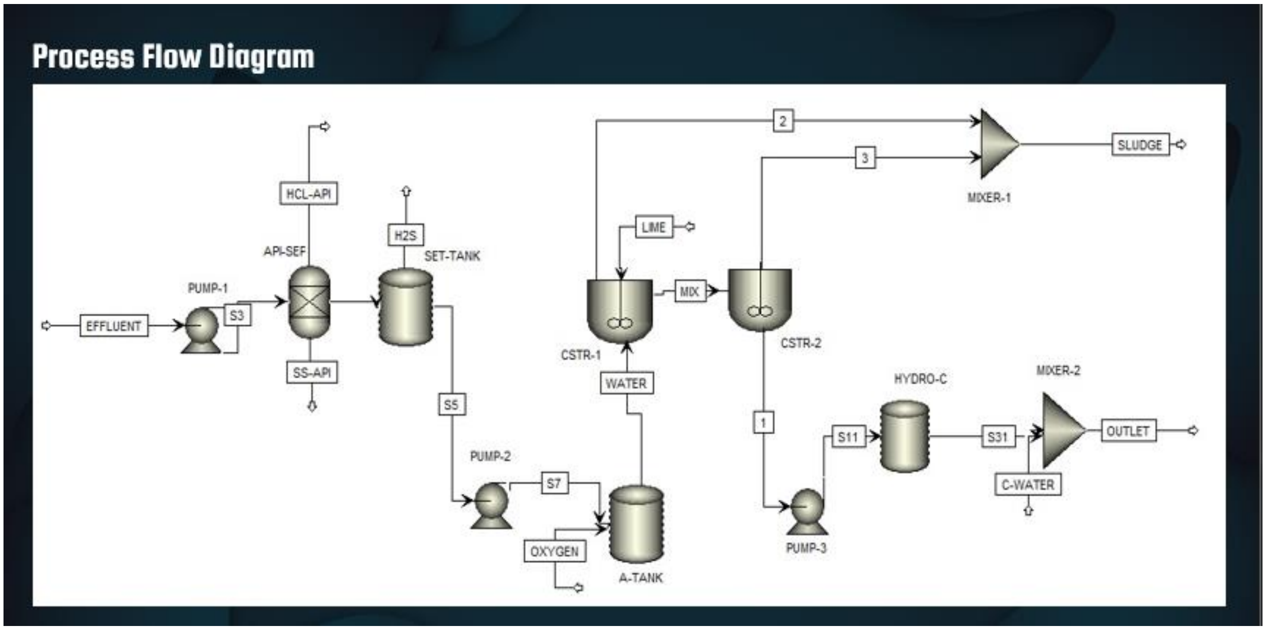
CHAPTER 3

PROCESS DESIGN METHODOLOGY

Designing is an action meant at giving a complete explanation of a manufacturing system or part of a system. For successive engineering and utilization these explanations characterize an explicit specification of size, performance and other characteristics are important.

3.1 Process Flow Diagram

The process flow diagram for the treatment of textile wastewater is developed so that the material and energy balances on the equipment can be applied.



3.2 Material Balance and Energy Balance

Material and Energy balance is applied on every equipment of the whole unit to calculate the flow rates and other parameters for every stream. Following are the assumptions we have taken for our material balance:

1. Steady State System
2. Basis 1h
3. In=out

3.2.1 Pump 1:

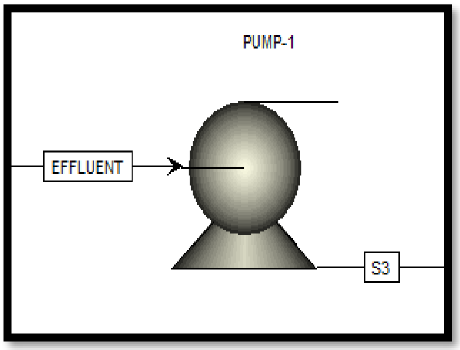


Figure 2. Pump 1

Components	Composition in	Composition out
Sodium sulphate/sulphide	0.065	0.065
HCL	0.395	0.395
Water	0.54	0.54

3.2.2 API Separator:

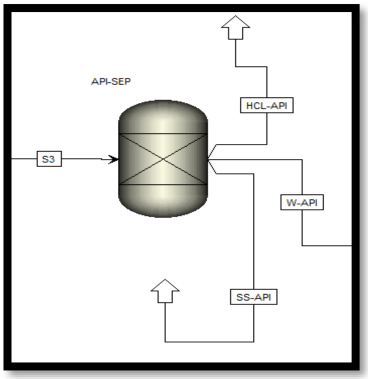


Figure 3. API Separator

Components	Composition in	Composition out
Sodium sulphate/sulphide	0.065	0.05
HCL	0.395	0.3
Water	0.54	0.65

3.2.3 Settling tank:

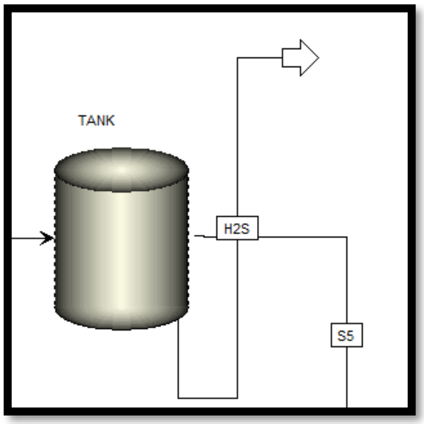


Figure 4. Set-Tank

Components	Composition in	Composition
Sodium sulphate/sulphi	0.05	0.00031
HCl	0.3	0.00048
Water	0.65	0.998862
NaCl	0	0.000348

3.2.4 Pump 2:

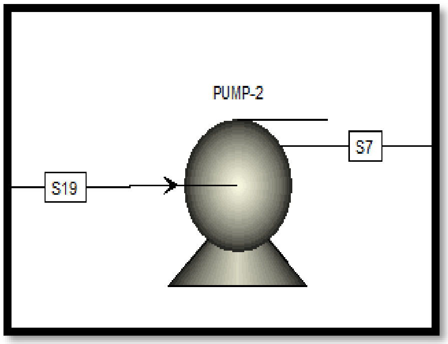


Figure 5. Pump 2

Components	Composition in	Composition out
Sodium sulphate	0.00031	0.00031
HCL	0.00048	0.00048
Water	0.998862	0.999246

3.2.5 Aeration Tank:

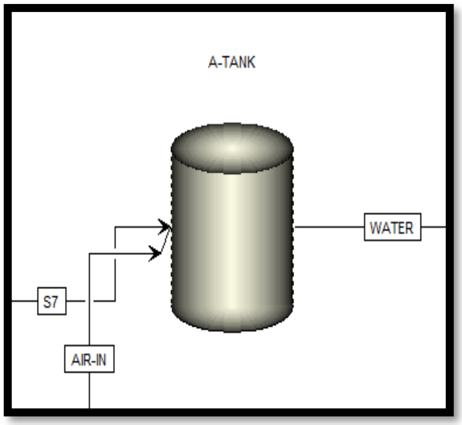


Figure 6. A-tank

Components	Composition in	Composition out
Sodium sulphate	0.00031	0.000154
HCL	0.00048	0.00048
Water	0.998862	0.99921
Oxygen	0	0.00016

3.2.6 CTR-1:

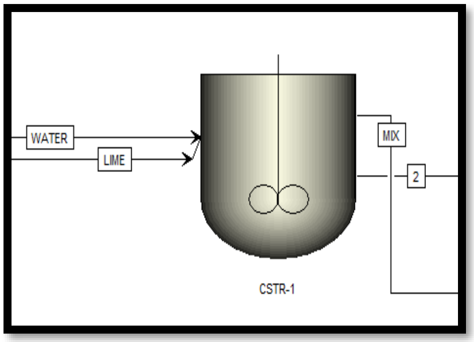


Figure 7. CSTR 1

Components	Composition in	Composition
Sodium sulphate	0.000154	0.00014
HCL	0.00048	0.32756
Water	0.99921	0.606827
Oxygen		0
NaOH	0.00016	0.065473

3.2.7 CSTR-2

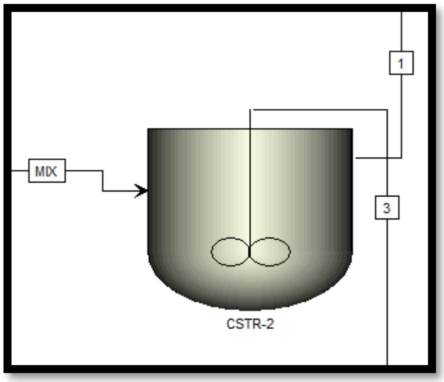


Figure 8. CSTR 2

Components	Composition	Composition
Sodium	0.00014	0.00014
HCL	0.32756	0
Water	0.606827	0.999343
NaOH	0.06547	0.000473
NaCl	0	0.0000473

3.2.6 Mixer 2:

Components	S31	C-waterer	Stream 4 out
Sodium sulphate	0	0	0
Gypsum	0	0	0
Water	1	1	1
NaCl	0	0	0
NaOH	0	0	0

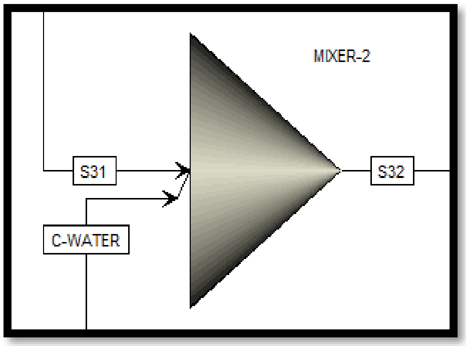


Figure 9. Mixer 2

3.2.7 Pump 3:

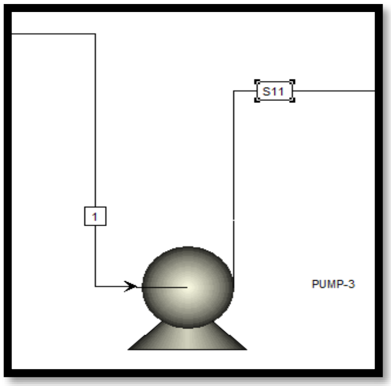


Figure 10. Pump 3

Components	Composition in	Composition out
Sodium sulphate	0.00014	0.0014
HCL	0	0
Water	0.999343	0.9943
NaOH	0.000473	0.0000473
NaCl	0.0000473	0.0000473

3.2.8 Hydrodynamic cavitator:

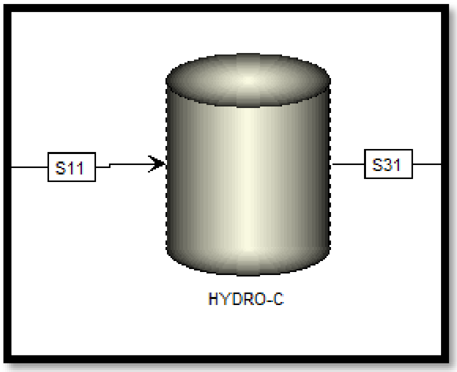
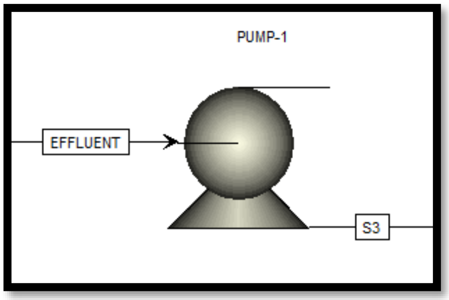


Figure 11. Hydro-C

Components	Composition in	Composition out
Sodium sulphate	0.00014	0
HCL	0	0
Water	0.999343	1
NaOH	0.000473	0
NaCl	0.0000473	0

Energy Balance

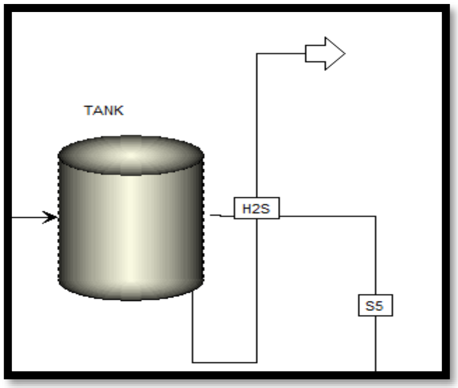
4.2.1 Pump 1:



Power Supplied(KW)	Efficiency	Power required (KW)	Enthalpy in(KJ/Kg)	Enthalpy out(KJ/Kg)
13	0.7	18.57	105.21	105.414

Figure 12. Pump 1

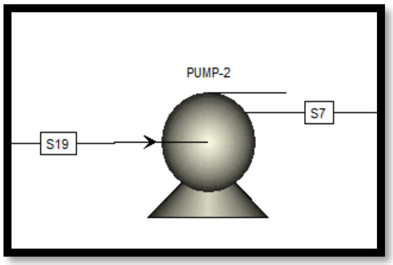
4.2.2 Settling Tank:



Enthalpy in(KJ/Kg)	ΔH(R)	Enthalpy out(KJ/Kg)
105.414	-22.29	83.124

Figure 13. Set-Tank

4.2.3 Pump 2:



Power Supplied(KW	Efficiency	Power required(KW)	Enthalpy in(KJ/K	Enthalpy out(KJ/
13	0.7	18.57	82.92	83.124

Figure 14 . Pump 2

4.2.4 CSTR-1:

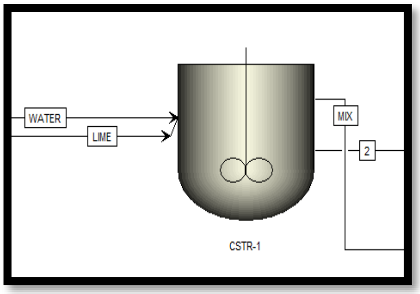
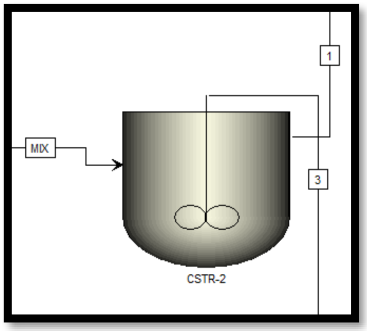


Figure 15 . CSTR 1

Enthalpy In (KJ/KG)	Enthalpy Out (KJ/KG)	ΔH(R)
82.92	-418.63	-501.55

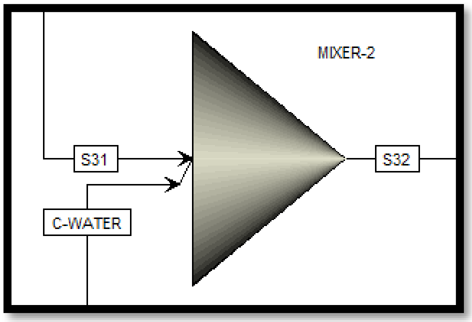
4.2.5 CSTR-2:



Enthalpy In (KJ/KG)	ΔH(R)	Enthalpy Out (KJ/KG)
-418.63	-179.143	-597.77

Figure 16. CSTR 2

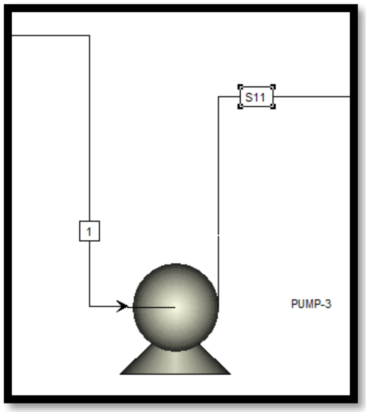
4.2.6 Mixer 2:



Enthalpy In (KJ/KG)	Enthalpy C-water (KJ/KG)	Enthalpy Out (KJ/KG)	Stream 4 out
938.141	102.9	1041.041	0

Figure 17. Mixer 2

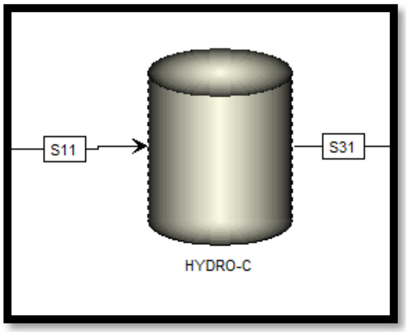
4.2.7 Pump 3:



Power Supplied(KW)	Efficiency	Power required(KW)	Enthalpy in(KJ/Kg)	Enthalpy out(KJ/Kg)
20	0.8	25	-597.77	-593.95

Figure 18. Pump 3

4.2.8 Hydrodynamic Cavitator:



Enthalpy In (KJ/KG)	ΔH(R)	Enthalpy Out (KJ/KG)
-593.95+mgh	0	938.141

Figure 19. Hydro-C

Overall Mass and Energy Balance

4.2.9 Overall Mass Balance:

Equipment	API Separator		Settling Tank		Aeration Tank		CSTR 1		CSTR 2		HC	
Components	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
Ca(OH)2	-	-	-	-	-	-	0.07	-	-	-	-	-
CaS04. 2H20	-	-	-	-	-	-	-	-	-	-	-	-
NaOH	-	-	-	-	-	-	-	85.81	85.81	0.61	0.61	-
Na2S04	108.3	74.63	74.63	3.46	3.46	0.16	0.16	0.03	0.03	0.18	0.18	-
NaCl	-	-	-	-	-	-	-	-	-	0.06	0.06	-
HCl	658.3	445.72	445.72	0.71	0.71	0.63	0.63	428.93	428.93	-	-	-
H2O	900	960.00	960.00	1482.2	1482.2	1,311.50	1,311.50	794.66	794.66	1,306.92	1,306.92	1308
H2S	-	-	-	-	-	-	-	-	-	-	-	-
Oxygen	-	-	-	-	500.00	0.21	0.21	-	-	-	-	-

$$In + Generation = Out + Consumption + Accumulation$$

$$55600 + 560.046 = 24897.8652 + 30399.6320 + 862.5488$$

$$56160.05\ Kg = 56160.05\ Kg$$

4.2.20 Overall Energy Balance:

Equipment	Hin (KJ/Kg)	Hout (KJ/Kg)	ΔH (KJ/Kg)
Pump-1	105.21	105.414	0.0204
Settling Tank	105.414	82.92	207.23
Pump-2	82.92	83.124	0.204
CSTR-1	83.124	-418.63	-501.754
CSTR-2	-418.63	-597.77	-179.14
Pump-3	-597.77	-593.95	3.82
HC	-587.41	938.141	1525.551
Mixer-2	938.141	1041.041	102.9

$$\boldsymbol{In + Generation = Out + Consumption + Accumulation}$$

$$5185 + 7.679 = 5111.479 + 58.6 + 22.6$$

$$5192.68\ MJ = 5192.68 MJ$$

CHAPTER 4

DESIGN CALCULATIONS

4.1 Reactor Design (CSTR):

A reactor is device in which a chemical reaction takes place along with heat and mass transfer. Almost every chemical process involves reactor. Designing of reactor helps to find out the economics of overall process. Basically, its vessel that is specially designed according to reaction conditions. Vessels are of two types:

1. Tank type
2. Pipe type

4.1.1 Types of Reactors:

There are three main types of reactor

1. Batch Reactor
2. Continuous Stirred reactor
3. Plug Flow Reactor

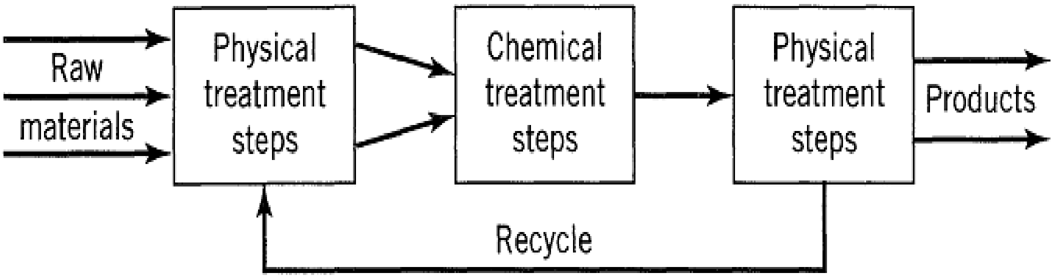


Figure 18 Description of a Chemcial Process

Batch Reactor:

Batch reactor is used for small scale operations in which product is removed after a certain time. It is usually used in a steady state process where large amount of product is required. It requires equipment for support. It provides good quality control of product. It is widely used in oil industry.

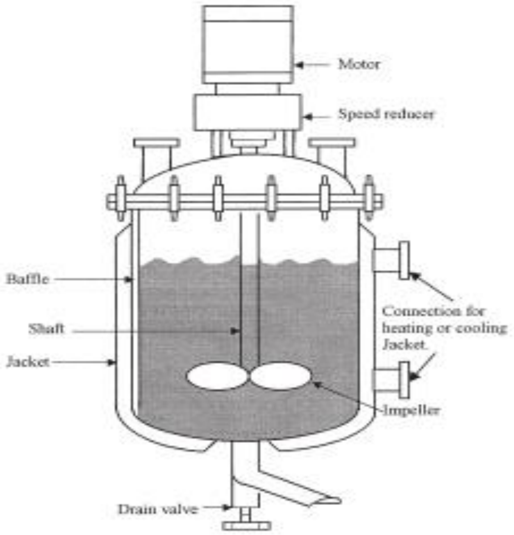


Figure 20. Diagram of a batch reactor

Continuous Stirred Tank Reactor (CSTR):

One or more reactant is introduced in the tank and mixture is well mixed with agitator to disperse the reagent thoroughly into reaction mixture just after entering in reactor. Concentration is constant throughout the reactor and product is removed continuously.

Key features of CSTR:

- It has a tank that is equipped with impeller and cooling jackets.
- More than one reactant can be introduced in this reactor.
- Mass flow rate is same at entrance and exit because it is steady state reactor.
- The assumption of all calculations is perfect mixing means no concentration gradient.
- The reaction continues with final concentration in rate equation.
- It can be operating in series and parallel from economical point of view.
- When CSTR are connected in series their efficiency is equal to PFR.

Space time $=\tau = \frac{V}{v_0}$

τ = space time

V = volume of reactor

V_o = Volumetric flow rate

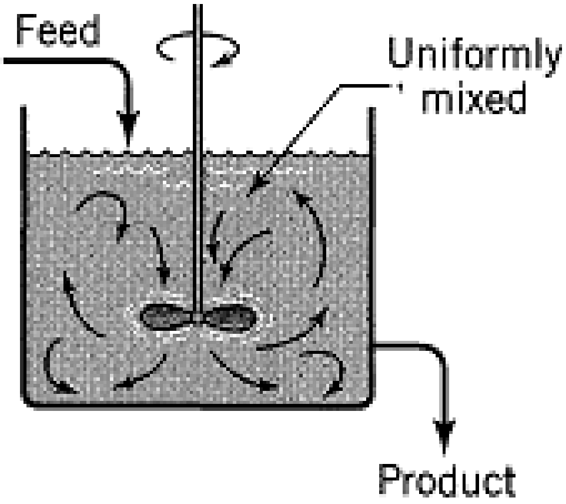


Figure 21. Diagram of a CSTR

PFR (Plug Flow Reactors):

In plug flow reactor reactants pass through pipe and the concentration of product increases gradually as the reaction proceeds. There is no homogenous mixing in this reactor. It has efficiency higher than CSTR. Best suit for gaseous reactions.

Key features:

- Steady-state operation
- In axial direction there lies spatial changes but not in radial direction
- Best suit for fast reaction
- difficult to control temperature
- no moving parts

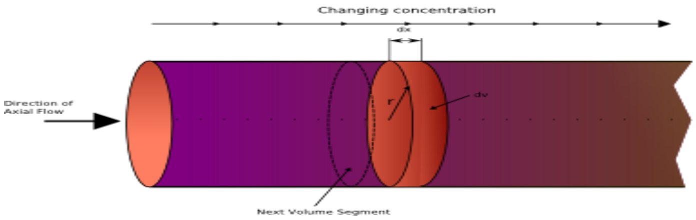


Figure 22. Diagram of a PFR

4.1.2 Reason of Choosing CSTR:

We have selected CSTR because homogenous mixing was required throughout the reaction. It also provides good heat and mass transfer. For mixing of liquid reactant this reactor was suitable.

Approach to reactor selection:

1. Identification of number of phases means homogenous or heterogenous phase.
2. To find out the stoichiometry of reaction, number of reactions taking place and energy requirement
3. To study the mechanism of reaction in detail
4. Decision of selection of reactor. For this kinetics, data for scale up and commercial design is required.

4.1.3 Reactor Design :

- Rate equation tells how homogenous reaction proceeds. It is an intensive measure and explains how fast a component disappear or generate in a given reaction as a function of reaction condition. For example, in some reactions rate equation is function of volume.
- The purpose of reactor design is to find out size and type of reactor. How reaction condition changes with respect to space and time can only be find out by proper integration of rate equation.

CSTR-1

Volume: -

$$Volume = Volumetric\ flow\ rate\ \times\ mass\ flow\ rate\ \times\ 1/density$$
$$\times\ Residence\ time$$

$$Volume = 29997.8314\ \times\ 1/1000\ \times\ 1$$

$$Volume\ =\ 29.997\ m3$$

$As\ volume\ used\ is\ 85\%$

$$Actual\ Volume\ =\ .85\ \times\ 29.997$$

$$Actual\ Volume\ =\ 25.49815\ m3$$

Diameter and height:-

$$Using\ volume\ =\ 3.14\ D2/4\ \times\ H$$

$$As\ the\ ratio\ of\ diameter\ to\ height\ for\ CSTR\ is\ 1:2$$

$$25.4982\ =\ (3.14\ X\ D2\ \times\ 2D/4)$$

$$D = (4X25.4982/3.14\ \times\ 2)1/2$$

$$D = 2.532\ m$$

$$H = 2\ \times\ 2.532$$

$$H = 5.064\ m$$

$\boldsymbol{Impeller\ diameter = 0.4\ X\ Tank\ diameter}$

$$Impeller\ diameter =\ 0.4\ \times\ 2.532$$

$$Impeller\ diameter =\ 1.0128\ m$$

$$Impeller\ opening\ =\ Impeller\ diameter$$

$$Length\ of\ impeller\ blade\ =\ Impeller\ blade\ diameter\ \times\ 0.025$$

$$Length\ of\ Impeller\ blade\ \ =\ 0.02532\ m$$

$$\boldsymbol{Number\ of\ impellers\ =\ 3}$$

$$\boldsymbol{Number\ of\ blades\ =\ 6}$$

$$Tip\ velocity =\ 3-6\ m/sec$$

$$Using\ tip\ velocity =\ 5m/sec$$

$$And\ now\ by\ using\ formula:$$

$$Tip\ velocity\ =\ 3.142\ X\ N\ X\ 1.0128\ X\ 1/60$$

$$N\ =\ 94\ RPM$$

Baffle design :-

$$4\ flat\ baffles\ in\ 900\ centre$$

$$Width\ of\ baffle\ =\ 0.8\ \times\ tank\ diameter$$

$$Width =\ 0.8\ \times\ 2.532\ m$$

$$Width =\ 2.0256\ m$$

Power requirement :

$$\boldsymbol{Power\ =\ Power\ number\ X\ density\ X\ N3\ X\ Impeller\ diameter}$$

$$For\ Radial\ Impeller, the\ power\ number\ =\ 06$$

$$Power =\ 6\ \times 1000\ \times\ (94/60)3\ \times\ 1.0128$$

$$Power\ =\ 839\ W$$

$$Power = \ 0.839\ KW$$

CSTR-2

Volume:-

$$Volume = Volumetric\ flow\ rate\ X\ mass\ flow\ rate\ X\ 1/density\ X\ Residence\ time$$

$$Volume = 3343`.78\ X\ 1/1000\ X\ 1$$

$$Volume\ = \ 33.43\ m^3$$

$$As\ volume\ used\ is\ 85\%$$

$$Actual\ Volume\ = \ 0.85\ X\ 33.43$$

$$Actual\ Volume\ = \ 28.42\ m^3$$

Diameter and height:-

$$Using\ volume\ = \ 3.14\ D2/4\ X\ H$$

$$As\ th\ ratio\ of\ diameter\ to\ height\ for\ CSTR\ is\ 1:2$$

$$25.4982\ = \ (3.14\ X\ D2\ X\ 2D/4)$$

$$D = (4X28.42/3.14\ X\ 2)1/2$$

$$D = 2.63\ m$$

$$H = 2X2.532$$

$$H = 5.26\ m$$

Impeller diameter=0.4 × Tank diameter

$$= \ 0.4\ \times\ 2.63$$

$$Impeller\ diameter = \ 1.052\ m$$

$$Impeller\ opening\ =\ Impeller\ diameter$$

$$Length\ of\ impeller\ blade\ =\ Impeller\ blade\ diameter\ \times\ 0.025$$

$$Length\ of\ the\ Impeller\ Blade =\ 0.0263\ m$$

$$Number\ of\ impellers\ =\ 3$$

$$Number\ of\ blades\ =\ 6$$

$$Tip\ velocity =\ 3-6\ m/sec$$

$$Using\ tip\ velocity =\ 5m/sec$$

$$And\ now\ by\ using\ formula:$$

$$5\ =\ 3.142\ X\ N\ X\ 1.052\ X\ 1/60$$

$$Number\ of\ revolutions = N\ =\ 92\ RPM$$

Baffle design:-

$$4\ flat\ baffles\ in\ 900\ centre$$

$$Width\ of\ baffle\ =\ 0.8\ X\ tank\ diameter$$

$$Width\ =\ 0.8\ X\ 2.63\ m$$

$$Width =\ 2.104\ m$$

Power requirement:

$$Power\ =\ Power\ number\ \times\ density\ \times\ N3\ \times\ Impeller\ diameter$$

$$For\ Radial\ Impeller, the\ power\ number\ =\ 06$$

$$Power\ =\ 6\ X\ 1000\ \times\ (92/60)3\ \times\ 1.052$$

$$Power =\ 871\ W$$

$$Power = 0.871\ KW$$

4.2 Design Calculations of API Separator

$$Length\ to\ Width\ ratio\ =\ 5{:}\ 1$$

$$Depth\ to\ Width\ ratio\ =\ 0.3{:}\ 0.5$$

$$Maximum\ channel\ width\ =\ 20ft\ or\ 6.1\ meters$$

$$Maximum\ depth\ =\ 8ft\ or\ 2.44\ meters$$

$$Horizontal\ Velocity\ =\ not\ more\ than\ 3ft/min\ or\ 0.015m/s\ (to\ minimize\ turbulence)$$

$$Size\ of\ particles\ to\ be\ removed\ =\ 0.2mm\ or\ greater$$

$$For\ this\ sized\ particle, settling\ rate/\ velocity\ =\ 0.075ft/s\ or\ 0.023m/s$$

$$Depth\ of\ wastewater\ in\ the\ channel\ =\ 1ft$$

$$Settling\ time, s\ =\ depth/(settling\ rate)\ =\ 1/(0.075) = 13.3s$$

$$Hence, if\ effluent\ is\ flowing\ at\ 1\ ft/s\ then\ it\ would\ take\ 13.3s\ for\ the\ particles\ (0.2mm)\ to\ settle.$$

Nozzles:

If the vessel diameter is less than 0.5 m, the feed nozzle should be fitted with a half-open pipe inlet device, with the opening directed downwards. For vessel diameters of 0.5 m and larger and inlet nozzle sizes of 0.15 m and larger, a Schoepentoeter inlet device is recommended.

4.3 Design Calculations of Settling Tank

$$Us = settling\ velocity$$

$$Density\ of\ liquid = 1570kg/m3$$

$$Density\ of\ gas = 1.36\ kg/m3$$

$$Us = 0.51m/s$$

$$Volume = \pi/4 \times D2\ L$$

$$Where, V = 2.4\ m3$$

$$D = internal\ diameter$$

$$L = 3D$$

$$V = \pi/4 \times D2 \times 3D$$

$$D3 = (4 \times 2.4)/3\pi$$

$$D = 1m$$

$$L = 3m$$

$$Pressure\ Drop:$$

$$\Delta P = 0.5\ mv2m, in + 0.22\ gu2s, out$$

$$\Delta P = 0.254\ bar$$

4.4 Design Calculations of Aeration Tank

$$MLSS\ Concentration = 4000mg/L$$

$$Depth = 4m$$

$$Width\ =\ 35m$$

$$Length\ =\ 112.5m$$

$$Aeration\,Volume\ required\ =\ 4\ \times\ 35\ \times\ 112.5$$

$$Aeration\,Volume\ required\ =\ 15750\ m3$$

$$BODS\ Concentration\ in\ settled\ water\ =\ 250mg/L$$

$$Effluent\ soluble\ BODL\ =\ 6.2mg/L$$

$$Settled\ to\ soluble\ BOD\ Conversion\ factor, f\ =\ 0.68$$

$$Assuming\ temperature\ =\ 25^{\circ}C$$

$$Increase\ in\ mass\ of\ MLVSS, Px\ =\ 1646\ kg/day\ or\ 68.6\ kg/hr$$

$$O2\ required\ =\ V\ (BODS\ -\ BODL\ )\ (103\ g/kg) - 1$$

$$O2\ required\ = \frac{15750(250 - 6.2)}{0.68 \times 1000} - 1.42(1646)$$

$$O2\ required\ = 3309.52kg/day$$

4.5 Design of Hydrodynamic Cavitator:

We begin off with conversions required for the design calculations:

Conversions:

1 bar = 0.986923atm

1 inch = 0.0254m

1 hr = 3600 seconds

1. Starting off by determining the upstream velocity U_S:-

With the aid of continuity equation, we have:

$$m = \rho\ \times A \times U_S \qquad \text{———————} \quad \textbf{(1)}$$

$where,$

$$\rho = 1000\ kg/m^3$$

$$dia = 2\ invhes = 0.0508m$$

$$A = \frac{\pi d^2}{4} = \frac{\pi(0.0508)^2}{4} = 0.00203m^2$$

$$m = ?$$

But,

$$Molar\ flow\ rate = 1307.452\frac{kmol}{hr}$$

And

$$m = Molar\ flow\ rate\ \times MWmix$$

Hence,

$$MWmix = \sum x_i MW_i$$

Components	**Mol Fraction**
NaOH	0.000467
Na_2SO4	0.000140
NaCl	0.000047
H_2O	0.999394

$$MWmix = 18.03042\frac{kg}{kmol}$$

Now,

$$m = 1307.452\ \times 18.03042$$

$$m = 23573.918\frac{kg}{hr}$$

Going back to our **Equation (1)** to find $\boldsymbol{U_S}$:

$$U_S = \frac{\rho \ \times A}{m}$$

$$U_S = \frac{1000 \ \times 0.00203}{23573.918}$$

$$U_S = 11630.93 \frac{m}{hr} \times \frac{1\ hr}{3600\ seconds}$$

$$U_S = 3.23 \frac{m}{sec}$$

2. Secondly, we calculate the Cavitation number, by the following equation:

$$\sigma = \ \frac{P_S - P_V}{0.5 \ \times \ \rho_L \times U_S}$$

$where,$

$$P_S = Upstream\ pressure = 1.5\ bar = 1.4804\ atm$$

$$P_V = Vapor\ pressure = 3.17\ kPa = 0.0313\ atm$$

$$\rho_L = Density\ of\ fluid = 1000 \frac{kg}{m^3}$$

$$U_S = Upstream\ velocity = 3.23 \frac{m}{sec}$$

Therefore,

$$\sigma = \frac{1.4804 - 0.0313}{0.5 \times 1000 \times 3.23} = 8.97 \times \ 10^{-4}$$

3. For describing the variation in the nozzle cross sectional area in the direction of flow, we utilize the following expression:

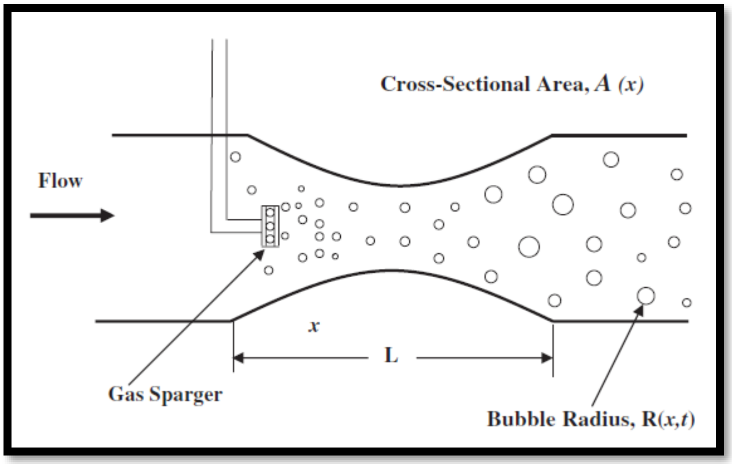


Figure 23. Variation in Nozzle cross-sectional area in the direction of flow

$$A(x) = \begin{cases} \left\{1 - \frac{1}{2} C_{PMIN}\left[1 - \cos\left(\frac{2\pi x}{L}\right)\right]\right\}^{-1/2}; & 0 \le x \le L \\ 1; \quad x < 0 \text{ and } x > L \end{cases}$$

$where,$

$A \ = Cross\ sectional\ area\ of\ nozzle\ normalized\ by\ upstream$

$cross\ sectional\ area\ (dimensionless)$

$L = Length\ of\ nozzle = 500mm$

$C_{PMIN} = MInimum\ pressure\ coefficient\ at\ nozzle\ throat = -1\ (i.e$
$< \ \sigma)$

Value of $-C_{PMIN}$ relative to cavitation number, σ, represents the intensity of surface tension in flow. If $-\boldsymbol{C_{PMIN}} \ > \ \boldsymbol{\sigma}$ minimum flui8d pressure experienced by the individual bubbles will be lower than vapor pressure and bubbles will cavitate

The flow region between **x=0** and **L** is divided in significantly large number of intervals almost 100. These intervals will have a total have a total of 101 nodes.

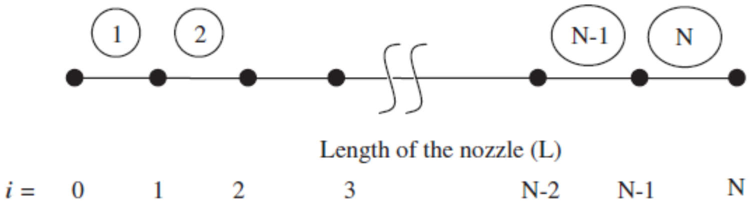


Figure 24. Number of nodes and the length of the nozzle

The encircled numbers portray intervals and dots indicate the node.

Values of the distance coordinate, **x** are then calculated as:

$$x_{i+1} = x_i + (\frac{L}{100})$$

Calculating Cross sectional area **(A)** at different nodal points (x), and summarizing these quantities in a table:

Halfway →

x (mm)	A(x)
0	1
50	0.9554
100	0.8621
150	0.7774
200	0.7246
250	0.7071
300	0.7246
350	0.7774
400	0.8621
450	0.9554
500	1

The above table indicates that the cross-sectional area decreases up to the throat of the nozzle and then increases back to pipe diameter at nozzle end.

4. Now, we intend to find throat velocity U_t:-

By incorporating the Bernoulli's Equation:

$$P_! + \frac{1}{2}\,\rho {v_1}^2 + \rho g h_1 = P_2 + \frac{1}{2}\,\rho {v_2}^2 + \rho g h_2$$

Applying above equation between points **x=0** and **x=L/2**:

$$P_! + \frac{1}{2}\,\rho {U_S}^2 + \cancel{\rho g h_1} = P_2 + \frac{1}{2}\,\rho {U_t}^2 + \cancel{\rho g h_2}$$

Considering the limiting case, where pressure at throat is equal to vapor pressure of fluid ($P_2 = P_v$), hence

$$U_t = \sqrt{\frac{P_1 - P_v}{0.5 \times \rho} + {U_S}^2}$$

$$U_t = 3.23045\,\frac{m}{sec}$$

As can be seen, there hasn't been a significant change in velocity due to a reduction in cross-sectional area. This is because, there has been a major reduction in pressure of fluid that cause it to cavitate.

Velocity at other nodal points can be determined by:

$$U_i A_i = U_t A_t$$

$$U_i = \frac{U_t A_t}{A_i}$$

Generating a table with these values:

x (mm)	A(x)	U(x) (m/sec)
0	1	2.3196
50	0.9554	2.4279
100	0.8621	2.6906
150	0.7774	2.9838
200	0.7246	3.2012
250	0.7071	3.2805
300	0.7246	3.2012
350	0.7774	2.9839
400	0.8621	2.6906
450	0.9554	2.4279
500	1	2.3196

At the entrance of the nozzle there is a sudden decrease in velocity of fluid compared to the upstream velocity. This is due to the sudden obstruction in flow being provided at the nozzle opening. In overall, the velocity is seen to be increasing up till the throat of nozzle and then decreases. A drastic increase in velocity is not observed due to a significant decrease in pressure.

5. **As we know the velocity at each nodal point, we can now find the pressure as well, with the aid of Bernoulli Equation:**

$$P_i + \frac{1}{2}\rho {U_i}^2 + \cancel{\rho g h_i} = P_{i-1} + \frac{1}{2}\rho {U_{i-1}}^2 + \cancel{\rho g h_{i-1}}$$

Tabulating these values:

x (mm)	A(x)	U(x)	P(x) (atm)
0	1	2.3196	2.838
50	0.9554	2.4279	2.575
100	0.8621	2.6906	1.909
150	0.7774	2.9838	1.078
200	0.7246	3.2012	0.405
250	0.7071	3.2805	0.0313
300	0.7246	3.2012	0.405
350	0.7774	2.9838	0.908
400	0.8621	2.6906	1.032
450	0.9554	2.4279	1.247
500	1	2.3196	1.295

Pressure initially increases due to the sudden obstruction in flow, as can be seen from the table. After the sudden increase, an exponential drop can be observed up to nozzle throat, where it reaches equivalent to the vapor pressure of the fluid. Post throat, the pressure increases but only a certain percentage of the pressure is recovered.

6. **Time taken to travel between consecutive nodes is given by:**

$$t_{i+1} = \frac{x_i - x_{i+1}}{(U_{i+1} + U_i)/2}$$

Incorporating these values into a table:

x (mm)	A(x)	t(X) (seconds)
0	1	-
50	0.9554	2.0067
100	0.8621	1.8686
150	0.7774	1.6834
200	0.7246	1.5659
250	0.7071	1.5243
300	0.7246	1.5582
350	0.7774	1.6682
400	0.8621	1.8479
450	0.9554	2.0504
500	1	2.1550

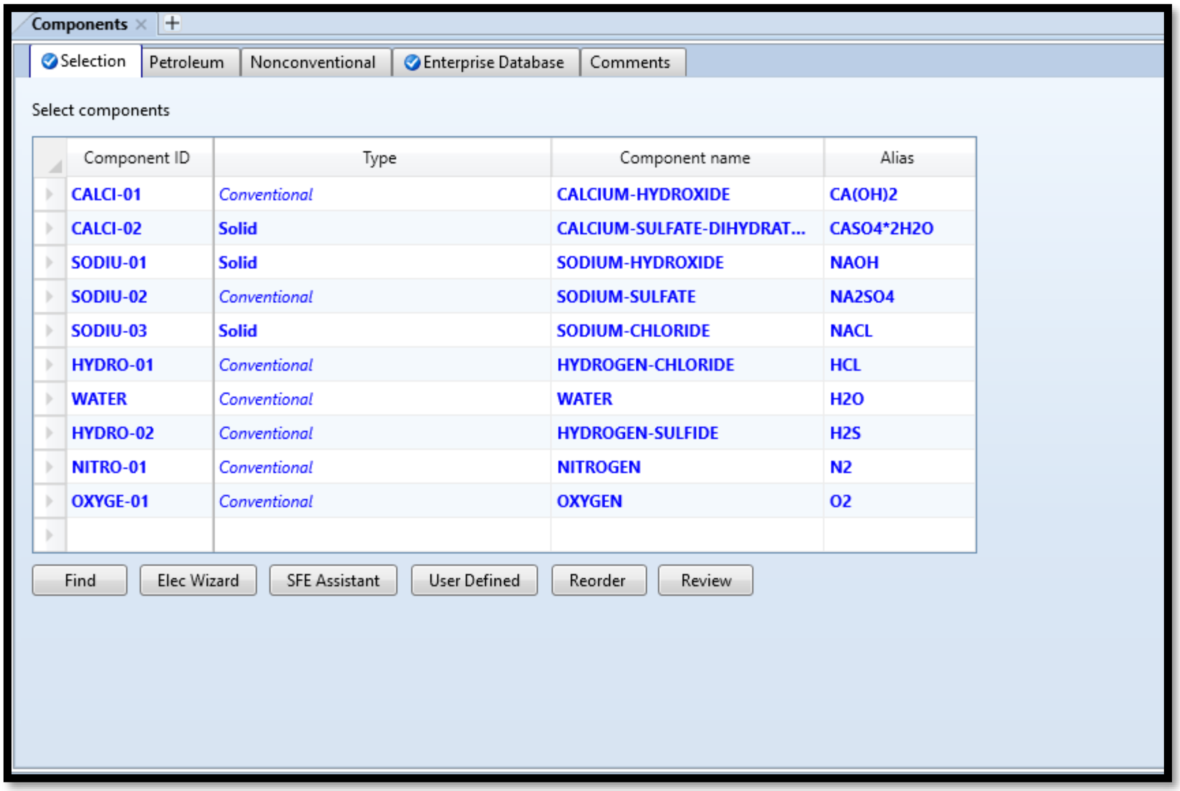
The time taken by the fluid to travel between consecutive nodes decreases until the midway of nozzle, i.e until it reaches the throat and then it starts to increase till the very end.

CHAPTER 5

PROCESS MODELLING & SIMULATION

5.1 Selection of Components

The components were selected from the ASPEN PLUS library and some of them were added manually as hypothetical components using their boiling point ranges and densities.



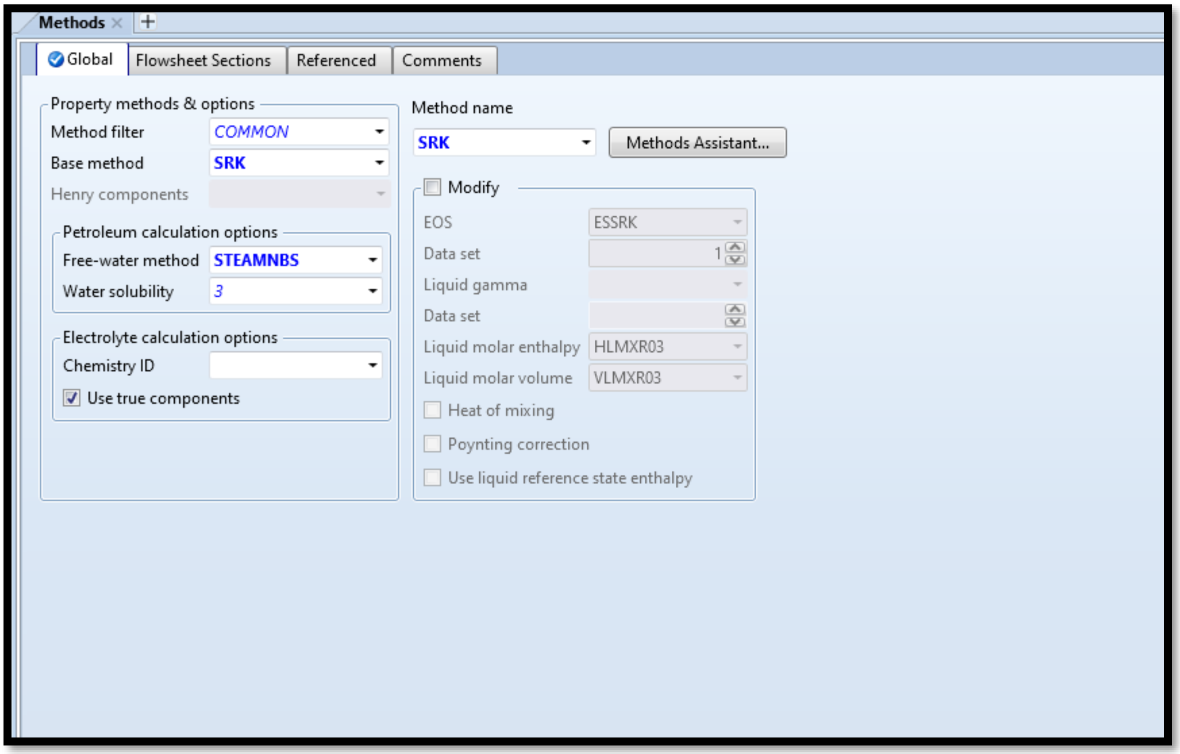
Select components

Component ID	Type	Component name	Alias
CALCI-01	Conventional	CALCIUM-HYDROXIDE	CA(OH)2
CALCI-02	Solid	CALCIUM-SULFATE-DIHYDRAT...	CASO4*2H2O
SODIU-01	Solid	SODIUM-HYDROXIDE	NAOH
SODIU-02	Conventional	SODIUM-SULFATE	NA2SO4
SODIU-03	Solid	SODIUM-CHLORIDE	NACL
HYDRO-01	Conventional	HYDROGEN-CHLORIDE	HCL
WATER	Conventional	WATER	H2O
HYDRO-02	Conventional	HYDROGEN-SULFIDE	H2S
NITRO-01	Conventional	NITROGEN	N2
OXYGE-01	Conventional	OXYGEN	O2

Figure 25. Components list

5.2 Selection of Fluid Package

The fluid package was selected to be **SRK,** on the basis of compatibility with the selection of components as well as the pressure ranges were less than 10 bars. The ASPEN PLUS method assistant was also used and the final selection was done.



Property methods & options
Method filter: COMMON
Base method: SRK
Henry components:
Petroleum calculation options
Free-water method: STEAMNBS
Water solubility: 3
Electrolyte calculation options
Chemistry ID:
☑ Use true components

Method name: SRK
☐ Modify
EOS: ESSRK
Data set: 1
Liquid gamma:
Data set:
Liquid molar enthalpy: HLMXR03
Liquid molar volume: VLMXR03
☐ Heat of mixing
☐ Poynting correction
☐ Use liquid reference state enthalpy

Figure 26. Fluid package

5.3 Process Flowsheet Modelling and Simulation

The process flow diagram was replicated as the flowsheet on Aspen HYSYS as shown by the snippet. The molar flows were the same as that of our manual calculations. The temperature and pressure parameters were also defined according to the requirements and then the simulation was run to obtain the final composition of the treated effluent water at the exit of Hydrodynamic Cavitator.

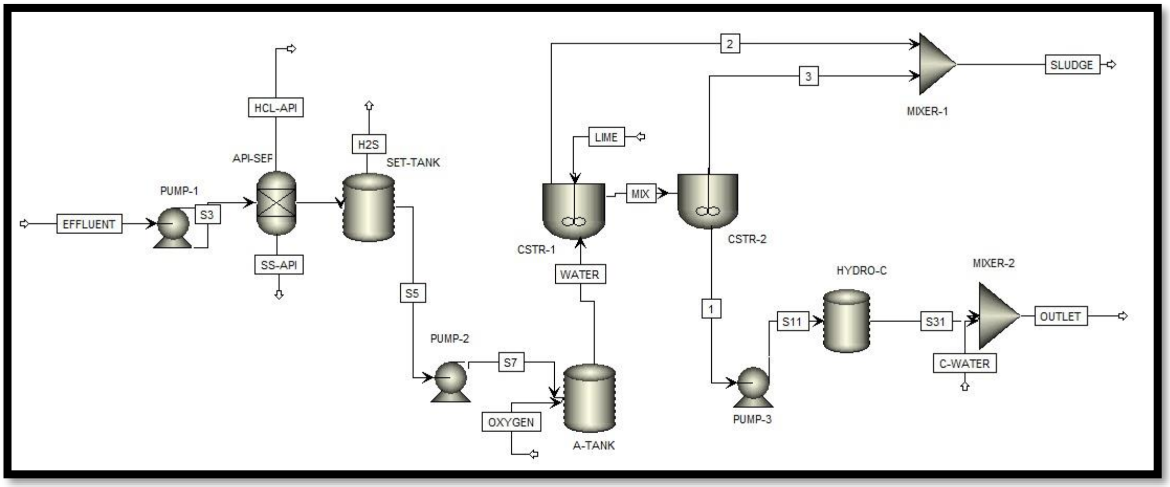
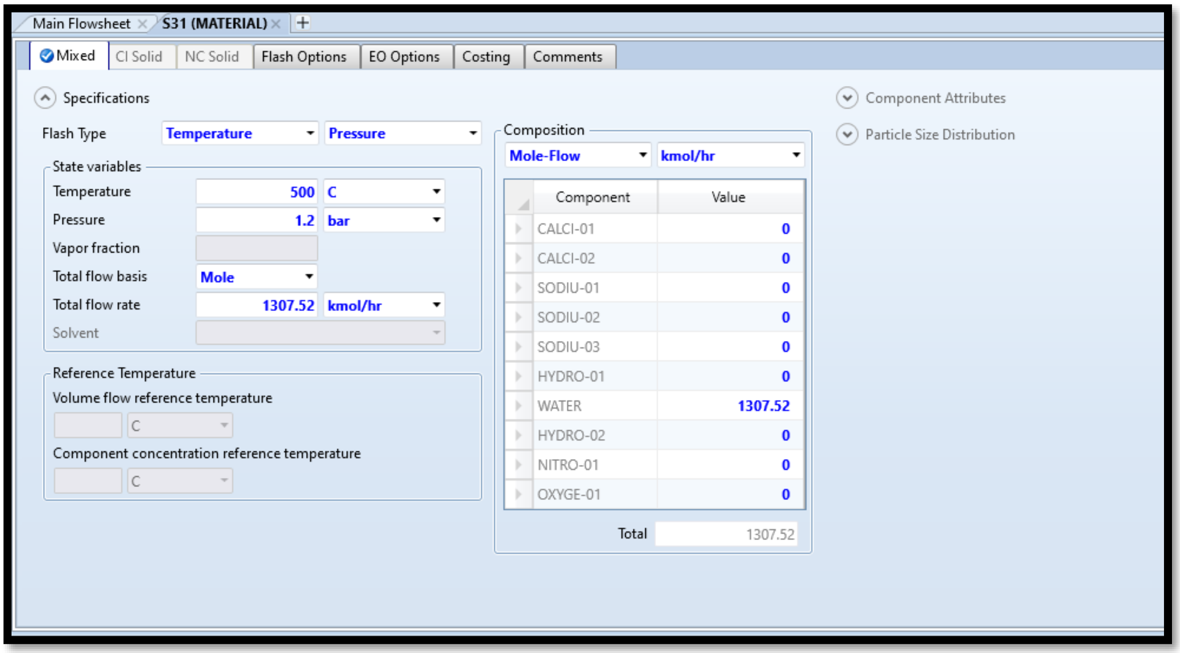


Figure 27. Process flow diagram on aspen one

5.4 Results

After the successful simulation of the model, the results were obtained that were close to our theoretical calculations. The exit stream of Hydrodynamic Cavitator was free of any sort of impurities.



Flash Type: Temperature, Pressure

State variables
Temperature: 500 C
Pressure: 1.2 bar
Vapor fraction:
Total flow basis: Mole
Total flow rate: 1307.52 kmol/hr
Solvent:

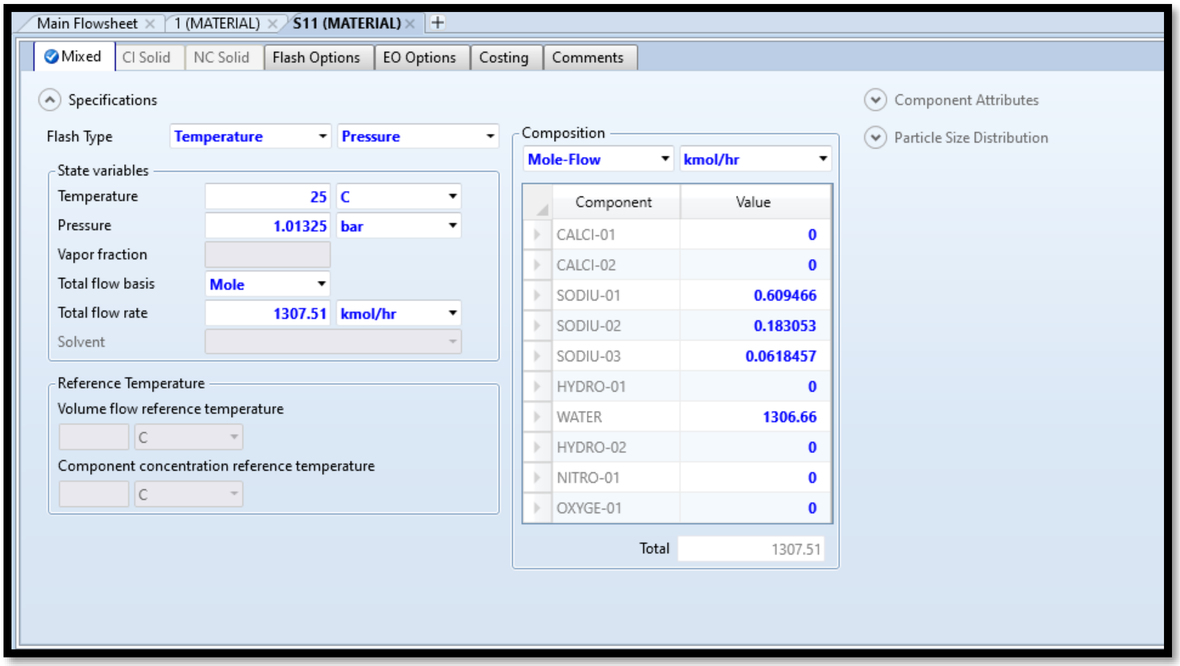
Reference Temperature
Volume flow reference temperature: C
Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	0
SODIU-03	0
HYDRO-01	0
WATER	1307.52
HYDRO-02	0
NITRO-01	0
OXYGE-01	0

Total: 1307.52

Figure 28. Conditions of S31 stream



Flash Type: Temperature, Pressure

State variables
Temperature: 25 C
Pressure: 1.01325 bar
Vapor fraction:
Total flow basis: Mole
Total flow rate: 1307.51 kmol/hr
Solvent:

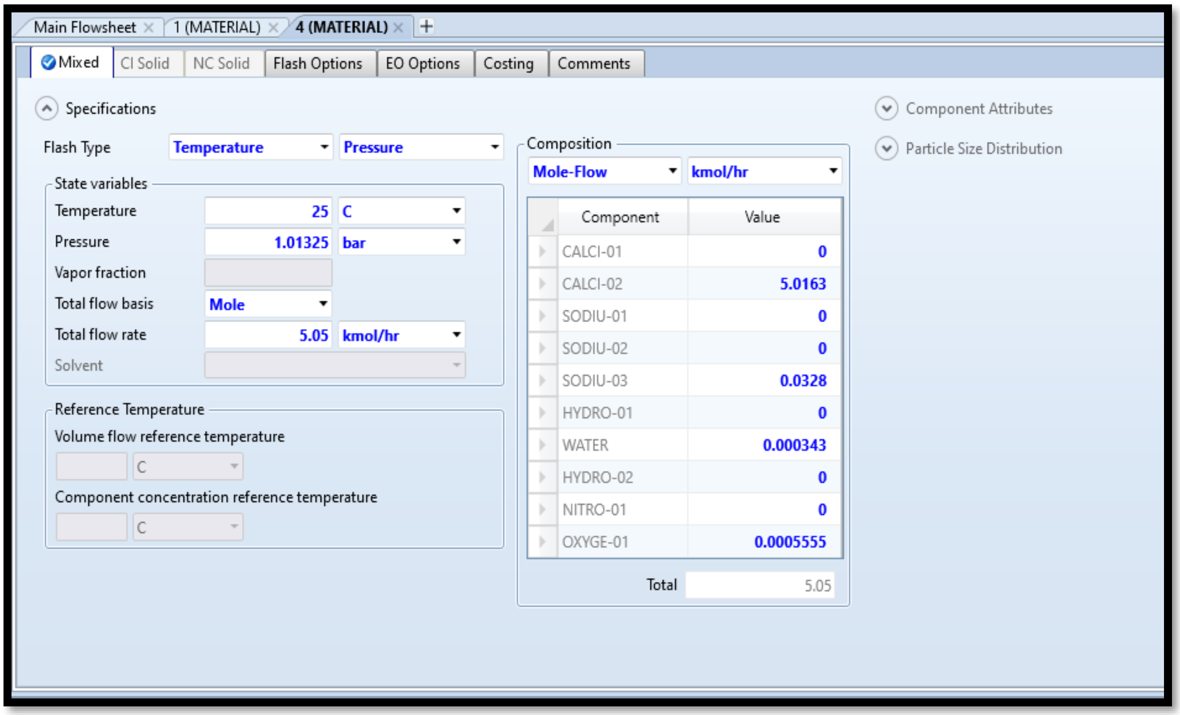
Reference Temperature
Volume flow reference temperature: C
Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0.609466
SODIU-02	0.183053
SODIU-03	0.0618457
HYDRO-01	0
WATER	1306.66
HYDRO-02	0
NITRO-01	0
OXYGE-01	0

Total: 1307.51

Figure 29. Conditions of S11 Stream



Flash Type: Temperature, Pressure

State variables

Temperature: 25 C

Pressure: 1.01325 bar

Vapor fraction:

Total flow basis: Mole

Total flow rate: 5.05 kmol/hr

Solvent:

Reference Temperature

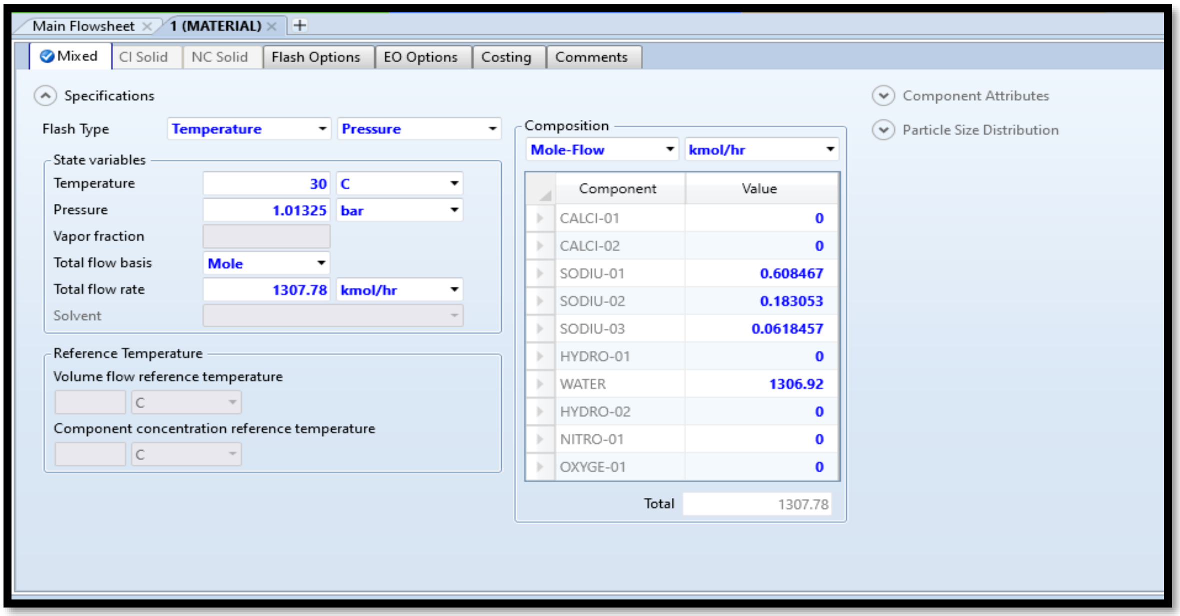
Volume flow reference temperature: C

Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	5.0163
SODIU-01	0
SODIU-02	0
SODIU-03	0.0328
HYDRO-01	0
WATER	0.000343
HYDRO-02	0
NITRO-01	0
OXYGE-01	0.0005555
Total	5.05

Figure 30. Conditions of Stream 4



Flash Type: Temperature, Pressure

State variables

Temperature: 30 C

Pressure: 1.01325 bar

Vapor fraction:

Total flow basis: Mole

Total flow rate: 1307.78 kmol/hr

Solvent:

Reference Temperature

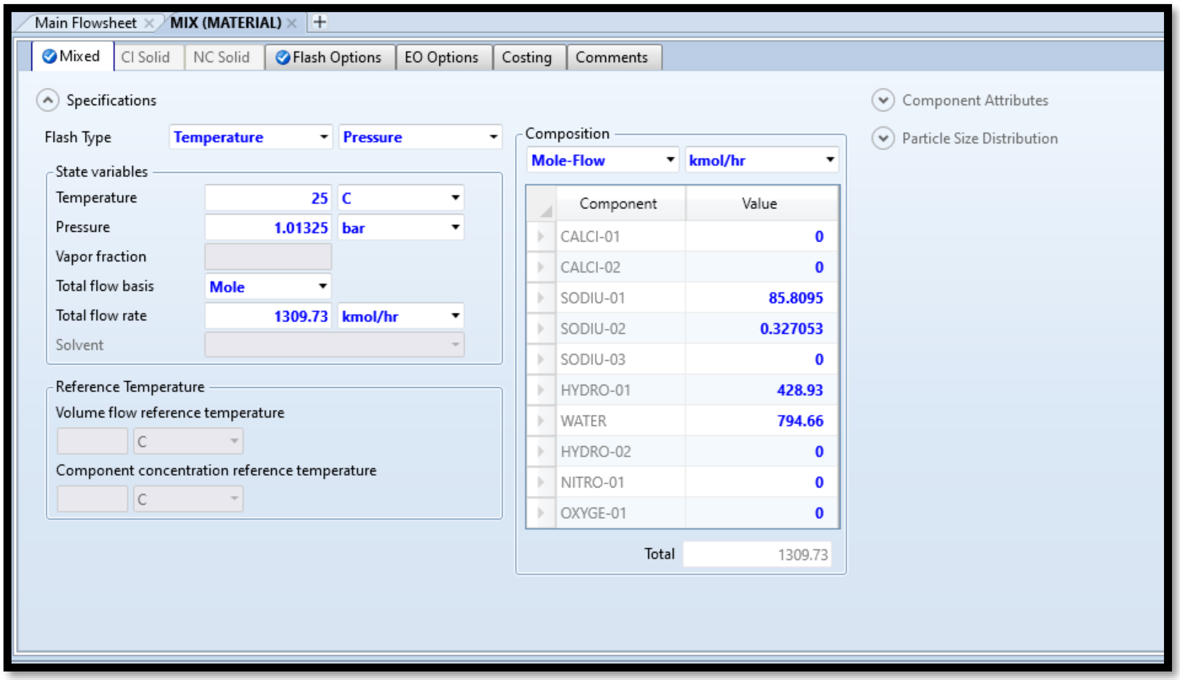
Volume flow reference temperature: C

Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0.608467
SODIU-02	0.183053
SODIU-03	0.0618457
HYDRO-01	0
WATER	1306.92
HYDRO-02	0
NITRO-01	0
OXYGE-01	0
Total	1307.78

Figure 31. Conditions of Stream 1



Flash Type: Temperature, Pressure

State variables

Temperature	25	C
Pressure	1.01325	bar
Vapor fraction		
Total flow basis	Mole	
Total flow rate	1309.73	kmol/hr
Solvent		

Reference Temperature

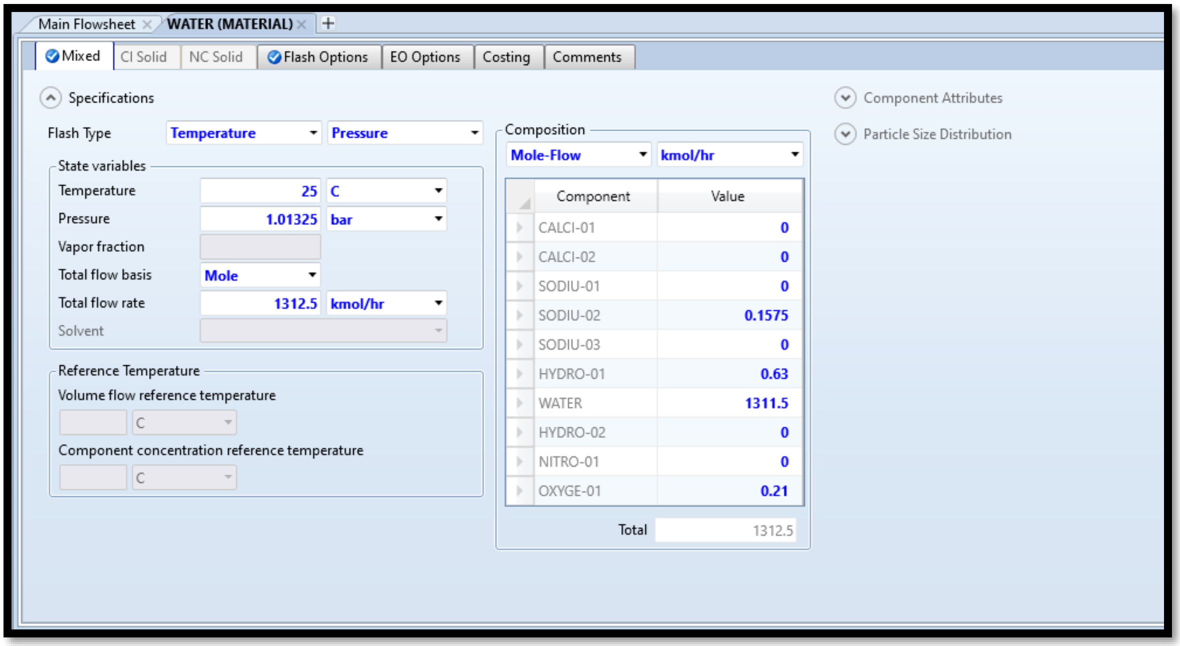
Volume flow reference temperature: C

Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	85.8095
SODIU-02	0.327053
SODIU-03	0
HYDRO-01	428.93
WATER	794.66
HYDRO-02	0
NITRO-01	0
OXYGE-01	0
Total	1309.73

Figure 32. Conditions of Mix Stream



Flash Type: Temperature, Pressure

State variables

Temperature	25	C
Pressure	1.01325	bar
Vapor fraction		
Total flow basis	Mole	
Total flow rate	1312.5	kmol/hr
Solvent		

Reference Temperature

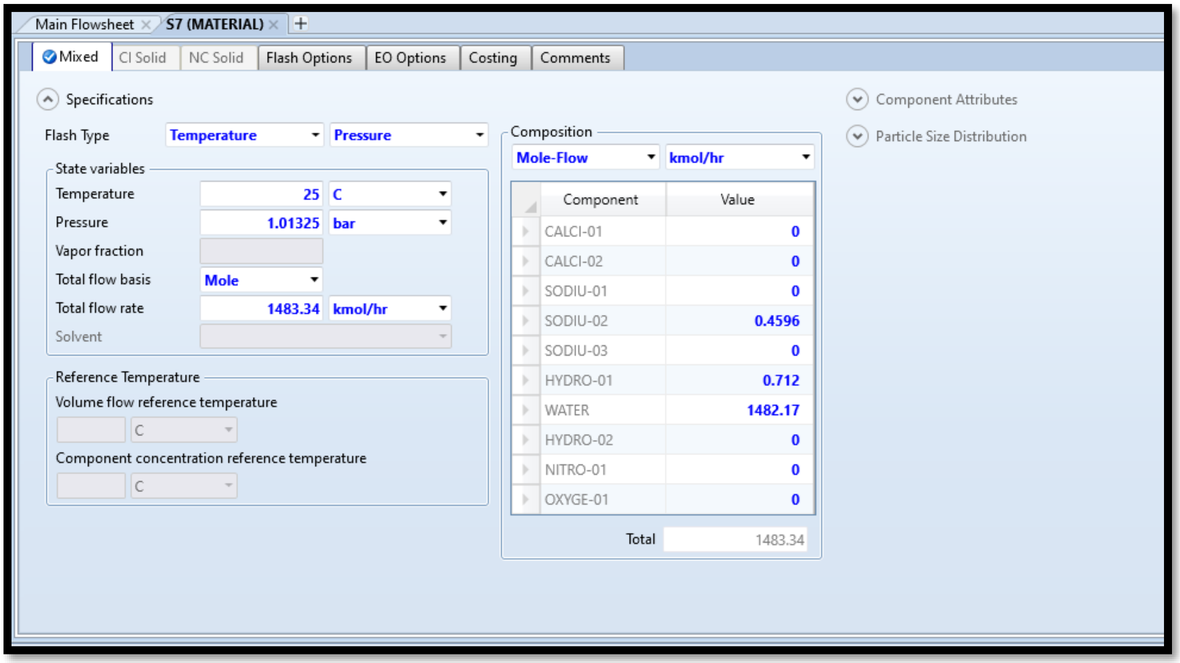
Volume flow reference temperature: C

Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	0.1575
SODIU-03	0
HYDRO-01	0.63
WATER	1311.5
HYDRO-02	0
NITRO-01	0
OXYGE-01	0.21
Total	1312.5

Figure 33. Conditions of Water Stream



Flash Type: Temperature, Pressure

State variables

Temperature: 25 C

Pressure: 1.01325 bar

Vapor fraction:

Total flow basis: Mole

Total flow rate: 1483.34 kmol/hr

Solvent:

Reference Temperature

Volume flow reference temperature: C

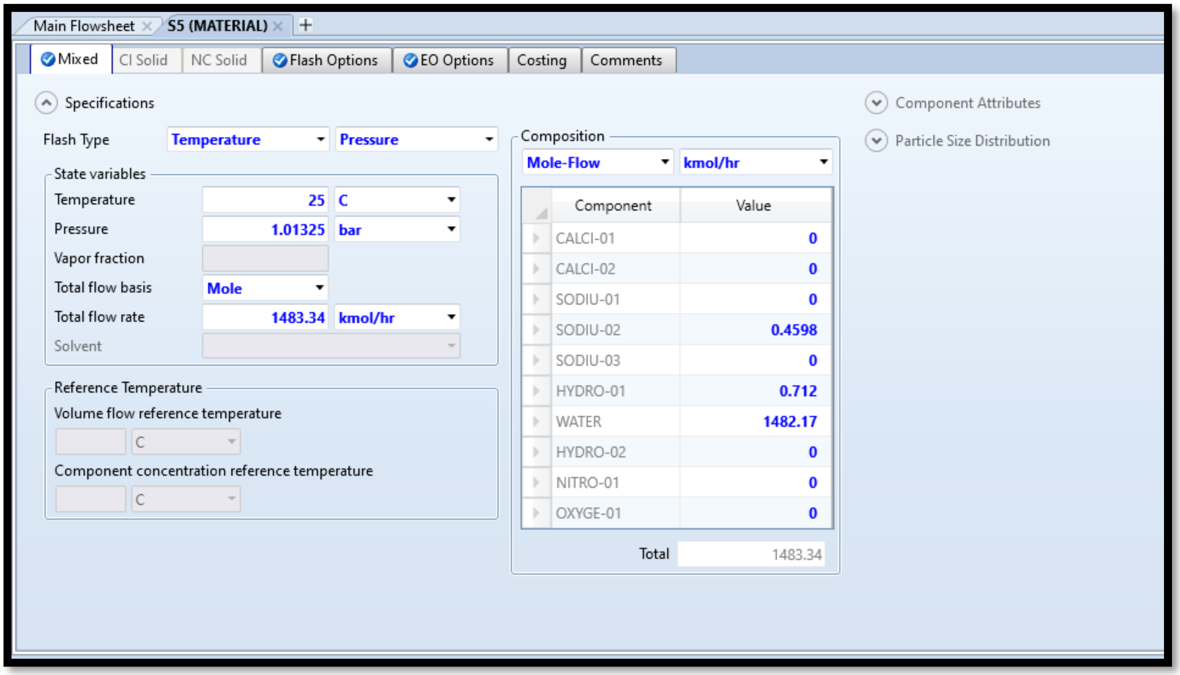
Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	0.4596
SODIU-03	0
HYDRO-01	0.712
WATER	1482.17
HYDRO-02	0
NITRO-01	0
OXYGE-01	0

Total: 1483.34

Figure 34. Conditions of S7 Stream



Flash Type: Temperature, Pressure

State variables

Temperature: 25 C

Pressure: 1.01325 bar

Vapor fraction:

Total flow basis: Mole

Total flow rate: 1483.34 kmol/hr

Solvent:

Reference Temperature

Volume flow reference temperature: C

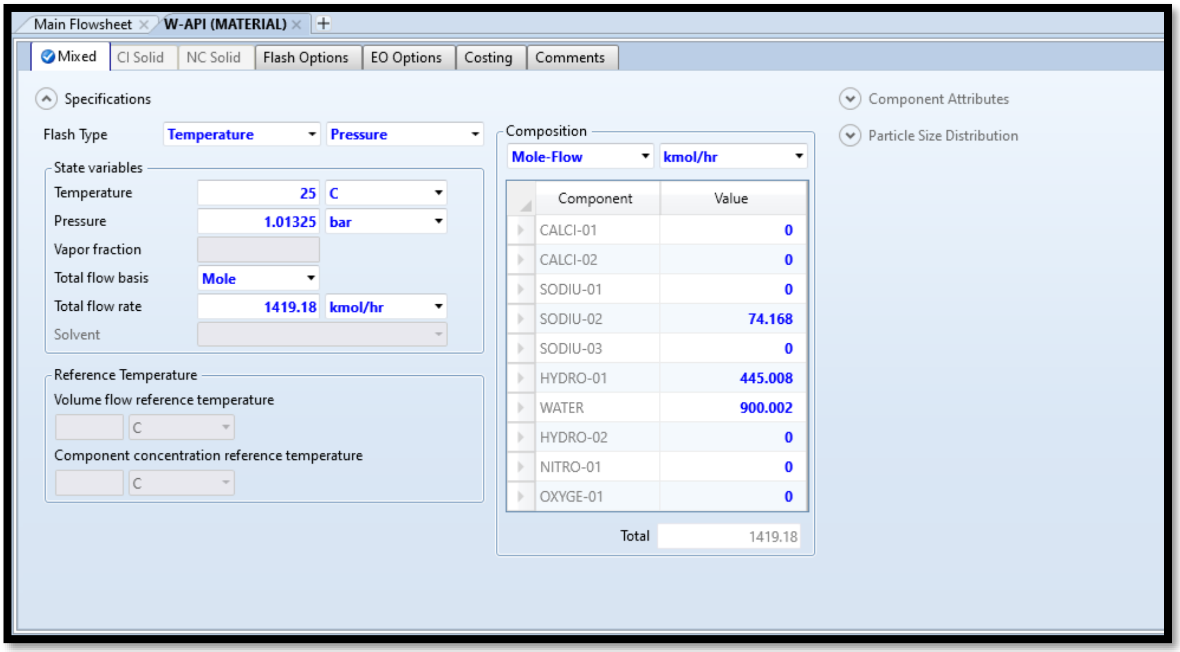
Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	0.4598
SODIU-03	0
HYDRO-01	0.712
WATER	1482.17
HYDRO-02	0
NITRO-01	0
OXYGE-01	0

Total: 1483.34

Figure 35. Conditions of S5 Stream



Flash Type: Temperature, Pressure

State variables

Temperature	25	C
Pressure	1.01325	bar
Vapor fraction		
Total flow basis	Mole	
Total flow rate	1419.18	kmol/hr
Solvent		

Reference Temperature

Volume flow reference temperature: C

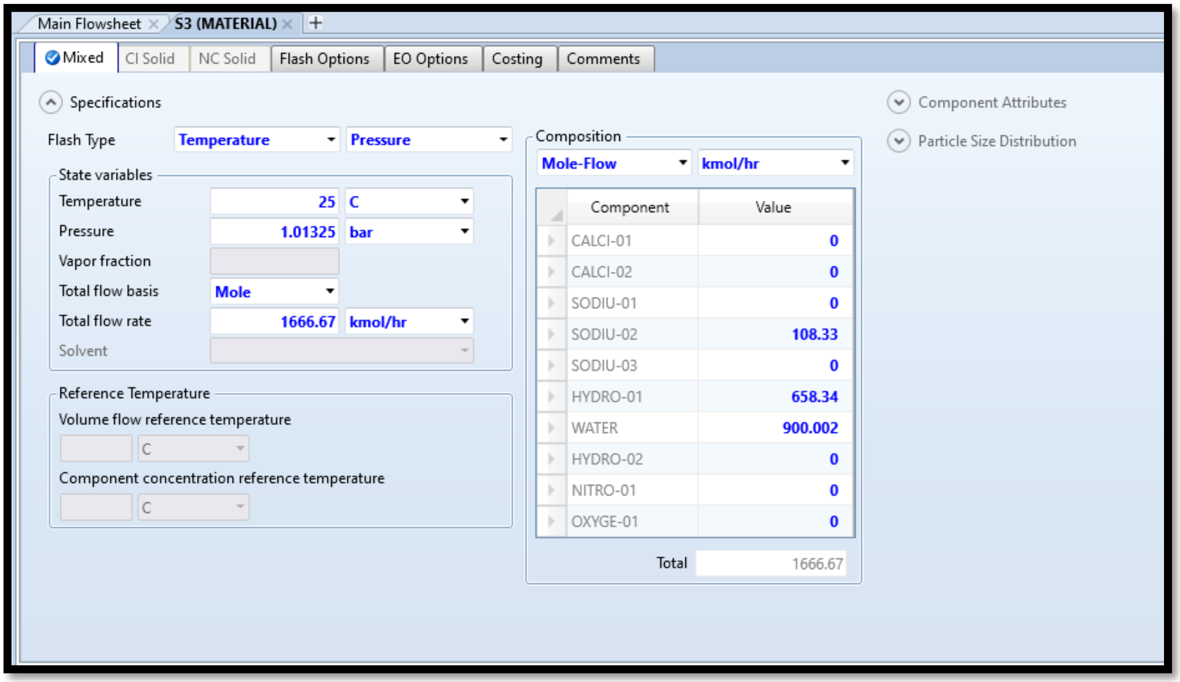
Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	74.168
SODIU-03	0
HYDRO-01	445.008
WATER	900.002
HYDRO-02	0
NITRO-01	0
OXYGE-01	0

Total: 1419.18

Figure 36. Conditions of W-API



Flash Type: Temperature, Pressure

State variables

Temperature	25	C
Pressure	1.01325	bar
Vapor fraction		
Total flow basis	Mole	
Total flow rate	1666.67	kmol/hr
Solvent		

Reference Temperature

Volume flow reference temperature: C

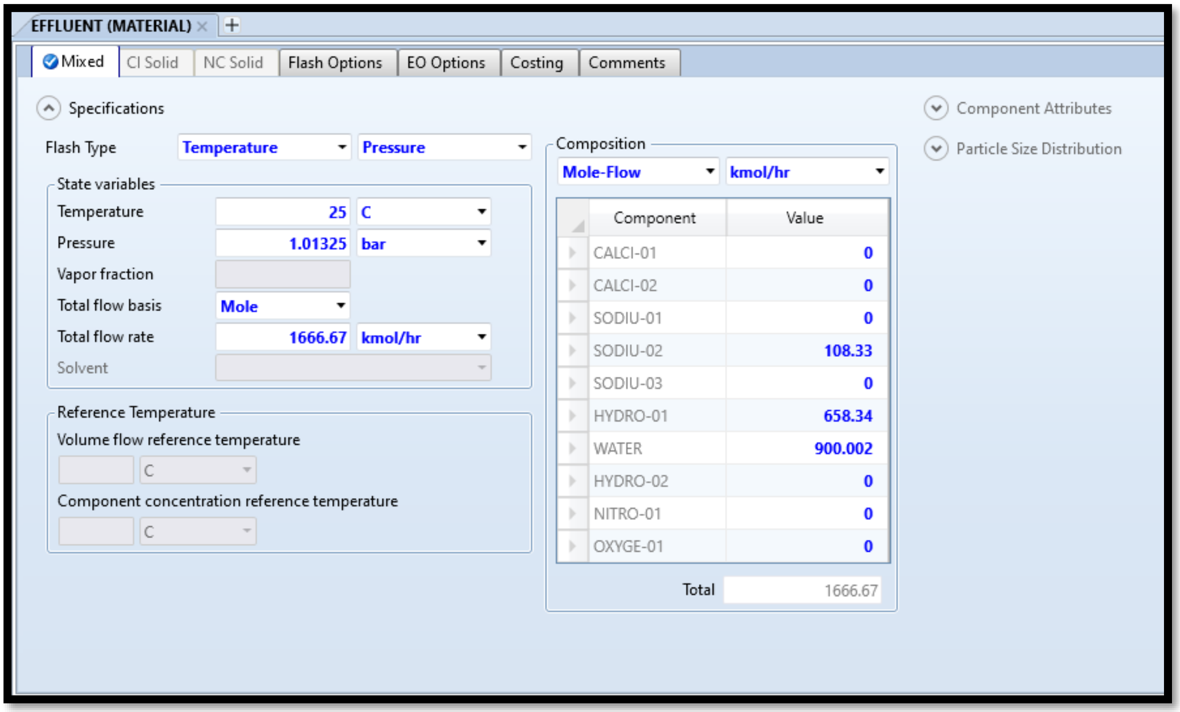
Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	108.33
SODIU-03	0
HYDRO-01	658.34
WATER	900.002
HYDRO-02	0
NITRO-01	0
OXYGE-01	0

Total: 1666.67

Figure 37. Conditions of S3 Stream



Flash Type: Temperature, Pressure

State variables

Temperature: 25 C

Pressure: 1.01325 bar

Vapor fraction:

Total flow basis: Mole

Total flow rate: 1666.67 kmol/hr

Solvent:

Reference Temperature

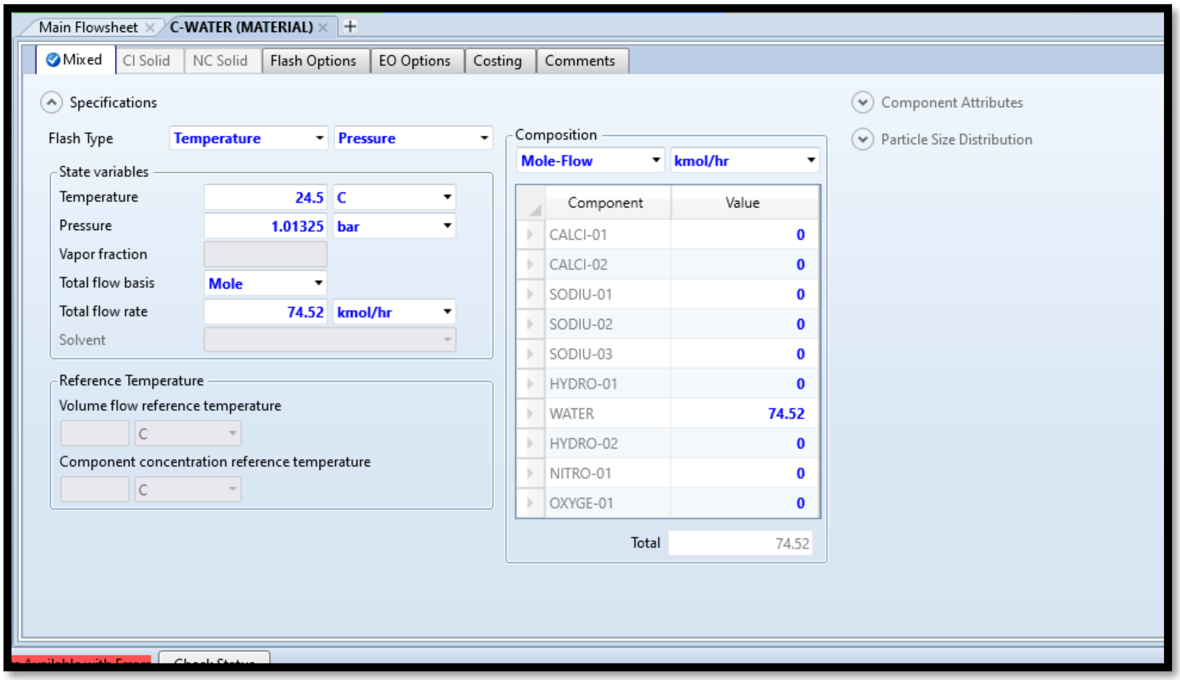
Volume flow reference temperature: C

Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	108.33
SODIU-03	0
HYDRO-01	658.34
WATER	900.002
HYDRO-02	0
NITRO-01	0
OXYGE-01	0
Total	1666.67

Figure 38. Conditions of Effluent



Flash Type: Temperature, Pressure

State variables

Temperature: 24.5 C

Pressure: 1.01325 bar

Vapor fraction:

Total flow basis: Mole

Total flow rate: 74.52 kmol/hr

Solvent:

Reference Temperature

Volume flow reference temperature: C

Component concentration reference temperature: C

Composition: Mole-Flow, kmol/hr

Component	Value
CALCI-01	0
CALCI-02	0
SODIU-01	0
SODIU-02	0
SODIU-03	0
HYDRO-01	0
WATER	74.52
HYDRO-02	0
NITRO-01	0
OXYGE-01	0
Total	74.52

Figure 39. Conditions of C-water

CHAPTER 6

INSTRUMENTATION

6.1 Introduction:

Instrumentation and Process Control play a key-role in the smooth functioning of a process plant. Instrumentation utilizes the hardware components that are also known as controllers to maintain and regulate the various variables that are essential for the process. To provide control and monitoring of our process, we have included the instrumentation and process control in our project. This is done by applying controls on major equipment, including the hydrodynamic cavitator, CSTRs, API Separator, Settling tank, aeration tank and the centrifugal pumps.

6.2 Requirements of control:

Control system must meet the following requirements and objectives during operation of chemical plant:

6.2.2 Safety:

The safe operation is very crucial for the well-being of the personnel working at the processing plant. The operating factors should not breach the safety limits, i.e. the concentration, temperature and the pressure limits should not be breached.

6.2.3 Product specification:

Some appropriate instrumentation is being used to achieve desired product quality and quantity. This is essential to have a work system that adds stability to the process .

6.2.4 Environmental Regulation:

There are standards for the safe limits for factors like concentration, pressure and temperature of the exhaust and purge releases from a typical industrial plant.

The conditions for the work also need to lie within the less cost and more benefit to the society limit. These standards are consistently maintained by the plants and the law and regulatory authorities keep a regular check and balance on the industrial plants for it. These standards are met to fulfil the objectives of an organization related to the achievement of their operational and development goals.

For the most part, a control framework fulfills the accompanying:

- Reducing the effect of external deviations
- Keeping the plant in a stable working environment
- Optimization of a chemical process

6.3 Control Parameters

There are variables that play a key role in controlling and regulating a process, these are defined as;

6.3.1 Manipulated variables:

The inputs given to the controller to control the desired part of the process are known as the manipulated variables. For example, in changing the opening of a valve to control the flow through a pipe, the valve opening is the manipulated variable.

6.3.2 Uncontrolled variables:

Some variables are unable to be controlled by using the controllers and these variables are known as uncontrolled variables.

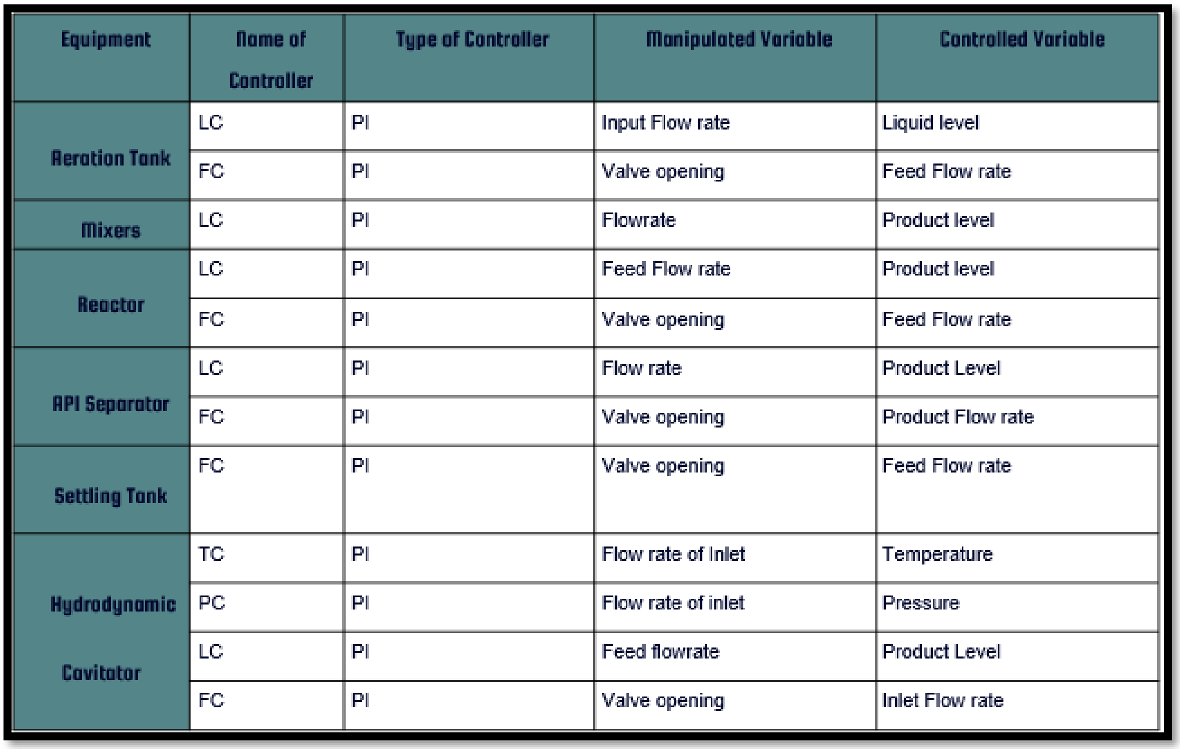
6.3.3 Controlled Variables:

These are the process conditions that the user decides to regulate using the controllers. For example; in the example of regulating the flow through a pipe by changing the valve opening, flow is the controlled variable.

6.4 Summary of the Defined Controllers

The controllers were defined on the basis of Proportional-Integral type, on the major equipment to monitor and control the fluid flows effectively. A number of level and flow controllers are required to be installed to maintain the liquid level in important equipment like the mixing vessels and the reactor.

The table below represents the summary of the controllers defined throughout our process flow diagram.



Equipment	Name of Controller	Type of Controller	Manipulated Variable	Controlled Variable
Aeration Tank	LC	PI	Input Flow rate	Liquid level
	FC	PI	Valve opening	Feed Flow rate
Mixers	LC	PI	Flowrate	Product level
Reactor	LC	PI	Feed Flow rate	Product level
	FC	PI	Valve opening	Feed Flow rate
API Separator	LC	PI	Flow rate	Product Level
	FC	PI	Valve opening	Product Flow rate
Settling Tank	FC	PI	Valve opening	Feed Flow rate
Hydrodynamic Cavitator	TC	PI	Flow rate of Inlet	Temperature
	PC	PI	Flow rate of inlet	Pressure
	LC	PI	Feed flowrate	Product Level
	FC	PI	Valve opening	Inlet Flow rate

Table SEQ Table \ Instrumentation Summary

CHAPTER 7

COST ESTIMATION AND ANALYSIS

The following equations were used to find out the production cost and the payout period of our plant.

$$Cost\ in\ year\ 2021\ =\ Cost\ in\ year\ 2004\ \times \frac{CPE\ Index\ 2021}{CPE\ Index\ 2004}$$

$$\frac{CPE\ Index\ 2021}{CPE\ Index\ 2004} = 1.65$$

$$Production\ Cost\ (\frac{USD}{kg}) = \frac{Annual\ Production\ Cost}{Annual\ Production\ Rate}$$

7.1 API Separator:

$$7.5\ \times 1000 \times 1 \times 1$$

$$£7500\ \times \$1.42$$

$$\$10612.88$$

7.2 Settling tank:

$$Ce = CS^n$$

$$Ce = 2300(50)^{0.6}$$

$$Ce = \$25095.35$$

7.3 Pump:

$$300\ \times 3$$

$$\$900$$

7.4 Mixer:

$$Ce = CS^n$$

$$Ce = 1900(5)^{0.5}$$

$$Ce = \$4248.53 \times 2$$

$$Ce =\ \$8500$$

7.5 CSTRs:

$$Ce = CS^n$$

$$Ce = 31000(3.5)^{0.45} \times 2$$

$$Ce = \$108948.8$$

7.6 Aeration Tank:

$$V = 20m^3$$

$$Ce = CS^n$$

$$Ce = 2400(20)^{0.6}$$

$$Ce = \$14482$$

7.7 Hydrodynamic Cavitator:

$$dia = 2m$$

$$£14000 \times 2$$

$$£28000 \times \$1.42$$

$$\$39627$$

$$\boldsymbol{Purchase\ Cost\ of\ Equipment} = 10612.88 + 25095.35 + 900 + 8500 + 108948.8 + 14482 + 39627 = \$207716.03$$

$$\boldsymbol{Plant\ Physical\ Cost} = PCE(1 + 0.4 + 0.3 + 0.2 + 0.1) = \$498518.5$$

$$\boldsymbol{Fixed\ Capital} = PPC\ (1 + 0.3 + 0.1 + 0.1) = \$747777.75$$

$\boldsymbol{Working\ Capital} = 5\%\ of\ Fixed\ Capital = 5\% \times \$\ 747777.5 = \$\ 37388.9$

$\boldsymbol{Total\ Investment\ Cost} = \boldsymbol{Fixed\ Capital} + \boldsymbol{Working\ Capital}$

$\boldsymbol{Total\ Investment\ Cost} = \$785166.6$

$\boldsymbol{Plant\ attainment} = 95\%$

$\boldsymbol{Number\ of\ Working\ days} = 345$

$\boldsymbol{Operating\ time} = 345 \times 0.95 = 327.75 \frac{days}{year} = \frac{7866hours}{year}$

Variable cost:

Raw material: Oxygen and Calcium Hydroxide

Oxygen:

Quantity per year: (4500kg/hr × 24hr/day × 365days/year) / 1000

= 39420 MT/year

Cost= $40/MT × 39420 MT/year

Cost= 1.5768 M$/year

Calcium Hydroxide:

Quantity per year: (4.847kg/hr × 24hr/day × 365days/year) /1000

= 42.46 MT/year

Cost= $25/MT × 42.46 MT/year

Cost= 1061.5 $/year

1. Cost of Raw materials = 1.58M$
2. Maintenance = 5% of Fixed Capital =>0.05 × 747777.7 = $37388.9
3. Miscellaneous = 10 % of Maintenance => Maintenance = 5% of Fixed Capital = 10% × $37388.9 = $3738.9
4. Utilities: Cooling Water and Power = $1435

Cooling Water: £0.015/1000kg × $1.42/£ × 7866hr/year × 1341.36kg/hr

Cooling Water: $224.74

Power: £0.0012/10^6 J × $1.42/£ × 7866hr/year × 2.38KJ/s × (24 × 3600 × 365 s)

Power: $1210

Fixed Cost:

1. Maintenance = 5% of Fixed Capital =>0.05 × 747777.7 = $37388.9
2. Operating Labour = $42600
3. Plant Overheads = 50% of Operating Labour = $21300
4. Capital Charge = 6% of Fixed Capital = 6% × $747777.7 = $44866.6
5. Insurance = 1% of Fixed Capital = 1% × $747777.7 = $7477.8
6. Direct Production Cost = Fixed Cost + Variable Cost

Direct Production Cost = $166413.3 + $158173.9 = $1751587.2 = 1.75M$

Annual Operating Cost = 30% of DPC = $525476.2

Production rate= 23535.4Kg/hr × 1MT/1000Kg × (24 × 365 hr)/year

Production rate= 206170MT/year

Cost per production rate= DPC/Production Rate = 1751587.2/206170 = $8.5/MT

Revenue= 206170MT/year × $8.5/MT = $1752445

Profit= Revenue - Annual Operating Cost = $1752445 - $525476.2 = 1.23M$

Rate of Return= Revenue/ (Life of Project × Total Investment Cost)

Rate of Return = 1752445/ (5 × 785166.6) = 0.46 per year

Payback Period= 1/ROR = 1/0.46 = 2.25years

Costing Summary:

Equipment	Cost (USD $)
Pumps	**900**
API Separator	10612.88
Settling Tank	25095.35
Aeration Tank	14482
Reactors	108948.8
Mixers	8500
Hydrodynamic Cavitator	39627

Parameter	Cost (USD million $)
Fixed Capital	**0.747**
Total Investment Required	**0.785**
Annual Operating Cost	**0.525**
Annual Revenue	**1.752**
Annual Profit	**1.23**

CHAPTER 8

HAZOP ANALYSIS

HAZOP is a risk management method that is used to foresee the potential threats and operational hazards that might be present in the system, to eliminate these threats and ensure the proper safety of working personnel present on the plant and the surroundings. Just like in every industry involving processes and safety concerns, we performed HAZOP analysis on a few of our key important equipment.

This type of analysis is basically performed in a typical two types of methods, and these are Qualitative and Quantitative risk analysis. Qualitative is basically a prerequisite type of analysis whereas most industries usually adopt the Quantitative approach of analysis for better and thorough analysis of any situation. Both methods of analysis require different methods and require special types of people that are suited for this job to perform such tasks because it is a very risky analysis. There are a bunch of guide words for the type of deviations that can happen and as well as what are the causes, the direct consequences of the deviation and finally what action to take if a particular deviation occurs

HAZOP basically is finding out how a certain equipment or a process might deviate from what it was originally designed for, what are the possible scenarios, how to identify the problem even before there is a problem. It is basically finding out that everything is going just fine and probably identifying certain issues that might cause some major problems in the future if the problem is not addressed at the right time.

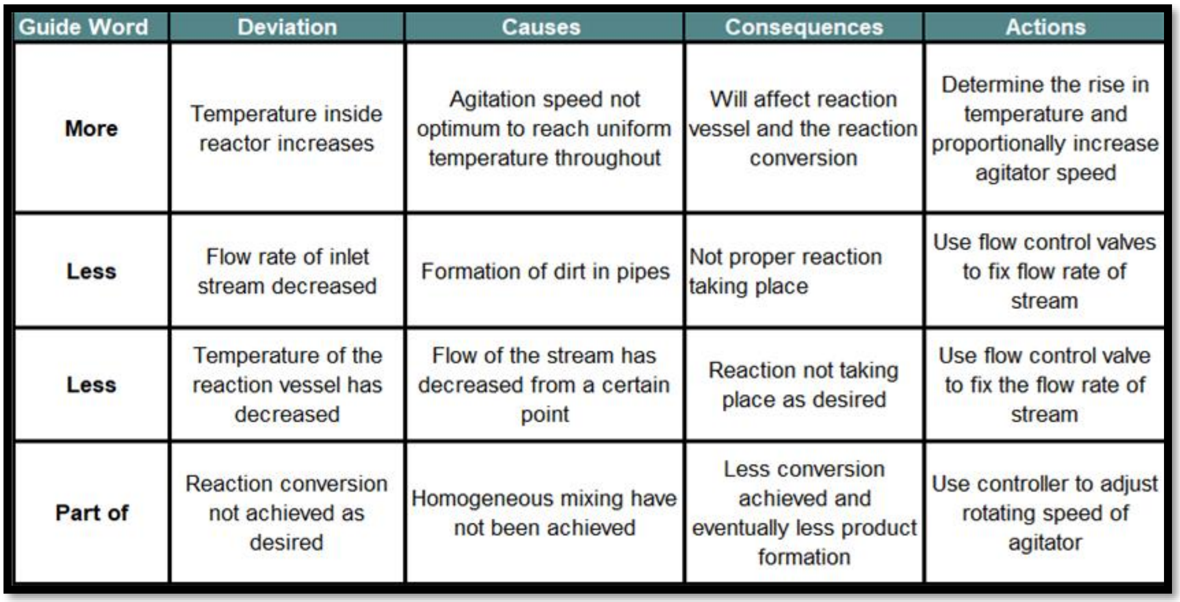
HAZOP can be summarized and understood by the following points:

- Try to identify possible issues in equipment/processes.
- Identify operation and design from an ideal working map.

- See how the problem can be prevented in order to reduce any type of risk that might involve it.
- Make the process more optimized to further

8.1 HAZOP on the CSTRs

Intention: This is where the chemical reactions take place.

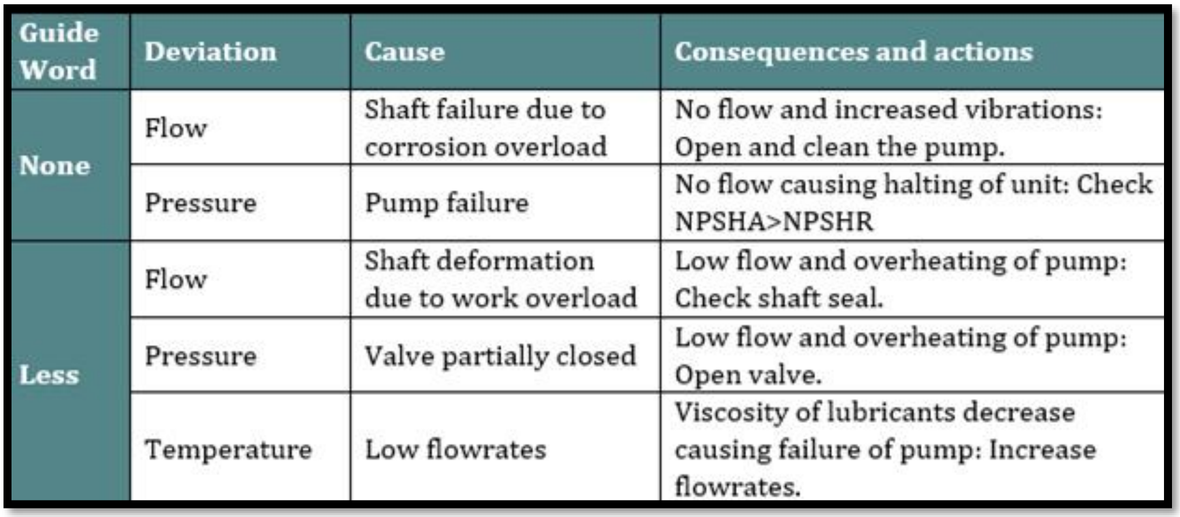


Guide Word	Deviation	Causes	Consequences	Actions
More	Temperature inside reactor increases	Agitation speed not optimum to reach uniform temperature throughout	Will affect reaction vessel and the reaction conversion	Determine the rise in temperature and proportionally increase agitator speed
Less	Flow rate of inlet stream decreased	Formation of dirt in pipes	Not proper reaction taking place	Use flow control valves to fix flow rate of stream
Less	Temperature of the reaction vessel has decreased	Flow of the stream has decreased from a certain point	Reaction not taking place as desired	Use flow control valve to fix the flow rate of stream
Part of	Reaction conversion not achieved as desired	Homogeneous mixing have not been achieved	Less conversion achieved and eventually less product formation	Use controller to adjust rotating speed of agitator

Table : HAZOP on the CSTRs

8.2 HAZOP on the Centrifugal Pump

Intention: To provide head for raising effluent to the hydrodynamic cavitator

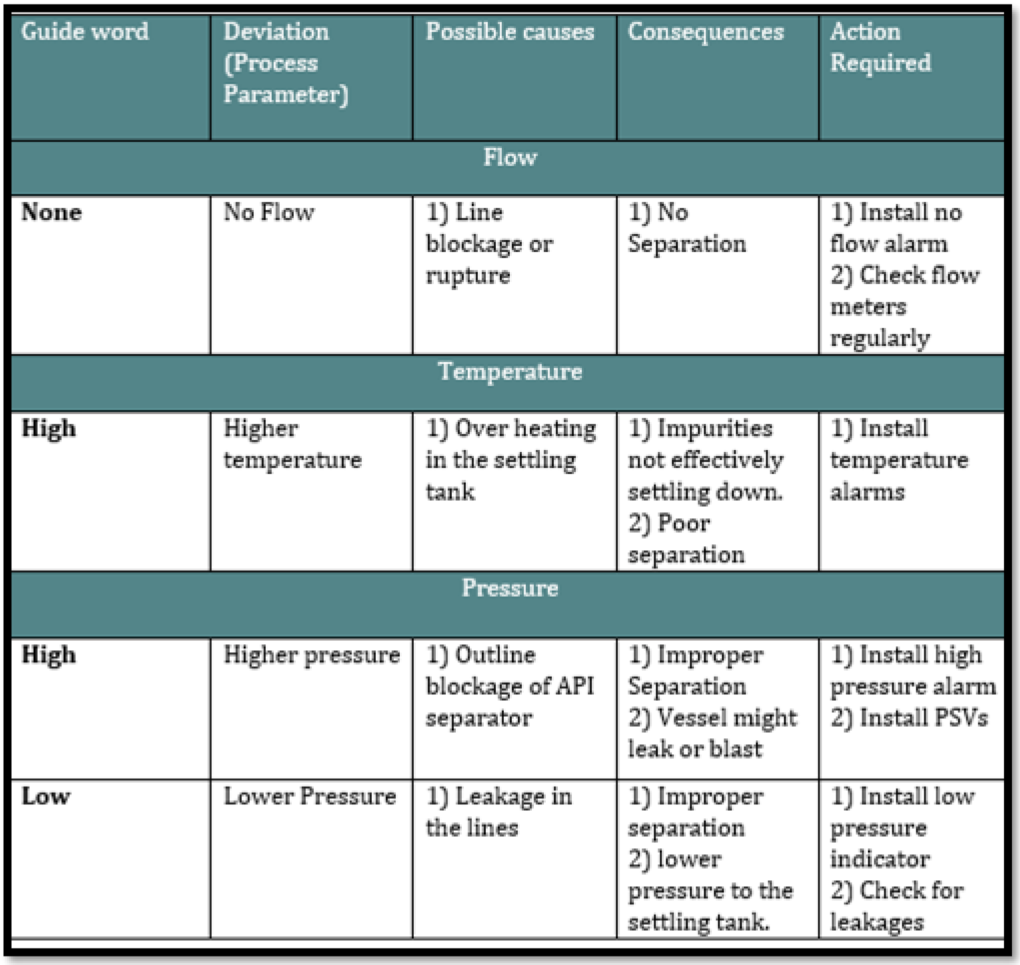


Guide Word	Deviation	Cause	Consequences and actions
None	Flow	Shaft failure due to corrosion overload	No flow and increased vibrations: Open and clean the pump.
	Pressure	Pump failure	No flow causing halting of unit: Check NPSHA>NPSHR
Less	Flow	Shaft deformation due to work overload	Low flow and overheating of pump: Check shaft seal.
	Pressure	Valve partially closed	Low flow and overheating of pump: Open valve.
	Temperature	Low flowrates	Viscosity of lubricants decrease causing failure of pump: Increase flowrates.

Table : HAZOP on the Centrifugal Pump

8.3 HAZOP on the API Separator

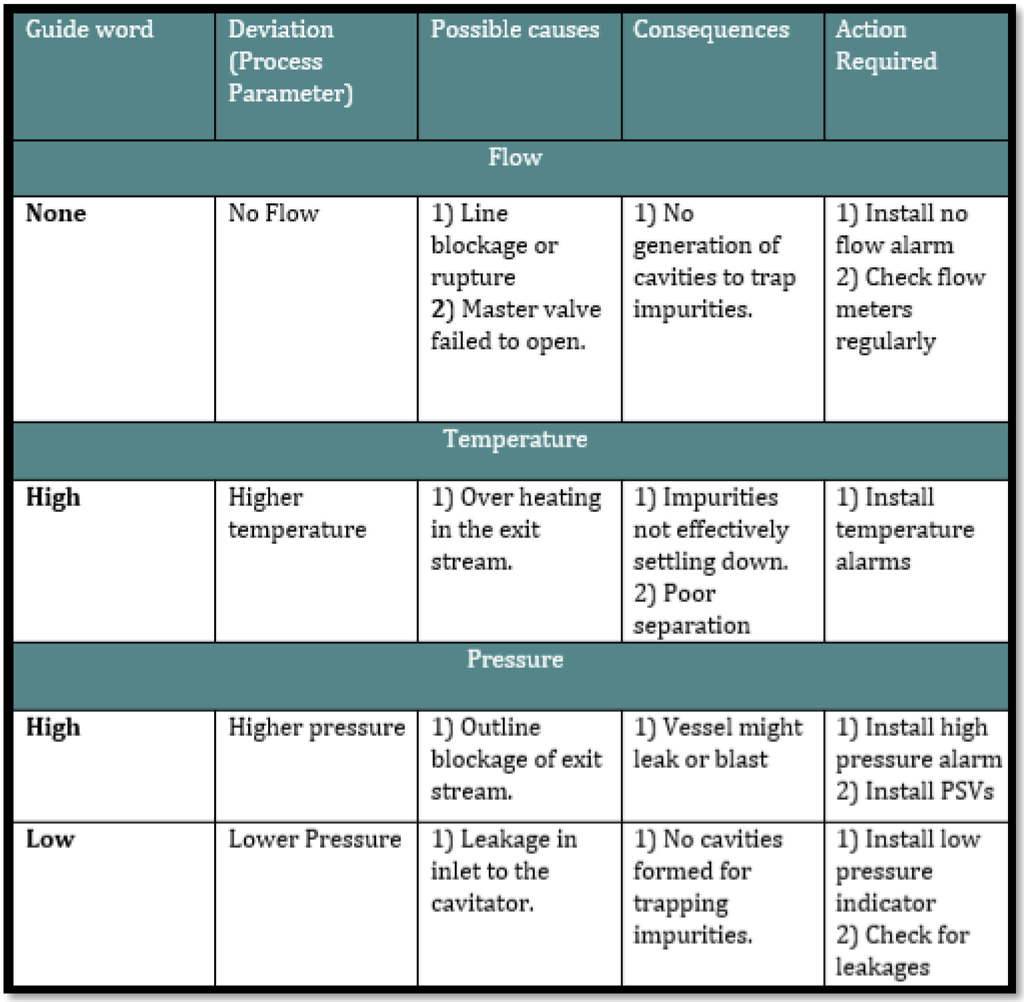
Intention: To separate impurities on the basis of difference in sp. gravity.



Guide word	Deviation (Process Parameter)	Possible causes	Consequences	Action Required
Flow				
None	No Flow	1) Line blockage or rupture	1) No Separation	1) Install no flow alarm 2) Check flow meters regularly
Temperature				
High	Higher temperature	1) Over heating in the settling tank	1) Impurities not effectively settling down. 2) Poor separation	1) Install temperature alarms
Pressure				
High	Higher pressure	1) Outline blockage of API separator	1) Improper Separation 2) Vessel might leak or blast	1) Install high pressure alarm 2) Install PSVs
Low	Lower Pressure	1) Leakage in the lines	1) Improper separation 2) lower pressure to the settling tank.	1) Install low pressure indicator 2) Check for leakages

Table : HAZOP on the API Separator

8.4 HAZOP on the Hydrodynamic Cavitator



Guide word	Deviation (Process Parameter)	Possible causes	Consequences	Action Required
Flow				
None	No Flow	1) Line blockage or rupture 2) Master valve failed to open.	1) No generation of cavities to trap impurities.	1) Install no flow alarm 2) Check flow meters regularly
Temperature				
High	Higher temperature	1) Over heating in the exit stream.	1) Impurities not effectively settling down. 2) Poor separation	1) Install temperature alarms
Pressure				
High	Higher pressure	1) Outline blockage of exit stream.	1) Vessel might leak or blast	1) Install high pressure alarm 2) Install PSVs
Low	Lower Pressure	1) Leakage in inlet to the cavitator.	1) No cavities formed for trapping impurities.	1) Install low pressure indicator 2) Check for leakages

Table : HAZOP on the Hydrodynamic Cavitator

CONCLUSION

After the completion of the project, we were able to achieve our desired objectives.
Following points briefly conclude our project.

- ✓ Designing of an effective wastewater treatment plant has been achieved, using a new technology with minimalistic investment cost.
- ✓ Simulation of the Process on Aspen Plus
- ✓ Reduction in the number of equipment and steps has resulted in low equipment operating cost.
- ✓ Profit per Annum up to 1.23M$
- ✓ Controlled limit of the Chloride and Sulphate ions in the treated Water
- ✓ With greater extent of purity reached, the treated wastewater now has a pH of 6.2-6.3, which can be used domestically and for drinking purposes, can be used to generate profit.

Our project is in line with the sustainable development goals by the United Nations which are:

- Climate Action
- Work Growth & Decent Economics
- Innovation, Industry & Infrastructure
- Responsible Production & Consumption

We were not only blessed enough to meet the desired needs of the plant but also enough to save water which will have a direct impact on the environment in a positive way.

REFERENCES

[1] Thanekar, P., & Gogate, P. (2018). Application of Hydrodynamic Cavitation Reactors for Treatment of Wastewater Containing Organic Pollutants: Intensification Using Hybrid Approaches. *Fluids*, *3*(4), 98.

[2] Tao, Y., Cai, J., Huai, X., Liu, B., & Guo, Z. (2016). Application of Hydrodynamic Cavitation to Wastewater Treatment. Chemical Engineering & Technology, 39(8), 1363–1376.

[3] Mancuso, G., Langone, M., & Andreottola, G. (2020). A critical review of the current technologies in wastewater treatment plants by using hydrodynamic cavitation process: principles and applications. Journal of Environmental Health Science and Engineering, 18(1), 311–333.

[4] Balasundaram, B., Pandit, A.B., (2001a). Selective release of invertase by hydrodynamic cavitation. Biochemical Engineering Journal 8, 251–256.

[5] Coulson and Richardson's Chemical Engineering Vol. 2 & 6

[6] Plesset, M. S., and hosperetti, A, (1977), "Bubble Dynamics and Cavitation," Annual Review of Fluid Mechanics, Vol. 9, pp. 145-185.

[7] M. Petkovšek, M. Zupanc, M. Dular, T. Kosjek, E. Heath, B. Kompare, B. Širok (2013) Rotation generator of hydrodynamic cavitation for water treatmentSep. Purif. Technol., 118, pp. 415-423

[8] P.S. Kumar, A.B. Pandit (1999) Modeling hydrodynamic cavitation Chem. Eng. Technol., 22, pp. 1017-1027

[9] K.K. Jyoti, A.B. Pandit (2003) Hybrid cavitation methods for water disinfection: simultaneous use of chemicals with cavitation Ultrason. Sonochem., 10, pp. 255-264

[10] A.G. Chakinala, P.R. Gogate, A.E. Burgess, D.H. Bremmer (2008) Treatment of industrial wastewater effluents using hydrodynamic cavitation and the advanced Fenton process Ultrason. Sonochem., 15, pp. 49-54

[11] M. Franke, P. Braeutigam, Z.L. Wu, Y. Ren, B. Ondruschka (2011) Enhancement of chloroform degradation by the combination of hydrodynamic and acoustic cavitation Ultrason. Sonochem., 18, pp. 888-894

[12] K. Hirooka, R. Asano, A. Yokoyama, M. Okazaki, A. Sakamoto, Y. Nakai (2009) Reduction in excess sludge production in a dairy wastewater treatment plant via nozzle-cavitation treatment: case study of an on-farm wastewater treatment plant Bioresour. Technol., 100, pp. 3161-3166

[13] M. Zupanc, T. Kosjek, M. Petkovšek, M. Dular, B. Kompare, B. Širok, Ž. Blaženka (2013), E. Heath Removal of pharmaceuticals from wastewater by biological

processes, hydrodynamic cavitation and UV treatment Ultrason. Sonochem., 20, pp. 1104-1112

[14] Chuah LF, Yusup S, Aziz ARA, Bokharia A, Klemesc JJ, Abdullah MZ. (2015b) Intensification of biodiesel synthesis from waste cooking oil (palm olein) in a hydrodynamic cavitation reactor: effect of operating parameters on methyl ester conversion. Chem Eng Process; 95: 235–240.

[15] Parthasarathy S, Siah Ying T, Manickam S. (2013) Generation and optimization of palm oil-based oil-in-water (O/W) submicron emulsions and encapsulation of curcumin using a liquid whistle hydrodynamic cavitation reactor (LWHCR). Ind Eng Chem Res; 52: 11829–11837.

[16] Rajoriya S, Carpenter J, Saharan VK, Pandit AB (2016) Hydrodynamic cavitation: an advanced oxidation process for the degradation of bio-refractory pollutants. Rev Chem Eng; 32: 379–411

[17] Yi C, Lu Q, Wang Y, Wang Y, Yang B. (2018) Degradation of organic wastewater by hydrodynamic cavitation combined with acoustic cavitation. Ultrason Sonochem.;43:156–65

[18] Mohod AV, Gogate PR, Viel G, Firmino P, Giudici R. (2017) Intensification of biodiesel production using hydrodynamic cavitation based on high-speed homogenizer. Chem Eng J.;316: 751–7.

[19] Ozonek J, Lenik K. (2011) Effect of different design features of the reactor on hydrodynamic cavitation process. Arch Mater Sci Eng.; 52:112–7

[20] Kim HJ, Nguyen DX, Bae JH (2008) The performance of the sludge pretreatment system with venturi tubes. Water Sci Technol.; 57:131–7