DESIGN OF COST-EFFECTIVE NOVEL TREATMENT OF PROCESS CONDENSATE CONTAINING HF, AMMONIA & AMMONIUM NITRATE

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CERTIFICATE

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DEDICATED

TO OUR PARENTS

Whose unwavering love and sacrifice laid the foundation upon which we stand.

And Teachers

Whose guidance has been a beacon of inspiration, illuminating our path throughout this journey

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With heartfelt gratitude to Allah, the Most Gracious and Merciful, for His unwavering support and countless blessings throughout this challenging endeavour. We are deeply humbled by His guidance and believe that our success is a testament to His divine grace.

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Authors

ABSTRACT

The industrial process condensate like phosphate fertilizer manufacture and petroleum refining contains hazardous compounds like hydrofluoric acid (HF), ammonia (NH3), and ammonium nitrate (NH4NO3). These substances are however toxic to the environment and to human health if not well managed. This thesis describes a new overall process that employs steam stripping, ion exchange, neutralization, evaporation, and crystallization to remove these impurities and obtain ammonium nitrate, an important fertilizer. It is a fast, effective and easy-to-implement technology that contrasts with the other treatment technologies. Combining mass and energy balances, equipment design and economic assessment proves that this new concept is feasible and can yield substantial benefits. Furthermore, there is a Hazard and Operability (HAZOP) study that examines possible hazards related to the process and methods to eliminate them to guarantee the process runs safely and efficiently. In this thesis, sustainable methods for treating process condensate wastewater for industries are developed.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AN	Ammonium Nitrate
AOP	Advanced Oxidation Process
CaF2	Calcium Fluoride
CaO	Calcium Oxide
CT	Condensate Treatment
DAP	Diammonium Phosphate
ED	Electrodialysis
F-	Fluoride Ion
H2O2	Hydrogen Peroxide
HAZOP	Hazard and Operability
MF	Membrane Filtration
NH3	Ammonia
NH4NO3	Ammonium Nitrate
NF	Nanofiltration
O3	Ozone
P&ID	Piping and Instrumentation Diagram
PCE	Purchase Equipment Cost
RO	Reverse Osmosis
TCI	Total Capital Investment
UV	Ultraviolet

CHAPTER 1

INTRODUCTION

1.1 Background

Process condensate, which is a common product in industries including phosphate fertilizers, petroleum refining, and chemical manufacturing, usually contains a complex mix of toxic substances. These wastewaters contain hydrofluoric acid (HF), which is a corrosive acid utilized in alkylation processes, and ammonia (NH3), used in fertilizer production. Also, it can contain ammonium nitrate (NH4NO3), which is an explosive and a fertilizer material. For instance, in the production of diammonium phosphate (DAP) fertilizer, process condensate normally consists of ammonia and fluoride ions which are environmental pollutants. The release of these pollutants continues unabated and affects the environment in detrimental ways. HF, even at low concentrations, can affect humans and wildlife by causing severe burns to the skin and respiratory system, and its acidic content affects water-borne organisms and the fertility of soil. An investigation of a case in a phosphate fertilizer plant in Florida showed that leakage of process condensate containing HF caused the death of fish in a river. Ammonia and ammonium nitrate for instance are known to cause eutrophication; this leads to the growth of algae that use up the oxygen in water bodies, suffocating the fishes and other water creatures. The economic impacts are also equally disturbing. In 2022, a large oil refinery in Texas was penalized $1.5 million for noncompliance with wastewater discharge standards, especially high ammonia content in process condensate. Moreover, HF is highly corrosive in nature, and hence, equipment and pipelines need to be made of costly specific materials, thus increasing operating expenses. Traditional techniques such as steam stripping can be very effective in stripping off volatile substances like ammonia but are less useful when it comes to HF which is not as volatile. Likewise, adsorption techniques involving the use of activated carbon may be expensive and less effective because condensate originating from the process may contain high levels of contaminants. It is therefore imperative to explore more efficient and cost-effective strategies that would effectively address these different and often dangerous pollutants.

1.2. Problem Statement

Concentrations of hydrofluoric acid (HF), ammonia (NH3), and ammonium nitrate (NH4NO3) in process condensate especially in phosphate fertilizer and oil refining industries is an alarming environmental and economic issue. These substances are used in industrial processes, but they become dangerous if not properly treated before being released into the environment. As a highly corrosive acid, HF poses significant risks of causing burns and respiratory illness in humans and animals, pollutes water bodies and makes the soil infertile. For instance, in 2019, the Mosaic Company's plant in Florida leaked water containing HF that killed thousands of fish and other aquatic life forms (Nace, 2016). Although much less toxic when ingested, ammonia and ammonium nitrate are involved in eutrophication, which causes depletion of oxygen in water sources, negatively impacting fish and upsetting the balance of aquatic ecosystems. Additionally, the consequences of condensate treatment inefficiency in terms of lost revenue are significant. A 2021 EPA report anticipated that industrial facilities in the United States spend more than $1 billion on wastewater treatment with nitrogen individual such as ammonia and ammonium nitrate. However, the current treatment technologies do not meet the requirements of solving this problem comprehensively and efficiently. Steam stripping and adsorption methods suffer from limitations in removing such a complex mixture of HF, NH3 and NH4NO3 requiring multiple stages of treatment and highly expensive operations. The need to come up with a new treatment process that can handle this particular set of contaminants in a cost effective manner is therefore of paramount importance. Such a breakthrough will not only reduce the likelihood of environmental disasters and protect the health of employees but also increase the productivity of industries and organizations and save money. This research seeks to address this major gap by identifying and examining new treatment strategies for HF, NH3, and NH4NO3-containing process condensate streams.

1.3 Project Objectives

The objective of the present work is to design a new treatment process and to assess its effectiveness in the—removal of hydrofluoric acid (HF), ammonia (NH3) and ammonium nitrate (NH4NO3) from the industrial process condensate. In this new concept an attempt is made to provide solution for the drawbacks of this existing technologies which are not able to eliminate both these types of pollutants effectively and economically. Therefore, the following specific objectives have been developed in a bid to meet the broad objective: First and foremost, the flowchart under the treatment process will be provided and aligned so as to increase the capacity in a bid to minimize the costs of production. This involves optimising the process parameters such as pH, temperature and time in order to achieve maximum removal efficiency of each pollutant. Secondly, there will be an assessment of the impact of the treated condensate on the environment as a whole. This involves examining the residual pollutants in the treated water, assessing its impact on the aquatic life and defining its readiness for discharge or re-use. Also, the effectiveness of the proposed new treatment method will be substantiated in other industries as well. This involves use of the process on actual condensate samples collected from phosphate fertilizer manufacturers, oil refineries and chemical producing industries. Thus, the effectiveness of the treatment method can be proven with regard to its applicability and efficacy in different areas of industry. Last but not the least, the economic feasibility of the proposed novel treatment process will also be discussed in detail. In this analysis, capital and operating costs regarding equipment, chemicals, energy, and waste disposal will also be evaluated. Therefore, a comparison with existing technologies allows to define the potential savings in the industries which will prove the significance and practicability of the results of the present research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Process condensate contamination by hydrofluoric acid (HF), ammonia (NH3), and ammonium nitrate (NH4NO3) poses significant environmental and operational challenges. This literature review critically assesses existing research on this issue, identifying knowledge gaps and contextualizing the current research within the broader field to inform effective remediation strategies.

2.2. Sources and Characteristics of Process Condensate

2.2.1. Industrial Processes Generating Process Condensate

Process condensate generated from industrial operations may include different types of impurities that present both environmental and operational issues. In the fertilizer industry, the synthesis of phosphate fertilizer entails the formation of process condensate with specific properties. This wastewater stream comes from different parts of the production line such as phosphoric acid, DAP formation and scrubber circuits. Phosphoric acid is produced by the reaction of phosphate rocks with sulfuric acid, in which gaseous fluoride compounds are formed, and these gases are scrubbed and condensed to form hydrofluoric acid (HF) in the condensate. The concentration of HF depends on scrubbing efficiency, with reported values above 1000 mg/L in special cases (Levels, 2014). In the granulation of DAP, ammonia (NH3) is added to react with phosphoric acid. When there is an accumulation of ammonia it can evaporate and then condense leading to high levels of NH3 in the condensate. Researches have documented NH3 concentration of between 100 and 500 mg/L in DAP granulation condensate. Furthermore, ammonium nitrate (NH4NO3) may also be found in process condensate when nitric acid is used in the production of phosphate fertilizer or when ammonia and nitrogen oxides react in scrubbing systems. The amount of NH4NO3 can differ greatly, however, concentrations of more than 1000 mg/L have been found in some cases. It is therefore important for these contaminants to undergo some treatment process in order to meet the established environmental standard and avoid corrosion of equipment. Other treatment technologies like neutralization, stripping and biological treatment have also been studied for the removal of HF, NH3 and NH4NO3 from process condensate. Still, the most suitable treatment method is influenced by the contaminant levels and the required level of purity in the effluent. Additionally, innovations in the fertilizer industry are being sought in an effort to reduce the production of contaminated process condensate. Some of these are process optimization, better scrubbing systems, and closed system designs for water management. It is such programs that seek to minimize the impact of fertilizers on the environment and at the same time increase efficiency.

Contaminant	Concentration Range (mg/L)
Hydrofluoric Acid (HF)	100 - 1000+
Ammonia (NH3)	100 - 500
Ammonium Nitrate (NH4NO3)	10 - 1000+

Table 1: Process Condensate Composition

The constant concern of the fertilizer industry in addressing the problem of process condensate contamination is an indication of the industry's sustainability and environmental consciousness. Analyzing the sources and characteristics of these contaminants, it is possible for researchers and engineers to devise suitable solutions to this significant problem.

2.2.2. Chemical Composition of Process Condensate

The chemical composition of process condensate varies according to the industrial source and the treatment that the water undergoes. Nevertheless, there are some contaminants that are mentioned frequently in relation to certain industries. Three of the most common and potent pollutants include hydrofluoric acid (HF), ammonia (NH3), and ammonium nitrate (NH4NO3). That is why the process of condensate in the phosphate fertilizer industry contains relatively high concentrations of fluoride ions (F-) and ammonia (NH3). These concentrations can vary from several hundred to several thousand milligrams per litre (mg/L). Condensate may contain HF which is used in petroleum refineries as a catalyst in alkylation processes, therefore content of HF may fluctuate depending upon the operation of the alkylation unit and wastewater treatment facilities (Nafis et al., 2015). Likewise, Condensate may contain ammonia because it is utilized in many refinery processes including pH change and corrosion prevention Such compounds also react chemically and can generate other pollutants. For instance, ammonia can react with fluoride ions to give ammonium fluoride (NH4F) which is also toxic to aquatic life. Further, in certain conditions, the ammonia is oxidized to nitrate (NO3-), which amplifies the eutrophication impact of the condensation water (Soaresa et al., 2011). Environmental laws set limits on the emission of such pollutants in a bid to enhance the quality of water and aquatic life.

Contaminant	Phosphate Fertilizer Industry (mg/L)	Petroleum Refining Industry (mg/L)	US EPA Discharge Limit (mg/L)
HF	100 - 5000	10 - 100	1.4 (as F-)
NH3	500 - 10,000	100 - 1000	Varies by state/facility
NH4NO3	10 - 500	10 - 100	10 (as N)

Table 2: EPA Discharge Limits

These regulatory limits call for efficient treatment procedures to eliminate or minimize the levels of pollutants to permissible levels for discharge. The variability of conditions and the composition of process condensate, coupled with the increasingly stringent environmental requirements, indicate the need for new effective methods of treating the condensate depending on the situation in the industries and conforming to the standards for discharge.

2.3 Environmental and Health Impacts

According to the available literature, the ecotoxicological impacts of hydrofluoric acid (HF), ammonia (NH3), and ammonium nitrate (NH4NO3) on many biological systems have been well-documented. HF, a highly reactive chemical compound, can have severe effects on aquatic life forms. When it comes into contact with body fluids, it easily crosses cell membranes quickly and can cause systemic acidosis, electrolyte disturbance and tissue coagulation. In fish, acute HF exposure leads to gill hyperplasia, hemorrhage, respiratory dysfunction, and ultimately death. Skeletal deformities and osmoregulation are affected even with low concentrations that are sustained over time. Similar results were found in invertebrate animals: the inhibition of growth and reproductive dysfunction in crustaceans and molluscs that contain HF. Ammonia is a common nitrogenous compound that causes toxicity through the following mechanisms. In the water bodies, high concentrations of ammonia induces hyperammonemia in the fish whereby the blood ammonia levels rise, the neurological disorders and a compromised immune system occurs (Ali & Nagalli, 2023). Ammonia toxicity can also lead to gill necrosis, stunted growth, and increased vulnerability to diseases and parasites. In terrestrial ecosystems, deposition of ammonia causes soil acidification, change in nutrient status of the soil, and shifts in plant species. Though less acute toxic than HF and NH3, ammonium nitrate is dangerous due to eutrophication effects. High nitrates in water bodies promote growth of algae which after breaking down consume dissolved oxygen leading to hypoxic conditions and hence death of fish and other aquatic species (Yang et al., 2018). In humans, high concentrations of ammonium nitrate can lead to methemoglobinemia, which breaks down the blood's ability to transport oxygen leading to cyanosis and respiratory problems. These contaminants are a matter of concern when workers in industries handling process condensate come across them. Inhalation of HF can cause severe respiratory irritation, pulmonary edema and long term health effects to the lungs. Contact with the skin may cause third-degree burns as well as systemic fluoride poisoning. Inhalation of ammonia may cause inflammation of the airways, bronchospasm, and respiratory failure may ensue. Ammonium nitrate dust is known to cause respiratory irritation and possibly carcinogenic effects after long periods of exposure to it.

2.4 Current Treatment Technologies

2.4.1 Physical Treatment Methods for Process Condensate

There are numerous physical treatment methods to eliminate impurities such as HF, NH3, and NH4NO3 from process condensate, each having its own working principles, strengths, and limitations.

a. Stripping

Steam stripping is one of the most known and used methods of separation of volatile components from aqueous solutions (Brouwers & Gilding, 2006). This involves passing steam through the condensate which leads to the vaporization of the target pollutants and thus removal. Among the constituents of process condensate, steam stripping is most suitable for ammonia (NH3) removal because of its high volatility. The efficiency of ammonia removal can be further improved by controlling the pH of the condensate to increase the part of NH3 in the gas phase.

Advantages	**Disadvantages**
Effective removal of volatile contaminants (e.g., NH3)	Less effective for non-volatile contaminants (e.g., HF, NH4NO3)
Relatively simple process	High energy consumption for steam generation
Established technology with available equipment	Potential for scaling and fouling in equipment
Can be integrated with other treatment processes	May require pH adjustment for optimal performance

Table 3: Advantages and Disadvantages of Stripping

b. Adsorption

Adsorption involves the use of materials with high surface area like activated carbon or zeolites to remove the contaminants from the condensate (Xanthopoulou & Katsoyiannis, 2023). Activated carbon is highly effective at removing pollutants due to its porous properties and surface chemistry, as well as its ability to remove organic and inorganic compounds. It has been revealed to be effective in the removal of HF from aqueous solutions with research revealing high adsorption of the compound at acidic pH. While other cations are not selectively adsorbed, zeolites have the ability to selectively remove ammonium ions (NH4+).

Advantages	Disadvantages
Effective for a wide range of contaminants	Limited adsorption capacity, requiring regeneration or replacement
Can be selective for specific contaminants	The regeneration process can be complex and costly
Relatively simple operation	Disposal of spent adsorbent can be challenging
Can be used as a polishing step after other treatment processes	May require pre-treatment of condensate to remove interfering substances

Table 4: Advantages and Disadvantages of Adsorption

c. Membrane Filtration

Some other techniques for the treatment of process condensate are membrane filtration processes like reverse osmosis (RO) and nanofiltration (NF). Despite the fact that RO membranes have very small pore sizes, they can effectively reject a number of dissolved ions and molecules such as HF, NH3, and NH4NO3. NF membranes, with slightly bigger pore sizes, can selectively exclude multivalent ions as well as larger organic molecules and allow monovalent ions to pass through.

Advantages	Disadvantages
High removal efficiency for multiple contaminants	Susceptible to membrane fouling, requiring frequent cleaning
Can produce high-quality treated water	High energy consumption for pressurization
Relatively compact footprint	Membrane replacement can be expensive
Can be combined with other treatment processes	Pre-treatment of condensate is often necessary

Table 5:Advantages and Disadvantages of MF

2.4.2 Chemical Treatment Methods for Process Condensate

Chemical treatment methods are one of the best methods for combating contamination in process condensate through the deployment of chemical reactions. These methods are more specific to the type of contaminant and can be used alone or in combination with other methods.

a. Chemical Precipitation

Chemical precipitation involves the use of chemicals that enable the formation of compounds that do not dissolve again in the liquid phase (Li et al., 2018). This method is relatively effective in the removal of heavy metals, fluoride ions as well as phosphorus-containing compounds.

Treatment for Fluoride Removal

Lime treatment is a frequently used chemical precipitation technique for the removal of fluoride ions (F-) from wastewater.

$$CaO + H2O \rightarrow Ca(OH)2$$

$$Ca(OH)2 + 2F- \rightarrow CaF2(s)\downarrow + 2OH-$$

The fluoride ions react with calcium ions to form insoluble calcium fluoride (CaF2), which precipitates out of the solution. The pH of the condensate is raised due to the formation of hydroxide ions (OH-), which can help to precipitate other metal hydroxides.

Sludge Generation and Disposal

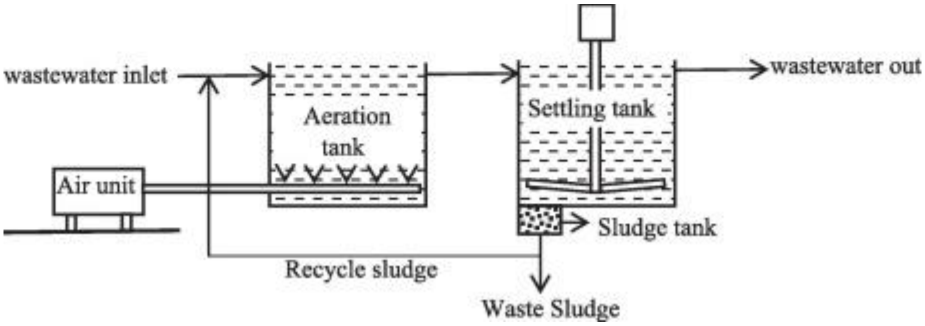


Figure 1 Sludge Generation and Disposal

A major disadvantage of chemical precipitation is the production of sludge, a semi –solid waste with precipitated contaminants. The amount of sludge generated and its properties vary depending on the type and concentration of pollutants and the reagents used in the precipitation process. Sludge management remains an issue and may involve dewatering, stabilization and disposal through landfilling. Some of the costs that may be incurred in sludge management are rather high, thus affecting the overall economic feasibility of chemical precipitation.

2.4.3. Other Chemical Methods

Oxidation

Some of the oxidation processes include the use of oxidizing agents such as ozone, hydrogen peroxide or chlorine in the condensate. These agents interact with contaminants and transform them into less toxic or more washable or soluble forms. For instance, oxidation can convert ammonia (NH3) into nitrogen gas (N2) or nitrate (NO3-), which can then be removed by other treatment methods.

Figure 2 Oxidation

Neutralization

Neutralization is aimed at adjusting the pH of the condensate to a certain value. It is usually done to increase the efficiency of other treatment procedures or to satisfy the discharge standards. For example, it is feasible to alter the pH of the condensate to a slightly acidic level in order to enhance the air stripping of ammonia. The decision as to which chemical treatment of the condensate stream is most appropriate depends on the nature of the contaminants and the level of purification required. In some cases, it may be necessary to apply two or more chemical methods at the same time in order to eliminate certain impurities. However, chemical treatment may lead to formation of several secondary pollutants and these have to be regulated or avoided in order to enhance environmental quality of the treated effluent.

2.5 Emerging Technologies

2.5.1 Membrane Processes for Process Condensate Treatment

Membrane processes employ a barrier that separates contaminants from process condensate under the influence of size and charge. These processes are gradually being applied because they offer high removal efficiencies of several contaminants at the same time, thus being appropriate for complicated wastewaters.

Reverse Osmosis (RO)

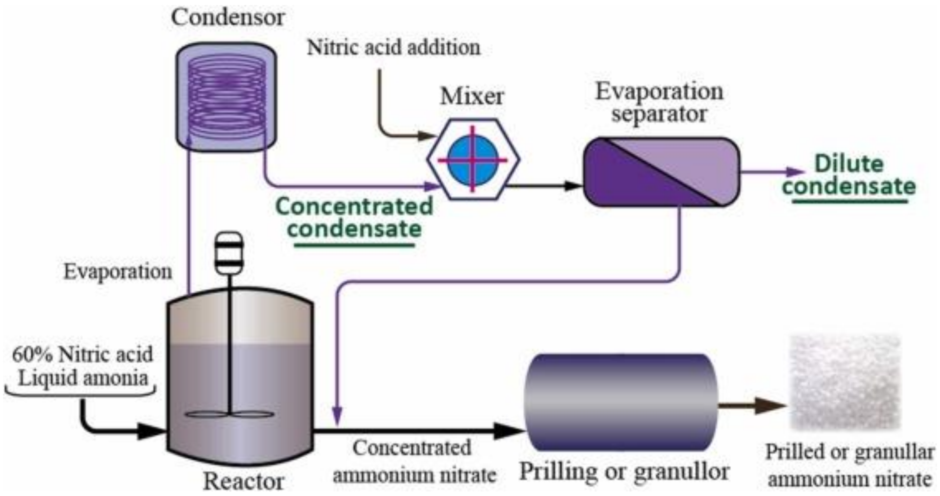


Figure 3 Reverse Osmosis (RO)

Reverse osmosis is a pressure-stimulated membrane technique that separates water from dissolved ions and other larger molecules through a semi-permeable membrane (Duong et al., 2021). Some of the contaminants which can be removed by RO membranes include HF, NH3, and NH4NO3. The pore size of RO membranes is in the range 0. 1-1 nm, which means that even dissolved gases are rejected by the membrane.

Advantages	Disadvantages
High rejection of dissolved ions and molecules	Susceptibility to membrane fouling
Produces high-quality treated water	High energy consumption for pressurization
Effective for simultaneous removal of multiple contaminants	Relatively high capital and operating costs

Table 6: Advantages and Disadvantages of RO

Nanofiltration

Nanofiltration can be defined as membrane filtration with a slightly larger pore diameter than RO (1-10 nm). This enables the exclusion of multivalent ions as well as larger organic molecules while allowing monovalent ions to pass through. NF membranes are highly efficient for the removal of hardness ions (Ca, Mg) and some organic substances.

Advantages	Disadvantages
Selective removal of multivalent ions and larger molecules	Lower rejection of monovalent ions compared to RO
Lower energy consumption than RO	Susceptible to membrane fouling
Can be used for softening and decolorization	May require pre-treatment to prevent fouling

Table 7: Advantages and Disadvantages of NF

Electrodialysis

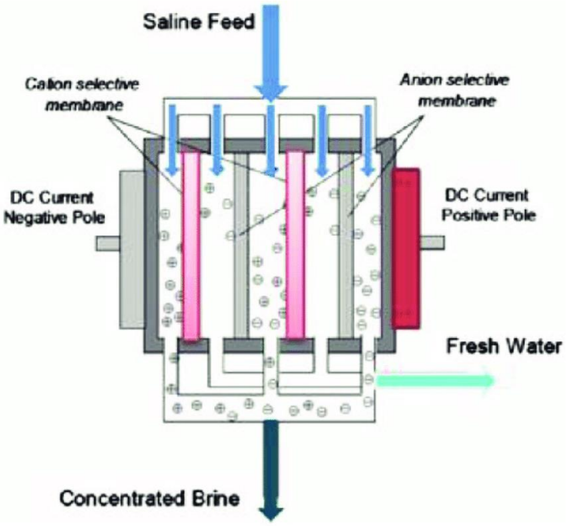


Figure 4 Electrodialysis

Electrodialysis is a type of membrane separation that employs the use of an electric field to move ions across the ion exchange membranes. ED is mainly employed in water desalination and the removal of charged impurities. However in the case of process condensate treatment, it is not very effective due to the presence of uncharged species such as HF.

Advantages	Disadvantages
Effective for removing charged contaminants	Not effective for removing uncharged contaminants
Low chemical consumption	Relatively high energy consumption

Can concentrate contaminants for recovery or disposal	Requires pre-treatment to remove fouling agents

Table 8: Advantages and Disadvantages of ED

2.5.2. Advanced Oxidation Processes (AOPs)

Advanced oxidation processes are chemical treatment technologies that use hydroxyl radicals to remove organic pollutants. These processes are more suited for treating non-degradable organic compounds that cannot be treated through conventional biological methods.

Ozone Treatment

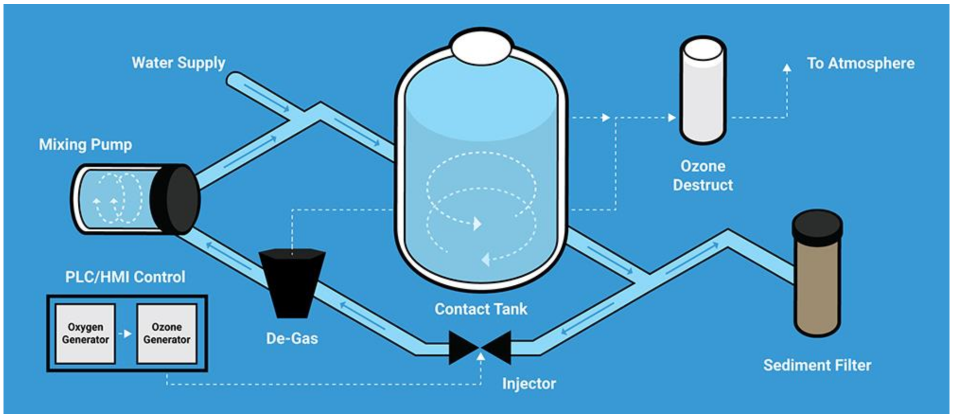


Figure 5 Ozone Treatment

Ozone (O3) is a very strong oxidizing agent capable of breaking down a vast number of organic pollutants within a short span of time. Ozone treatment entails passing ozone gas through the condensate leading to the formation of hydroxyl radicals. These radicals then initiate with organic pollutants and proceed to alter them to less dangerous particles.

Advantages	Disadvantages
Effective for degrading a wide range of organic contaminants	Relatively high capital and operating costs
Does not produce sludge	Requires careful control of ozone dosage
Can disinfect water and remove taste and odor compounds	May form harmful byproducts if not properly managed

Table 9: Advantages and Disadvantages of Ozone Treatement

UV/H2O2 Treatment

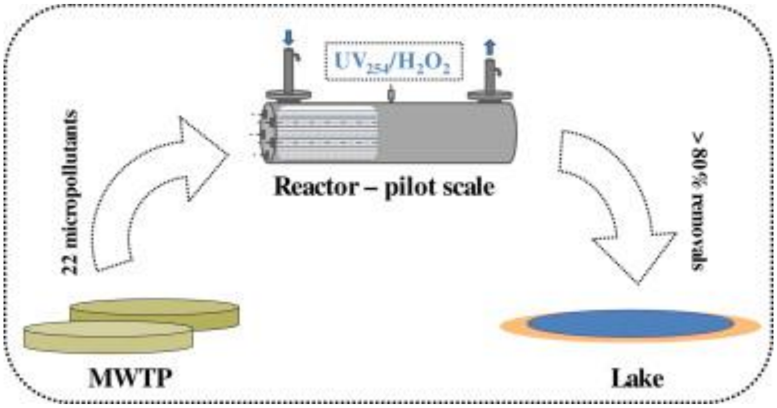


Figure 6 UV/H2O2 Treatment

UV/H2O2 is a process using ultraviolet (UV) light in conjunction with hydrogen peroxide (H2O2) to produce hydroxyl radicals. The UV light activates the H2O2 which leads to the formation of high-concentration hydroxyl radicals. These radicals then attack and degrade organic contaminants in the condensate.

Advantages	Disadvantages
Effective for degrading a wide range of organic contaminants	Requires a UV light source and H2O2 dosing system
Does not produce sludge	May require pre-treatment to remove UV-absorbing substances
Can be combined with other treatment processes	H2O2 can be hazardous if not handled properly

Table 10 Advantages and Disadvantages of UV

AOPs are typically applied in combination with other treatment processes to enhance the efficiency of the latter. For instance, AOPs can be used before the biological treatment processes to break down large molecules so that they can easily be degradable by microorganisms. Also, AOPs can be applied as a post-treatment after physical or chemical treatment methods to further eliminate remaining pollutants and enhance the quality of the treated water.

2. 6 Research Gaps and Opportunities

Current technologies for treating process condensate are capable of removing individual contaminants but are inefficient when used to treat a combination of HF, NH3, and NH4NO3. This limitation requires more elaborate, faster and cheaper solutions to be provided. Possible future research directions could include the analysis of how using a combination of physical, chemical and biological methodologies can have amplified impacts. Moreover, exploring the possibility of converting waste materials like industrial wastes or agricultural wastes into adsorbents or catalysts may offer an effective and cheaper way of eliminating contaminants.

CHAPTER 3

PROCESS DESCRIPTION

3.1. Introduction

The literature review provided in Chapter 2 established the rationale and importance of coming up with new approaches towards the treatment of process condensate containing hydrofluoric acid (HF), ammonia (NH3), and ammonium nitrate (NH4NO3). Currently available treatment technologies are capable of treating some of the individual components individually, but lack efficiency, versatility, and cost optimality in addressing this cocktail of contaminants. Simple techniques such as steam stripping cannot eliminate non-volatile impurities including HF and NH4NO3, while adsorption can be a challenge since adsorbents get saturated, and may require constant regeneration or replacement. While membrane filtration can reduce contaminants to very low levels, there are issues of fouling and energy costs. Third, chemical precipitation methods used to treat wastewater result in the production of large volumes of sludge that in turn have to undergo further processing and disposal. It is against this backdrop that this chapter presents an integrated treatment process to overcome the challenges facing conventional processes.

3.2 Overview of the Proposed Integrated Treatment Process

The proposed treatment of process condensate contaminated with HF, NH3, and NH4NO3 is a stage-wise process involving physical, chemical, and biological methods. It is a flexible technique that relies on the properties of the condensate and the purpose of the treatment. Condensate pre-treatment starts with the heating of the incoming condensate to facilitate the efficiency of the subsequent steps. Subsequently, the preheated condensate is recycled back to the steam stripping column where the vapour phase is used to strip out the volatile compounds such as ammonia from the fluid. The stripped ammonia is then taken to another unit where it is condensed and used in the production of another product which is the ammonium nitrate. The condensate, having no ammonia in it now, is passed to an ion exchange membrane system to eliminate other non-volatile substances like HF and NH_4NO_3. The ion exchange process uses a set of cationic and anionic membranes to eliminate cations and anions selectively. The concentrated brine that is produced during ion exchange is processed individually to remove or discharge the concentrated impurities. The treated condensate with reduced levels of contaminants is then passed through additional polishing stages, including filtration and disinfection to meet discharge requirements. The clean water can then be recirculated back in the industrial facility or discharged to the environment. It has the following advantages over other treatment methods:The integration of the technologies means that the process can deal with a number of contaminants ranging from volatile to non volatile. The reuse of ammonia as a saleable product helps to minimize wastewater volume in addition to encouraging firms to invest in the treatment process. Moreover, the design of the process is modular, which means that it may be easily adjusted to the requirements of different industries and condensate properties. The proposed process is not only efficient and effective, but also sustainable to the greatest extent possible. Hence, in avoiding waste production, optimizing resource utilization, and following legal environmental requirements, the process offers a more sustainable approach to industrial wastewater treatment. The subsequent sections discuss each unit operation individually and provide insight into the design and functioning of this innovative treatment process.

3.2.1 Pre-Treatment: Heating Process Condensate

The first stage within the framework of the proposed treatment process is the heating of the incoming process condensate using a shell and tube heat exchanger. This has a two-fold advantage. Firstly, it reheats the condensate to a temperature of approximately 95 ° C. This is crucial as it optimises the subsequent steam stripping process by raising the volatility of ammonia (NH_3) for separation. Second, preheating also enables the reduction of viscosity of the condensate, which may contain dissolved solids and other suspensions. This reduction in viscosity enhances flow ability and other subsequent processes like ion exchange and evaporation. The shell-and-tube heat exchanger is used because of its high mechanical strength, large heating surface, and the fact that the condensate is corrosive. This heat exchanger is designed in such a manner that it is capable of raising the required temperature within the shortest time possible and yet consumes a minimal amount of energy. This is made possible by using heat generated from another process in the plant thus lowering the energy intensity of the treatment process. The preheated condensate is then taken to the steam stripping column for the next step in the process..

3.3 Steam Stripping

The process condensate preheated is then fed into a trayed stripping column (P-100) for the purpose of stripping volatile impurities, chiefly ammonia (NH3) from the process stream. Ultra 654 SMO stainless steel was used to make the column because of the corrosiveness of the condensate, and has a diameter of 3000 mm and a height of 14000 mm, and includes 29 bubble-cap trays separated by 600 mm. The stripping process is based on the concept of vapour-liquid equilibrium.

Figure 7 Steam Stripper

Low-pressure (LP) steam enters the column at the bottom and flows upward in the opposite direction to the descending liquid condensate. When the steam rises, it comes into contact with the liquid and evaporates ammonia through heat exchange. This is due to the vapor-liquid equilibrium which regulates the distribution of the more volatile ammonia between the vapor and liquid phases. The ammonia-rich vapour is at the top while the stripped liquid without the ammonia is at the bottom of the column. There are various factors that determine the efficiency of the stripping process such as temperature, pressure, and the rate of steam flow. The high temperature of the preheated condensate increases the volatility of ammonia, and the counterflow of the steam and the liquid provides the maximum concentration difference to drive the mass transfer of ammonia from the liquid phase to vapor phase. The steam flow rate is closely regulated to guarantee adequate stripping without wasting to much energy. There is a partial condenser at the top of the stripping column to capture the stripped HF vapour at a more concentrated solution. The condenser is intended to cool the vapour stream, and part of it, including the HF and water vapour, condenses. The condensate formed which contains a high concentration of HF is collected and pumped to the next processing station or destination. The remaining vapour, mostly ammonia and a small amount of water vapour, is taken to the ammonia recovery and conversion section. The partial condenser is a shell and tube type heat exchanger having a heat transfer surface of 18. 116 m^2. The cooling medium is demineralized process condensate which is easily accessible at the site of the plant. The temperature of the cooling medium is maintained in order to obtain the required condensation rate and the concentration of HF in the recovered liquid. The criteria involved in the design of the partial condenser include heat transfer rate, pressure drop across the partial condenser and materials compatibility with the corrosive HF vapour.

3.4. Ion Exchange Membrane Treatment

Subsequent to the steam stripping operation, the process condensate now relatively low in ammonia content undergoes further purification using an ion exchange (IX) membrane. This system is intended to eliminate the final traces of non-volatile impurities, particularly hydrofluoric acid (HF) and ammonium nitrate ($NH4NO3$). The IX system consists of three distinct stages: cationic exchange, anionic exchange, and mixed bed polishing.

3. 4. 1 Membrane Configuration

The cationic exchange stage employs three cationic resin filters in a single string. Each filter contains Lewatit K 2629 resin which selectively removes cations such as H+ and NH4+

from the condensate. The anionic exchange stage also uses three filter units with Lewatit S 4428 resin to remove anions such as F^- and NO_3^-. Last but not the least; a Lewatit S 100 cationic and anionic mixed bed filter is employed in the final polishing step where all the ions are removed. It has a flow rate of 64 m^3/hr and each filter is made from stainless steel for relatively close resistance to corrosion. The cation and anionic filters are 1. 6m in diameter and the mixed bed filter is 1. 2m in diameter. The cation filters are 10m high while the anionic filters are 12m high. The mixed bed filter is 5. 8m high. The ion exchange process involves the differential selectivity of the resin for ions in the condensate. The resin beads contain groups of chemicals that are capable of attracting ions with the opposite charge of the functional groups of the beads. For instance, the cationic resin has a functional group of sulfonic acid ($-SO_3H$) that directly displaces H^+ with cations like NH_4^+ and Ca^{2+}. Likewise, the anionic resin has quaternary ammonium groups ($-NR_3^+$) and OH^- ions are exchanged for anions such F^- and NO_3^-. Some of the parameters that affect the performance of ion exchange membranes include the concentration of the feed solution, the rate of flow and temperature. Higher feed concentrations and flow rates also lead to resin saturation at a faster pace, and the rate of the ion exchange process is also influenced by temperature.

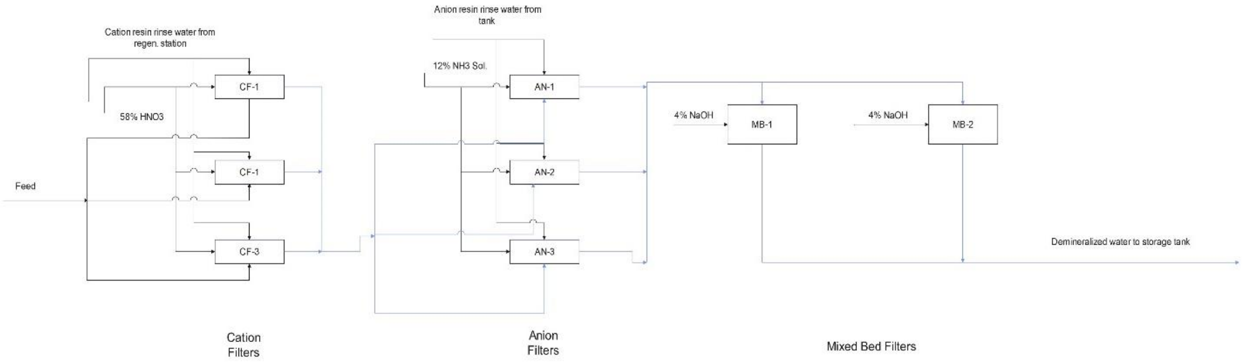


Figure 8 IX Process Flow Diagram

3.4.2 Regeneration Process

The ion exchange resins used in the process have a limited ion-capturing capacity and need to be regenerated after some time. To regenerate the cationic resin, a 58% nitric acid (HNO_3) solution is used for the purpose. This solution washes out the adsorbed cations and replaces them with H^+ ions, thus regenerating the cation exchange resin. Likewise, the anionic resin is treated with 12% ammonia (NH_3) solution to strip off the adsorbed anions with OH^- ions to regain its capacity for anion exchange. The mixed bed resin comprises of both the cationic and anionic types and is regenerated with 6 per cent sulfuric acid (H_2SO_4) and 4 per cent sodium hydroxide (NaOH). The sulfuric acid acts on the cationic resin, and the sodium hydroxide acts on the anionic resin. However, the process of regeneration results in waste streams including the displaced contaminated and regenerant chemicals. These waste streams need to be treated or disposed of well so that they do not pollute the environment. Regeneration frequency is not constant and varies as a function of the influent flow rate, the concentration of contaminants in the feed solution, and the inherent capacity of the resin. To determine when and how often the resin should be regenerated, it is necessary to regularly track the efficiency of the utilized resin.

3.5 Ammonia Recovery and Conversion

The ammonia-rich vapour that flows out of the stripping column is then directed to the Uhde ammonia converter or the Neutralization Reactor which plays an important role in the process of ammonia recovery and utilization. Its main application is to convert the gaseous ammonia to liquid ammonium nitrate which is a very useful fertiliser product.

$NH_3 (g) + HNO_3 (aq) \rightarrow NH_4NO_3 (aq)$

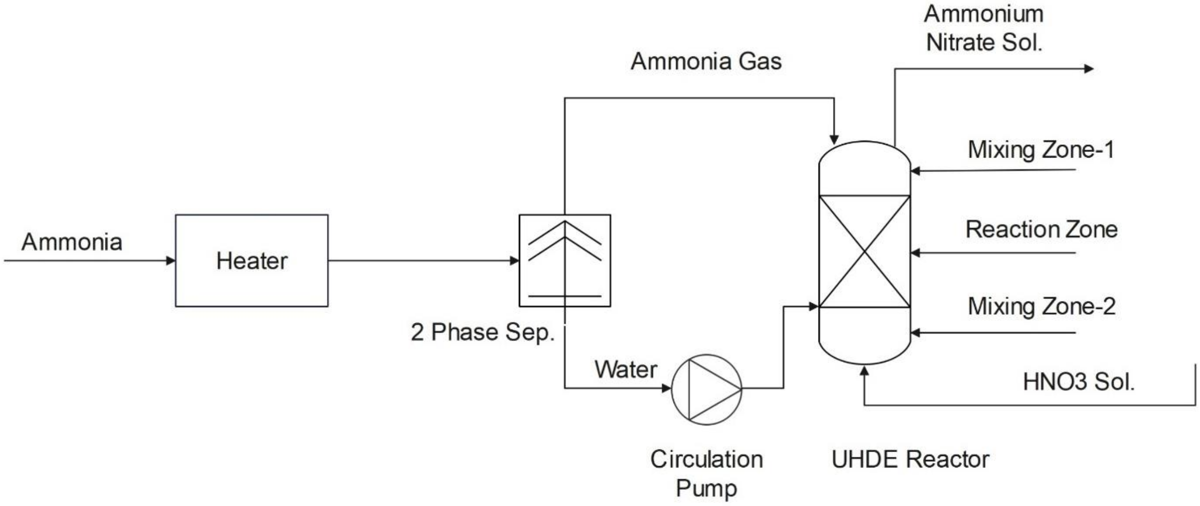


Figure 9 UHDE Reactor

This is safely and efficiently achieved in the Uhde converter which is designed for the above reaction. It often includes a reactor vessel with an impeller to enhance the interaction between the gaseous ammonia and the nitric acid solution. It also has a cooling system that helps in the dissipation of heat that is produced in the exothermic process of the reactor. To enhance the safety of the converter, safety devices such as pressure relief valves, temperature sensors, and alarms have been installed to avoid overpressure and reaction runaway. The heat produced during the neutralization reaction is useful and can be used to provide energy recovery. In the proposed process, this heat is used to create steam that is then employed in other stages of evaporation. The integration of the ammonia conversion process with the evaporation system not only enhanced the energy efficiency of the treatment but also minimized the use of external heat source which is cost-effective and environmentally friendly.

3.6 Evaporation

After the ion exchange process, the solution containing ammonium nitrate is evaporated several times in order to enhance the concentration of the solution, which in turn enhances the formation of ammonium nitrate crystals. The evaporation system comprises three triple-effect falling film evaporators: Evaporator-1, Evaporator-2, and Evaporator-3 connected in series. Each evaporator uses heat to turn a part of the water contained in the ammonium nitrate solution into vapour thus concentrating it. The falling film design enhances heat transfer and minimizes the time the solution spends in the heat exchanger thus ensuring that ammonium nitrate does not undergo thermal degradation. The vapour produced in each effect is used to heat the next effect hence making it very energy efficient. The last effect works under a vacuum to reduce the boiling point of the solution and support evaporation additionally. Several factors affect the performance of the evaporators- the temperature and pressure of each effect, heat transfer area, and the concentration of the solution. The evaporation rate is controlled by strictly regulating the temperature and pressure so as not to let ammonium nitrate decompose. This is achieved through the use of falling film evaporators that offer a thin film of the liquid through heat exchange. The concentration of the solution increases as it passes through each effect and when the solution becomes saturated ammonium nitrate crystals start to precipitate. The solution that is concentrated in the final evaporator is then transferred to a crystallizer where cooling and stirring cause the formation of ammonium nitrate crystals. The crystals are then separated from the rest of the liquid and dried to become a valuable product in the form of fertilizer. The remaining liquid after the crystallization of ammonium nitrate can be treated or even used again in the process.

3.7 Process Flow Diagram

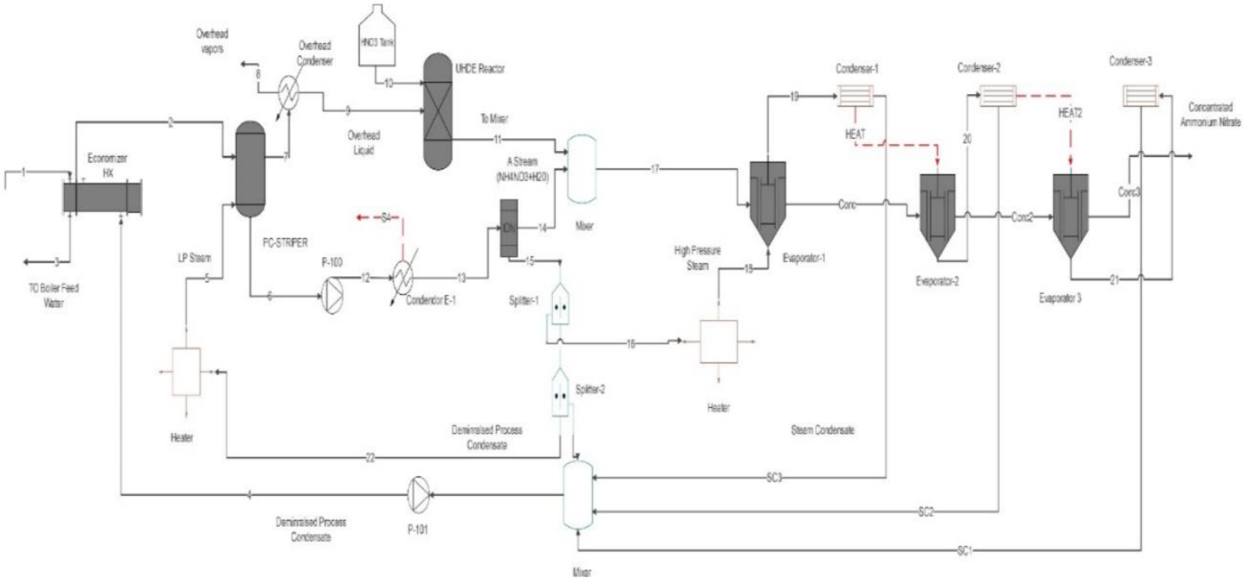
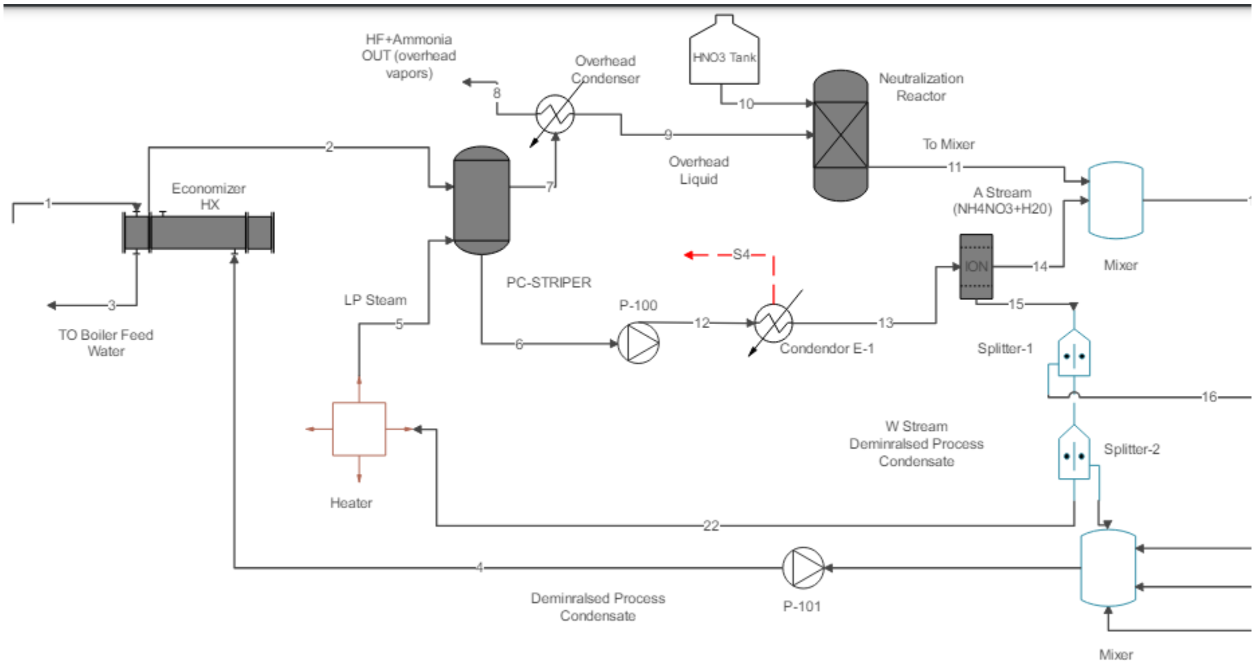
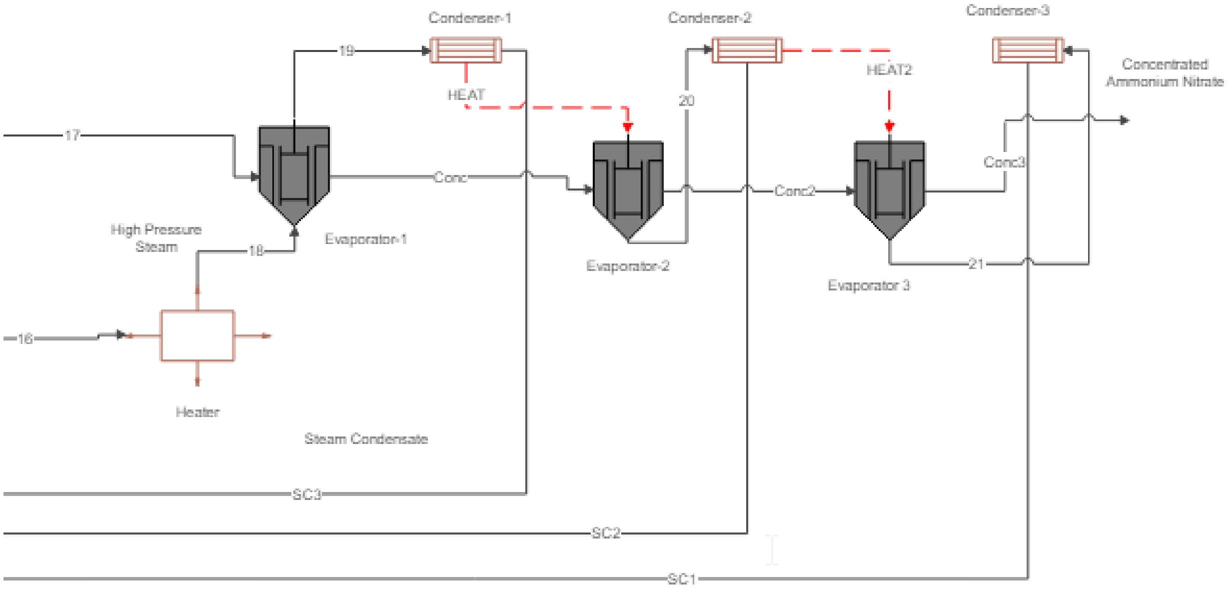


Figure 10 Purposed Process Flow Diagram




Condenser-1
Condenser-2
Condenser-3
19
HEAT
20
HEAT2
Concentrated
Ammonium Nitrate
17
Conc
Conc2
Conc3
High Pressure
Steam
18
Evaporator-1
Evaporator-2
Evaporator 3
21
16
Heater
Steam Condensate
SC3
SC2
SC1

CHAPTER 4

MASS BALANCE

The mass balance analysis is essential for understanding the flow of materials and energy throughout the proposed treatment process. It provides valuable insights into the efficiency of each unit operation and the overall performance of the system. The following table summarizes the mass balance for key components (HF, NH3, NH4NO3, and water) in various stages of the process.

4.1. Stripper (P-100)

Stream	HF (kg/hr)	NH3 (kg/hr)	NH4NO3 (kg/hr)	Water (kg/hr)	Total (kg/hr)
Process Condensate (Inlet)	2	2000	800	77100	80000
Low Pressure (LP) Steam	0	0	0	12072	12072
Overhead Vapor	2	1700	4E-06	2089	3869.000004
Overhead Liquid	1E-05	300	1E-06	4652	4952.000011
Bottom Product	2E-05	<4 mg/L	800	82431	83231.00002

Table 11 Material Balance Stripper

The stripper effectively removes most of the NH3, while a small amount of HF is also volatilized. The majority of the NH4NO3 and water remain in the bottom product.

4.2. Reactor (Neutralization)

Component		Output from Reactor (kg/hr)
NH3	300.00005	0
Ammonium Nitrate	800.00001	1100
Water	87823.4	87823.4

HNO3	1850.95	0

Table 12 Material Balance on Reactor

The reactor consumes NH3 and HNO3 to produce additional NH4NO3, with no net change in water.

4.3. Ion Exchange

Component	Input (kg/hr)
NH3	0.0005
Ammonium Nitrate	800
Water	82431
Total In	83231.0005

Table 13 Material Balance IX

The ion exchange process removes the remaining NH3 and NH4NO3 from the condensate.

4.4. Mixer

Component	Stream 14 (kg/hr)	Stream A (kg/hr)
Ammonium Nitrate	300	800
Water	740.4	200

Table 14 Material Balance Mixer

The mixer combines the ammonium nitrate solutions from the reactor and the stripper bottoms.

4.5 Evaporator 1, 2, 3 (Effects):

Component	Input (kg/hr)	Input Concentration (%)	Output (kg/hr)	Output Concentration (%)
Evaporator 1				
Ammonium Nitrate	1100	59.78	1100	64.54
Water	740	40.22	609.62	-
Evaporator 2				
Ammonium Nitrate	1100	64.54	1100	69.63
Water	609.62	35.46	479.24	-
Evaporator 3				
Ammonium Nitrate	1100	69.63	1100	85
Water	479.24	30.37	348.86	-

Table 15 Material Balance Evaporator

Each evaporator stage concentrates the ammonium nitrate solution by removing water. The final evaporator achieves a concentration of 85% ammonium nitrate.

4.6. Economizer

Component	Economizer Shell Side (kg/hr)	Economizer Tube Side (kg/hr)
Process Condensate (To Boiler Feed S1)	88181.14	-
HF	-	100
NH3	-	2000
Ammonium Nitrate	-	800
Water	-	77100

Table 16 Material Balance Economizer

The economizer recovers heat from the treated condensate to preheat the incoming feed, maximizing energy efficiency.

This comprehensive mass balance analysis demonstrates the effectiveness of the integrated treatment process in removing and recovering valuable resources from the process condensate.

CHAPTER 5

ENERGY BALANCE

5.1. Energy Balance Analysis

Energy balance analysis is used to determine energy requirement and distribution in the proposed treatment process. It calculates the heat load and energy consumption for each unit operation and helps in determining the possible area for heat integration and energy utilization

5.2. Stripper (P-100)

The stripping process involves energy exchange between the process condensate and the low-pressure (LP) steam. The energy balance for the stripper is as follows:

Input:

- Process Condensate (65°C):
    - Mass flow rate: 80,000 kg/hr
    - Specific heat capacity (Cp): 4.18 kJ/kg°C
    - Enthalpy change (ΔH): 80,000 kg/hr * 4.18 kJ/kg°C * (120°C - 65°C) = 18.792 MJ/hr
- LP Steam (111.3°C):
    - Mass flow rate: 12,072 kg/hr
    - Latent heat of vaporization (Lv): 2257 kJ/kg (at 1 atm)
    - Enthalpy change (ΔH): 12,072 kg/hr * 2257 kJ/kg = 27.259 MJ/hr

Output:

- Overhead Vapor:
    - Mass flow rate: 3869 kg/hr
    - Specific heat capacity (Cp): Assumed to be similar to water vapor
    - Enthalpy change (ΔH): Calculated based on the temperature and composition of the vapor
- Overhead Liquid:
    - Mass flow rate: 4952 kg/hr

  - Specific heat capacity (Cp): Assumed to be similar to water
  - Enthalpy change (ΔH): Calculated based on the temperature and composition of the liquid
- Bottom Product (120°C):
  - Mass flow rate: 83231 kg/hr
  - Specific heat capacity (Cp): Assumed to be similar to water
  - Enthalpy change (ΔH): 83231 kg/hr * 4.18 kJ/kg°C * (120°C - 65°C) = 19.153 MJ/hr

The energy balance for the stripper demonstrates that the energy input from the LP steam is utilized to heat the process condensate and volatilize the ammonia. The energy output is distributed among the overhead vapour, overhead liquid, and bottom product streams.

5. 3 Reactor (Neutralization)

The neutralization reaction between ammonia and nitric acid in the reactor is highly exothermic, releasing a significant amount of heat. The energy balance for the reactor is as follows:

Streams	Q (kJ/hr)
S2 (NH3)	7.98E+06
S9 (HNO3)	1.41E+08
S14 (NH4NO3 solution)	20.48E+05
S4 (Cooling water)	1.50E+08

Table 17 Energy Balance Reactor

The energy released from the reaction (Q) is absorbed by the cooling water (S4), maintaining the reactor temperature within safe operating limits.

5.4 Evaporators

The evaporation and crystallization phase involves concentrating the dilute ammonium nitrate solution from the ion exchange process and the recovery of the NH4NO3 as a solid and valuable fertilizer product. The system comprises three triple-effect falling film evaporators in forward-feed configuration: Evaporator-1, Evaporator-2, and Evaporator-3. This design is chosen because the vapour produced in one effect is sent to the next effect, thus requiring little external steam. The falling film evaporators are preferred as they provide high heat transfer coefficients, very short residence time and gentle treatment of the heat-sensitive ammonium nitrate solution. In this configuration, the dilute NH4NO3 solution from the ion exchange unit is pumped to the first evaporator (Evaporator-1). The solution is guided to trickle down along the inner surface of several vertical tubes while steam condenses on the outer surface of the tubes making water evaporate. The concentrated NH4NO3 solution from the bottom of Evaporator-1 is then sent to Evaporator-2, where it is concentrated to a higher concentration using the vapour produced in Evaporator-1 as the heat source. The same process is carried out in the Evaporator-3 while using the vapour from the Evaporator-2 for heating. The vapor produced in each effect is then cooled and condensed in another condenser after which the condensate can be returned to the system or disposed of. The concentrated NH4NO3 solution from the final evaporator is transferred to a crystallizer where cooling as well as stirring facilitate the formation of NH4NO3 crystals. These crystals are then isolated from the remaining liquid, dried, and then collected as the end product. The heat for the first effect is the steam produced in the neutralization reactor while for the other effects, the vapor produced in the previous effect is used as the heat source. This cascading effect has the effect of reducing the total energy utilization of the evaporation process. Demineralized process condensate is also employed as an auxiliary heat supply to enhance energy intensity. The evaporators are made from stainless steel because of the corrosive nature of ammonium nitrate solutions. This is because the system is intended to get a final concentration of ammonium nitrate of 85% for crystallization purposes.

Parameter	Value
Number of Effects	3
Type of Evaporators	Triple-effect falling film
Material of Construction	Stainless Steel
Heat Source	Steam from the neutralization reactor and demineralized process condensate
Evaporation Rate (per effect)	130.38 kg/hr
Steam Consumption (total)	707 kg/hr

Overall Heat Transfer Coefficient (U)	600 W/m2°C

Table 18 : Evaporator Design

5.5. Economizer

The economizer recovers heat from the hot process condensate exiting the stripper to preheat the incoming feed. The energy balance for the economizer is as follows:

Shell Side (Process Condensate):

- Mass flow rate: 87981.14 kg/hr
- Specific heat capacity (Cp): 4.18 kJ/kg°C
- Temperature change (ΔT): 22.58°C (120°C - 97.42°C)
- Heat transfer (Q): 8.33 MJ/hr

Tube Side (Mixed Components):

- Total heat transfer (Q): 8.33 MJ/hr (equal to the heat transferred from the shell side)

The energy balance for the economizer demonstrates the efficient transfer of heat from the hot condensate to the incoming feed, reducing the overall energy consumption of the process.

CHAPTER 6

EQUIPMENT DESIGN AND SPECIFICATIONS

6.1 Introduction

The objective of this process is to manage process condensate containing HF, NH_3, and NH_4NO_3 and convert it to demineralized water for recycling or discharge along with the recovery of ammonium nitrate. This goal requires careful choice of equipment and its design since each unit operation is an integral part of the treatment process. Therefore, the design and specification of each component is crucial to the efficiency, reliability, and cost of the system.

This chapter discusses the details of the principal equipment gear pertaining to the process, namely the heat exchanger, stripping column, neutralization reactor, ion exchange unit, and evaporator section. The selection criteria for each component will be further explained, including material compatibility, heat transfer rate, pressure drop and safety considerations.

6.2. Heat Exchanger (Economizer HX)

The economizer heat exchanger is one of the integral parts of the proposed process condensate treatment system, its function is not only to preheat the process condensate entering the system but also to recover waste heat within the system. This heat integration technique greatly improves the overall energy efficiency and lowers the cost of operating the treatment process. The main objective of the economizer is to heat the cold, untreated condensate that enters the system with the heat from the hot, treated process condensate coming from the stripping column. This causes the temperature of the incoming condensate to rise to 95°C and hence the energy needed to heat in the stripping column is minimized. Also, the economizer captures waste heat that would have been discharged in the environment, making a positive contribution to the effectiveness and sustainability of the process. When designing the economizer, the following factors are taken into consideration. Due to the high corrosiveness of the process condensate, the heat exchanger is made of Stainless Steel Grade 302 since this material has exceptional corrosion resistance in acidic and high-temperature conditions. The tube and shell side design parameters, such as tube diameter (OD: 25. 4 mm for the inner diameter, the number of tubes is 112 with two passes for a total length of 4. 87 m. The total number of tubes and the specifications of the tubes decide the heat transfer area (32. 6 m^2) which is a significant factor for the heat transfer rate. The number of passes and baffle spacing (203mm) affect the flow configuration and turbulence and thus the heat transfer coefficient. Fouling is the formation of dead layers at the heat transfer surfaces and greatly affects the performance of the heat exchanger. One way of preventing fouling is through the use of appropriate materials, avoidance of rough surfaces and designing the equipment for ease of cleaning. The economizer is a shell and tube heat exchanger with the internal diameter of the shell being 438. 15 mm thickness and 4 baffles. The pressure drop in the tube side is 15. The pressure at the tube side is 168 kPa, and on the shell side is 0. 552 kPa.

Parameter	Value
Type	Shell and tube heat exchanger
Heat Transfer Area	32.6 m^2
Tube Material	Stainless Steel 302
Tube Outer Diameter (OD)	25.4 mm
Tube Inner Diameter (ID)	19.05 mm
Number of Tubes	112
Number of Passes	2
Tube Length	4.87 m
Shell Internal Diameter	438.15 mm
Number of Baffles	4
Baffle Spacing	203 mm
Pressure Drop (Tube Side)	15.168 kPa
Pressure Drop (Shell Side)	0.552 kPa

Table 19 Heat Exchanger Design

6.3 Stripping Column (P-100)

The condensate is preheated and fed to trayed stripping column P-100 to strip out volatile impurities mainly ammonia. Made of ultra 654 SMO stainless steel due to the corrosiveness of the condensate, the column measures 3000 mm in diameter and 14000 mm in height, with a total of 29 bubble-cap trays, which are equally spaced at 600 mm intervals to offer a vast surface for adequate contact between vapour and liquid. The stripping process works on the basis of vapour-liquid equilibrium where the volatile ammonia is passed through a liquid phase and vapor phase through contact with low-pressure (LP) steam which is provided at the bottom of the column. The steam moves in the opposite direction to the falling liquid condensate. When the steam rises, it comes into contact with the liquid where it transfers heat and encourages the evaporation of ammonia. The vapour-liquid equilibrium determines how much ammonia is present in each phase, with the more volatile ammonia being present primarily in the vapour phase. The high concentration of ammonia vapor is leaving the top of the column while the bottom liquid is low in ammonia content. Temperature, pressure, and flow rate of steam use during the stripping process can also have an impact on the efficiency of the process. The high temperature of the preheated condensate (95°C) increases the volatility of ammonia and counter flow of steam and liquid provides steepest concentration gradient to facilitate the mass transfer of ammonia from the liquid to the vapor phase. In order to have adequate stripping while minimizing energy use the steam flow rate is well regulated. Partial condenser (E-1) is set at the top of the stripping column to collect the stripped HF vapor at a concentrated solution. The condenser is a shell and tube type heat exchanger utilizing demineralized process condensate as the cooling medium. The temperature of cooling medium is regulated to get the optimal condensation rate as well as the amount of HF in the recovered liquid. To find out the number of trays needed in order to achieve the desired removal of ammonia, the McCabe-Thiele technique was used. This graphical method involves drawing of the equilibrium curve for ammonia-water system and the operating line for the stripping column. The number of theoretical stages, also known as equilibrium stages, needed for the desired separation is then obtained by drawing the operating line and stepping off the stages with the help of the equilibrium line. The O'Connell method was applied to calculate the overall tray efficiency of the stripping column recognizing the fact that the trays are not perfectly mixed. The actual number of trays needed was then determined by dividing the number of theoretical trays by the tray efficiency. From the above calculations, it was determined that 29 bubble-cap trays are required to provide an efficiency of the ammonia removal of 99%.

Parameter	Value
Material of Construction	Ultra 654 SMO stainless steel
Column Type	Trayed
Height	14000 mm
Diameter	3000 mm
Number of Trays	29
Tray Type	Bubble Cap
Tray Spacing	600 mm
Pressure Drop	0.2 bar
Heat Transfer Area (Partial Condenser)	18.116 m^2

Table 20 Stripper Design

6.4 Neutralization Reactor

The neutralization reactor as presented in the proposed process condensate treatment system plays a major role in the reaction of ammonia gas (NH3) that has been recovered from the stripping column with nitric acid (HNO3) to form ammonium nitrate (NH4NO3) in a highly exothermic reaction.

6.4.1 Reactor Design

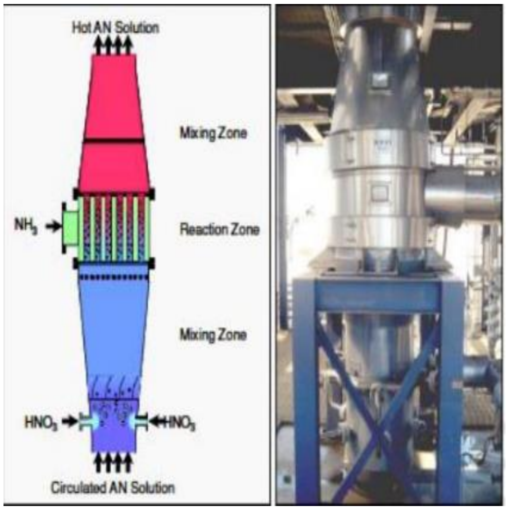


Figure 11 UHDE REACTOR

The reactor will help enhance the conversion of ammonia gas to ammonium nitrate in an efficient and safe manner. The reaction between ammonia and nitric acid is a strong exothermic reaction and give a large amount of heat. Consequently, the choice of the reactor design focuses on the efficient heat management ensuring the proper reaction conditions and absence of the thermal catastrophe. The reactor also incorporates a cooling jacket where the cooling water is passed in order to cool the excess heat produced during the reaction. The heat transfer area of the cooling jacket is 6 m^2 which provides for sufficient cooling capability. Thorough contact between the ammonia gas and nitric acid solution is important to ensure proper neutralization for better yield of ammonium nitrate. To achieve the required level of mixing, the reactor is provided with a mixing system, impeller or static mixer. The mixing operation is performed delicately to reduce shear rates that are likely to degrade the product or induce side reactions. The reactor is made from stainless steel; a material that has good corrosion resistance in acidic conditions. The thickness of the reactor vessel is 2mm which is adequate in terms of mechanical strength to support the operating pressure of 1. 2 bar. The cooling jacket is also made of stainless steel with a thickness of 8mm to make sure that it does not leak. This is an important consideration when designing the neutralization reactor. There are pressure relief valves to ensure that the pressure in the reactor does not exceed a certain value, temperature indicators to keep track of the reaction temperature and alarms to warn the operators of any unusual state. These safety features are important to prevent the hazards arising from the exothermic reaction and for the efficient functioning of the reactor.

Parameter	Value
Heat Transfer Area	6 m^2
Height	1700 mm
Diameter	1120 mm
Volume	2.2 m^3
Volume of Mixing Zone	0.66 m^3
Number of Tubes (Cooling Jacket)	300
Design Pressure	1.2 bar
Reactor Thickness	2 mm
Cooling Jacket Thickness	8 mm
Material	Stainless Steel

Table 21 UHDE Reactor Design

6.5 Ion Exchange Membrane Treatment

The ion exchange (IX) membrane system plays a crucial role in the process condensate treatment system with the purpose of eliminating the remaining nonvolatile impurities after the steam stripping step. These are hydrofluoric acid (HF) and ammonium nitrate (NH_4NO_3), and are very dangerous if not properly managed.

6.5.1 Membrane System Design

The IX system employs a series of ion exchange resin filters to remove these contaminants based on the charge they have. These are three cationic filters, three anionic filters and a final mixed bed filter. This configuration enables the ionizer to effectively eradicate both the positive and the negative ions. The cationic filters are meant for the elimination of positively charged ions such as ammonium (NH_4^+) and hydrogen(H^+).

Feature	Cation Filter	Anion Filter	Mixed Bed
Total Filters	3	3	3
Flowrate (m^3/hr)	64	64	64
Ionic Charge (meq/hr)	157 as NH_4^+	156 as NO_3^-	4.1 as NH_4NO_3
Diameter (mm)	1600	1600	1200
Vessel Height (mm)	10000	12000	5800
Material	Stainless Steel	Stainless Steel	Stainless Steel
Lewatit Resin Type	K 2629	S 4428	S 100

Table 22 IX Design

6.5.2 Regeneration Process

With time the ion exchange resins get to be saturated with the adsorbed contaminants and thus they are less effective. However, the adsorbent resins have to be regenerated periodically in order to regain their original capacity. In the regeneration process, a concentrated solution of regenerant chemicals is passed through the resin bed to remove the adsorbed ions.The cationic resin is regenerated using a 58% nitric acid (HNO_3) solution through which the adsorbed cations are displaced by hydrogen ions (H^+). The anionic resin is regenerated by washing it with a 12% ammonia (NH_3) solution in which the anions are displaced by OH^- ions. To regenerate the mixed bed resin, a 6% sulfuric acid (H_2SO_4) and 4% sodium hydroxide (NaOH) solution is used to regenerate the cationic and anionic resins respectively. The regeneration process produces waste streams of the displaced contaminants and the regenerant chemicals. These waste streams have to be properly dealt with to ensure that they do not cause harm to the environment. The rate at which regeneration is done depends on the flow rate of influent, concentrations of contaminants, and the capacity of the resin. This means that the resin performance should be checked regularly to identify the regeneration frequency that would be most suitable in maintaining the efficiency of the ion exchange system.

6.6 Evaporation

The evaporation and crystallization stage is very important for the purpose of concentrating the dilute ammonium nitrate solution from the ion exchange process and obtain the solid ammonium nitrate product. The system comprises of three triple effect falling film evaporators in series namely Evaporator 1, Evaporator 2, and Evaporator 3. This configuration is selected for its operating efficiency since the vapor generated in one effect is utilized for heating the next effect as far as possible, reducing the need for external steam. Falling film evaporators are used because it is characterized by high heat transfer coefficients, short stay time and gentle treatment of the heat-sensitive ammonium nitrate solution. Several factors affect the performance of the evaporators and these are the temperature and pressures in each effect, the heat transfer area, and the concentration of the solution. The temperature and pressure are maintained in a manner that favours evaporation while avoiding the decomposition of ammonium nitrate. To enhance the heat transfer area, falling film evaporators are used as they allow for a thin film of liquid for heat transfer. Facing a high concentration of the solution along each of the effects, the mixture reaches a point where ammonium nitrate crystallizes. The strong concentrated ammonium nitrate solution coming out from the final evaporator is then transferred to a crystallizer where cooling and stirring take place to facilitate the crystallization of ammonium nitrate. The crystals are then separated from the rest of the liquid, dried and collected as a fertiliser product. The remaining liquid after ammonium nitrate has been precipitated can undergo further processing or be reused in the process. The heat input for the first effect is steam produced in the neutralization reactor, whereas the following effects use the vapour produced in the previous effect. This cascading effect causes a considerable decrease in the total energy required for the evaporation process. Demineralized process condensate is also utilized as a makeup water and as a supplementary heat source to enhance energy efficiency.

Parameter	Value
Number of Effects	3
Type of Evaporators	Triple-effect falling film
Material of Construction	Stainless Steel
Heat Source	Steam from the neutralization reactor and demineralized process condensate
Evaporation Rate (per effect)	130.38 kg/hr
Steam Consumption (total)	707 kg/hr

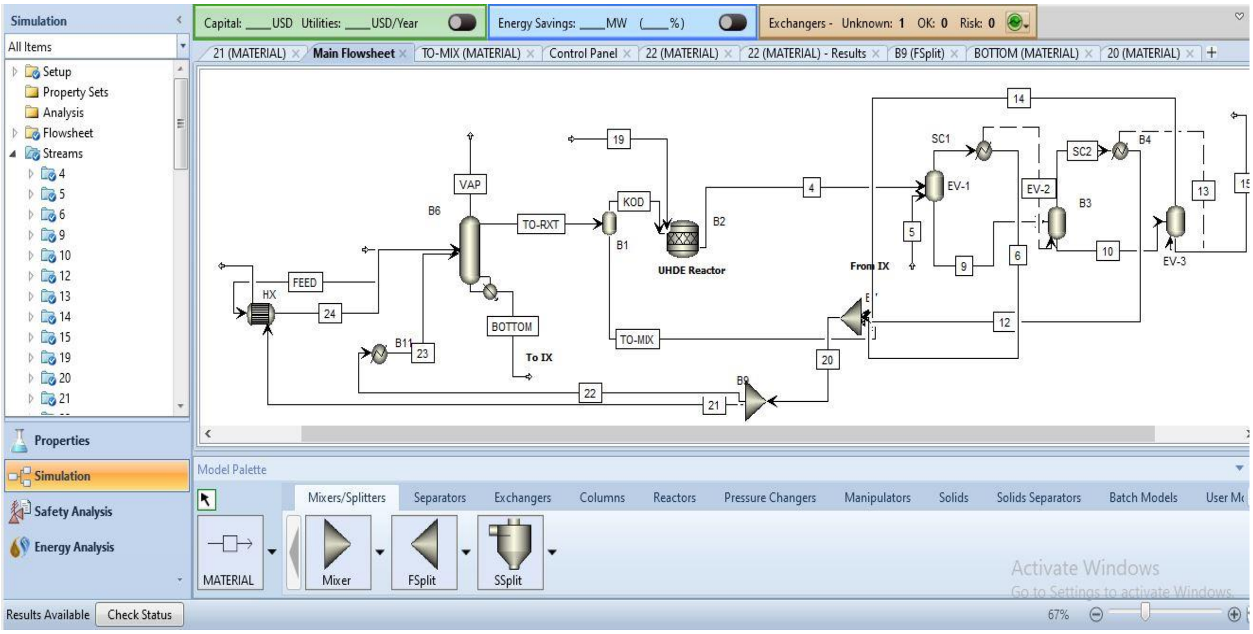
Table 23 Evaporator Design

6.7. Conclusion

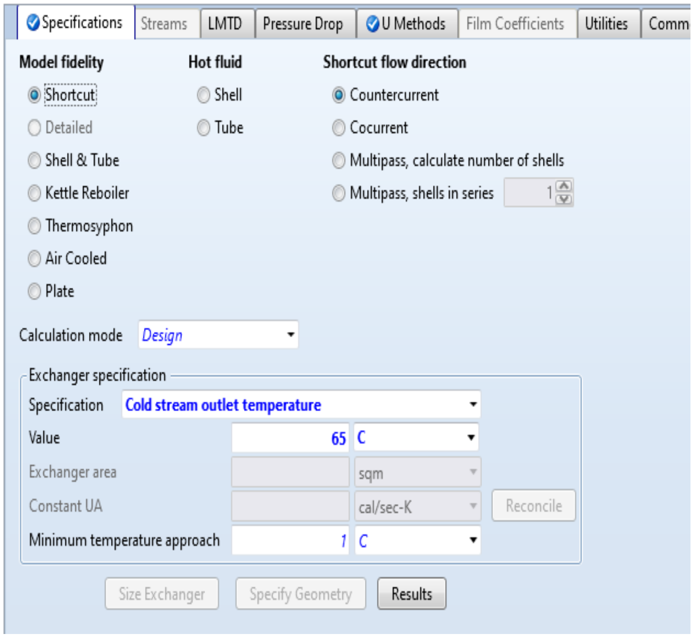
Each equipment of the process condensate treatment system is selected carefully to enhance the operating efficiency, safety, and economy. The heat exchanger made of corrosion-resistant stainless steel optimizes the heat exchange and minimizes the energy loss. The stripping column equipped with bubble-cap trays and particular dimensions allows ammonia removal effectively and reduces pressure drop. Among the key components of the neutralization reactor, there are pressure relief valves and temperature sensors for safety, the cooling jacket and the mixing system for maintaining the optimal reaction parameters. The ion exchange system is comprised of a sequence of specific resin filters, able to remove NVs, and the regeneration process of the filter was planned in a way to reduce waste and increase the life of the resin. Lastly, the triple-effect falling film evaporators are used to concentrate the ammonium nitrate solution with high energy utilisation and is a factor that enhances the economy of the process. Possible areas for more improvements are the investigation of some other materials for the construction of the heat exchanger and the reactor to improve the issue of corrosion and to minimize the costs..

CHAPTER 7

SIMULATION



7.1. Heat Exchanger



Model fidelity

- ● Shortcut
- ○ Detailed
- ○ Shell & Tube
- ○ Kettle Reboiler
- ○ Thermosyphon
- ○ Air Cooled
- ○ Plate

Hot fluid

- ● Shell
- ○ Tube

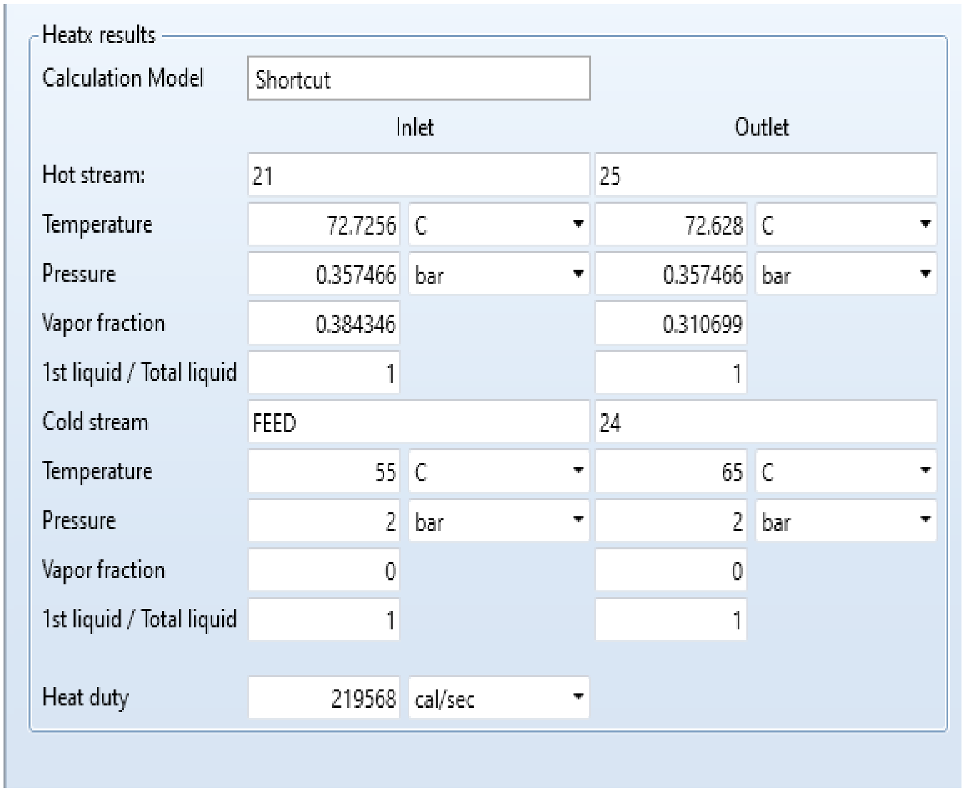
Shortcut flow direction

- ● Countercurrent
- ○ Cocurrent
- ○ Multipass, calculate number of shells
- ○ Multipass, shells in series 1

Calculation mode: *Design*

Exchanger specification

Specification	Cold stream outlet temperature	
Value	65	C
Exchanger area		sqm
Constant UA		cal/sec-K
Minimum temperature approach	1	C



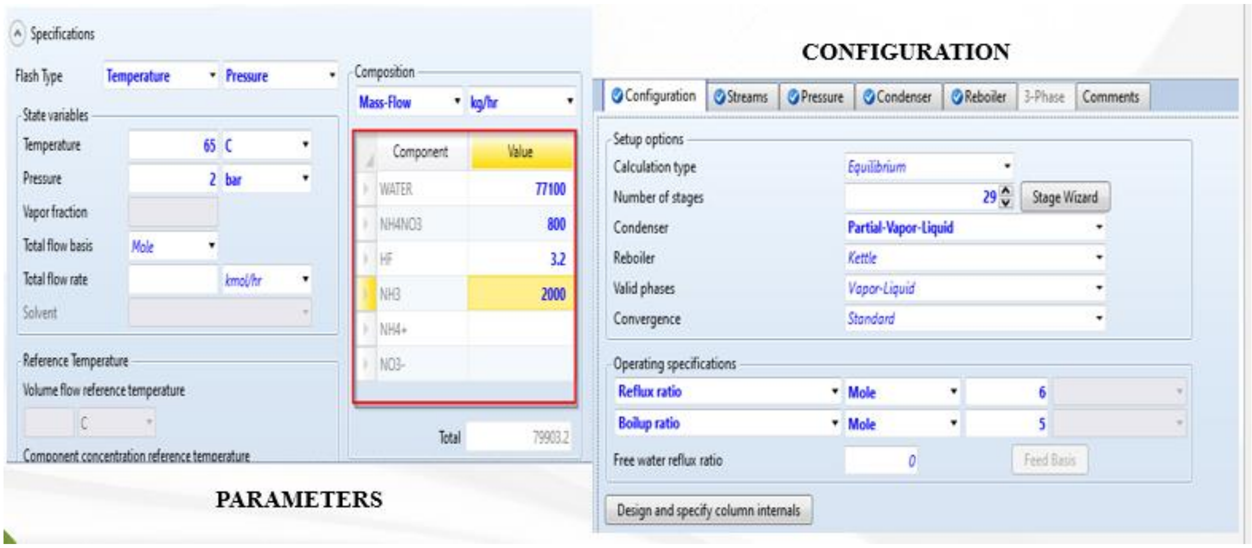
Heatx results

Calculation Model: Shortcut

	Inlet		Outlet	
Hot stream:	21		25	
Temperature	72.7256	C	72.628	C
Pressure	0.357466	bar	0.357466	bar
Vapor fraction	0.384346		0.310699	
1st liquid / Total liquid	1		1	
Cold stream	FEED		24	
Temperature	55	C	65	C
Pressure	2	bar	2	bar
Vapor fraction	0		0	
1st liquid / Total liquid	1		1	

Heat duty: 219568 cal/sec

7.2. Stripper



Specifications

Flash Type: Temperature, Pressure

State variables

Temperature	65	C
Pressure	2	bar
Vapor fraction		
Total flow basis	Mole	
Total flow rate		kmol/hr
Solvent		

Reference Temperature

Volume flow reference temperature: C

Component concentration reference temperature

Composition: Mass-Flow, kg/hr

Component	Value
WATER	77100
NH4NO3	800
HF	3.2
NH3	2000
NH4+	
NO3-	

Total: 79903.2

PARAMETERS

CONFIGURATION

Setup options

Calculation type	Equilibrium
Number of stages	29
Condenser	Partial-Vapor-Liquid
Reboiler	Kettle
Valid phases	Vapor-Liquid
Convergence	Standard

Operating specifications

Reflux ratio	Mole	6
Boilup ratio	Mole	5

Free water reflux ratio: 0

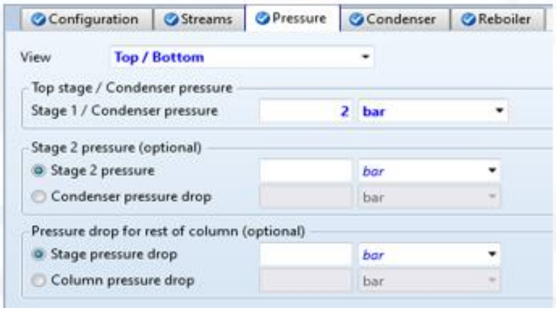
SPECIFICATIONS

Feed streams

Name	Stage	Convention
1	28	Above-Stage
2	2	Above-Stage

Product streams

Name	Stage	Phase	Basis	Flow	Units	Flow Ratio	Feed Specs
3	1	Vapor	Mole		kmol/hr		Feed basis
4	29	Liquid	Mole		kmol/hr		Feed basis
5	1	Liquid	Mole		kmol/hr		Feed basis

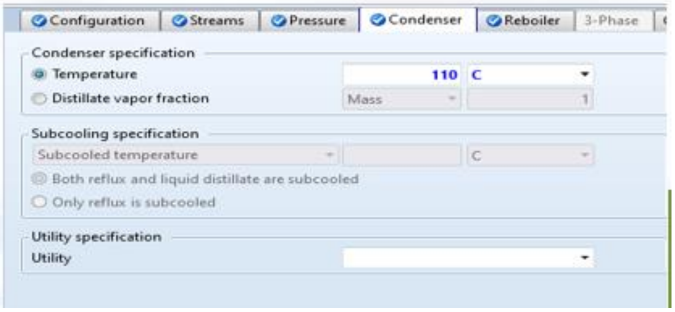


View: Top / Bottom

Top stage / Condenser pressure
Stage 1 / Condenser pressure: 2 bar

Stage 2 pressure (optional)
● Stage 2 pressure: bar
○ Condenser pressure drop: bar

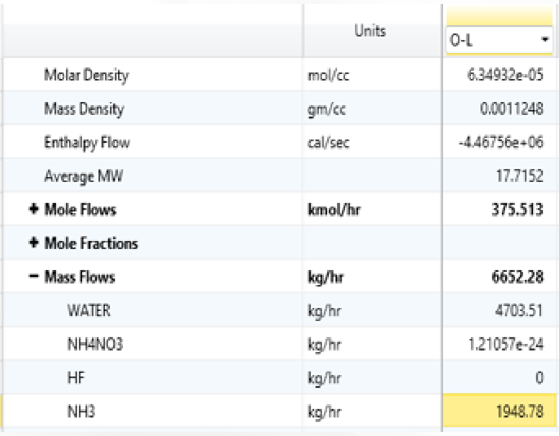
Pressure drop for rest of column (optional)
● Stage pressure drop: bar
○ Column pressure drop: bar



Condenser specification
● Temperature: 110 C
○ Distillate vapor fraction: Mass 1

Subcooling specification
Subcooled temperature C
○ Both reflux and liquid distillate are subcooled
○ Only reflux is subcooled

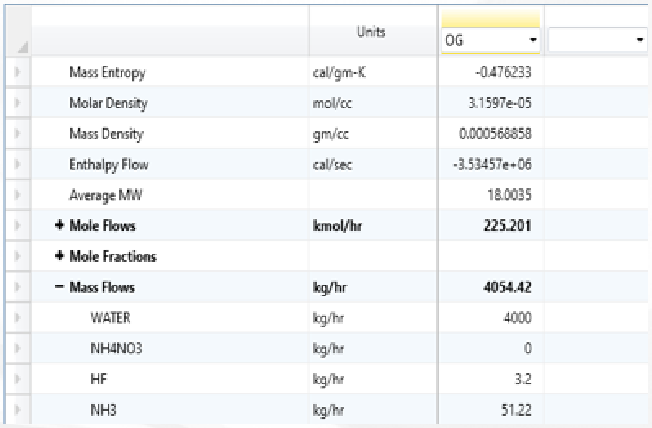
Utility specification
Utility:



	Units	O-L
Molar Density	mol/cc	6.34932e-05
Mass Density	gm/cc	0.0011248
Enthalpy Flow	cal/sec	-4.46756e+06
Average MW		17.7152
+ Mole Flows	**kmol/hr**	**375.513**
+ Mole Fractions		
− Mass Flows	**kg/hr**	**6652.28**
WATER	kg/hr	4703.51
NH4NO3	kg/hr	1.21057e-24
HF	kg/hr	0
NH3	kg/hr	1948.78

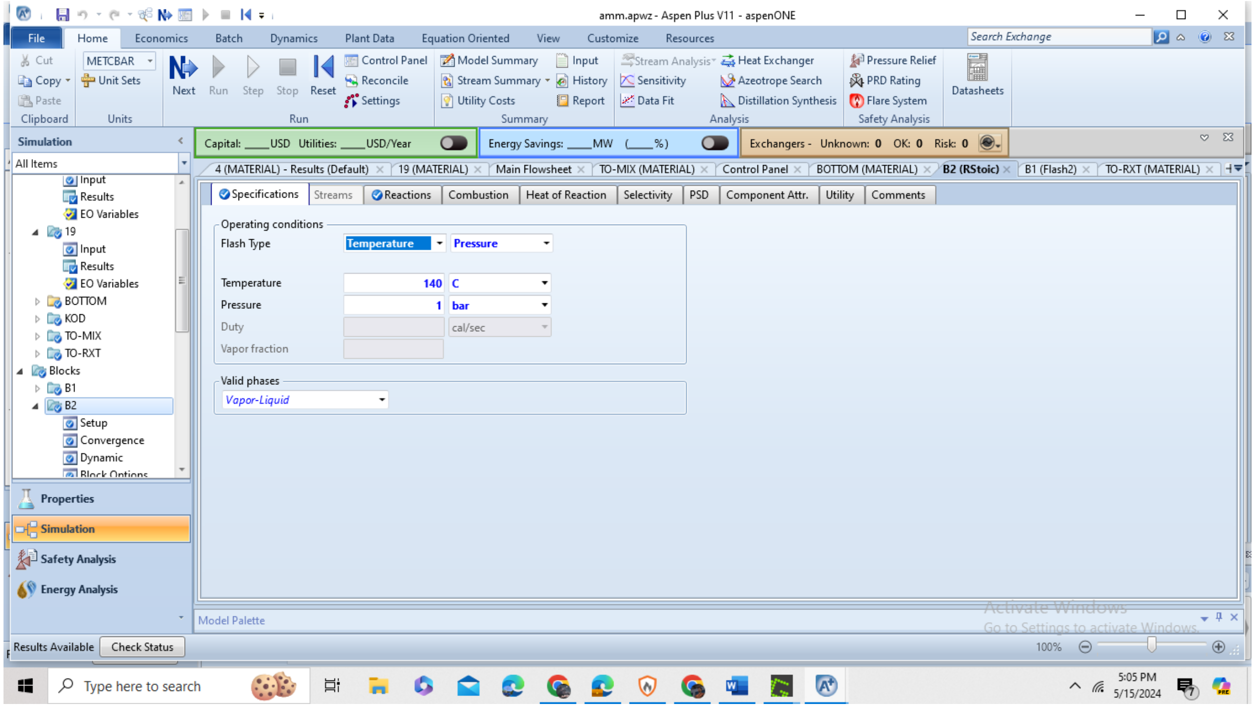
OVERHEAD LIQUID

OVERHEAD GAS



	Units	OG
Mass Entropy	cal/gm-K	-0.476233
Molar Density	mol/cc	3.1597e-05
Mass Density	gm/cc	0.000568858
Enthalpy Flow	cal/sec	-3.53457e+06
Average MW		18.0035
+ Mole Flows	**kmol/hr**	**225.201**
+ Mole Fractions		
− Mass Flows	**kg/hr**	**4054.42**
WATER	kg/hr	4000
NH4NO3	kg/hr	0
HF	kg/hr	3.2
NH3	kg/hr	51.22

7.3 Reactor



Operating conditions

Flash Type: Temperature, Pressure

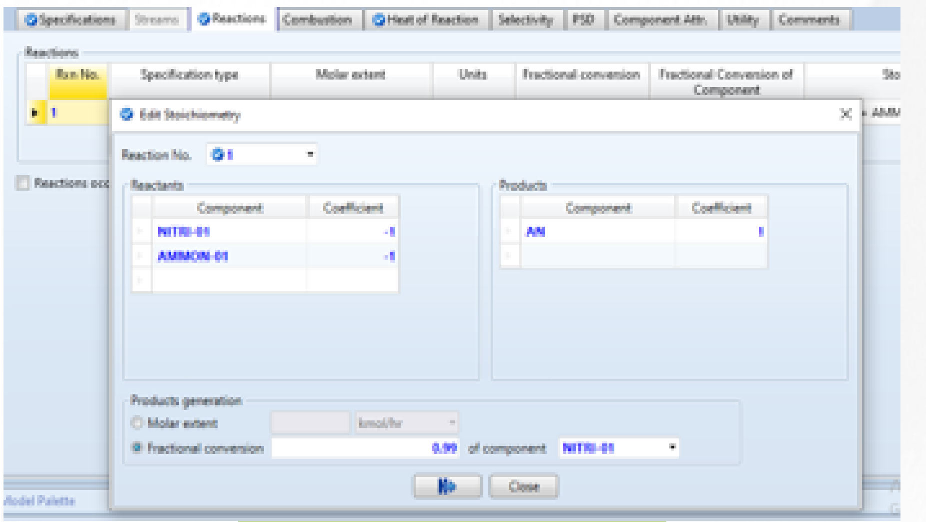
Temperature: 140 C

Pressure: 1 bar

Duty: cal/sec

Vapor fraction

Valid phases: Vapor-Liquid



Reaction No.: 1

Reactants

Component	Coefficient
NITRI-01	-1
AMMON-01	-1

Products

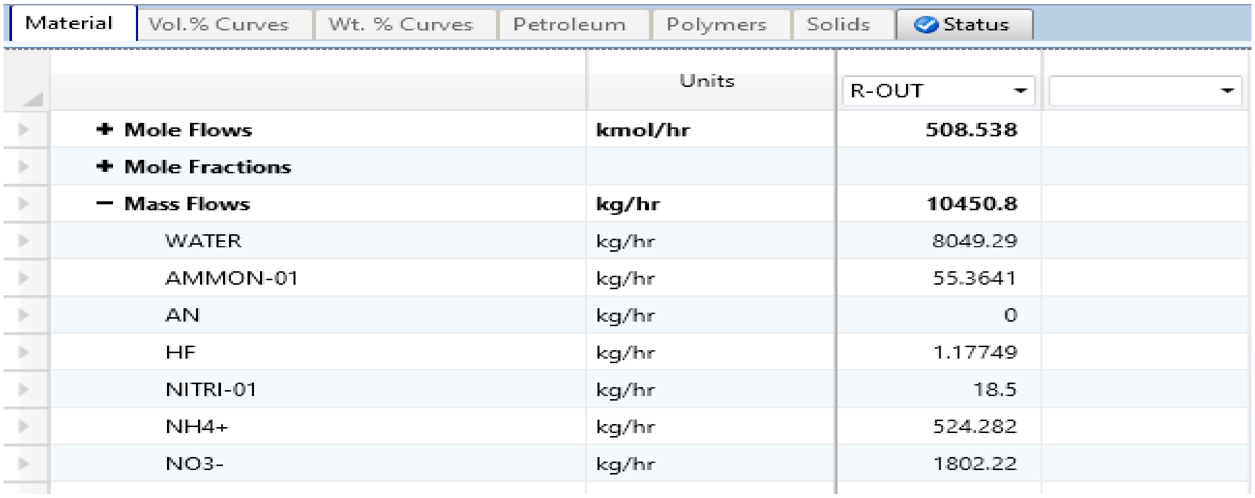
Component	Coefficient
AN	1

Products generation

○ Molar extent kmol/hr

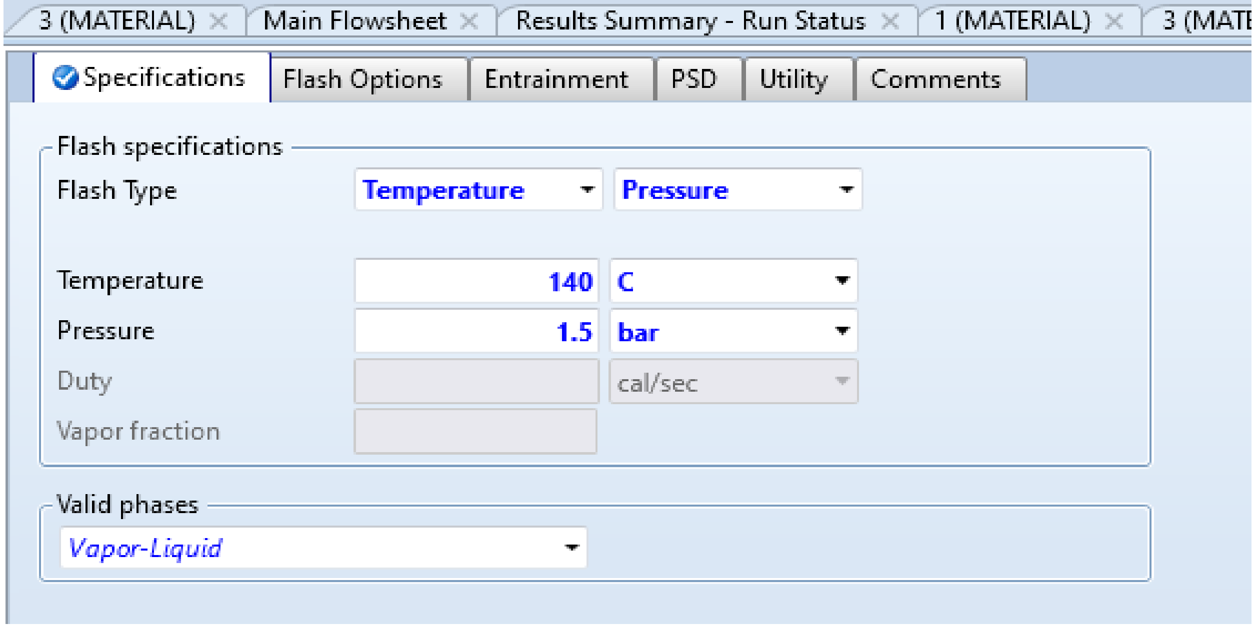
● Fractional conversion 0.99 of component NITRI-01

REACTION INPUT



	Units	R-OUT
+ Mole Flows	**kmol/hr**	**508.538**
+ Mole Fractions		
− Mass Flows	**kg/hr**	**10450.8**
WATER	kg/hr	8049.29
AMMON-01	kg/hr	55.3641
AN	kg/hr	0
HF	kg/hr	1.17749
NITRI-01	kg/hr	18.5
NH4+	kg/hr	524.282
NO3-	kg/hr	1802.22

7.4. Evaporator



Flash specifications

Flash Type: Temperature, Pressure

Temperature: 140 C

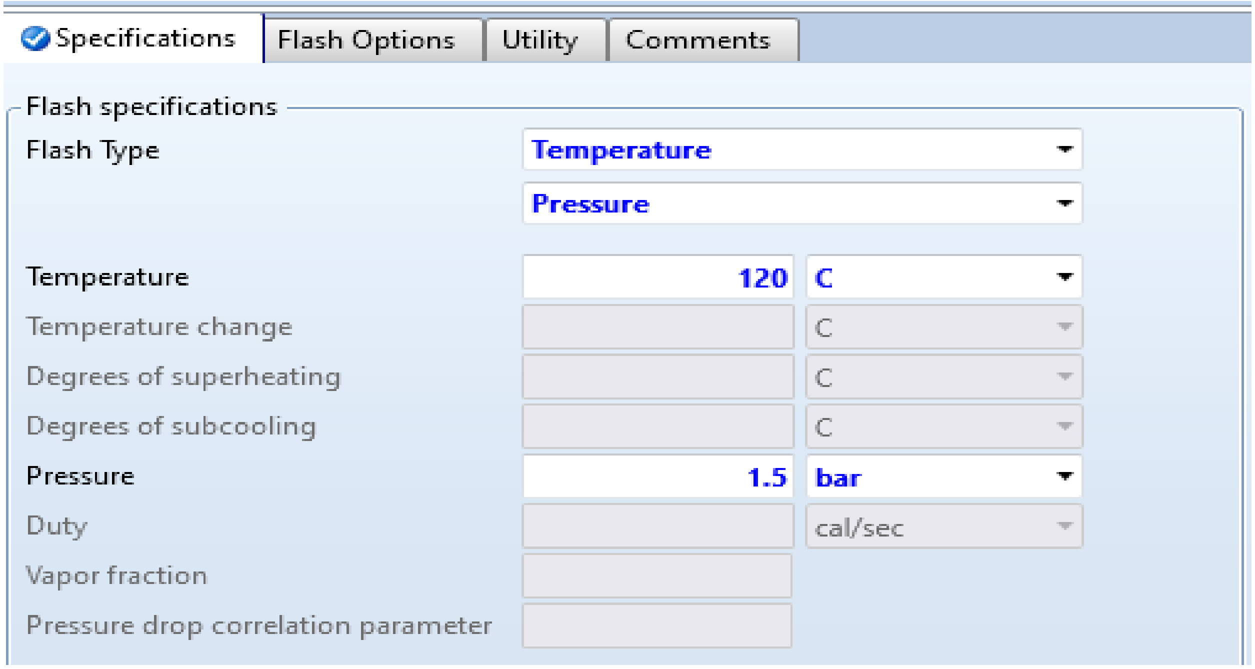
Pressure: 1.5 bar

Duty: cal/sec

Vapor fraction:

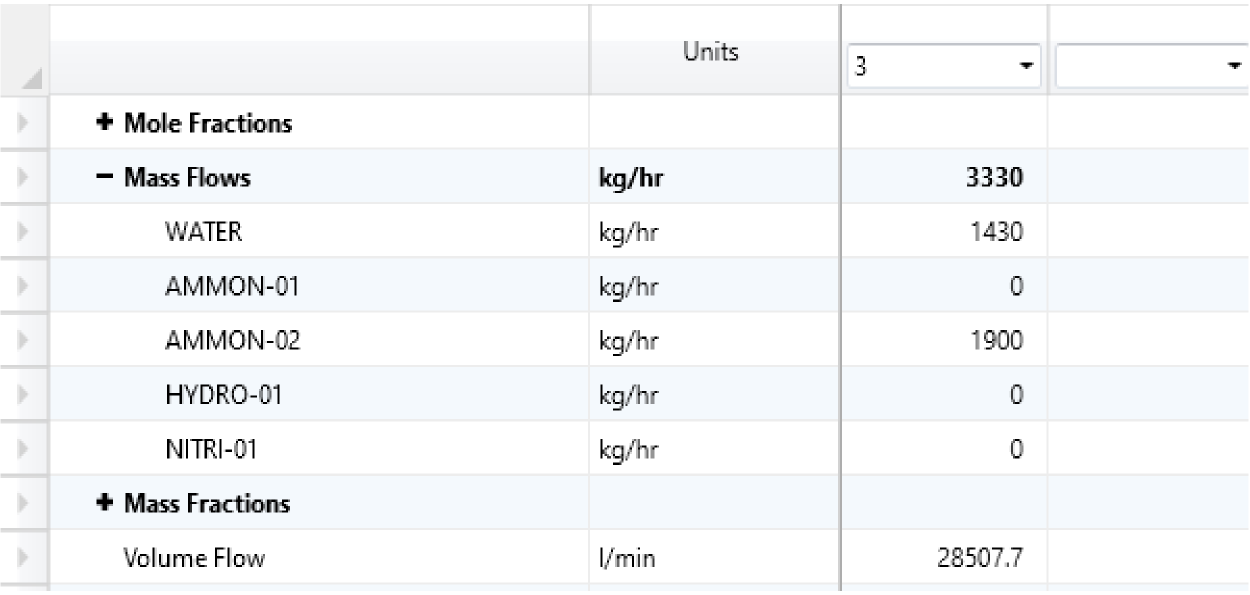
Valid phases

Vapor-Liquid

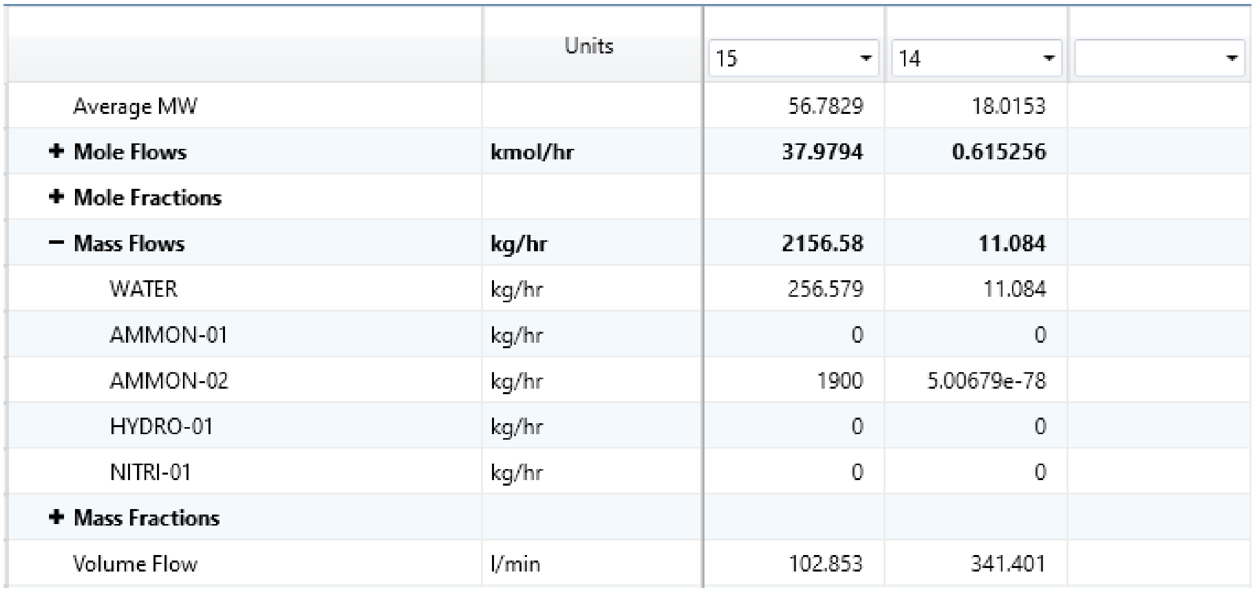


Flash specifications

Flash Type	Temperature	
	Pressure	
Temperature	120	C
Temperature change		C
Degrees of superheating		C
Degrees of subcooling		C
Pressure	1.5	bar
Duty		cal/sec
Vapor fraction		
Pressure drop correlation parameter		



	Units	3	
+ Mole Fractions			
− Mass Flows	kg/hr	3330	
WATER	kg/hr	1430	
AMMON-01	kg/hr	0	
AMMON-02	kg/hr	1900	
HYDRO-01	kg/hr	0	
NITRI-01	kg/hr	0	
+ Mass Fractions			
Volume Flow	l/min	28507.7	



	Units	15	14	
Average MW		56.7829	18.0153	
+ Mole Flows	**kmol/hr**	**37.9794**	**0.615256**	
+ Mole Fractions				
− Mass Flows	**kg/hr**	**2156.58**	**11.084**	
WATER	kg/hr	256.579	11.084	
AMMON-01	kg/hr	0	0	
AMMON-02	kg/hr	1900	5.00679e-78	
HYDRO-01	kg/hr	0	0	
NITRI-01	kg/hr	0	0	
+ Mass Fractions				
Volume Flow	l/min	102.853	341.401	

CHAPTER 8

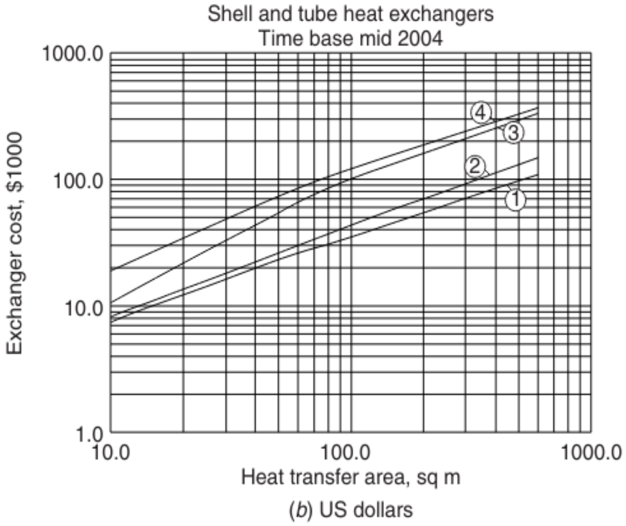
ECONOMIC ANALYSIS

8.1. Economic Analysis

Essential to the feasibility of the proposed process is the economical nature of the condensate treatment system. This section undertakes a comprehensive economic evaluation of the capital and operational costs as well as the anticipated revenues from the recovered ammonium nitrate.

8.2 Capital Costs

The capital costs refer to the costs involved in acquiring and putting in place the equipment necessary for the treatment process.



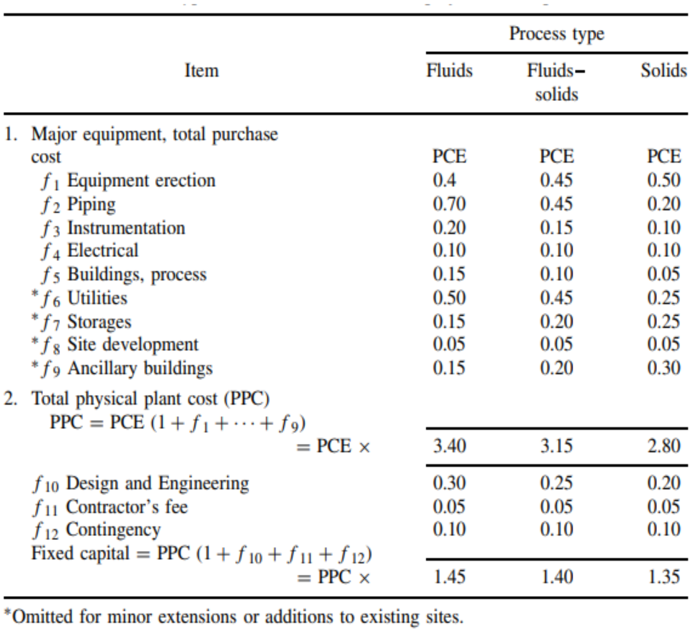
Materials		Pressure factors		Type factors	
Shell	Tubes	1–10 bar	× 1.0	Floating head	× 1.0
① Carbon steel	Carbon steel	10–20	× 1.1	Fixed tube sheet	× 0.8
② C.S.	Brass	20–30	× 1.25	U tube	× 0.85
③ C.S.	Stainless steel	30–50	× 1.3	Kettle	× 1.3
④ S.S.	S.S.	50–70	× 1.5		

Figure 6.3*a*, *b*. Shell and tube heat exchangers. Time base mid-2004
Purchased cost = (bare cost from figure) × Type factor × Pressure factor

Equipment	Cost (USD)
Stripper (P-100)	450,000
Anion Exchanger	228,888
Cation Exchanger	80,170
Mixed Bed Exchanger	24,768
UHDE Reactor	86,595
Evaporators	238,713
Heat Exchanger	21,700
Total Purchase Equipment Cost (PCE)	**1,130,834**

Table 24 Purchase Equipment Cost

Besides the cost of the equipment, other charges like installation, pipes, instruments and electricals have to be taken into consideration. These costs are usually quantified on the basis of some fraction of the PCE.



Item	Process type Fluids	 Fluids–solids	 Solids
1. Major equipment, total purchase cost	PCE	PCE	PCE
f_1 Equipment erection	0.4	0.45	0.50
f_2 Piping	0.70	0.45	0.20
f_3 Instrumentation	0.20	0.15	0.10
f_4 Electrical	0.10	0.10	0.10
f_5 Buildings, process	0.15	0.10	0.05
*f_6 Utilities	0.50	0.45	0.25
*f_7 Storages	0.15	0.20	0.25
*f_8 Site development	0.05	0.05	0.05
*f_9 Ancillary buildings	0.15	0.20	0.30
2. Total physical plant cost (PPC) PPC = PCE $(1 + f_1 + \cdots + f_9)$ = PCE ×	3.40	3.15	2.80
f_{10} Design and Engineering	0.30	0.25	0.20
f_{11} Contractor's fee	0.05	0.05	0.05
f_{12} Contingency	0.10	0.10	0.10
Fixed capital = PPC $(1 + f_{10} + f_{11} + f_{12})$ = PPC ×	1.45	1.40	1.35

*Omitted for minor extensions or additions to existing sites.

TCI = PCE + Installation Factor + Piping Factor + Instrumentation Factor + Electrical Factor

By applying the conventional factors from the chemical industry of 0. 4 for installations, 0. 7 for piping, 0. 2 for instrumentation, and 0. 1 for electrical; the TCI is expected to be 2. 64 million USD.

8.3 Operating Costs

The operating costs include the expenses associated with running the treatment system, such as energy consumption, chemical usage, labour, maintenance, and waste disposal. The energy consumption of the major equipment items is summarized in the following table:

Equipment	Energy Consumption (MW)
Heat Exchanger	2.314
Stripper	0.833
Reactor	42.5
Evaporator Section	17.3

Table 25 Operating Cost

8.4 Revenue Generation

The indicated treatment method not only purges the process condensate from potentially dangerous impurities but also reclaims ammonium nitrate for use as a fertilizer. The earnings made from the sales of the ammonium nitrate can help in cutting down the operating costs hence making the process more economical. The yield of ammonium nitrate can be determined from the above mass balance calculations, while the total revenue can be calculated using the market price of ammonium nitrate.

8.5 Economic Analysis

The proposed condensate treatment plan is financially viable and a good investment opportunity. Thus, by using waste condensate in the production of high-value ammonium nitrate, industries can recover their investment in only 1.5 years and an impressive return on investment (ROI) of 67%. This economic evaluation proves the feasibility of this new process and identifies potential sources of financial savings and revenue.

Metric	Formula	Value
Payback Period	Total Investment / Annual Cash Flow	1.5 years
ROI	(Annual Profit / Total Investment) * 100%	67%

Table 26 Payback Period

CHAPTER 9

HAZARD AND OPERABILITY (HAZOP) ANALYSIS

The Hazard and Operability (HAZOP) analysis is a structured and systematic technique used to identify potential hazards and operational issues in a process plant. It involves a multidisciplinary team reviewing the process and instrumentation diagrams (P&IDs) and systematically questioning every part of the process to identify potential deviations from the design intent and their consequences. The HAZOP team then recommends actions to mitigate or eliminate these potential hazards.

9.1 HAZOP Analysis of Key Equipment and Process Parameters

9.1.1 Heat Exchanger (Economizer HX)

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations/Actions	Risk Assessment
Flow Rate (Tube/Shell Side)	No	No Flow	Pump failure, valve malfunction, blockage	Loss of heat transfer, reduced process efficiency, potential for overheating	Install redundant pumps, regular maintenance of valves and pumps, implement blockage detection systems	High
Temperature (Tube/Shell Side)	More/Less	High/Low Temperature	Fouling, scaling, control system failure	Reduced heat transfer efficiency, thermal	Regular cleaning and descaling, implement temperature alarms and control systems, use corrosion-resistant	Moderate

				stress on materials, potential for equipment damage	materials	
Pressure (Tube/Shell Side)	More/Less	High/Low Pressure	Valve malfunction, pump failure, blockage	Equipment damage, leakage, reduced heat transfer efficiency	Install pressure relief valves, pressure sensors, and alarms, regular maintenance of valves and pumps	High

9.1.2 Stripping Column (P-100)

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations/Actions	Risk Assessment
Steam Flow Rate	More/Less	High/Low Flow	Control valve malfunction, steam supply issues	Flooding/drying of trays, reduced stripping efficiency, increased energy consumption	Install redundant steam control valves, monitor steam supply pressure, implement flow alarms	High
Temperature	More/Less	High/Low Temperature	Heating/cooling system failure, control system malfunction	Thermal degradation of NH4NO3, reduced stripping efficiency, potential for hazardous	Install redundant temperature control systems, implement temperature alarms, regular maintenance of heating/cooling systems	High

				byproducts		
Pressure	More/Less	High/Low Pressure	Blockage, valve malfunction, pump failure	Equipment damage, reduced stripping efficiency, potential for vaporization	Install pressure relief valves, pressure sensors, and alarms, regular maintenance of valves and pumps	High
Liquid Level	More/Less	High/Low Level	Feed flow rate fluctuations, pump malfunction, tray damage	Flooding/drying of trays, reduced stripping efficiency, potential for equipment damage	Install level sensors and alarms, implement level control systems, regular inspection of trays	Moderate

9.1.3 Neutralization Reactor

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations/Actions	Risk Assessment
NH3 Flow Rate	More/Less	High/Low Flow	Control valve malfunction, ammonia supply issues	Incomplete neutralization, excess ammonia in product, potential for environmental pollution	Install redundant control valves, monitor ammonia supply pressure, implement flow alarms	High
HNO3 Flow Rate	More/Less	High/Low Flow	Control valve malfunction, nitric acid supply issues	Incomplete neutralization, excess nitric acid in product, potential for corrosion	Install redundant control valves, monitor nitric acid supply pressure, implement flow alarms	High
Temperature	More/Less	High/Low	Cooling	Thermal	Install redundant	High

		Temperature	system failure, control system malfunction, heat exchanger fouling	runaway, incomplete reaction, reduced product yield, potential for equipment damage	temperature control systems, implement temperature alarms, regular maintenance of cooling system and heat exchanger	
Pressure	More/Less	High/Low Pressure	Blockage, valve malfunction, pump failure	Equipment damage, leakage, potential for vaporization of reactants	Install pressure relief valves, pressure sensors, and alarms, regular maintenance of valves and pumps	High

9.1.4 Ion Exchange Unit

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations/ Actions	Risk Assessment
Flow Rate	More/Less	High/Low Flow	Pump failure, valve malfunction, blockage	Incomplete ion exchange, premature resin exhaustion, reduced treatment efficiency	Install redundant pumps, regular maintenance of valves and pumps, implement blockage detection systems	High
Feed Concentration	More/Less	High/Low Concentration	Upstream process upset, measurement error	Resin overloading/underutilization, reduced treatment efficiency, increased operating costs	Continuous monitoring of feed composition, adjust flow rate and regeneration frequency accordingly	Moderate
Regeneration	No	No Regeneration	Pump failure, chemical	Resin exhaustion, breakthrough of contaminants, reduced	Install redundant pumps, ensure reliable chemical	High

			supply interruption, timer malfunction	effluent quality	supply, and implement alarms for a regeneration cycle	

9.1.5 Evaporator Section

Parameter	Guide Word	Deviation	Causes	Consequences	Recommendations/Actions	Risk Assessment
Feed Flow Rate	More/Less	High/Low Flow	Pump failure, valve malfunction, blockage	Fluctuations in concentration, scaling/fouling, reduced evaporation rate	Install redundant pumps, regular maintenance of valves and pumps, implement blockage detection systems	Moderate
Steam Flow Rate	More/Less	High/Low Flow	Control valve malfunction, steam supply issues	Energy wastage/increased operating costs, incomplete evaporation, reduced product yield	Install redundant steam control valves, monitor steam supply pressure, implement flow alarms	High
Temperature	More/Less	High/Low Temperature	Heat exchanger fouling, control system malfunction	Thermal degradation of NH4NO3, reduced evaporation rate, potential for hazardous byproducts	Regular cleaning of heat exchangers, implement temperature alarms and control systems	High
Pressure	More/Less	High/Low Pressure	Valve malfunction, pump failure, blockage	Equipment damage, reduced evaporation rate, potential for vaporization	Install pressure relief valves, pressure sensors, and alarms, regular maintenance of valves and pumps	High
Liquid Level	More/Less	High/Low Level	Feed flow rate fluctuations, pump malfunction	Flooding/drying of tubes, reduced heat transfer efficiency, potential for equipment damage	Install level sensors and alarms, implement level control systems	Moderate

CONCLUSION

The purpose of this thesis was to create an efficient and environmentally friendly method for treating process condensate containing hydrofluoric acid, ammonia, and ammonium nitrate. These are chemicals that are used in processes like phosphate fertilizer production and petroleum refining and are known to cause environmental and health hazards. The study was undertaken in order to respond to the inefficiencies of current treatment technologies that are usually unable to treat this particular mixture of pollutants economically and efficiently. Based on a literature review of the current research, the study established major issues relating to process condensate treatment and reviewed numerous physical, chemical, and biological treatment techniques. From the abovementioned analysis, a new integrated treatment process was recommended including steam stripping, ion exchange, neutralization, evaporation, and crystallization. The process was developed to achieve the highest level of clean-up of the process stream, to recover resources such as ammonia and to reduce the generation of waste. The process description and design were developed, identifying the main process units and their parameters. The efficiency and performance of the process was determined using mass and energy balances. HAZOP analysis was performed to highlight possible hazards and operational problems and possible solutions were discussed. Last but not the least, an economic consideration proved the technical feasibility of the proposed process and its capability to bestow enormous economic advantages to industries. Therefore, the proposed process condensate treatment system is a viable fix for issues arising from HF, NH3, and NH4NO3 presence in industrial wastewater. Nevertheless, more work is needed to fine-tune the method and investigate its potential to the fullest. Future research could therefore involve running laboratory scale experiments for the process to establish the feasibility of the process and optimize the operating conditions. Moreover, exploring the possibility of integrating other new technologies like AOPs, or membrane distillation can improve contaminants' removal as well. Other extensions of the process could also be useful, for example, the phosphorus or other valuable secondary product recovery from the process condensate. Lastly, a life cycle assessment to assess the environmental costs involved in the overall treatment process starting from raw material acquisition and ending with waste disposal would also be useful in determining the sustainability of the designed system. With these research gaps in mind, the proposed process condensate treatment system can be fine-tuned and scaled up for use in various industries and applications, which will help promote the sustainable and eco-friendly treatment of wastewater.

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