DEMINERALIZED WATER PRODUCTION SYSTEM FOR HIGH PRESSURE BOILERS

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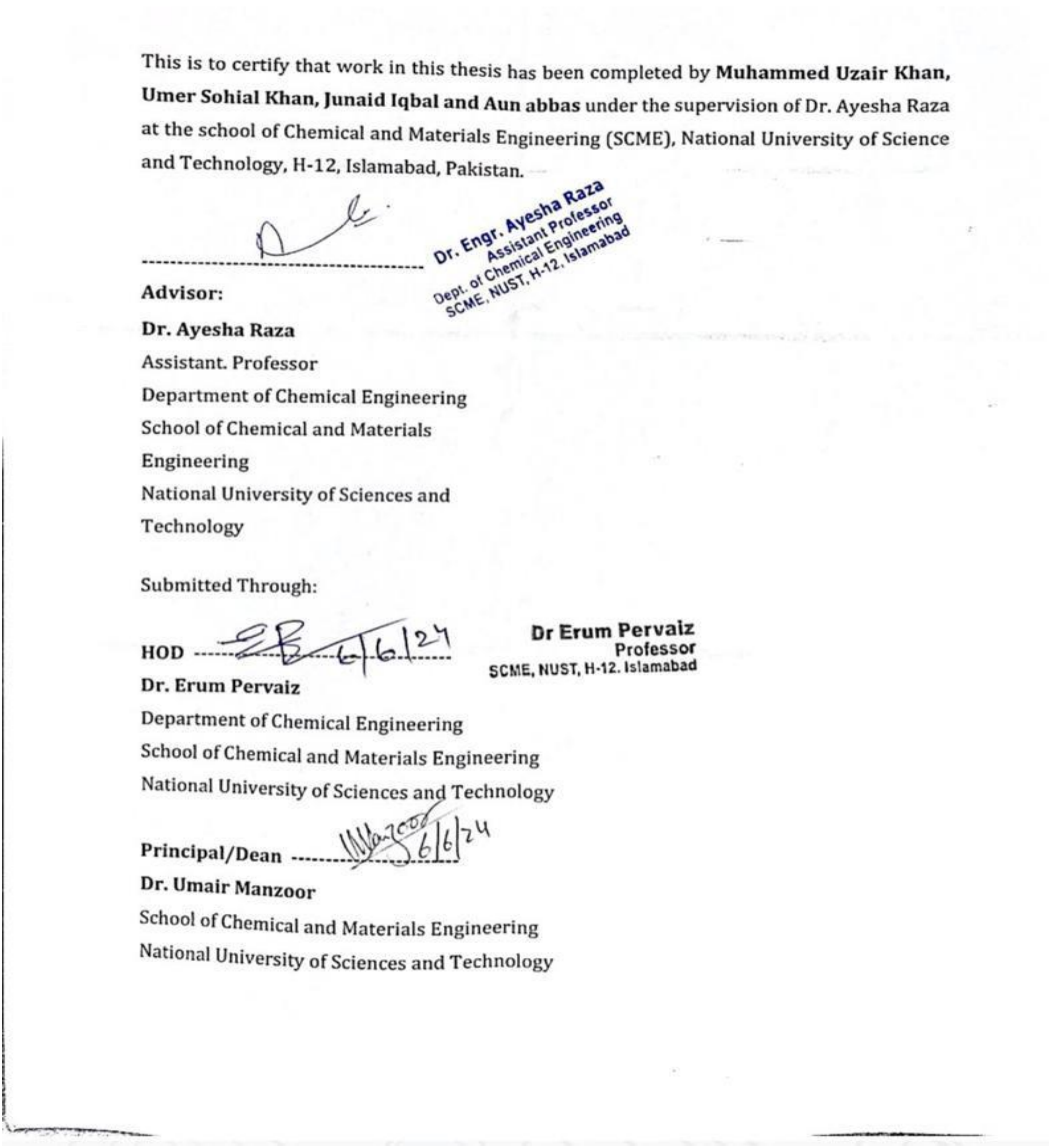

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DEDICATED

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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ABSTRACT

This thesis presents a comprehensive study on the production of demineralized water for high-pressure boilers, focusing on a comparative analysis of two predominant processes: In the purification process, two common methods include reverse osmosis, and ion exchange. A steam boiler operating at high pressures requires water of very high quality because hardness could lead to fouling and corrosion, so a good demineralization system is called for here. The research questions are geared towards determining performance of RO and IX processes in terms of cost, operational efficiency of the system and effectiveness in producing water that meets required quality needed for high pressure boiler applications.

The way of treatment of the research materials is to study general principles of operation, system configurations, and maintenance requirements for RO and IX processes. It involved performance analysis of activities such as ion removal efficiency, cost of operating the system, energy, and need for negative environmental impact. Random experiments together with pilot-scale testings as well as industrial tests were used to provide comparative information.

Thus, comparing both methods, it is evident that RO is indeed effective in achieving higher purity water as necessary for usage in high pressure boilers as compared to the IX process. From these observations, the RO process depicts the following advantages of higher cost efficiency than the IX process due to the following factors: In addition, RO systems are found to have lower operational as well as maintenance costs, and still result in minimal impact to the community.

Therefore, this thesis concludes that Reverse Osmosis in the production of demineralized water right for the high-pressure boiler industries as compared to the cost and sustainability of the method. The information derived from this research can be of great use to engineers and policymakers who have to make the right choice in the use of water treatment systems that best suit high-pressure boilers.

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CHAPTER 01

INTRODUCTION AND BACKGROUND

1.1 Introduction to Water Filteration

High-pressure boilers are some of the most important apparatuses used in different industries that may include generation of power, chemists, and food processing, among others. They are most used where temperatures and pressures are high, to generate steam for purposes of generation of power or for industrial use. For this reason, water applied in boilers in such environments requires better quality to support performance efficiency and safety. Deionized water also known as demin water, is water which has been treated to remove all the ion content from it, and it is very essential in high pressure boilers. Demineralized water can be described as water which has been treated through a process of demineralization to remove dissolved minerals, salts and impurities which are present in raw water and untreated water which are used in some industrial, food processing and household applications. The generation of demineralized water normally requires sound production of water that has undergone multiple treatment to meet high standard as per the warrant needed.

1.2. Importance of Demineralized Water In High-Pressure Boilers Systems

Prevention of Scale Formation: Some of the wide applications of demineralized water include when used as feed water in high pressure boilers to reduce the formation of scales. Also, if water containing dissolved minerals like calcium, magnesium and silica is used in the heating process and evaporated in boiler systems the molecules solidify and form deposits on the heat transfer surfaces. Scale Deposition results to Reduction of heat transfer, Increased energy, Reduced equipment life and possess time to equipment. This is true because water with low mineral content in this case doesn’t form scale which increases boiler efficiency as well as its reliability.

Corrosion Control: Another factor which can lead to corrosion of high-pressure boiler system is dissolved minerals and other impurities in water used in the formation of scales. Boiler corrosion is the process through which the metal surfaces of the boilers are attacked chemically by water and therefore lead to the deterioration in the efficiency of the boiler. Non mineralized water maintains low conductivity, minimal dissolved solids, and diminishes corrosiveness decreasing the abrasion on boiler equipment and piping.

Steam Purity: The feedwater utilization plays a paramount significance in ensuring that high elevations of the boiler system produce steam of high quality. Since water can pick up contaminants as it flows through the boiler and heats up to produce steam, the fed water brings impurities which has an adverse effect by causing corrosion and /or fouling to other parts of the system such as turbines and condenser. In general, demineralized water has the capability to lower impurities and contaminants contained within the boiler feedwater, therefore it also protects and optimizes the entire steam cycle.

Compliance with Regulations: This paper aims to establish the significance of boiler feedwater by highlighting that regulatory standards and guidelines prescribe the required water quality for boiler feedwater to promote operations' safety, environmental conservation, and public health safeguarding. Such kind of demineralized water production systems aims to fulfill these regulating strictures by preparing the water having the solubility limit, Conductivity, and dirt which assists the industries to follow the current standard and regulation.

In conclusion, while feed water should be free from mineral deposits, demineralized water can ought to be used for high pressure boiler because it prevents scale deposit, controls corrosion, maintains steam purity and meet the operational standards. The concept of demineralized water in boiler systems therefore plays a very crucial role in the health of industries where proper water treatment measures need to be taken to maintain boiler efficiency, avoid frequent breakdowns and minimize any mishap related to water supply.

1.3 Two Most Leading Processes Used To Produce Demineralized Water.

The preparing of demineralized water to be used in high-pressure boiler system, would most of the time involve the use of more sophisticated treatment process such as the Reverse Osmosis (RO) and the Ion exchange (IO). Each offers benefits and drawbacks, rendering them ideal for variety uses depending on the demands of water quality, how the system will function, and the ecosystem for each process.

1.4. Reverse Osmosis (RO):

Reverse osmosis is a computer aided water purification process, which employ a semi permeable membrane to filtrate dissolved solids, ions, and other contaminants from water. The working principle of RO is based on osmotic pressure where the purified water is forced through the membrane under the influence of high hydraulic pressure while the unwanted substances are held back and accumulate at one side in the process of formation of concentrate that are eventually discharged as waste products.

1.4.1. Advantages of RO Include:

High Efficiency: RO systems can offer significant rates of dissolved solids rejection and water purification, incorporating salts, minerals, and organic chemicals, to create high-quality water to feed boiler systems.

Compact Design: Conventional RO installations are compact and occupy less space than many other water treatment processes, which is advantageous in myriad installation environments.

Versatility: As depicted above, RO has the potential of treating diverse water sources such as surface water, ground water and brackish water, making the system especially useful in various feedwater calibre and qualities.

Energy Efficiency: Despite this, energy is needed to drive the high-pressure pumps necessary to counteract osmotic pressures in the operation of RO systems: the energy consumption however has been optimised with the continued improvement of membrane technology and system design.

1.4.2. Limitations of RO

Membrane Fouling: Phest alcohol also precursor RO membranes to fouling, scaling, and fouling as a result of suspended solid, organic matters and microorganisms in the feed water. Fouling is known to be able to damp system performance, increase the running expenses and in the end the membranes would require cleaning and replacement more often.

Limited Removal of Certain Ions: Here, RO is a remarkable technology, which efficiently separates most of dissolved solids however some ions may continue to permeate the membrane, especially when concentration is high, or water chemical conditions are unfavourable. This limitation could necessitate extra steps or even post treatment to realize the intended water quality parameters.

1.5. Ion Exchange (IO):

Ion exchange is a water treatment process that uses chemicals, the process entails the exchange of ions in water with ions found in the exchange material, more often ion exchange resins. They reduce the concentration of certain ions in water by a process which depends on the type of resin and the conditions under which it is operating.

1.5.1 Advantages of IO include:

Selective Ion Removal: IO systems provide fixed removal of ions that require selective action and include buildup of hardness ions (calcium and magnesium), silica, and heavy metals. This selective ion removal guarantees the generation of high-purity demineralized water, specific in types and qualities of feedwater for boilers.

Renderability: Cationic resins on the other hand can be regenerated via chemical regeneration processes like using acids, or caustic soda to bring it back to use level. This regeneration capability also lowers the amount of money spent in running the plant and helps in generation of less waste as contrasted to sole use elimination processes.

Robustness: IO systems are sound and effective to treat difficult raw water with elevated level of total dissolved solids, colour, taste and odour, and chemicals. They can work very well in response to feed water quality variation and its flow rate and does not affect the machines performance.

1.5.2. Limitations of RO

However, IO also has some limitations: However, IO also has some limitations:

Waste Generation: They produce waste brine during the regeneration process that is intensely contain the ions and other chemical removed from the feedwater. Disposal or treatment of waste brine are critical to avoid effects on environment, and to avoid legal cases against industries.

Operational Complexity: Turning to the operation of its IO systems, it is critical for a company to continually monitor and manage operational control variables including resin bed depth or thickness, flow rates, and the rates and cycles of regeneration. There are various sources of error in the operations and maintenance of these systems that result in resin deterioration, fouling, or deficient performance.

In conclusions, while the results demonstrate the typical applicability of both reverse osmosis (RO) and ion exchange (IO) processes for producing demineralized water for high-pressure boilers, both processes present their own merits and demerits of their use. The choice between RO and IO therefore about water quality requirements, the feed water quality, systems integration, and operations style and preferences. Although each process operates somewhat independently, industries should strive to match the fundamental principles of each process to improve water treatment and boiler outputs and reduce regulatory compliance issues.

1.6. The Critical Role of Ions, TSS, and TDS in Feed Water Quality for Boilers

It was found that the life of these industrial boilers and its efficiency increases to a large extent depending on the feed water composition. Three key parameters significantly impact boiler operation: ations are one on cations, other on anions, total dissolved solids (TDS), and total suspended solids (TSS). Studying this kind of behavior and the impact which it has in the functioning of the plants is highly recommended for reaching the maximum efficiency in the working of the boilers as well as for avoiding all the risks which this activity can bring.

The Ionic Landscape: It is time to focus on cations and anions While the most attention is paid to the interaction of an atom with molecules /particles/, the behavior of cations and anions in a nonpolar solvent is also attracting interest.

Feed water is a solution of dissolved inorganic salts also has ions which occur when the dissolves in water dissociates into charged particles. These ions fall into two categories:These ions fall into two categories:

Cations: Cations which are usually positively charged ions and the common ones are; Calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}), sodium ion (Na^{+}) and potassium ion (K^{+}). These two cations are considered as the most problematic because they are highly capable of scaling and corrosion in the boiler system when concentrated.

Anions: There are also the negative ions, for instance the chloride ions, (Cl^{-}), sulfate ions, (SO_4^{2-}), bicarbonate ions (HCO_3^{-}) and nitrate ions (NO_3^{-}). Whereas some ions, such as chloride ions, have little scaling effects, the others, particularly sulfate ions, are known to advance scaling in combination with certain cations.

The cation and anion concentration of the feed water can be regarded as the most crucial factor since they directly influence salinity levels. This salinity particularly influenced the characteristic ionic flow that occurred affecting the boilers.

Total Dissolved Solids (TDS): A Measure of dissolved impurities Sometimes in polymers processing a measure of dissolved impurities is critical in determining the characteristics of the final product. Depending on the type of polymer being processed and the final use of the product the level of dissolved impurities is critical in determining the final characteristics of the product.

It refers to the total dissolved solids in the solution, which consists of both inorganic and organic materials. Expressed in milligrams per litre (mg/L), it quantifies the total mass of all the ions in water, as well as other molecules that do not ionise and all organic species. Elevated TDS levels can lead to several detrimental effects:

Scaling: When temperatures increase in boilers and the concentrations of solution containing certain dissolved salts reach solubility limits, then those salts start depositing themselves in the form of scales on the surfaces of boiler tubes. This scale also restricts heat transfer, to affect boiler efficiency and fuel consumption.

Increased Viscosity: Boiler water TDS in high quantity can raise the viscosity of the fluid in the boiler. This makes the water in the HPHE thicker hence in need of more pumping energy is uneven and also this also affects the heat transfer rates.

Conductivity: Water which contain dissolved ions produces high electrical conductivity compared to water with low dissolve ions. Though not really damaging in some way, high conductivity can cause even higher rates of corrosion in some boilers.

Total Suspended Solids (TSS): The threat from undissolved particles There is a serious threat from undissolved particles that continue to be suspended in a solution or a solution mixture.

TSS stands for the total suspended solid which is a measure of the mass per unit volume of the suspended material in the feed water comprising sand, clay, silt, and organic matter. Measured in mg/L, high TSS levels pose distinct threats to boiler operation:Measured in mg/L, high TSS levels pose distinct threats to boiler operation:
Abrasion: Suspended particles are abrasive and therefore can easily wear out the inner parts of the boilers and other equipment such as the valves in the system to the extent of causing leaks.

Clogging: TSS can pose a problem to operation since it can block filters, feedwater lines, and heat exchange sections; hence impeding water circulation and affecting the boilers.

Biofouling: Organic particulate matter settling on the surface of the boiler system can offer appropriate anchorage for biomass growth, resulting in biofouling. For example, chemical and mechanical factors worsen scaling and corrosion problems, while biofilms can also pose a problem.

Even though TDS encompasses all dissolved content, the particular ions involved are the most critical in defining scaling and corrosion potentials. Thus, the impact of TDS on scale formation can be considered minimal if the TDS is not accompanied by specific cations and anions that intensify scaling even at moderate TDS levels. For example, calcium and sulfate ions have been identified to easily formulate forming hard and adherent scales.

On the other hand, TSS is unrelated to dissolved matters and is a factor related to a different set of operations. However, the elimination of TSS can influence TDS, although this is considered inasmuch as the particulate matter includes soluble minerals. For instance, any procedure that filters TSS may well filter TDS after realized that the removed particles held tangible amounts of dissolved salt.

When water enters the boiler, it is knows as feed water and its management plays a critical role in how the boiler performs.

Thus, the purposeful treatment of feed water by means of precise ICP, TSS and TDS control allows to perform the necessary operations by boiler operators and provide for the effective and reliable function. Here are some common treatment methods employed to address specific concerns:Here are some common treatment methods employed to address specific concerns:

Filtration: This filters out suspended solids (TSS) in the feed water thus preventing abrasion, fouling, and clogging of surfaces in or on water related equipments.

Demineralization: Technique such as ion exchange or reverse osmosis reduce dissolved ions in the feed water or scale forming potential of TDS because the majority of the dissolved ions are removed from the feed water.

Softening: A process essentially used to soften the water and the main focus is on scale forming ions such as calcium and magnesium. The beneficial effect of softening is that it reduces hard scale risks and also helps improve the efficiency of the boiler.

Therefore, it could be concluded that improperly balanced feed water composition containing ions, TSS and TDS may results into deteriorated boiler performance. Therefore it is believed that through keen observation of these parameters and ensuring they apply correct treatment options, the industrial facilities will enhance operation of the boilers, reduce down time resulting from mechanical breakdowns and prolong the general lifecycle of the critical plant machinery.

CHAPTER 02

OBJECTIVE OF RESEARCH

The generation of demineralized water for high-pressure boiler applications is an essential component of boiler designs and used in styles of top performing, long-lasting boiler systems in numerous industries. In this context, choice of the proper and suitable process for water treatment is a critical factor that defines the extent of final water quality as well as the reliability of operations and costs involved. Sometimes though, the choice can be intricate, as it requires the consideration of the conflicted criteria which include the treatment function rate, the system structure and strength, practical aspects, and possible effects on the environment.

The research problem addressed in this study revolves around the comparative analysis of two leading demineralized water production processes: Water purification methods that were considered include: basic water filtration; distillation; reverse osmosis (RO) and ion exchange (IO). Despite the benefits and drawbacks of each method noted above, the decision on the best strategy for use in any given situation hinges on certain parameters such as effectiveness, cost, and applicability in each water quality context. Furthermore, the research problem is embedded in the quest for factors determining the probability of RO over IO systems and practical solutions for stakeholders engaged in high-pressure boiler operation.

Primary Objectives

The primary objectives of this study are mentioned below:

- To Compare the Performance of RO and IO Processes: RO and IO system: This objective revolves around ascertaining the viability and reliability of IO and RO systems for demineralized water production to support high-pressure boiler services. Performance measures that would be deemed necessary include water quality characteristics, ability of the system in removing dissolved solids and contaminants, time availability of the system and the frequency of the system maintenance.

- To Assess the Economic Viability of RO and IO Systems: This objective seeks to identify the economic consequences that accustom with RO and IO processes in demineralised water production. Some of cost considerations include capital costs, operational costs, energy, and utilization costs, and maintenance costs and life cycle of the product. It is aimed at offering a basis for the audience to make a comprehensive cost-benefit analysis for the respective stakeholders.
- To Identify Factors Influencing the Selection Between RO and IO Systems: To achieve this objective the following details of knowledge should be pursued; The factors explaining the choice of the RO or the IO processes for generating demineralized water in high-pressure boiler applications. Some of the aspects that need to be analysed are water source type, water demand specifications for feedwater, the ability to control the system size, the other system's ability to be easily managed, and compliance with the existing legal norms.

CHAPTER 03

LITERATURE REVIEW

Such water plays an especially key role for high pressure boilers especially in power plants as well as in the various industries. The main purpose of high purity water is to reduce various problems such as the formation of scale, corrosion and other problems that affect the performance of the boilers and as well their life span. Some of the methods and technologies used to generate demineralized water includes Depending on the various methods and technologies, their effectiveness depends on the following recent development.

Ion exchange is one of the most popular techniques used for water softening where undesirable ions present in water is replaced by the preferred ones with the help of resins beads. Ions can be exchanged and successfully neutralized as elucidated by Helfrich (1995), which makes the process ideal for water purification where regeneration of high purity water is desired. Nevertheless, ion exchange systems are influenced with the impact of organic matters along with some varieties of fouling (Snoeyink & Jenkins, 1980). Another method widely used in the preparation of demineralized water is reverse osmosis (RO). RO technique employs the usage of a semi-permeable membrane that helps in the removal of ions, molecules as well as other exceptionally large particles in water. According to Baker (2012), some of the specific functions of RO system are that they are used to remove a variety of particulates and dissolved substances such as dissolved salts and organic matter. The advancement in membrane technology over the recent past has enabled increasing the efficiency and declining the operation cost of RO systems (Greenlee et al. , 2009).

EDI is a process that involves using ion exchange resin and electrical current to remove ions from water at an equal rate. Such as Hichour, et al in 2000, the authors also concluded the several important use of the EDI systems to produce almost 100% pure water in an environment friendly way as compared to other conventional techniques. EDI has proven to be one of the most proficient and eco-friendly techniques used in the removal of ions in the preparation of high purity water due to the feature of constant run or minimal end-use chemical regeneration (Krol et al. , 2014). Singh and Singh, 2013 has done a comparative study that recommended ion exchange is also used, but the RO has higher percent removal efficiency of many of the contaminants more than the ion exchange. Another method, ion exchange systems, costs less than methods such as RO; however, the quality of water they produce is not as good when the source water is of low contamination. As for the advantages – there are some non-negligible benefits: On the one hand, EDI implementation is much more expensive as compared to the paper-based system; on the other hand, the maintenance costs are lower and the wonderful news for the environment is also worth mentioning.

However, there are several disadvantages when using the demineralized water process: fouling of membranes and the resin bed can lower the efficiency of the process and increase the cost of maintenance services. Effective carrier pre-treatment through processes such as ultra-filtration and advanced oxidation processes (AOPs) have been observed to minimise fouling and prolong the useful life of demineralisation systems (Othman et al. , 2021). Furthermore, the application of advanced smart monitoring and control systems has been of significant value in streamlining the operations of demineralization plants. Using online sensors and other feedback controls, water quality parameters can be monitored in real-time, and thus adjusting the process conditions can help avoid fouling and minimize the need for chemicals and energy (Sharma, Zhu, and Ronen, 2024).

Concerning the sociological aspect, it would be relevant to focus on the effects of demineralization processes on the environment. Some other conventional approaches, which employ chemical regeneration, are often voluminous and can produce extensive waste materials together with chemicals. The traditional methods include Reverse Osmosis (RO) and Electrodialysis Inverse (EDI) for desalination, however, research done recently shows that a combination of the two systems will reduce wastages and energy usage with greater water purity (Chen et al. , 2018). They mention that the trends in demineralized water production are innovations in the membranes and ion exchange materials that help decrease fouling and improve the efficiency of the membranes as well as the ion exchange materials. There is also a need for the optimization of demineralization processes to improve the overall efficiency of water reuse while at the same time giving consideration to the environmental impact of the waste stream produced during these processes with research being carried on the recovery of these waste products (Yuan et al. , 2016).

To sum up, the present work deals with an elaboration of novel method for the preparation of demineralized water necessary for the supplying of high-pressure boilers in industrial and electric power production industries. Application of ion exchange, reverse osmosis, and electrode ionization technologies have given an improved form of demineralized water in terms of quality as well as cost. Regarding issues like fouling and the environment, using novel chemical treatments and efficient control procedures for further advancements in this area is critical. It is expected in future study and development to work more on improving the feasibility and worldwide applicability of demineralized water production systems.

CHAPTER 04

METHODOLOGY

Under this subheading, the overall strategy for comparative evaluation of the two processes, namely reverse osmosis (RO) and ion exchange (IO) for the production of demineralised water for high pressure boiler application have been clearly outlined. This subsection focuses on giving a detailed understanding of the practical techniques used in the course of the experiment and illustrating the systematic approaches to gather data and carry out of several analysis in order to determine the effectiveness, cost effectiveness, and profitability of RO and IO systems.

The experiment was designed with a view of having a structured approach for the experiment and thus the following process to follow the standard operating procedures and set the operational parameters for RO and IO systems for the experiment. These systems were set up to run in conditions within which the demineralization efficiency could be achieved to the best standards by accounting for aspects including the feed water, membrane health in the case of RO systems, and frequency of regeneration of the resins for the IO systems.

Data collection moved on systematically and entailed daily tracking of various performance indicators at various stages of the ongoing processes. Some of them include feed water quality, permeate quality, recovery rates, energy consumption, and chemicals required were monitored at least at daily bases in order to capture changes if any at different time intervals. Beside the current comparative research, this rígorous method helped not only real time changes, but offered also a solid base to build the future data for comparative analysis.

Concerning the assessment of RO and IO systems effectiveness, several analytical tools were used. Ion rejection rates, TDS rejection and specific ion concentrations of the permeate samples were measured given that they are useful indicators of the performance of the FO process. Quantitative performance measures also included, for example, metrics for RO membrane fouling and changes in IO resin bed structure, which were supported by qualitative methods for blog assessment of system operational dependability and maintenance needs.

Economic aspects such as capital costs, operating expenses, molded and chemical costs, and the life cycle analysis of RO and IO systems were compared. Cost considerate estimates included system lifetime, energy intensity, as well as the cost of compliance, enabling a financial comparison of each technology’s total cost and return on investment.

Therefore, this subsection provides a comprehensive and step-by-step account of the experimental setup and procedures used in the research to ensure objective, reliable, and accurate assessment and comparison of RO and IO systems for demineralized water production to meet high-pressure boilers’ needs. Applying the choice of practical methods, the systematic approach to data collection, and set of comprehensive analytical tools, the research goals are to identify the principal approaches, tools, and key factors for selecting the most suitable water treatment technology taking into consideration the performance, costs, and sustainability factors.

CHAPTER 05

DATA COLLECTION

Feed water quality and the quality of permeate produced were some of the measured parameters alongside signalling system features such as pressure, flow rates and temperature; energy used; and IO revivification chemicals used. Specifically, water samples were taken at the pre-treatment, post filtration and post reverse osmosis stages were taken using professionally rated sampling devices to analyse the quality of water in terms of dissolved solids, ions, and other impurities.

5.1 Analysis Techniques:

The analysis of RO and IO systems encompassed several key aspects, including:

Water Quality Analysis: Conducting water quality analysis to assess the removal efficiency of dissolved solids, ions, and contaminants by RO and IO processes. This involved comparing feedwater and permeate samples to evaluate treatment performance and compliance with boiler feedwater standards. Carrying out the study of water quality to determine the suitability of RO & IO using the effectiveness of dissolved solids, ions & other substituent and contaminant of water. This specific research entails a comprehensive collection and analysis of feedwater and permeate from the two stages of the treatment process. The intent with such samples is to compare which out of the treatments is most effective in the process of relative reduction of impurities. This analysis is important as a device to guarantee that the treated water has the standards suitable for boiler feed water. The TDS and specific ions like calcium, magnesium, sodium, chloride and sulfate are measured and more potential pollutants are also estimated. Therefore, the obtained outcomes facilitate the analysis of the impact of the operating conditions on the performance and, consequently, on the efficiency of RO and IO systems, as well as the enhancement of the methodology of optimizing the water treatment process and meeting the requirements for the quality of the feedwater used for boilers.

The desired levels of various water compositions depend on the intended use of the water (e.g., drinking water, industrial processes, irrigation, etc.). Here are some typical standards and guidelines for different types of water use:

Industrial Water Standards

Standards vary greatly depending on the specific industrial application. Here are some general guidelines for boiler feedwater and cooling water:

Boiler Feedwater

pH: 8.5 - 9.5 (for medium-pressure boilers)

Conductivity: < 10 µS/cm

Hardness: 0 mg/L (as $CaCO_3$)

Silica (SiO_2): < 0.02 mg/L

Iron (Fe): < 0.1 mg/L

Copper (Cu): < 0.01 mg/L

Dissolved Oxygen (DO): < 0.007 mg/L

CHAPTER 06

PROCESS DESCRIPTION

6.1. Ion Exchange Process Description

Feed water treatment by ion exchange is a complex process, which requires several steps and specific devices to facilitate the procedure of elimination of ions and obtaining pure water. Then the treatment process involves the clarifier through which the water to undergo treatment is filtered in order to remove suspended solid particles. This is the stage where substances that cause coagulation are introduced into the water to combine the fine particles in to a bottle which will sink at the bottom and form what is known as sludge. The water that has been treated and has thus reduced turbidity, flows over the top of the clarifier, overflows for additional treatment.

Subsequently, the water is passed through sand filters With this clarification, it is then passed through sand filters. These filters are used to trap any solids and fine particles that might be left behind in the process since at this point clarified water is almost free of suspended solids. The water is then pumped through a layer of sand and gravel in the filters in this case the dirt may be deposited hence getting water with low turbancy.

Pumps have a very crucial role to play in the ion exchange system since they provide the means for moving the water from one stage to the next and, therefore, ensures that the water moves through the treatment system at the proper pressure. These pumps are particularly significant to ensure that constant rates of flow and pressure are maintained to support the effectiveness of the subsequent ion exchange units.

It then flows to the cation exchangers where calcium, magnesium and sodium ions are ions which are positive and are get rid of from the water. These ions are exchanged with hydrogen ions by cation exchange resin which takes place in the next process. In the context of these processes, this exchange process helps to soften the water in preparation for the next steps.

Afterwards, there is the flow of water in to the anion exchangers The flow of water in to the anion exchangers They encompass processes like; anion exchange that involves the removal of negatively charged ions like chloride, sulfate, and nitrate and replaced with hydroxide ions from the anion exchange resin. This step is vital for the reduction of dissolved inorganic load and attainment of water richness in lower ion content.

But before passing through a degasifier to eliminate dissolved gases including carbon dioxide, the water is treated at this stage. These gases are normally removed by a process known as degasification using a vacuum and air stripping in order that these gases do not intrude with the process of ion exchange and to improve the quality of the treated water.

The last step of water purification leaves it to the mixed bed exchanger for polishing. It combines both cation and anion exchange resins within this unit so that there is an overall pessimion as it aims to rid water with any more ionic materials. The mixed bed exchanger helps to fulfill efficient and high quality of pure water that fits the specific usages.

Yet, let us briefly discuss the ion exchange process, which is initiated by clarification in order to remove such big particles of solid and then followed by the sand filtration to eliminate finer particles. Pumps then aid in moving and pressurizing the water through cation and anion exchangers through which positive and negative ions such as sodium, chloride, nitrate and sulfate are removed and replaced by hydrogen and hydroxide ions respectively. A degasifier is employed for demineralized water to remove dissolved gases and the final touch-up is done by a mixed bed exchanger. Therefore, with the several stations and the tools used in the process, the feed water undergoes several stages to meet the required standard quality before entering the steam generating section.

6.2 Reverse Osmosis Process Description

Feed water treatment under reverse osmosis system includes several vital phases and apparatus to eliminate undesirable particles and to generate deionized water efficiently. We start with the storage tank which is a tank that holds the raw feed water in store 1. This tank maintains a constant and adequate feed flow for the subsequent stages of treatment process. This raw water that is stored here can be sourced from several categories, such as; river water, well water or municipal water.

Subsequent to passing through the water, it goes to the clarifier which plays a critical role in addressing the issue of turbidity through removal of solids in solution. This is the stage where coagulants (Al2SO4) are introduced into water to form bigger flocs in order to eliminate fine particles. The initial solid components of these flocs settle at the bottom of the clarifier forming sludge while the top region isOverflow Creek, which is now relatively clear water, is collected to undergo other processes in the treatment plant.

In order to exclude the sand, silt and other contaminants, the water is first passed through the sand filters after clarification. These filters are designed to hold any residual suspended solid and fine particles that might still be in the liquor after passing through the clarifier. Another advantage of the filters is the ability to pull out, as the water percolates through the layers of sand and gravel, particulate matter that causes high levels of turbidity, thereby producing water that is ready for use in the subsequent process.

To achieve this, pumps assist in the transport of water from one stage to the other, and offer the pressure needed for the RO system. The most important application within the RO stage is again high-pressure pumps which encourage the pressure of the purified water to a level that can overcome osmotic pressure to force water molecules through the RO membranes.

The central element within the process is referred to as the reverse osmosis unit, commonly abbreviated to RO. This unit is another one that is comprised of membranes fully or partially permeable to let out dissolved salts and organic molecules as well as other impurities present in the water. At high pressure, while permeating the membranes, water molecules' passed through leaving dissolved salts and impurities to be concentrated in the brine (reject) stream. The remaining is permeate, the water with low concentrations of minerals and solutes that emerge through the membranes for some uses. It is normally discharged or sent to a further treatment depending on the requirements of the set qualities of the environment in line with the regulatory policies for the systems used in the facility.

In conclusion, the steps of the reverse osmosis process include: pre-treatment, which involves storing raw water in the storage tank; sedimentation to remove large solid particles from the raw water; sand filtering in order to remove even the finer particles within the water; and high-pressure pumping in order to push the water through the membranes of the reverse osmosis system. The above steps together make it sure that the feed water is treated properly to produce permeate water of high purity suitable for several applications. This integrated plan underscores the significance of all outlined steps and components of equipment in attaining the accomplished water quality benchmarks. To achieve this, pumps assist in the transport of water from one stage to the other, and offer the pressure needed for the RO system. The most important application within the RO stage is again high-pressure pumps which encourage the pressure of the purified water to a level that can overcome osmotic pressure to force water molecules through the RO membranes.

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CHAPTER 07

MATERIAL BALANCE

Performing material balance calculations to quantify mass flows, recoveries, and rejection rates across the treatment system. Material balance analysis helped assess the overall mass transfer efficiency and utilization of treatment media (membranes or resins) in RO and IO processes.

To do the material balance we'll use the general material balance equation:

7.1 Equation For Mass Balance:

$$\text{In} = \text{Out} - \text{Generation} + \text{Consumption} + \text{Accumulation}$$

7.2 Assumptions and Basis:

- Feed Flow Rate: 100 L/hr or 100 kg/hr water (density assumed to be 1 kg/L)
- Feed Water Composition assumed to be same as that available in FFC Goth Machhi Plant
- Concentrations of components are taken in $\text{mg/L}_{\text{feed}}$
- Efficiencies of equipment are taken from research papers and existing thesis

Since, we had a comparative analysis we'll perform material balance on each equipment once. Begining with the clarifier till RO.

7.3 Material Balance on Clarifier

As we can observe in the stream analysis diagram of Clarifier, we have multiple streams telling different observance about the composition of clarifier.

- Stream 1: Ground water to clarifier
- Stream 2: Clarified Water
- Stream 3: Sludge Waste

Clarifier Efficiency: 80%

Al_2SO_4 is added as a flocculant to improve clarification.

Components removed:

- Carbonates
- Suspended Solids
- SiO_2

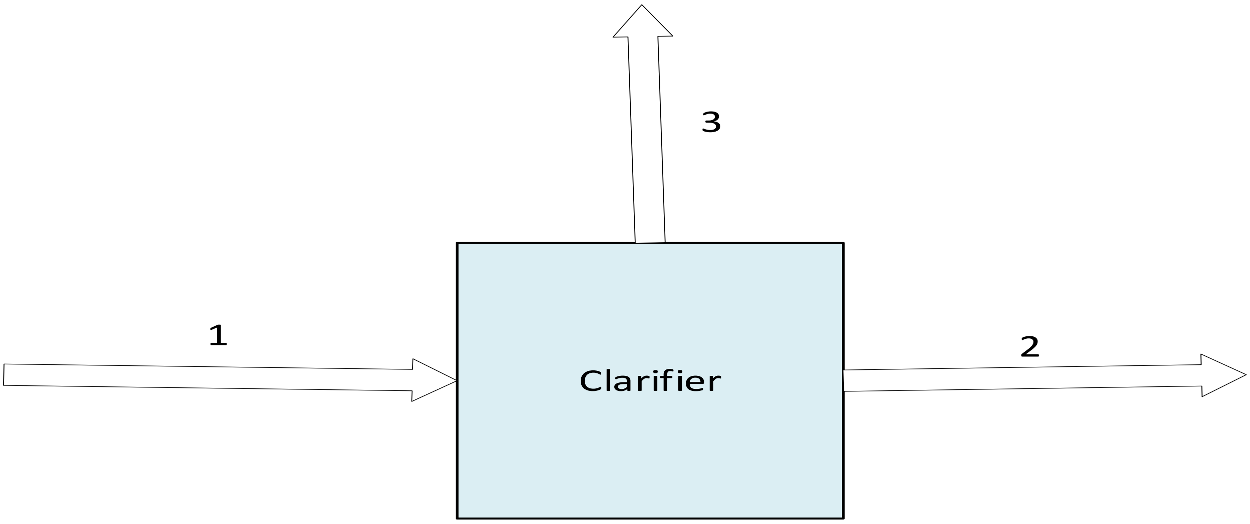


Figure 7.4.1 Stream analysis on clarifier

Below is a table giving all the material balance applied to clarifier, and hence giving the values of components in and componets out along with concentration and flow rate.

Table 1 Material Balance on clarifier

Clarifier				
Component	**In**		**Out**	
	Conc (mg/L)	**Flow rate (kg/hr)**	**Conc (mg/L)**	**Flow rate (kg/hr)**
Calcium	116	11.6	116	11.6
Magnesium	90	9	90	9
Chlorides	47	4.7	47	4.7
Nitrates	3.8	0.38	3.8	0.38
Sulphates	100	10	115	11.5
Carbonates	330	33	66	6.6
Iron	0.8	0.08	0.8	0.08
Turbidity SiO_2	25	2.5	5	0.5
TSS	46	4.6	9.2	0.92
Total Hardness (TH)	660.272		660.272	
TDS	712.6		443.6	
Conductivity	1063.6		662.1	
	Total Ions	75.86	**Total Ions**	45.28

Moving on we have sand filter and well perform material balance on sand filter.

7.4 Material Balance on Sand Filter

Stream 2 4 5 6 7 are streams for a sand filter each of them have. In the water treatment process, Stream 2 provides clarified water, while Stream 4 delivers filtered water from Stage 1. Stream 5 handles removed residue from Stage 1, ensuring the elimination of suspended solids and silica dioxide (SiO2). Moving to Stage 2, Stream 6 supplies filtered water, complemented by Stream 7, which manages removed residue from Stage 2. The sand filter exhibits a notable efficiency of 90% in removing contaminants, underscoring its critical role in maintaining water quality standards.

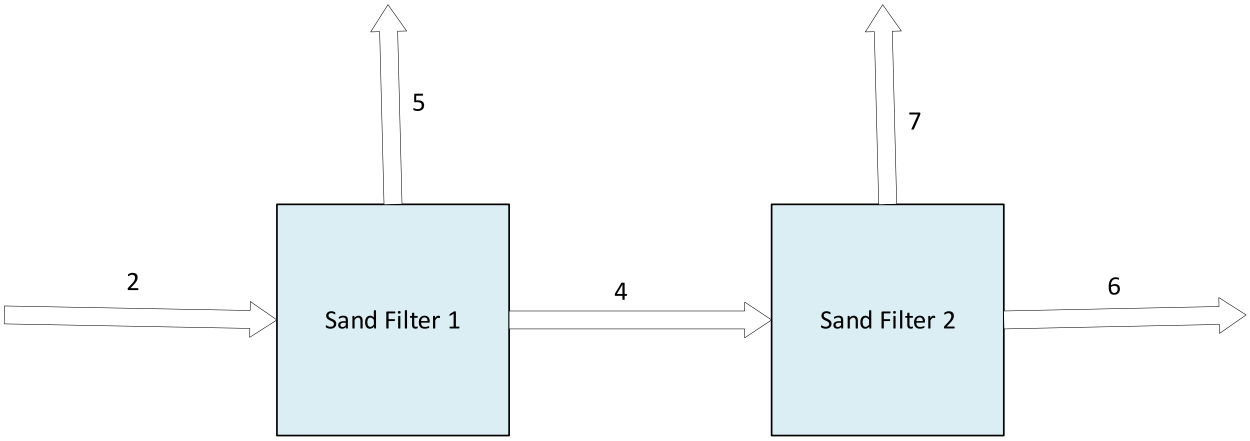


Figure 7.4.2 stream tracing on sand filters

- Stream 2: Clarified Water
- Stream 4: Filtered Water Stage 1
- Stream 5: Removed Residue Stage 1
- Stream 6: Filtered Water Stage 2
- Stream 7: Removed Residue Stage 2

Sand Filter Efficiency: 90%

Components removed:

- Suspended Solids
- SiO_2

Below we have a table which shows in and out along with concn. And flow rate on sand filter.

Table 2 Material Balance on sand filters

Sand Filters						
Component	**In**		**Out (Filter 1)**		**Out (Filter 2)**	
	Conc (mg/L)	**Flow rate (kg/hr)**	**Conc (mg/L)**	**Flow rate (kg/hr)**	**Conc (mg/L)**	**Flow rate (kg/hr)**

Calcium	116	11.6	116	11.6	116	11.6
Magnesium	90	9	90	9	90	9
Chlorides	47	4.7	47	4.7	47	4.7
Nitrates	3.8	0.38	3.8	0.38	3.8	0.38
Sulphates	115	11.5	115	11.5	115	11.5
Carbonates	66	6.6	66	6.6	66	6.6
Iron	0.8	0.08	0.8	0.08	0.8	0.08
Turbidity SiO_2	5	0.5	0.5	0.05	0.05	0.005
TSS	9.2	0.92	0.92	0.092	0.092	0.0092
Total Hardness (TH)	660.272		660.272		660.272	
TDS	443.6		439.1		438.65	
Conductivity	662		655		655	
	Total Ions	45.28	**Total Ions**	44.002	**Total Ions**	43.8742

The sand filters play a crucial role in reducing turbidity and total suspended solids (TSS) in the water treatment process. Initially, the water has a turbidity (SiO2) of 5 mg/L and TSS of 9.2 mg/L. After passing through Filter 1, these values are significantly reduced to 0.5 mg/L for turbidity and 0.92 mg/L for TSS. The efficiency continues with Filter 2, bringing turbidity down further to 0.05 mg/L and TSS to 0.092 mg/L. The total dissolved solids (TDS) also see a slight reduction, from an initial 443.6 mg/L to 439.1 mg/L after Filter 1 and 438.65 mg/L after Filter 2. Additionally, the total ion concentration decreases from 45.28 mg/L initially to 44.002 mg/L after Filter 1, and then to 43.8742 mg/L after Filter 2. While other components like calcium, magnesium, chlorides, nitrates, sulphates, carbonates, and iron remain unchanged, the overall reduction in turbidity, TSS, and ion concentration demonstrates the effectiveness of the sand filters in improving water quality.

Moving on we have ion exchanger and we apply material balance on ion exchanger.

7.5 Material Balance on Ion Exchanger

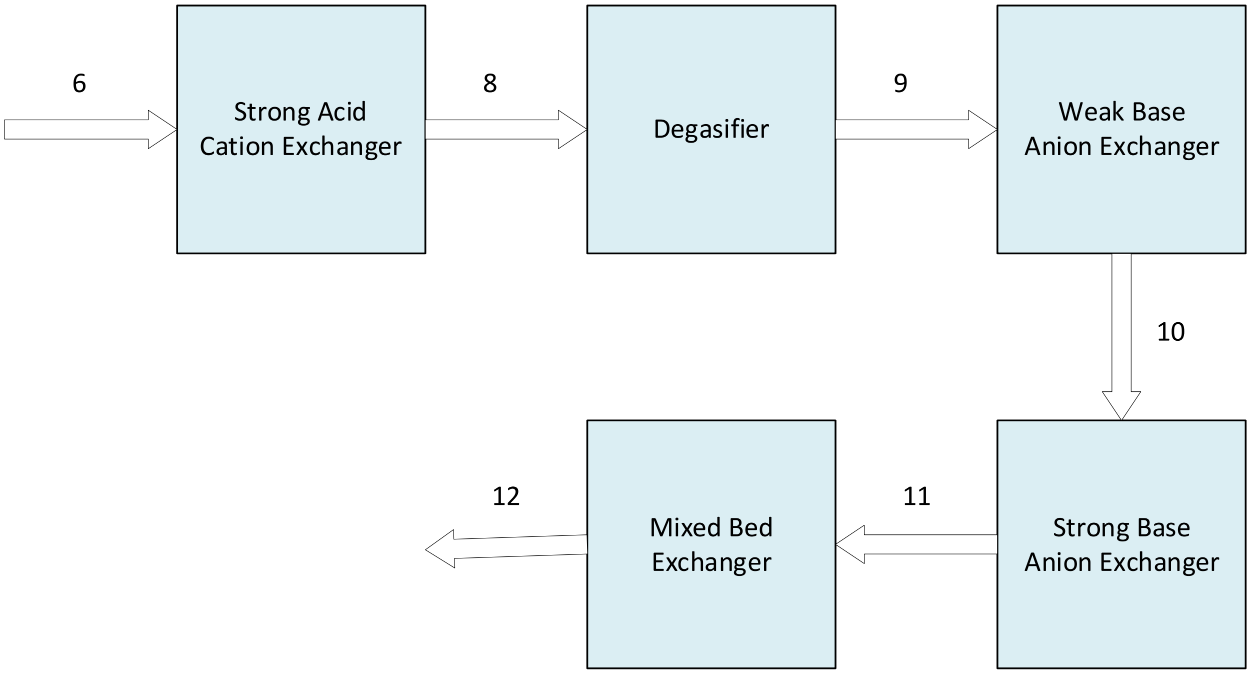


Figure 7.4.3

Given below are the streams of IX:

- Stream 6: Filtered Water
- Stream 8: SAC Outlet
- Stream 9: Degasified Water
- Stream 10: WBA Outlet
- Stream 11: SBA Outlet
- Stream 12: Demineralized Water

Efficiencies of Different Exchangers installed

- Efficiency of SAC: 98%
- Efficiency of Degasifier: 95%
- Efficiency of WBA: 90%
- Efficiency of SBA: 90%
- Efficiency of MB: 98%

Components removed in SAC:

- Calcium
- Magnesium
- Iron

Components removed in Degasifier:

- Bicarbonate

Components removed in WBA:

- Chloride
- Nitrate
- Sulphate

Components removed in SBA:

- Chloride
- Nitrate
- Sulphate
- Bicarbonate

Components removed in MB:

- Calcium
- Magnesium
- Chloride
- Nitrate
- Sulphate
- Bicarbonate

- Iron

The water treatment process involves several stages to remove various components and achieve high-quality water. In the cation exchange resins regeneration section, commonly known as the Strong Acid Cation (SAC) unit, calcium, magnesium, and iron are efficiently eliminated. This step is crucial for preventing scale formation and corrosion in subsequent operations. The degasifier then plays a vital role in removing bicarbonates, which reduces the alkalinity of the water and further minimizes scale formation.

Following this, the Weak Base Anion (WBA) unit effectively removes soluble chloride, nitrate, and sulfate ions. This step is important for reducing the corrosive properties of water and ensuring it meets environmental discharge standards. The Strong Base Anion (SBA) unit provides an additional level of purification by targeting the removal of chloride, nitrate, sulfate, and bicarbonate ions, further minimizing the ionic load in the water.

Finally, the Mixed Bed (MB) unit offers extensive purification. This unit removes a comprehensive range of ions, including calcium, magnesium, chloride, nitrate, sulfate, bicarbonate, and iron, ensuring that the water meets the rigorous standards required for various industrial applications. The MB unit's ability to eliminate these components ensures that the water is of the highest quality, suitable for even the most demanding uses.

The accompanying figure illustrates the changes in concentration of each component throughout the treatment process, along with the flow rates at each phase. This detailed material balance on the ion exchangers provides a clear understanding of the efficiency of the treatment process. By highlighting the removal efficiency at each stage, the figure helps to comprehend how each unit contributes to the overall water purification, ensuring that the final output meets the desired quality standards for industrial applications. This systematic approach ensures that the treated water is free from harmful contaminants, scale-forming substances, and corrosive ions, making it suitable for various high-quality industrial uses.

Table 3 Material Balance on Ion Exchanger

Ion Exchanger						
Component	**In**		**Strong Acid Cation Exchanger**		**Degasifier**	
	Conc (mg/L)	**Flow rate (kg/hr)**	**Conc (mg/L)**	**Flow rate (kg/hr)**	**Conc (mg/L)**	**Flow rate (kg/hr)**
Calcium	116	11.6	2.32	0.232	2.32	0.232
Magnesium	90	9	1.8	0.18	1.8	0.18
Chlorides	47	4.7	47	4.7	47	4.7
Nitrates	3.8	0.38	3.8	0.38	3.8	0.38
Sulphates	115	11.5	115	11.5	115	11.5
Carbonates	66	6.6	66	6.6	3.3	0.33
Iron	0.8	0.08	0.016	0.0016	0.016	0.0016
Turbidity SiO$_2$	0.05	0.005	0.05	0.005	0.05	0.005
TSS	0.092	0.0092	0.092	0.0092	0.092	0.0092
Total Hardness (TH)	660.272		13.20544		13.20544	
TDS	438.65		235.986		173.286	
Conductivity	655		352		259	
	Total Ions	43.8742	**Total Ions**	23.6078	**Total Ions**	17.3378

Below we have material balance on a degasifier, result obtained are in a table form.

Table 4 Material Balance on Degasifier

Component	Degasifier	Weak Base Anion Exchanger	Strong Base Anion Exchanger	Mixed Bed Exchanger
Calcium	2.32 (0.232)	2.32 (0.232)	2.32 (0.232)	0.0464 (0.00464)
Magnesium	1.8 (0.18)	1.8 (0.18)	1.8 (0.18)	0.036 (0.0036)
Chlorides	47 (4.7)	3.76 (0.376)	0.3008 (0.03008)	0.006016 (0.0006016)
Nitrates	3.8 (0.38)	0.304 (0.0304)	0.02432 (0.002432)	0.0004864 (0.00004864)
Sulphates	115 (11.5)	9.2 (0.92)	0.736 (0.0736)	0.01472 (0.001472)
Carbonates	3.3 (0.33)	3.3 (0.33)	0.264 (0.0264)	0.00528 (0.000528)
Iron	0.016	0.016 (0.0016)	0.016 (0.0016)	0.00032 (3.2E-05)
Turbidity SiO2	0.05	0.05 (0.005)	0.05 (0.005)	0.05 (0.005)
TSS	0.092	0.092 (0.0092)	0.092 (0.0092)	0.092 (0.0092)
Total Hardness (TH)	13.20544	13.20544	13.20544	0.2641088
TDS	173.286	20.75	5.51112	0.1592224
Conductivity	258.6358209	31	8.225552239	0.23765
Total Ions	17.3378	2.0842	0.560312	0.02512224

The table shows concentrations (mg/L) and flow rates (kg/hr) of various components through stages: Degasifier, Weak Base Anion Exchanger, Strong Base Anion Exchanger, and Mixed Bed Exchanger. It highlights significant reductions in calcium, magnesium, chlorides, nitrates, sulphates, carbonates, iron, turbidity, TSS, total hardness, TDS, conductivity, and total ions across the treatment process.

Now we move on to material balance on Reverse Osmosis.

7.7 Material Balance on Reverse Osmosis

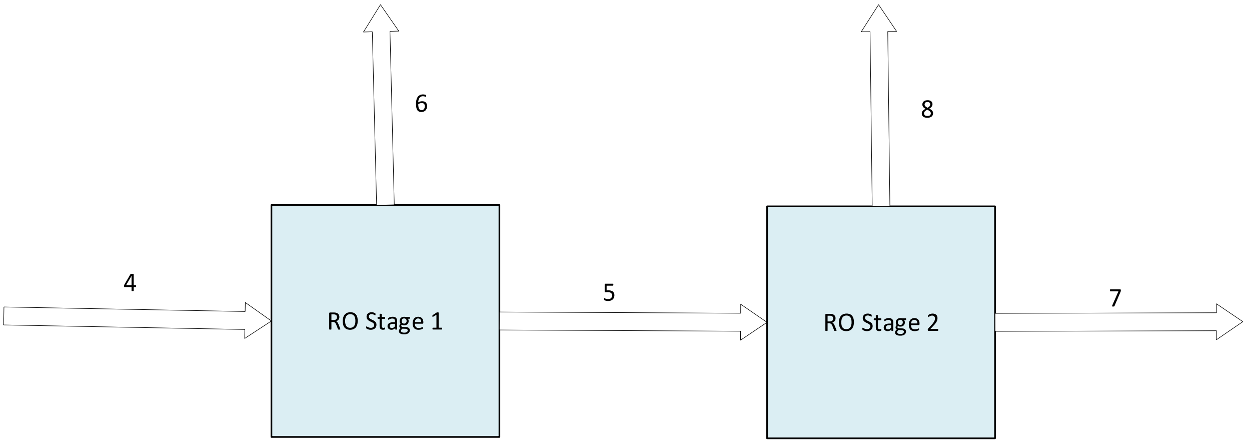


Figure 1 RO diagram

Below are all the streams of both RO, RO1 and RO2

- Stream 4: Filtered Water
- Stream 5: RO Stage 1 Permeate
- Stream 6: RO Stage 1 Concentrate
- Stream 7: RO Stage 2 Permeate
- Stream 8: RO Stage 2 Concentrate

All components have different rejection rates as given below in the table.

In Reverse Osmosis, initial concentrations (mg/L) and flow rates (kg/hr) are compared with percentage rejections and final permeate concentrations (mg/L) at Stage 1 and Stage 2. The process demonstrates substantial reductions in calcium, magnesium, chlorides, nitrates, sulphates, carbonates, iron, turbidity, TSS, total hardness, TDS, conductivity, and total ions. These figures underscore the efficiency of RO in water treatment, achieving rejection rates such as 98% for calcium and magnesium, 95% for chlorides, and maintaining stringent purity standards in the permeate with minimal concentrations like 0.0464 mg/L for calcium and 0.00092 mg/L for TSS in Stage 2 permeate.

Table 5 Material Balance on RO

Reverse Osmosis							
Component	**In**		**% Rejection**	**Stage 1 (Permeate)**		**Stage 2 (Permeate)**	
	Conc (mg/L)	**Flow rate (kg/hr)**		**Conc (mg/L)**	**Flow rate (kg/hr)**	**Conc (mg/L)**	**Flow rate (kg/hr)**
Calcium	116	11.6	98%	2.32	0.232	0.0464	0.00464
Magnesium	90	9	99%	0.9	0.09	0.009	0.0009
Chlorides	47	4.7	95%	2.35	0.235	0.1175	0.01175
Nitrates	3.8	0.38	96%	0.152	0.0152	0.00608	0.000608
Sulphates	115	11.5	99%	1.15	0.115	0.0115	0.00115
Carbonates	66	6.6	97%	1.98	0.198	0.0594	0.00594
Iron	0.8	0.08	97%	0.024	0.0024	0.00072	7.2E-05
Turbidity SiO_2	0.5	0.05	85%	0.075	0.0075	0.01125	0.001125
TSS	0.92	0.092	90%	0.092	0.0092	0.0092	0.00092
Total Hardness (TH)	660.272			9.49924		0.1529228	
TDS	439.1			8.951		0.26185	
Conductivity	655			13		0.391	
	Total Ions	**44.002**		**Total Ions**	**0.9043**	**Total Ions**	**0.027105**

7.8 RO Material Balance

Table 6 Obtained Values from RO

	In	**Out**
TDS ppm	712.6	0.262

TSS ppm	46	0.0092
Hardness ppm	660.272	0.153
Conductivity µs/cm	1064	0.4

7.9 IX Material Balance

Table 7 Obtained Values from IX

	In	**Out**
TDS ppm	712.6	0.159
TSS ppm	46	0.092
Hardness ppm	660.272	0.264
Conductivity µs/cm	1064	0.2

This concludes our material balance analysis on ion exchange (IO) and reverse osmosis (RO) processes. Through comprehensive testing and comparison, we have determined that both IO and RO are equally reliable in removing total dissolved solids (TDS), total suspended solids (TSS), turbidity, and other contaminants. Both processes effectively reduce these parameters to acceptable levels, ensuring water quality meets the required standards. The consistent performance of IO and RO in maintaining low concentrations of impurities demonstrates their suitability for various applications, including boiler feedwater preparation and other industrial uses. Overall, our findings confirm the efficiency and reliability of both treatment methods.

CHAPTER 08

ENERGY BALANCE

Conducting energy balance calculations to estimate energy consumption for RO system operation, including power requirements for high-pressure pumps, membrane feed pumps, and ancillary equipment. Energy balance analysis provided insights into the energy efficiency and operational costs associated with RO treatment. Further we'll break down the energy balance separately and perform calculations on each:

8.1 Ion Exchange Method Energy Balance

Raw Water Pump:

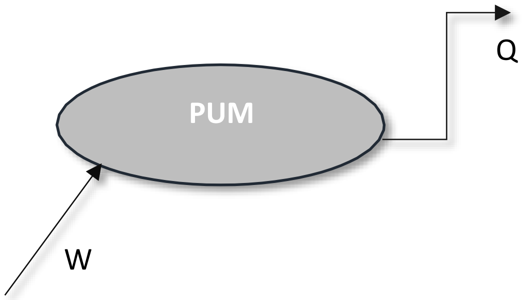


Figure 2 Energy Diagram

Overall relation for energy balance is given as

$\Delta \boldsymbol{H} = \boldsymbol{Q} + \boldsymbol{W}$

Thus, above relation is modified as follow:

$\eta \boldsymbol{P} = \boldsymbol{Volumetric\ flowrate} * (\boldsymbol{P}_2 - \boldsymbol{P}_1)$

Where

V'=volumetric flow rate of water= 100m^3/hr

Cp= specific heat of water= 4.18KJ/K-Kg

ΔP= difference in pressure of inlet and outlet streams= (202.6-101.3)kpa

η=efficiency of pump=75% (assumed to be isentropic)

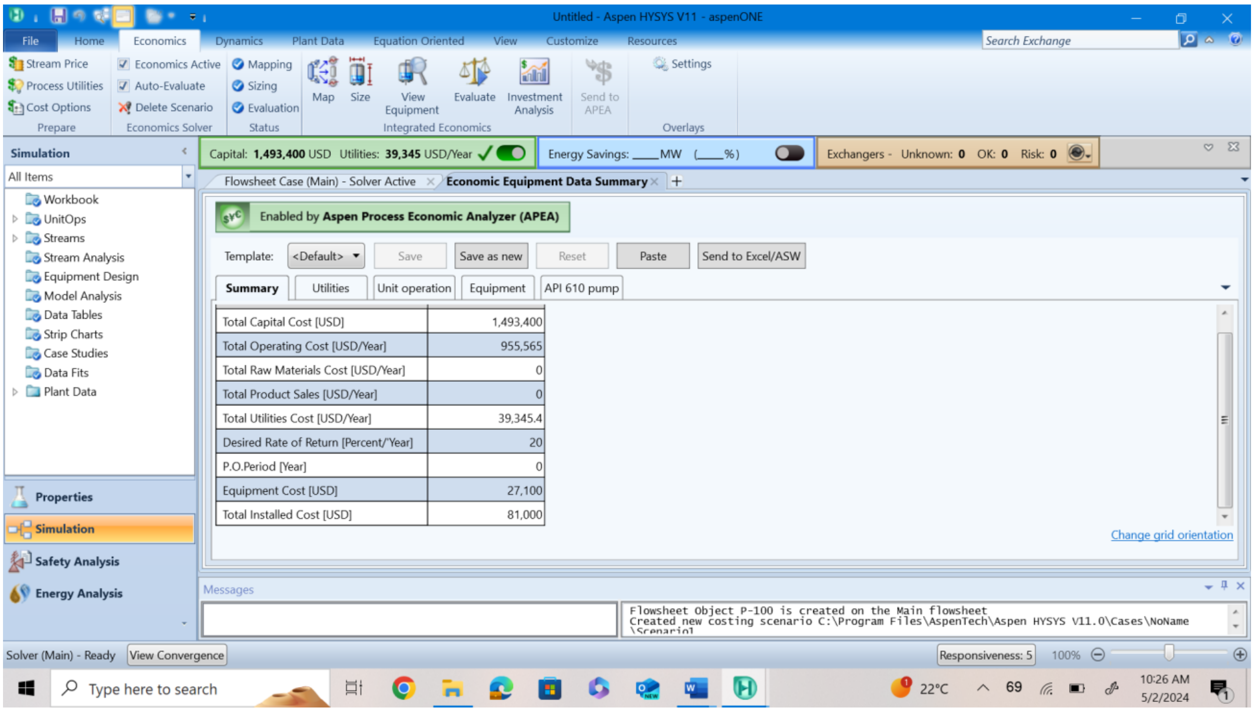
Substituting values in the given relation,

$0.75P = 100\text{m}^3/\text{hr} * (202.6 - 101.3)\text{kpa}$

$$\boldsymbol{P} = 3.725 \text{ KW}$$

$$\boldsymbol{DUTY} = \boldsymbol{P} = 3.725 \text{ KW}$$

Cost = $27,100



Capital: 1,493,400 USD Utilities: 39,345 USD/Year

Energy Savings: ____MW (____%)

Exchangers - Unknown: 0 OK: 0 Risk: 0

Total Capital Cost [USD]	1,493,400
Total Operating Cost [USD/Year]	955,565
Total Raw Materials Cost [USD/Year]	0
Total Product Sales [USD/Year]	0
Total Utilities Cost [USD/Year]	39,345.4
Desired Rate of Return [Percent/'Year]	20
P.O.Period [Year]	0
Equipment Cost [USD]	27,100
Total Installed Cost [USD]	81,000

```
Flowsheet Object P-100 is created on the Main flowsheet
Created new costing scenario C:\Program Files\AspenTech\Aspen HYSYS V11.0\Cases\NoName
\Scenario1
```

Figure 3 Installation cost on aspen hysys

Filter Feed Pump:

Filter Feed Pump:

$$\boldsymbol{\eta P = Volumetric\ flowrate * (P_2 - P_1)}$$

Where

V'=volumetric flow rate of water= 100m^3/hr

Cp= specific heat of water= 4.18KJ/K-Kg

ΔP= difference in pressure of inlet and outlet streams= (392.27-101.3)kpa

η= efficiency of pump=75% (assumed to be isentropic)

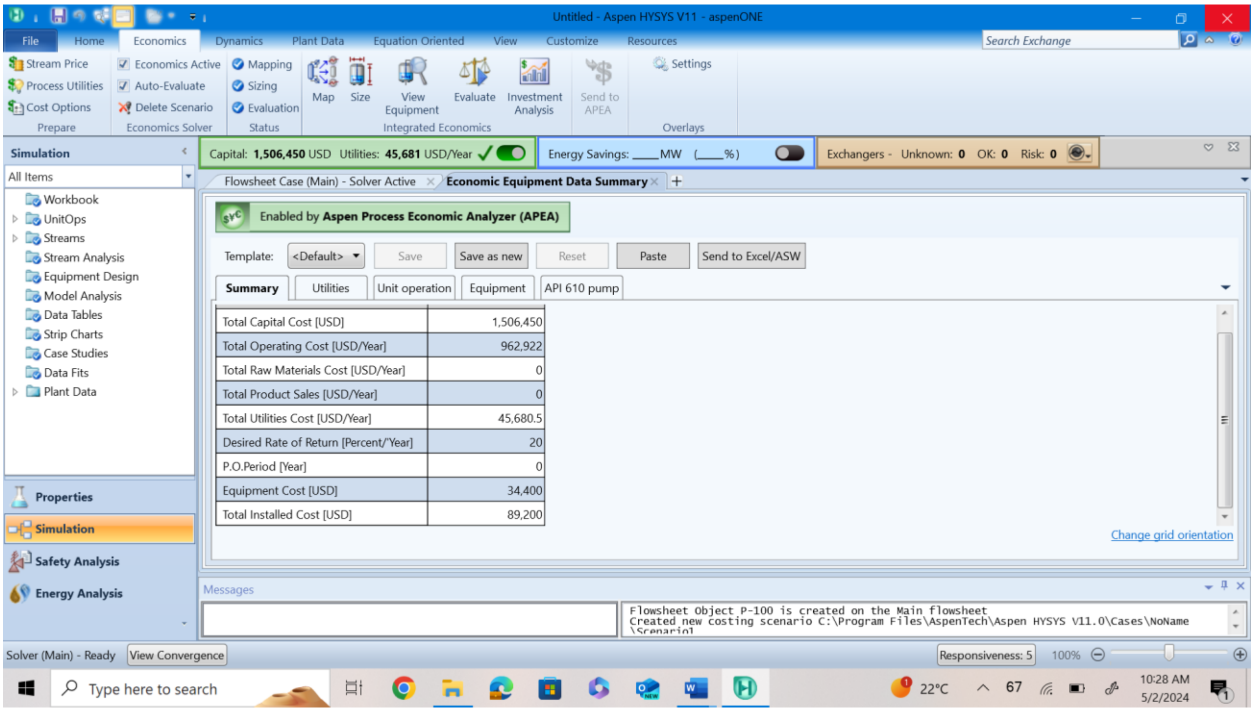
Substituting values in the given relation,

$$0.75P = 100\text{m\^{}3/hr} * (392.27 - 101.3)\text{kpa}$$

P = 10.70 KW

Duty = P = 10.70 KW

Cost = $34,400



Capital: 1,506,450 USD Utilities: 45,681 USD/Year

Energy Savings: ___MW (___%)

Exchangers - Unknown: 0 OK: 0 Risk: 0

Total Capital Cost [USD]	1,506,450
Total Operating Cost [USD/Year]	962,922
Total Raw Materials Cost [USD/Year]	0
Total Product Sales [USD/Year]	0
Total Utilities Cost [USD/Year]	45,680.5
Desired Rate of Return [Percent/'Year]	20
P.O.Period [Year]	0
Equipment Cost [USD]	34,400
Total Installed Cost [USD]	89,200

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Flowsheet Object P-100 is created on the Main flowsheet
Created new costing scenario C:\Program Files\AspenTech\Aspen HYSYS V11.0\Cases\NoName
\Scenario1
```

Figure 4 Filter cost on aspen hysys

Ion Exchange Feed Pump1:

$$\eta P = Volumetric\ flowrate * (P_2 - P_1)$$

Where?

V'=volumetric flow rate of water= 99.9 m^3/hr

Cp= specific heat of water= 4.18KJ/K-Kg

ΔP= difference in pressure of inlet and outlet streams= (202.6-101.3) Kpa

η=efficiency of pump=75% (assumed to be isentropic)

Substituting values in the given relation,

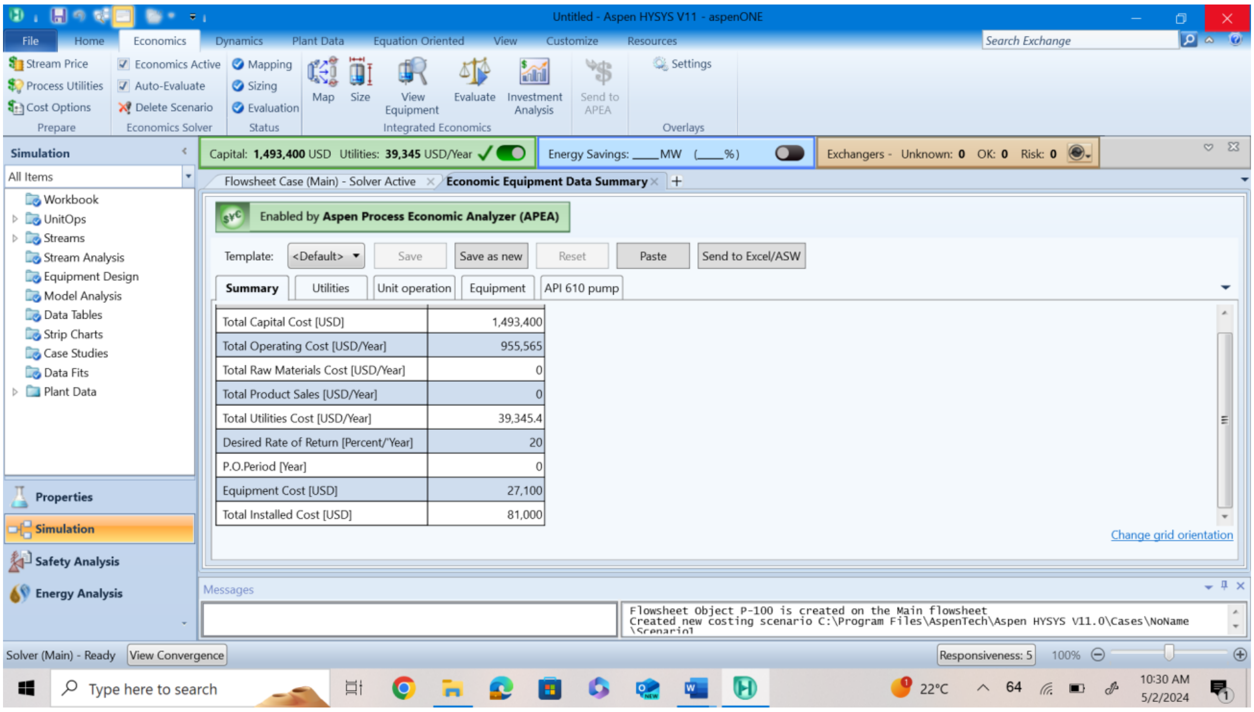
$0.75P$ = 99.9m^3/hr$*$ (202.6 − 101.3) Kpa

P = 3.721 KW

Duty = P= 3.721 *KW*

Cost = $27,100

Below, we performed this calculation using Aspen HYSYS and obtained the same results. The energy or duty requirements calculated in the simulation matched our manual calculations, confirming the accuracy and consistency of our findings. This validation through simulation ensures that both ion exchange and reverse osmosis processes are efficient and reliable in terms of energy consumption. The consistency between manual and simulated results reinforces our confidence in the methodologies used and the robustness of our conclusions. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation. The consistency between manual and simulated results reinforces our confidence in the methodologies used and the robustness of our conclusions. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation.



Capital: 1,493,400 USD Utilities: 39,345 USD/Year

Flowsheet Case (Main) - Solver Active | Economic Equipment Data Summary

Total Capital Cost [USD]	1,493,400
Total Operating Cost [USD/Year]	955,565
Total Raw Materials Cost [USD/Year]	0
Total Product Sales [USD/Year]	0
Total Utilities Cost [USD/Year]	39,345.4
Desired Rate of Return [Percent/'Year]	20
P.O.Period [Year]	0
Equipment Cost [USD]	27,100
Total Installed Cost [USD]	81,000

```
Flowsheet Object P-100 is created on the Main flowsheet
Created new costing scenario C:\Program Files\AspenTech\Aspen HYSYS V11.0\Cases\NoName
\Scenario1
```

Solver (Main) - Ready

Figure 5 Pump cost on aspen hysys

Ion Exchange Feed Pump 2:

$$\eta P = volumetric\ flowrate * (P_2 - P_1)$$

Where:

V'=volumetric flow rate of water= 99.80 m^3/hr

Cp= specific heat of water= 4.18KJ/K-Kg

ΔP= difference in pressure of inlet and outlet streams= (202.6-101.3) Kpa

η=efficiency of pump=75% (assumed to be isentropic)

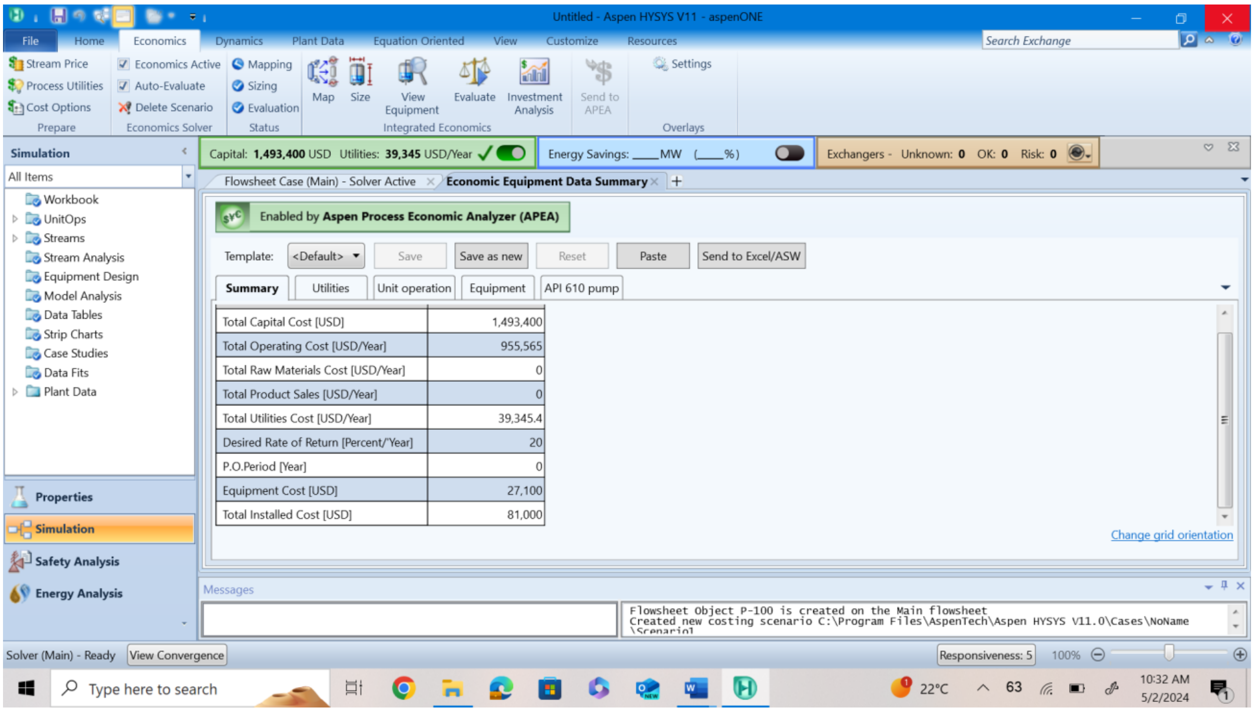
Substituting values in the given relation,

0.75P = 98.8m^3/hr∗ (202.6 − 101.3) Kpa

P = 3.717 KW

DUTY = P = 3.717 KW

Cost = $27,100



Total Capital Cost [USD]	1,493,400
Total Operating Cost [USD/Year]	955,565
Total Raw Materials Cost [USD/Year]	0
Total Product Sales [USD/Year]	0
Total Utilities Cost [USD/Year]	39,345.4
Desired Rate of Return [Percent/'Year]	20
P.O.Period [Year]	0
Equipment Cost [USD]	27,100
Total Installed Cost [USD]	81,000

```
Flowsheet Object P-100 is created on the Main flowsheet
Created new costing scenario C:\Program Files\AspenTech\Aspen HYSYS V11.0\Cases\NoName
\Scenario1
```

Figure 6 Pump 2 cost on aspen hysys

Below, we performed this calculation using Aspen HYSYS and obtained the same results. The energy or duty requirements calculated in the simulation matched our manual calculations, confirming the accuracy and consistency of our findings. This validation through simulation ensures that both ion exchange and reverse osmosis processes are efficient and reliable in terms of energy consumption. The consistency between manual and simulated results reinforces our confidence in the methodologies used and the robustness of our conclusions. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation. The consistency between manual and simulated results reinforces our confidence in the methodologies used and the robustness of our conclusions. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation.

8.2 RO Plant Energy Balance

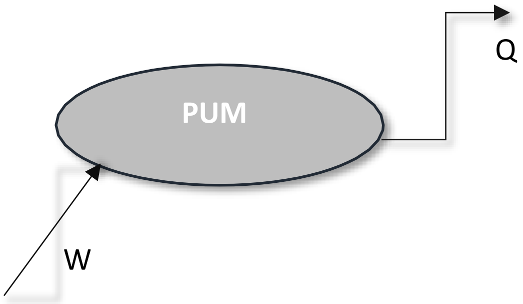


Figure 7 Energy flow diagram

Overall relation for energy balance is given as

$$\boldsymbol{\Delta H = Q + W}$$

Thus, above relation is modified as follow:

$$\boldsymbol{\eta P = Volumetric\ flowrate * (P_2 - P_1)}$$

Where

V'=volumetric flow rate of water= 100m^3/hr

Cp= specific heat of water= 4.18KJ/K-Kg

ΔP= difference in pressure of inlet and outlet streams= (202.6-101.3)kpa

η=efficiency of pump=75% (assumed to be isentropic)

Substituting values in the given relation,

$$0.75P = 100\text{m}^\wedge 3/\text{hr} * (202.6 - 101.3)\text{kpa}$$

$$\boldsymbol{P} = 3.725 \text{ KW}$$

$$\boldsymbol{DUTY} = \boldsymbol{P} = 3.725 \text{ KW}$$

Cost = $27,100

Filter Feed Pump:

$$\eta \boldsymbol{P} = \boldsymbol{Volumetric\ flowrate} * (\boldsymbol{P_2} - \boldsymbol{P_1})$$

Where

V'=volumetric flow rate of water= 100m^3/hr

Cp= specific heat of water= 4.18KJ/K-Kg

ΔP= difference in pressure of inlet and outlet streams= (392.27-101.3)kpa

η=efficiency of pump=75% (assumed to be isentropic)

Substituting values in the given relation,

$$0.75P = 100\text{m\^{}3/hr} * (392.27 - 101.3)\text{kpa}$$

$$\boldsymbol{P} = 10.70\ \text{KW}$$

$$\boldsymbol{DUTY} = \boldsymbol{P} = 10.70\ \text{KW}$$

Cost = $34,400

High Pressure Pump:

$$\eta \boldsymbol{P} = \boldsymbol{Volumetric\ flowrate} * (\boldsymbol{P_2} - \boldsymbol{P_1})$$

Where

V'=volumetric flow rate of water= 99.9 m^3/hr

Cp= specific heat of water= 4.18KJ/K-Kg

ΔP= difference in pressure of inlet and outlet streams= (202.6-101.3)kpa

η=efficiency of pump=75% (assumed to be isentropic)

Substituting values in the given relation,

$$0.75P = 99.9\text{m\^{}3/hr} * (202.6 - 101.3)\text{kpa}$$

$$\boldsymbol{P} = 3.721\ \text{KW}$$

$$\boldsymbol{DUTY} = \boldsymbol{P} = 3.721\ KW$$

Cost = $27,100

Below, we performed this calculation using Aspen HYSYS and obtained the same results. The energy or duty requirements calculated in the simulation matched our manual calculations, confirming the accuracy and consistency of our findings. This validation through simulation ensures that both ion exchange and reverse osmosis processes are efficient and reliable in terms of energy consumption. The consistency between manual and simulated results reinforces our confidence in the methodologies used and the robustness of our conclusions. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation**.** Below, we performed this calculation using Aspen HYSYS and obtained the same results. The energy or duty requirements calculated in the simulation matched our manual calculations, confirming the accuracy and consistency of our findings. This validation through simulation ensures that both ion exchange and reverse osmosis processes are efficient and reliable in terms of energy consumption. The consistency between manual and simulated results reinforces our confidence in the methodologies used and the robustness of our conclusions. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation**.**

8.3 Ion Exchange Energy Balance

Table 8 Ion Exchange Energy Balance

Feed Water Pump, P1-100	3.725 KW
Filter Feed Pump, P2-100	10.70 KW
Ion Exchange Pump-1, P3-100	3.721 KW

Ion Exchange Pump-2, P2-100	3.717 KW

8.5. RO Plant Energy Balance

Table 9 RO Energy Balance

Feed Water Pump, P1-100	3.725 KW
Filter Feed Pump, P2-100	10.69 KW
High Pressure Pump, P3-100	33.45 KW

Energy Balance for Poster:

Following calculations were presented before the open house

Ion Exchange

Feed Water Pump, P1-100	3.725 KW
Filter Feed Pump, P2-100	10.70 KW
Ion Exchange Pump-1, P3-100	3.721 KW
Ion Exchange Pump-2, P2-100	3.717 KW

RO Plant

Feed Water Pump, P1-100	3.725 KW
Filter Feed Pump, P2-100	10.69 KW
High Pressure Pump, P3-100	33.45 KW

We performed this calculation using Aspen HYSYS and obtained the same results. The energy or duty requirements calculated in the simulation matched our manual calculations, confirming the accuracy and consistency of our findings. This validation through simulation ensures that both ion exchange and reverse osmosis processes are efficient and reliable in terms of energy consumption. The consistency between manual and simulated results reinforces our confidence in the methodologies used and the robustness of our conclusions. Both processes effectively meet the energy requirements, further supporting their suitability for various applications, including industrial water treatment and boiler feedwater preparation. This concludes that our processes exhibit minimal variation in energy consumption, which can be considered negligible. Both ion exchange and reverse osmosis processes consume approximately the same amount of energy, ensuring consistent and reliable performance. The minor differences observed are not significant enough to impact the overall efficiency and effectiveness of either process. This parity in energy usage reinforces the suitability of both methods for applications requiring stringent water quality standards, such as boiler feedwater preparation and other industrial uses. Overall, our analysis confirms that both processes are equally viable options in terms of energy efficiency and reliability. This concludes that our processes exhibit minimal variation in energy consumption, which can be considered negligible. Both ion exchange and reverse osmosis processes consume approximately the same amount of energy, ensuring consistent and reliable performance. The minor differences observed are not significant enough to impact the overall efficiency and effectiveness of either process. This parity in energy usage reinforces the suitability of both methods for applications requiring stringent water quality standards, such as boiler feedwater preparation and other industrial uses. Overall, our analysis confirms that both processes are equally viable options in terms of energy efficiency and reliability.

CHAPTER 09

EQUIPMENT DESIGN

Developing conceptual designs for RO and IO systems based on experimental data and performance parameters. Cost estimation involved evaluating capital costs (equipment, installation, and commissioning) and operating costs (energy, chemicals, maintenance) for both treatment processes.

Here are the calculations performed for the design of all equipment’s and at the end cumulatively design parameters are given:

Clarifier Design:

We first find the settling velocity:

$$u = \sqrt{\frac{4D_p g(\rho_p - \rho)}{3C_D \rho}} \quad \text{- (Eq 1)}$$

$$N_{Re,p} = \frac{D_p u \rho}{\mu} \quad \text{- (Eq 2)}$$

Where:

u = Settling Velocity

D_p = Particle Diameter

g = Acceleration of Gravity

ρ_p = Density of Particle

ρ = Density of Fluid

C_D = Drag Coefficient

$N_{Re,p}$ = Reynolds number of particle μ = Viscosity of Fluid

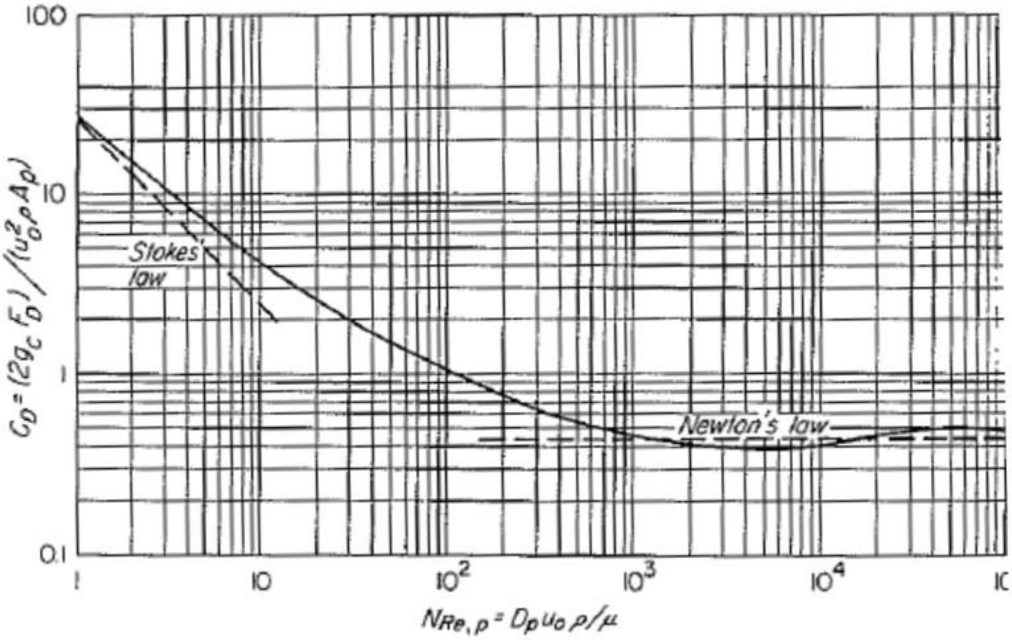


Figure 8 Settling Velocity

To find the settling velocity we use the hit and trial method. In this method we first assume a value of Settling Velocity (u). We use this value to find the Reynolds Number of particle. Then we find out the value of Drag Coefficient from the graph given above. This value is then used in "Eq 1" to find the value of Settling Velocity. If the assumed value and calculated value of "u" are within acceptable error range, then the value of "u" is correct. If not, then the process is repeated with a different value of "u".

We assume:

$$u = 2.5\, m/hr$$

$$D_p = 0.02\, mm$$

$$g = 35316\, m/hr$$

$$\rho_p = 1350\, kg/m^3$$

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

$$\mu = 8.9 \times 10^{-4}$$

By putting values in Eq 2 we get:

$$N_{Re,p} = 561.8$$

From Graph:

$$C_D = 0.52$$

By putting values in Eq 1 we get:

$$u = 2.52$$

The error between the two values is small hence Settling Velocity is correct.

Now we must design a Clarifier that has a Surface Overflow Rate lower than the Settling Velocity. This will ensure maximum separation of Suspended Solids from the water.

$$Volume\ of\ Clarifier = Flowrate\ \times Detention\ Time \quad \text{- (Eq 3)}$$

$$Surface\ Overflow\ Rate\ (SOR) = \frac{Volume\ of\ Clarifier}{Surface\ Area\ of\ Clarifier} \quad \text{- (Eq 4)}$$

We assume:

$$Inlet\ Flowrate = 100\ m^3/hr$$

$$Detention\ Time = 1.5\ hr$$

$$Depth\ of\ Tank = 3.5\ m$$

It is recommended that a clarifier should have a detention time within the range of 1.5 to 2.5 hrs. Generally, Clarifiers also have a depth of 3 to 4.5m.

By putting values in Eq 3 we get:

$$Volume\ of\ Clarifier = 100 \times 1.5 = 150\ m^3$$

And hence:

$$Surface\ Area\ of\ Clarifier = \frac{Volume\ of\ Clarifier}{Depth\ of\ Clarifier} = \frac{150}{3.5} = 42.86\ m^2$$

$$Diameter\ of\ Clarifier = 2\sqrt{\frac{S.A.of\ Clarifier}{\pi}} = 2\sqrt{\frac{42.86}{\pi}} = 7.4m$$

Finally, putting values in Eq 4:

$$Surface\ Overflow\ Rate = \frac{100}{42.86} = 2.33\ m/h$$

It is to be noted that the value of Surface Overflow Rate is less than the Settling Velocity for the Clarifier, hence the design will promote maximum extraction of TSS present within the water.

Table 10 Components in Clarifier

Component	ppm	Valency	Atomic Mass	meq/L
Calcium	116	2	40.078	5.788712012
Magnesium	90	2	24.305	7.405883563
Iron	26	2	55.845	0.931148715
			Total	14.12574429

MB Exchanger:

The ionic load in the MB is very low hence its design is primarily based on the flow rate only. Its job is to only polish the demineralized water to ensure good and consistent quality. Below we have listed all the composition of mixed bed exchanger in the table. This gives us the value of each component which has been changed or converted in a mixed bed exchanger.

In this case we will use Dupont Amberlite HPR1300 H and Dupont Amberlite HPR4700 Cl resins for the Mixed Bed Exchanger. Densities of these resins are 1.22 g/mL and 1.09 g/mL respectively. These are provided by the manufacturer. It is assumed that equal amounts of both resins are placed in the vessel. This implies that half of the total resin volume will be for each resin.

We choose specifications based on general recommendations:

$$Bed\ Height = 1600\ mm$$

$$Vessel\ Diameter = 500\ mm$$

Hence,

$$Cross\ Sectional\ Area = \frac{\pi}{4} d^2 = 0.12\ m^2$$

$$Total\ Resin\ Volume = Bed\ Height \times Cross\ Sectional\ Area = 0.314\ m^3$$

$$Mass\ of\ Resin\ (HPR1300\ H) = \ Resin\ Volume \times Density\ of\ Resin = \frac{0.314}{2} \times 1220$$

$$= 191.66\ kg$$

$$Mass\ of\ Resin\ (HPR4700\ Cl) = \ Resin\ Volume \times Density\ of\ Resin = \frac{0.314}{2} \times 1090$$

$$= 171.24\ kg$$

In an Ion Exchanger there is a freeboard present above the resin. It is an empty space in the vessel to accommodate any expansion in resin bed. It is normally taken as 30 percent of the bed height.

Hence,

$$Vessel\ Height = 1.3 \times Bed\ Height = 2080\ mm$$

Anion Exchanger:

We calculate the meq/L for each component by using the formula:

$$meq/L\ = \frac{(Conc.\ in\ ppm)(Valency)}{Atomic\ Mass}$$

Adding them all up we get Total Anion Concentration.

Number of Anions entering in anion exchanger varies from initial composition due to changes caused in clarifier and degasified.

The Resin used is Dupont Amberlite HPR4800 Cl. Its Density is 1.10 g/mL and its Operating Capacity is 1.30 eq/L both provided by the manufacturer.

We know that:

$$Flow\ Rate\ =\ 100\ m^3/hr$$

$$Total\ Anion\ Concentration =\ 3.89\ meq/L$$

We assume:

$$Running\ Time =\ 10\ hr$$

$$Vessel\ Diameter = 1000\ mm$$

Now, we calculate the following:

$$Cross\ Sectional\ Area = \frac{\pi}{4}d^2 = 0.79\ m^2$$

$$Throughput\ =\ Flow\ Rate \times Running\ Time\ =\ 1000\ m^3$$

$$Anionic\ Load\ =\ Total\ Anion\ Concentration \times Throughput\ =\ 3890\ eq$$

$$Resin\ Volume\ =\ \frac{Anionic\ Load}{Operating\ Capacity}\ = \frac{3890}{1.3} =\ 2992\ L$$

$$Mass\ of\ Resin = Resin\ Volume \times Density\ or\ Resin = 2.992 \times 1100 = 3291.54\ kg$$

$$Specific\ Flow\ Rate\ = \frac{Flow\ Rate}{Resin\ Volume}\ =\ 30.85\ h^{-1}$$

$$Bed\ Height = \frac{Resin\ Volume}{Cross\ Sectional\ Area} = \frac{2.992}{0.79} = 3787.73\ mm$$

It is to be noted that the recommended range of specific flow rate is 5 to 50 h^{-1}. However, a specific flowrate within the range of 30 to 35 h^{-1} depicts a compact plant with minimum investment cost. Hence the designed volume is optimum.

By adding freeboard, we get:

$$Vessel\ Height = 1.3 \times Bed\ Height = 4924\ mm$$

Cation Exchanger:

Like Anion Exchanger we find the Cation Concentration using the formula:

$$meq/L\ = \frac{(Conc.\, in\, ppm)(Valency)}{Atomic\ Mass}$$

Number of cations is the same as feed water composition as there is no change preceding it.

The resin used is Dupont Amberlite HPR1200 H. Its Density is 1.20 g/mL and its Operating Capacity is 1.80 eq/L both provided by the manufacturer.

We know that:

$$Flow\ Rate\ =\ 100\ m^3/hr$$

$$Total\ Cation\ Concentration =\ 14.13\ meq/L$$

We assume:

$$Running\ Time =\ 10\ hr$$

$$Vessel\ Diameter = 2000\ mm$$

Now, we calculate the following:

$$Cross\ Sectional\ Area = \frac{\pi}{4}d^2 = 3.14\ m^2$$

$$Throughput\ =\ Flow\ Rate \times Running\ Time\ =\ 1000\ m^3$$

$$Cationic\ Load\ =\ Total\ Cation\ Concentration \times Throughput\ =\ 14126\ eq$$

$$Resin\, Volume\ =\ \frac{Anionic\ Load}{Operating\ Capacity}\ = \frac{14126}{1.8} =\ 7848\ L$$

$$Mass\ of\ Resin = Resin\, Volume \times Density\ of\ Resin = 7.848 \times 1200 = 9417.6\ kg$$

$$Specific\ Flow\ Rate\ = \frac{Flow\ Rate}{Resin\, Volume}\ =\ 12.74\ h^{-1}$$

$$Bed\ Height = \frac{Resin\ Volume}{Cross\ Sectional\ Area} = \frac{7.848}{3.14} = 2500\ mm$$

The specific flowrate is within the recommended range of 5 to 50 h^-1.

By adding freeboard, we get:

$$Vessel\ Height = 1.3 \times Bed\ Height = 3250\ mm$$

Raw Water Storage Tank

$$Flow\ Rate = 100\ {}^{m^3}/_{hr}$$

$$Basis = 1\ day$$

$$Volume\ Required = 100\ \times 24 = 2400\ m^3$$

Let’s suppose tank is cylindrical vessel then.

$$V = \pi r^2 h$$

Assumption:

$$h = 1.5d$$

$$2400 = \pi \times \frac{d^2}{4} \times 1.5d$$

$$d^3 = \frac{2400\ \times 4}{\pi\ \times 1.5} = 2038.2$$

After taking cube root on both sides

$$d = 12.7\ m$$

Height of Tank

$$h = 1.5(12.7)$$

$$h = 19.05\ m$$

Sand Filter Design:

$$Flow\ rate\ =\ 100\ m^3/hr$$

We assume that:

$$Rate\ of\ Filtration = 5\ m/hr$$

$$Depth\ of\ Sand = 2\ m$$

$$Density\ of\ Sand = 2600\ kg/m^3$$

Now, we calculate:

$$Area = \frac{Flow\ Rate}{Rate\ of\ Filtration} = \frac{100}{5} = 20\ m^2$$

$$Volume\ of\ Sand = Depth\ of\ Sand \times Area = 40\ m^3$$

$$Mass\ of\ Sand = Density\ of\ Sand \times Volume\ of\ Sand = 104{,}000\ kg$$

$$Radius\ of\ Vessel = \sqrt{\frac{Area}{\pi}} = 2.52\ \approx 2\ m$$

Adding freeboard for expansion of bed:

$$Vessel\ Height = 1.3 \times Depth\ of\ Sand = 2.6\ m$$

The surface loading rate is the most important parameter in the design of filters. The recommended surface loading rate for rapid sand filters is 4-6m3/m2/hr. The dimensions of the filter will be used at which the surface loading rate does not exceed 6m3/m2/hr. when the treatment works operates at full design capacity.

Filter Vessel Length: 7

Filter Vessel Width: 3

Design Capacity: 100 m^3/hr.

Total surface area of filtration = Length * Width = 7*3 = 21 m^2

Surface Loading rate = Design Capacity / Surface Area = 100/21 = 4.8

Hence Dimensions of filter are 7m length and 3m width.

9.1 IX Design:

Table 11 Ion Exchange Design

Storage Tank	Cylindrical Vertical Vessel, Diameter: 12.7m, Height: 19.05m
Clarifier	Volume: 150m3, Diameter: 7.4m
Sand Filter 1 & 2	Vessel Height: 2.6m, Area: 20m2, Sand Depth: 2m
Cation Exchanger	Bed Height: 2.5m, Vessel Diameter: 2m, Vessel Height: 3.25m
Anion Exchanger	Bed Height: 3.79m, Vessel Diameter: 1m, Vessel Height: 4.92m
Mixed Bed Exchanger	Bed Height: 1.6m, Vessel Diameter: 0.5m, Vessel Height: 2.08m

9.2 RO Design:

Table 12 RO design

Storage Tank	Cylindrical Vertical Vessel, Diameter: 12.7m, Height: 19.05m
Clarifier	Volume: 150m3, Diameter: 7.4m
Sand Filter	Vessel Height: 2.6m, Area: 20m2, Sand Depth: 2m
Reverse Osmosis Membranes	Membrane Elements: 122, Vessel Height: 1m,

	Vessel Diameter: 0.2m

Our analysis of the water treatment system's components has yielded insightful results. The storage tank, a cylindrical vertical vessel with a diameter of 12.7 meters and a height of 19.05 meters, provides substantial capacity for holding treated water. The large dimensions ensure a significant storage volume, contributing to the system's ability to manage fluctuations in water demand effectively. The clarifier, with a volume of 150 cubic meters and a diameter of 7.4 meters, plays a crucial role in the initial treatment stages, efficiently removing suspended solids and reducing turbidity. Its design and capacity are optimized for high throughput, ensuring that large volumes of water can be treated quickly and effectively.

The sand filter, featuring a vessel height of 2.6 meters, an area of 20 square meters, and a sand depth of 2 meters, further enhances water quality by removing finer particulate matter and contaminants. This filtration stage is critical for achieving the necessary clarity and purity before the water undergoes reverse osmosis. The reverse osmosis system, comprising 122 membrane elements housed in vessels with a height of 1 meter and a diameter of 0.2 meters, ensures the removal of dissolved solids and other impurities to meet stringent water quality standards. This detailed evaluation of each component demonstrates the system's robustness and effectiveness in producing high-quality treated water, highlighting its suitability for various industrial applications, including boiler feedwater preparation.

The sand filter, featuring a vessel height of 2.6 meters, an area of 20 square meters, and a sand depth of 2 meters, further enhances water quality by removing finer particulate matter and contaminants. This filtration stage is critical for achieving the necessary clarity and purity before the water undergoes reverse osmosis. The reverse osmosis system, comprising 122 membrane elements housed in vessels with a height of 1 meter and a diameter of 0.2 meters, ensures the removal of dissolved solids and other impurities to meet stringent water quality standards. This detailed evaluation of each component demonstrates the system's robustness and effectiveness in producing high-quality treated water, highlighting its suitability for various industrial applications, including boiler feedwater preparation.

CHAPTER 10

EQUIPMENT COSTING

10.1 Ion Exchange Plant Costing:

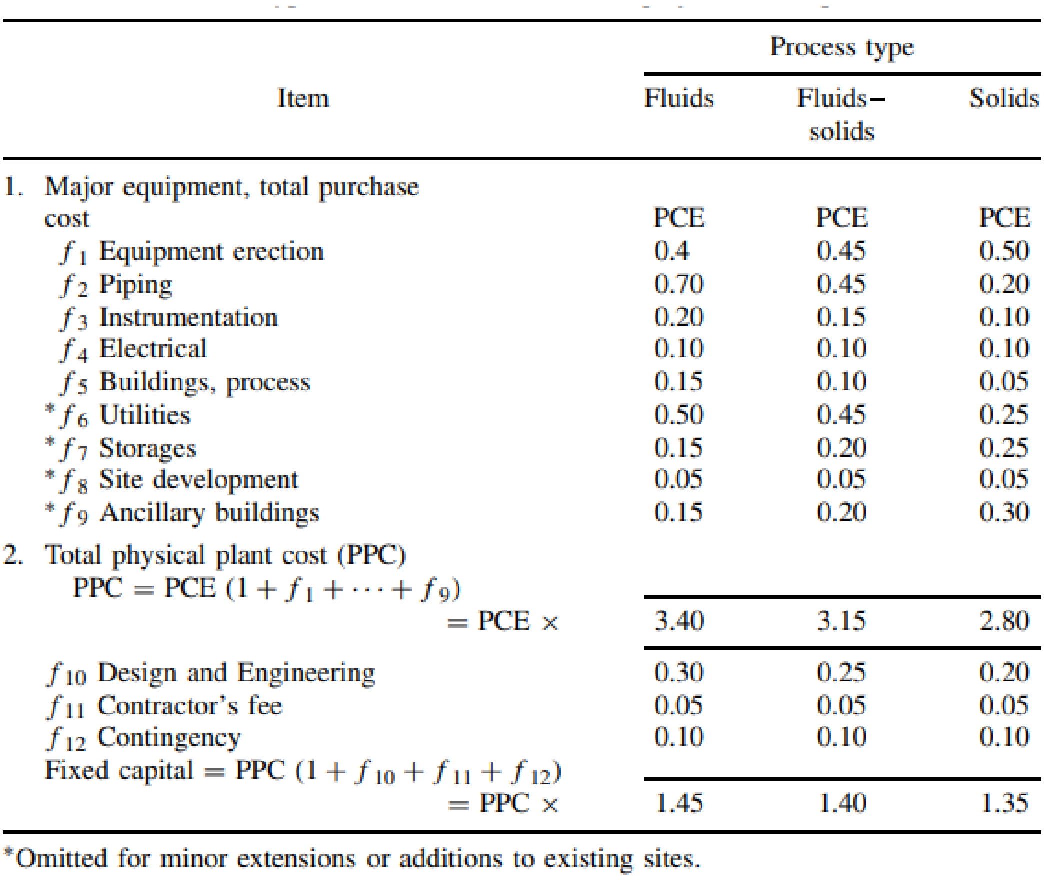
Purchased Cost of Equipment (PCE):

Table 13 PCE

Storage Tank	\$166,281
Clarifier	\$40,000
Sand Filter 1	\$45,079.52
Sand Filter 2	\$45,079.52
Cation Exchanger	\$170,680.25
Degasifier	\$10,000
Anion Exchanger	\$115,455.20
Mixed Bed Exchanger	\$23,694.26
Total	\$616,270

$$PCE = \$616{,}270$$

Physical Plant Cost (PPC) & Fixed Capital:



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.

Figure 9 PPC

$$PPC = PCE(1 + 0.4 + 0.7 + 0.2 + 0.1)$$

$$PPC = 616270(2.4)$$

$$PPC = \$1{,}479{,}048$$

$$FIxed\ Capital = PPC(1 + 0.3 + 0.05 + 0.1)$$

$$Fixed\ Capital = 1479048(1.45)$$

$$Fixed\ Capital = \$2{,}144{,}619.6$$

Working Capital:

$$Working\ Capital = Fixed\ Capital \times 0.05$$

$$Working\ Capital = \$107{,}231$$

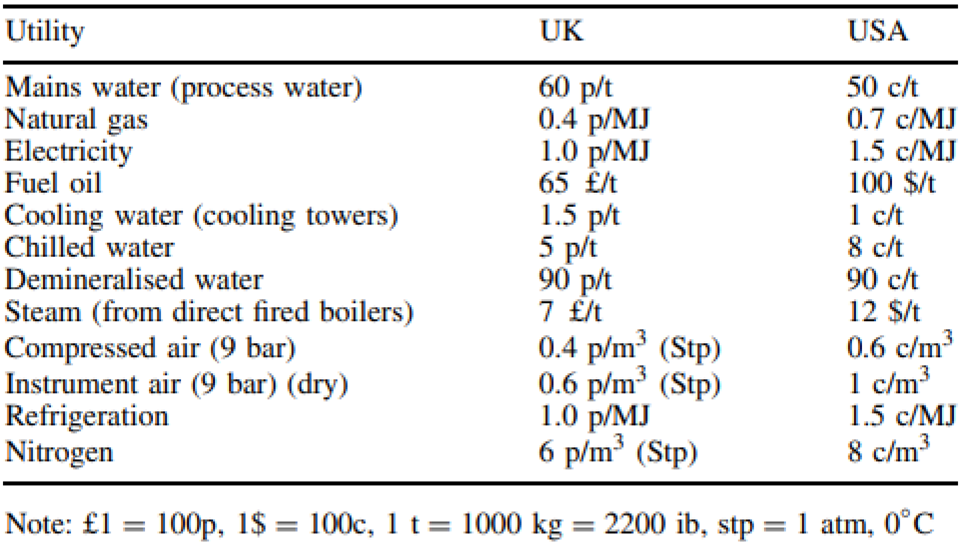
Total Investment Required:

$$Total\ Investment\ Required = Fixed\ Capital + Working\ Capital$$

$$Total\ Investment\ Required = \$2{,}251{,}850.6$$

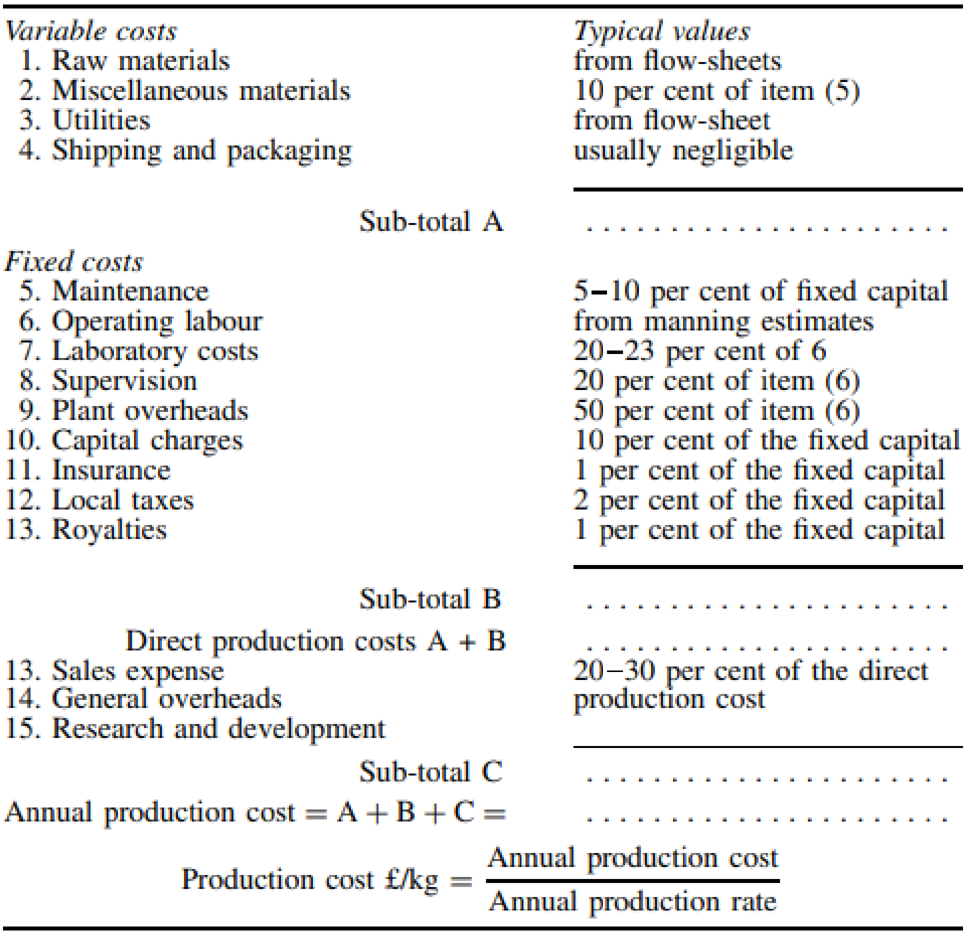
Annual Operating Costs:

$$Operating\ Time\ = \ 365 \times 0.95 = 347\ days$$



Utility	UK	USA
Mains water (process water)	60 p/t	50 c/t
Natural gas	0.4 p/MJ	0.7 c/MJ
Electricity	1.0 p/MJ	1.5 c/MJ
Fuel oil	65 £/t	100 \$/t
Cooling water (cooling towers)	1.5 p/t	1 c/t
Chilled water	5 p/t	8 c/t
Demineralised water	90 p/t	90 c/t
Steam (from direct fired boilers)	7 £/t	12 \$/t
Compressed air (9 bar)	0.4 p/m^3 (Stp)	0.6 c/m^3
Instrument air (9 bar) (dry)	0.6 p/m^3 (Stp)	1 c/m^3
Refrigeration	1.0 p/MJ	1.5 c/MJ
Nitrogen	6 p/m^3 (Stp)	8 c/m^3

Note: £1 = 100p, 1\$ = 100c, 1 t = 1000 kg = 2200 ib, stp = 1 atm, 0°C



Variable costs	*Typical values*
1. Raw materials	from flow-sheets
2. Miscellaneous materials	10 per cent of item (5)
3. Utilities	from flow-sheet
4. Shipping and packaging	usually negligible
Sub-total A	. . . .
Fixed costs	
5. Maintenance	5–10 per cent of fixed capital
6. Operating labour	from manning estimates
7. Laboratory costs	20–23 per cent of 6
8. Supervision	20 per cent of item (6)
9. Plant overheads	50 per cent of item (6)
10. Capital charges	10 per cent of the fixed capital
11. Insurance	1 per cent of the fixed capital
12. Local taxes	2 per cent of the fixed capital
13. Royalties	1 per cent of the fixed capital
Sub-total B	. . . .
Direct production costs A + B	. . . .
13. Sales expense 14. General overheads 15. Research and development	20–30 per cent of the direct production cost
Sub-total C	. . . .
Annual production cost = A + B + C =	. . . .

$$\text{Production cost £/kg} = \frac{\text{Annual production cost}}{\text{Annual production rate}}$$

Figure 10 Variable Cost

Variable Costs:

1. Raw Materials:

$$Cost\ of\ Water\ per\ tonne\ =\ \$0.5$$

$$Annual\ Requirement\ of\ Water\ =\ 100\frac{m^3}{hr} \times 24 \times 347 \times 1 = 832{,}800\frac{tonne}{year}$$

$$Cost\ of\ Water = 832{,}800 \times 0.5 = \$416{,}400$$

2. Miscellaneous Materials:

$$Misc\ Materials = 0.1 \times Maintenance\ Cost = \$10{,}723.1$$

3. Utilities: Not Applicable
4. Shipping & Packaging: Not Applicable

$Total\ Variable\ Cost = \$427{,}123.1$

Fixed Costs:

5. Maintenance Cost:

$$Maintenance\ Cost = 0.05 \times Fixed\ Capital = \$107{,}231$$

6. Operating Labor Cost:

$$Operating\ Labor\ Cost = \$40{,}000$$

7. Laboratory Cost:

$$Laboratory\ Cost = 0.2 \times 40{,}000 = \$8000$$

8. Supervision: Not Applicable

9. Plant Overhead Costs:

$$Plant\ Overheads = 0.5 \times Operating\ Labor = \$20{,}000$$

10. Capital Charges:

$$Capital\ Charges = 0.1 \times Fixed\ Capital = \$214{,}462$$

11. Insurance:

$$Insurance = 0.01 \times Fixed\ Capital = \$21{,}446.2$$

12. Local Taxes:

$$Local\ Taxes = 0.02 \times Fixed\ Capital = \$42{,}892.4$$

13. Royalties:

$$Royalties = 0.01 \times Fixed\ Capital = \$21{,}446.2$$

$Total\ Fixed\ Costs = \$475{,}477.8$

$$Annual\ Operating\ Cost = Fixed\ Cost + Variable\ Cost = \$902{,}600.9$$

Costing of other equipment:

Costing of Storage Tank:

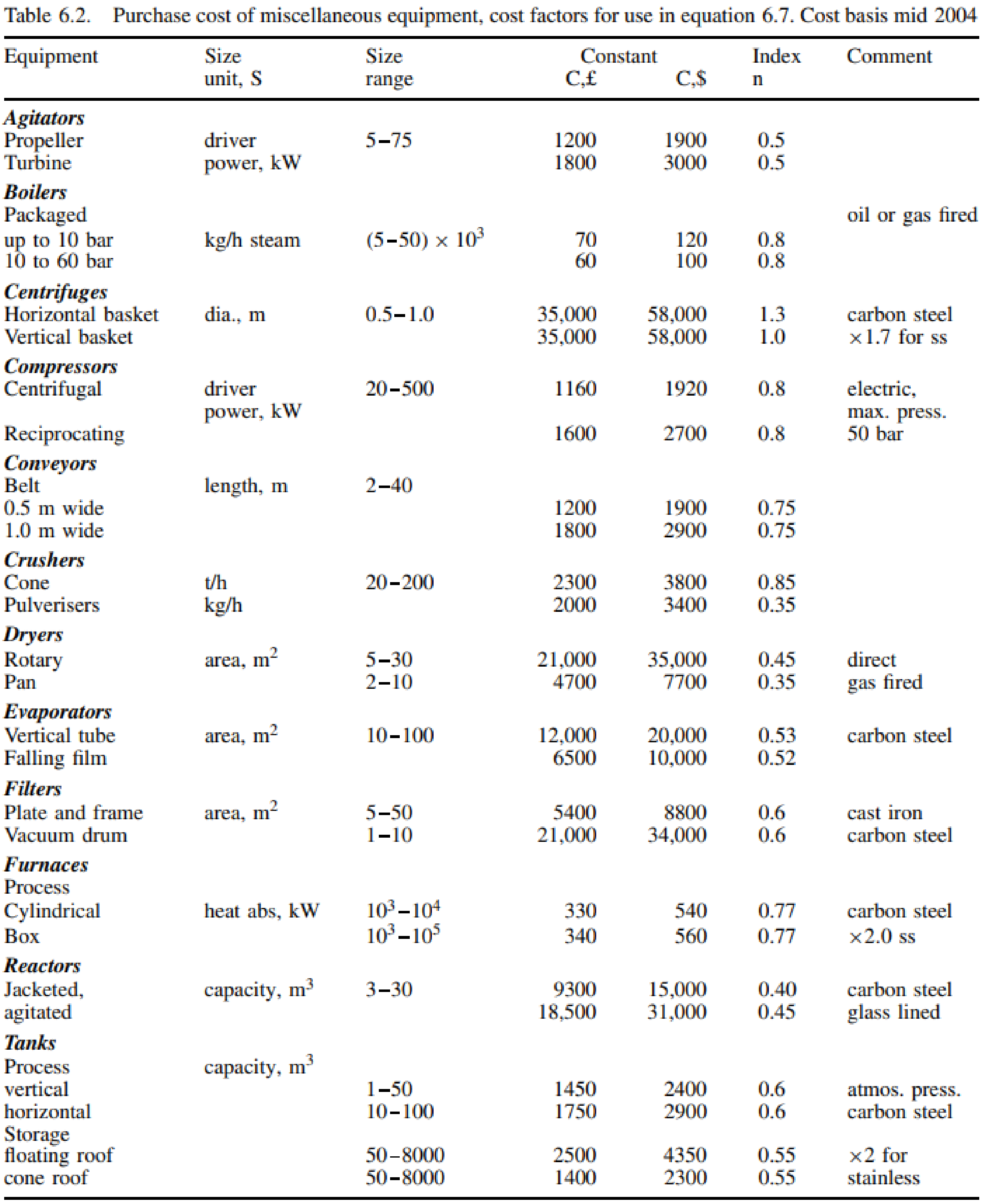


Table 6.2. Purchase cost of miscellaneous equipment, cost factors for use in equation 6.7. Cost basis mid 2004

Equipment	Size unit, S	Size range	Constant		Index n	Comment
			C,£	C,$		
Agitators						
Propeller	driver	5–75	1200	1900	0.5	
Turbine	power, kW		1800	3000	0.5	
Boilers						
Packaged						oil or gas fired
up to 10 bar	kg/h steam	(5–50) × 10^3	70	120	0.8	
10 to 60 bar			60	100	0.8	
Centrifuges						
Horizontal basket	dia., m	0.5–1.0	35,000	58,000	1.3	carbon steel
Vertical basket			35,000	58,000	1.0	×1.7 for ss
Compressors						
Centrifugal	driver power, kW	20–500	1160	1920	0.8	electric, max. press.
Reciprocating			1600	2700	0.8	50 bar
Conveyors						
Belt	length, m	2–40				
0.5 m wide			1200	1900	0.75	
1.0 m wide			1800	2900	0.75	
Crushers						
Cone	t/h	20–200	2300	3800	0.85	
Pulverisers	kg/h		2000	3400	0.35	
Dryers						
Rotary	area, m^2	5–30	21,000	35,000	0.45	direct
Pan		2–10	4700	7700	0.35	gas fired
Evaporators						
Vertical tube	area, m^2	10–100	12,000	20,000	0.53	carbon steel
Falling film			6500	10,000	0.52	
Filters						
Plate and frame	area, m^2	5–50	5400	8800	0.6	cast iron
Vacuum drum		1–10	21,000	34,000	0.6	carbon steel
Furnaces						
Process						
Cylindrical	heat abs, kW	10^3–10^4	330	540	0.77	carbon steel
Box		10^3–10^5	340	560	0.77	×2.0 ss
Reactors						
Jacketed,	capacity, m^3	3–30	9300	15,000	0.40	carbon steel
agitated			18,500	31,000	0.45	glass lined
Tanks						
Process	capacity, m^3					
vertical		1–50	1450	2400	0.6	atmos. press.
horizontal		10–100	1750	2900	0.6	carbon steel
Storage						
floating roof		50–8000	2500	4350	0.55	×2 for
cone roof		50–8000	1400	2300	0.55	stainless

Figure 11 Storage Tank Cost Parameters

We use the following Equation:

$$Ce = CS^{n}$$

Where:

$Ce = Purchased\ Equipment\ Cost$

$C = Cost\ Constant\ from\ table\ above$

$S = Characteristic\ Size\ Parameter\ from\ table\ above$

$n = Index\ from\ table\ above$

We will use a Cone Roof Storage Tank for this application.

From Table we find:

$$C(\$) = 2300$$

$$S = 2400\ m^{3}\ (Calculated\ in\ Design\ of\ Storage\ Tank)$$

$$n = 0.55$$

Hence:

$$Ce = 2300 \times (2400)^{0.55}$$

$$Cost\ of\ Storage\ Tank\ (Ce) = \$166281$$

After a thorough market research, the following equipment prices were taken keeping the required specifications in mind:

Cost of Clarifier = $40000

Cost of Degasifier = $10000

Sand Filter Costing:

Specs:

Vessel Diameter	2 m

Vessel Height	2.6 m

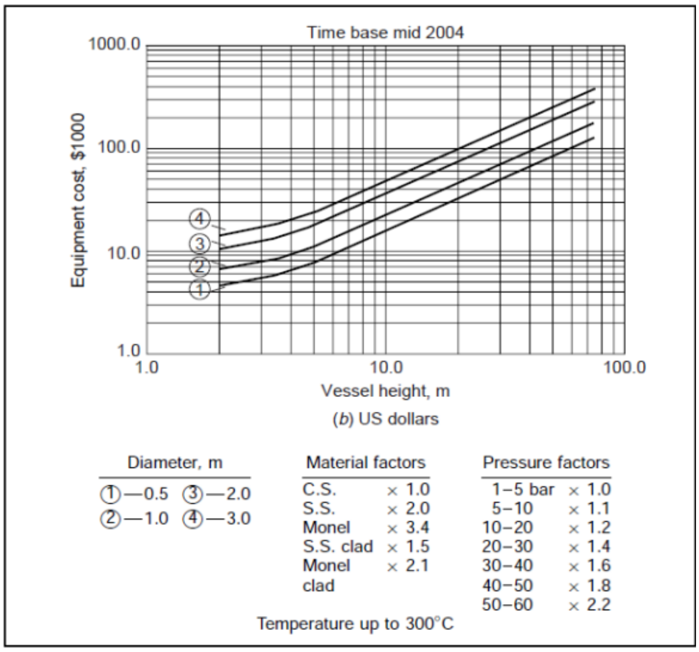


Figure 12 Vessel Parameters

Vessel Material: SS

From graph above:

$$Cost\ of\ Vessel\ in\ 2004 = \$12000\ \times 2 \times 1 = \$24000$$

Taking Time Correction Factor (2004 to 2024) = 1.79 (Found using CEPCI)

Hence,

$$Vessel\ Cost = Cost\ of\ Vessel\ in\ 2004 \times Time\ Correction\ Factor = \$24000\ \times 1.79$$
$$= \$42960$$

Sand Cost:

Cost per tonne of sand = $20.38

Mass of Sand = 104 tons

Cost of Sand = $2119.52

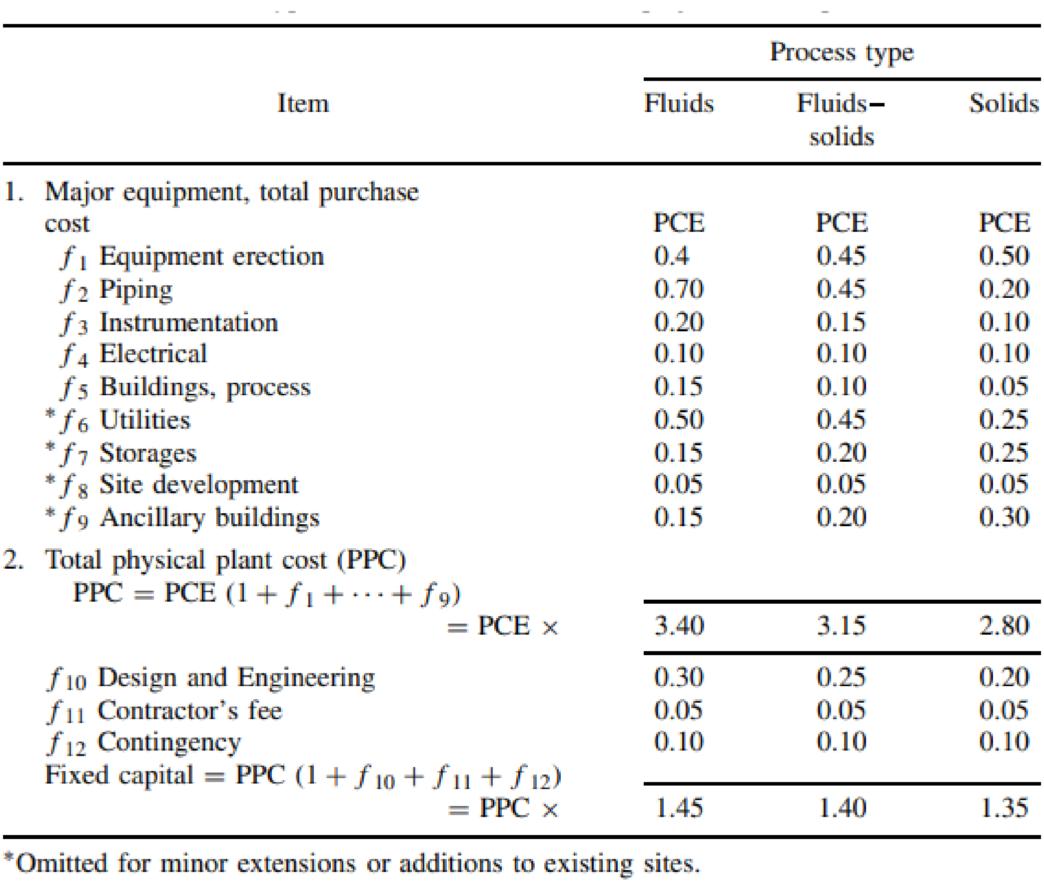
Total Cost of Sand Filter = Cost of Vessel + Cost of Sand = $\$42960 + \$2119.52 =$ $\$45079.52$

Purchased Cost of Equipment (PCE):

Storage Tank	$166,281
Clarifier	$40,000
Sand Filter 1	$45,079.52
Sand Filter 2	$45,079.52
Cation Exchanger	$170,680.25
Degasifier	$10,000
Anion Exchanger	$115,455.20
Mixed Bed Exchanger	$23,694.26
Total	$616,270

$$PCE = \$616{,}270$$

Physical Plant Cost (PPC) & Fixed Capital:



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) $PPC = PCE\,(1 + f_1 + \cdots + f_9)$ $= PCE\times$	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 $= PPC\,(1 + f_{10} + f_{11} + f_{12})$ $= PPC\times$	1.45	1.40	1.35

*Omitted for minor extensions or additions to existing sites.

$$PPC = PCE(1 + 0.4 + 0.7 + 0.2 + 0.1)$$

$$PPC = 616270(2.4)$$

$$PPC = \$1{,}479{,}048$$

$$FIxed\ Capital = PPC(1 + 0.3 + 0.05 + 0.1)$$

$$Fixed\ Capital = 1479048(1.45)$$

$$Fixed\ Capital = \$2{,}144{,}619.6$$

Working Capital:

$$Working\ Capital = Fixed\ Capital \times 0.05$$

$$Working\ Capital = \$107{,}231$$

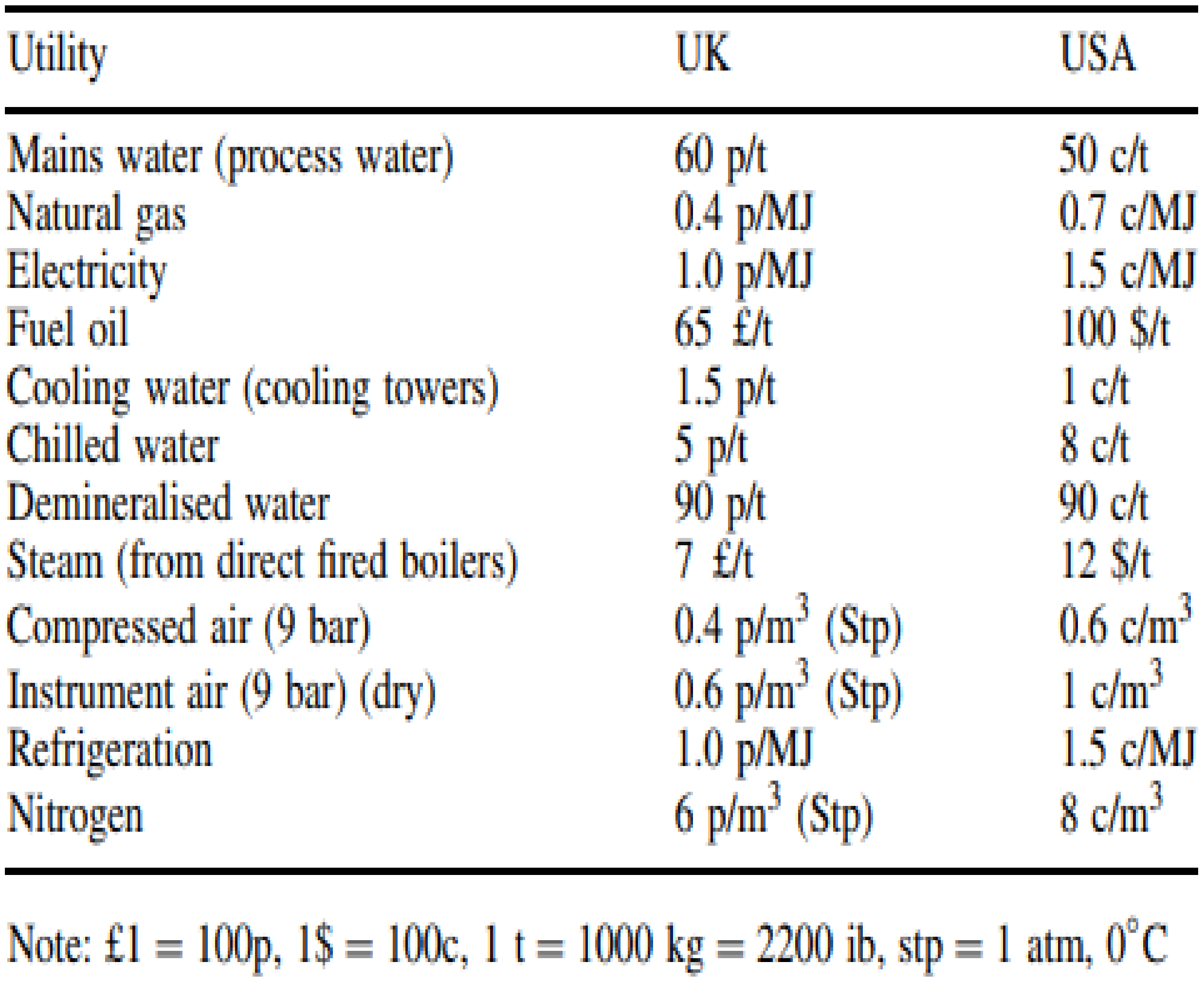
Total Investment Required:

$$Total\ Investment\ Required = Fixed\ Capital + Working\ Capital$$

$$Total\ Investment\ Required = \$2{,}251{,}850.6$$

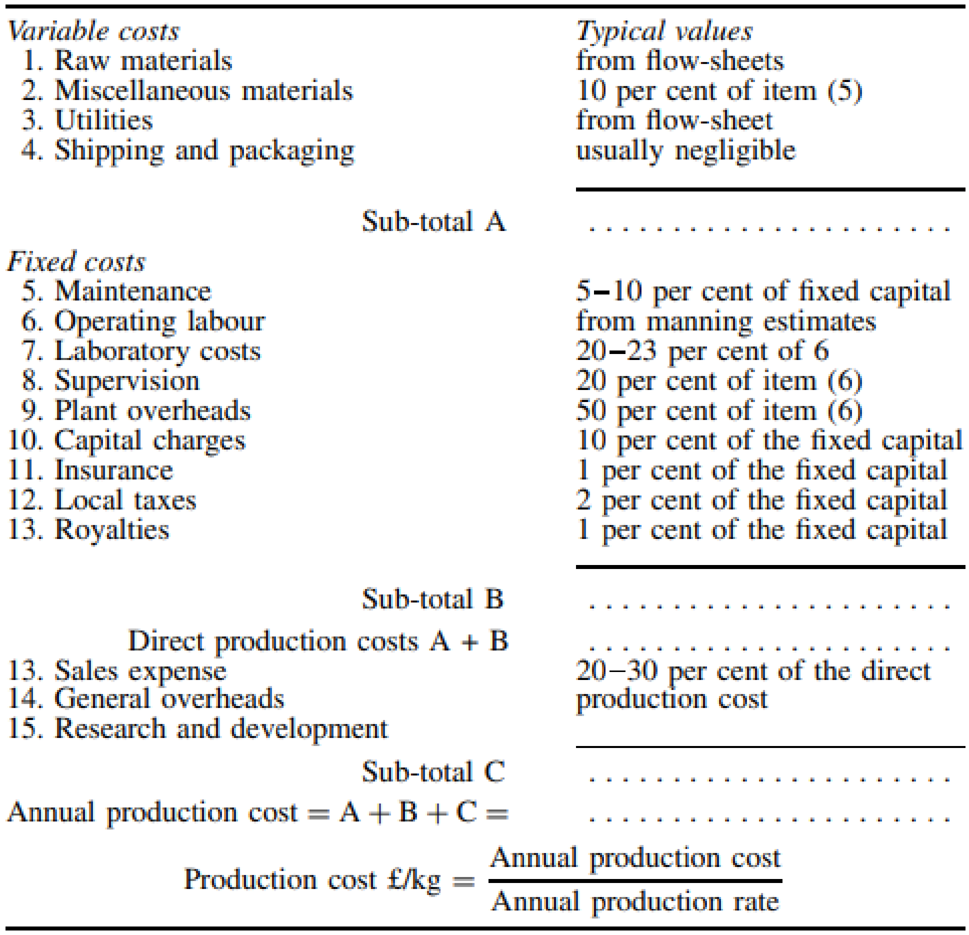
Annual Operating Costs:

$$Operating\ Time\ = \ 365 \times 0.95 = 347\ days$$



Utility	UK	USA
Mains water (process water)	60 p/t	50 c/t
Natural gas	0.4 p/MJ	0.7 c/MJ
Electricity	1.0 p/MJ	1.5 c/MJ
Fuel oil	65 £/t	100 $/t
Cooling water (cooling towers)	1.5 p/t	1 c/t
Chilled water	5 p/t	8 c/t
Demineralised water	90 p/t	90 c/t
Steam (from direct fired boilers)	7 £/t	12 $/t
Compressed air (9 bar)	0.4 p/m^3 (Stp)	0.6 c/m^3
Instrument air (9 bar) (dry)	0.6 p/m^3 (Stp)	1 c/m^3
Refrigeration	1.0 p/MJ	1.5 c/MJ
Nitrogen	6 p/m^3 (Stp)	8 c/m^3

Note: £1 = 100p, 1$ = 100c, 1 t = 1000 kg = 2200 ib, stp = 1 atm, 0°C



Variable costs	*Typical values*
1. Raw materials	from flow-sheets
2. Miscellaneous materials	10 per cent of item (5)
3. Utilities	from flow-sheet
4. Shipping and packaging	usually negligible
Sub-total A	. . . .
Fixed costs	
5. Maintenance	5–10 per cent of fixed capital
6. Operating labour	from manning estimates
7. Laboratory costs	20–23 per cent of 6
8. Supervision	20 per cent of item (6)
9. Plant overheads	50 per cent of item (6)
10. Capital charges	10 per cent of the fixed capital
11. Insurance	1 per cent of the fixed capital
12. Local taxes	2 per cent of the fixed capital
13. Royalties	1 per cent of the fixed capital
Sub-total B	. . . .
Direct production costs A + B	. . . .
13. Sales expense 14. General overheads 15. Research and development	20–30 per cent of the direct production cost
Sub-total C	. . . .
Annual production cost = A + B + C =	. . . .

$$\text{Production cost £/kg} = \frac{\text{Annual production cost}}{\text{Annual production rate}}$$

Variable Costs:

14. Raw Materials:

$$\text{Cost of Water per tonne} \;=\; \$0.5$$

$$\text{Annual Requirement of Water} \;=\; 100\,\frac{\text{m}^3}{\text{hr}} \times 24 \times 347 \times 1 = 832{,}800\,\frac{\text{tonne}}{\text{year}}$$

$$\text{Annual Cost of Water} = 832{,}800 \times 0.5 = \$416{,}400$$

15. Miscellaneous Materials:

$$\text{Misc Materials} = 0.1 \times \text{Maintenance Cost} = \$10{,}723.1$$

16. Utilities:

$$\text{Cost of Electricity per MJ} = \$0.015$$

$$\text{Energy Required Annually} = 30.96\ \text{kW} \times \frac{1}{1000} \times 3600 \times 24 \times 347 = 928{,}205.6\ \text{MJ}$$

$$\text{Annual Cost of Electricity} = 0.015 \times 928205.6 = \$13{,}923.1$$

17. Shipping & Packaging: Not Applicable

Total Variable Cost = \$441,046.2

Fixed Costs:

18. Maintenance Cost:

$$\text{Maintenance Cost} = 0.05 \times \text{Fixed Capital} = \$107{,}231$$

19. Operating Labor Cost:

$$\text{Operating Labor Cost} = \$40{,}000$$

20. Laboratory Cost:

$$\text{Laboratory Cost} = 0.2 \times 40{,}000 = \$8000$$

21. Supervision: Not Applicable

22. Plant Overhead Costs:

$$\text{Plant Overheads} = 0.5 \times \text{Operating Labor} = \$20{,}000$$

23. Capital Charges:

$$\text{Capital Charges} = 0.1 \times \text{Fixed Capital} = \$214{,}462$$

24. Insurance:

$$\text{Insurance} = 0.01 \times \text{Fixed Capital} = \$21{,}446.2$$

25. Local Taxes:

$$\text{Local Taxes} = 0.02 \times \text{Fixed Capital} = \$42{,}892.4$$

26. Royalties:

$$\text{Royalties} = 0.01 \times \text{Fixed Capital} = \$21{,}446.2$$

$$\text{Total Fixed Costs} = \$475{,}477.8$$

$$\text{Direct Costs} = \text{Fixed Cost} + \text{Variable Cost} = \$916{,}524$$

$$\text{Indirect Costs} = 0.2 \times \text{Direct Cost} = \$183{,}304.8$$

$$\text{Total Annual Operating Costs} = \text{Direct Costs} + \text{Indirect Costs} = \$1{,}099{,}829$$

10.2 RO Plant Costing:

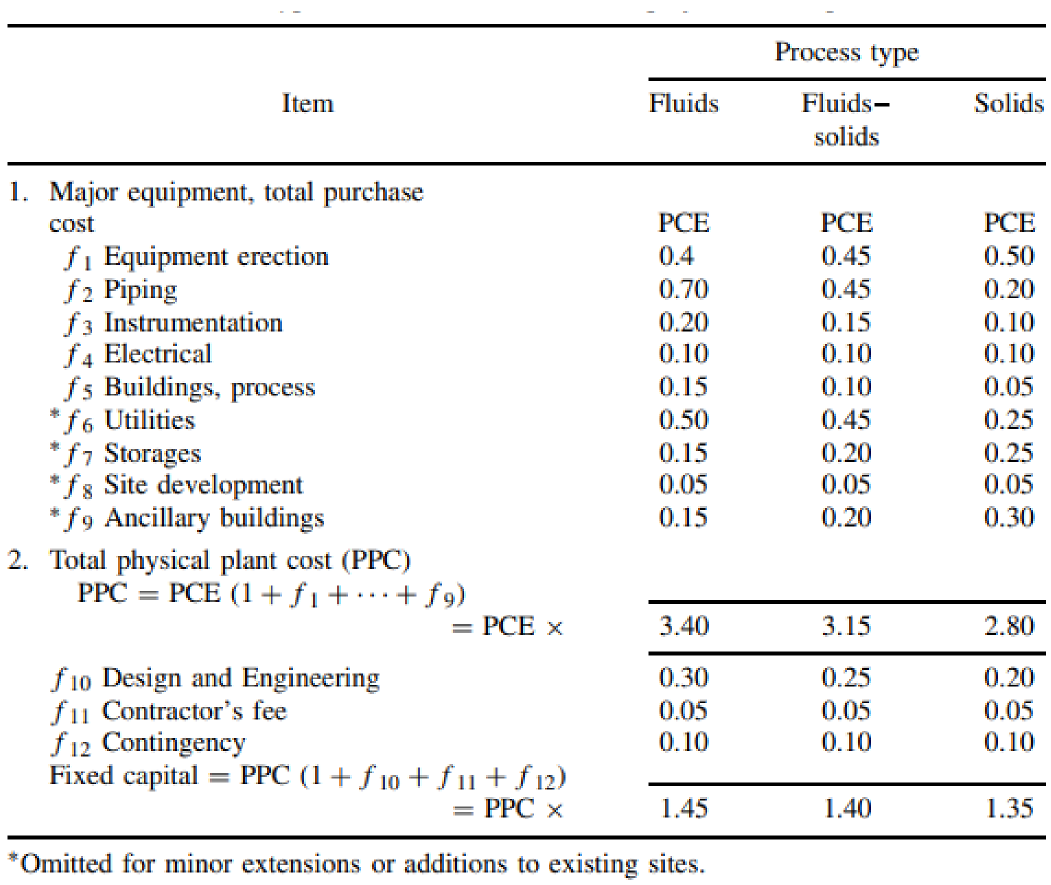
Purchased Cost of Equipment (PCE):

Table 14 PCE of RO

Storage Tank, TK1-100	$166,281
Clarifier, TK2-100	$40,000
Sand Filter, F-100	$45,079.52
Feed Water Pump, P1-100	$27,100
Filter Feed Pump, P2-100	$34,400
High Pressure Pump, P3-100	$31,400
RO Membrane, RO1-100	$120,676
RO Membrane, RO2-100	$116,557
Total	**$**

PCE = $581,463.52

Physical Plant Cost (PPC) & Fixed Capital:



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.

$$PPC = PCE(1 + 0.4 + 0.7 + 0.2 + 0.1)$$

$$PPC = 581{,}463.52(2.4)$$

$$PPC = \$1{,}395{,}512.448$$

$$FIxed\ Capital = PPC(1 + 0.3 + 0.05 + 0.1)$$

$$Fixed\ Capital = 1{,}395{,}512.448(1.45)$$

$$Fixed\ Capital = \$2{,}019{,}143.0496$$

Working Capital:

$$Working\ Capital = Fixed\ Capital \times 0.05$$

$$Working\ Capital = \$100{,}957.15$$

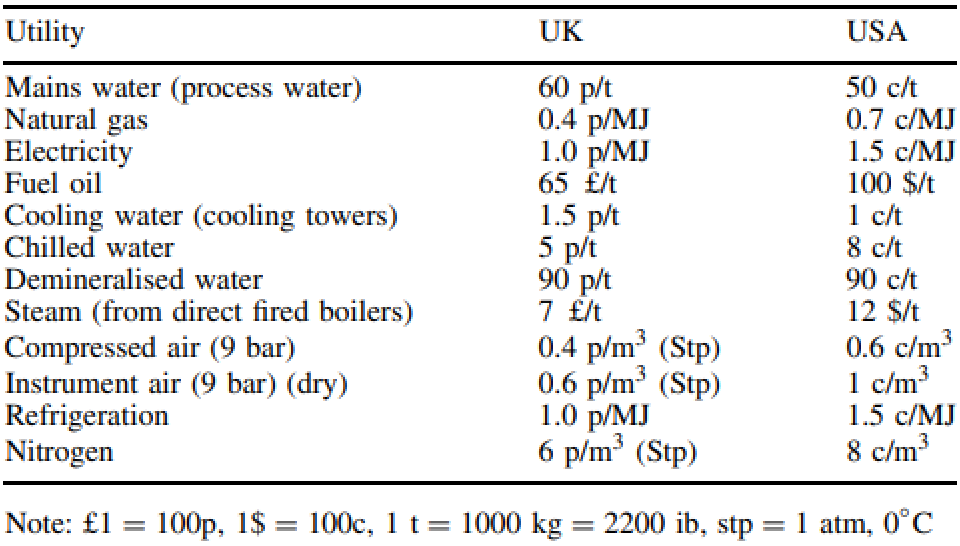
Total Investment Required:

$$Total\ Investment\ Required = Fixed\ Capital + Working\ Capital$$

$$Total\ Investment\ Required = \$2{,}120{,}100.1996$$

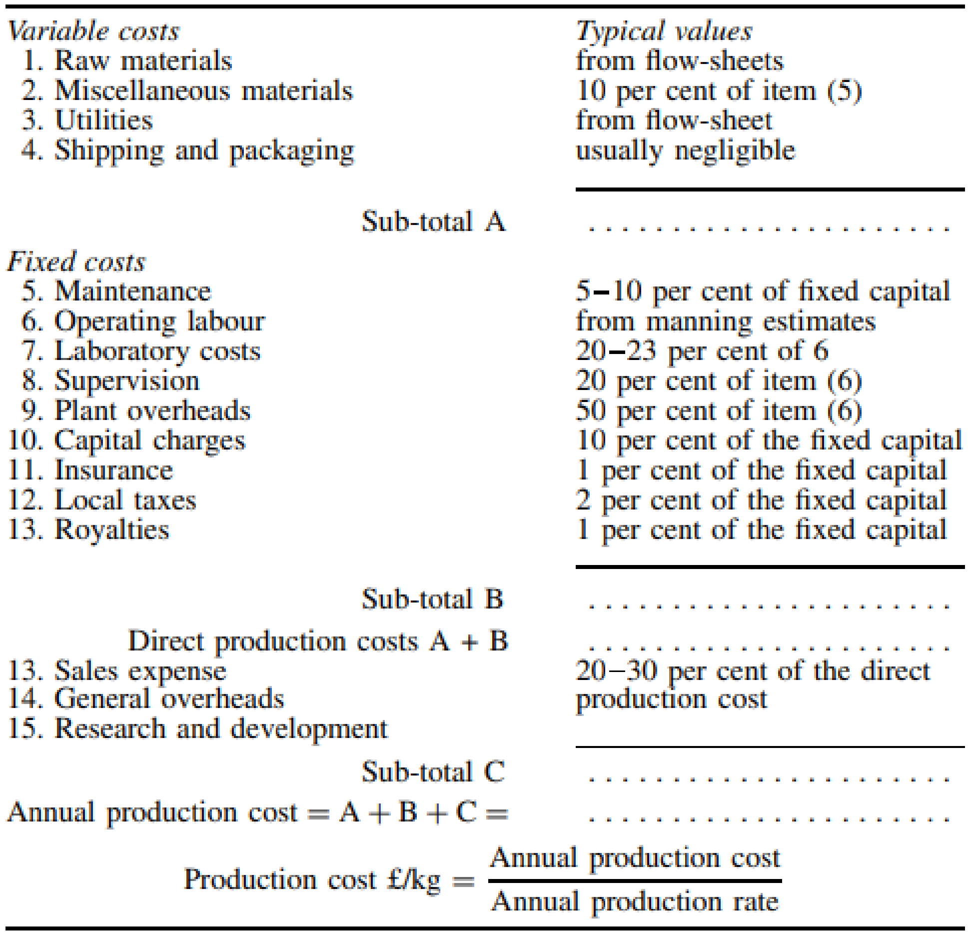
Annual Operating Costs:

$$Operating\ Time\ = 365 \times 0.95 = 347\ days$$



Utility	UK	USA
Mains water (process water)	60 p/t	50 c/t
Natural gas	0.4 p/MJ	0.7 c/MJ
Electricity	1.0 p/MJ	1.5 c/MJ
Fuel oil	65 £/t	100 $/t
Cooling water (cooling towers)	1.5 p/t	1 c/t
Chilled water	5 p/t	8 c/t
Demineralised water	90 p/t	90 c/t
Steam (from direct fired boilers)	7 £/t	12 $/t
Compressed air (9 bar)	0.4 p/m^3 (Stp)	0.6 c/m^3
Instrument air (9 bar) (dry)	0.6 p/m^3 (Stp)	1 c/m^3
Refrigeration	1.0 p/MJ	1.5 c/MJ
Nitrogen	6 p/m^3 (Stp)	8 c/m^3

Note: £1 = 100p, 1$ = 100c, 1 t = 1000 kg = 2200 ib, stp = 1 atm, 0°C



Variable costs	*Typical values*
1. Raw materials	from flow-sheets
2. Miscellaneous materials	10 per cent of item (5)
3. Utilities	from flow-sheet
4. Shipping and packaging	usually negligible
Sub-total A	. . . .
Fixed costs	
5. Maintenance	5–10 per cent of fixed capital
6. Operating labour	from manning estimates
7. Laboratory costs	20–23 per cent of 6
8. Supervision	20 per cent of item (6)
9. Plant overheads	50 per cent of item (6)
10. Capital charges	10 per cent of the fixed capital
11. Insurance	1 per cent of the fixed capital
12. Local taxes	2 per cent of the fixed capital
13. Royalties	1 per cent of the fixed capital
Sub-total B	. . . .
Direct production costs A + B	. . . .
13. Sales expense 14. General overheads 15. Research and development	20–30 per cent of the direct production cost
Sub-total C	. . . .
Annual production cost = A + B + C =	. . . .

$$\text{Production cost £/kg} = \frac{\text{Annual production cost}}{\text{Annual production rate}}$$

Variable Costs:

1. Raw Materials:

$$Cost\ of\ Water\ per\ tonne\ =\ \$0.5$$

$$Annual\ Requirement\ of\ Water\ =\ 100\frac{m^3}{hr} \times 24 \times 347 \times 1 = 832{,}800\frac{tonne}{year}$$

$$Annual\ Cost\ of\ Water = 832{,}800 \times 0.5 = \$416{,}400$$

2. Miscellaneous Materials:

$$Misc\ Materials = 0.1 \times Maintenance\ Cost = \$10{,}095.715$$

3. Utilities:

$$Cost\ of\ Electricity\ per\ MJ = \$0.015$$

$$Energy\ Required\ Annually = 47.835\ kW \times \frac{1}{1000} \times 3600 \times 24 \times 347$$
$$= 1{,}434{,}131.568\ MJ$$

$$Annual\ Cost\ of\ Electricity = 0.015 \times 1{,}434{,}131.568 = \$21{,}511.974$$

4. Shipping & Packaging: Not Applicable

$$Total\ Variable\ Cost = \$448{,}007.689$$

Fixed Costs:

5. Maintenance Cost:

$$Maintenance\ Cost = 0.05 \times Fixed\ Capital = \$100{,}957.15$$

6. Operating Labor Cost:

$$Operating\ Labor\ Cost = \$40{,}000$$

7. Laboratory Cost:

$$Laboratory\ Cost = 0.2 \times 40{,}000 = \$8000$$

8. Supervision: Not Applicable

9. Plant Overhead Costs:

$$Plant\ Overheads = 0.5 \times Operating\ Labor = \$20{,}000$$

10. Capital Charges:

$$Capital\ Charges = 0.1 \times Fixed\ Capital = \$201{,}914.305$$

11. Insurance:

$$Insurance = 0.01 \times Fixed\ Capital = \$20{,}191.43$$

12. Local Taxes:

$$Local\ Taxes = 0.02 \times Fixed\ Capital = \$40{,}382.86$$

13. Royalties:

$$Royalties = 0.01 \times Fixed\ Capital = \$20{,}191.43$$

$$Total\ Fixed\ Costs = \$451{,}637.175$$

$$Direct\ Costs = Fixed\ Cost + Variable\ Cost = \$899{,}644.864$$

$$Indirect\ Costs = 0.2 \times Direct\ Cost = \$179{,}928.973$$

$$Total\ Annual\ Operating\ Costs = Direct\ Costs + Indirect\ Costs = \$1{,}079{,}573.837$$

CHAPTER 11

HAZOP ANALYSIS

In the production of demineralized water for high-pressure boilers, we focus on several key components: the main subdivisions including the clarifier, sand filter, degasifier, and the comparative analysis of the use of IX and RO.

Clarifier: Among these, very high turbidity of the output water may be another potential deviation to watch; might be attributed to improper dosing of coagulant, incorrect mixing or failure of clarifier mechanism. This leads to slowing down of the efficiency of downstream process including sand filter, IX and RO units with chances of damaging the high pressure boilers. Other tertiary protection measures include; dosing equipment as this is normally calibrated for routine maintenance, online turbidity control, and the mixer type with a stand-by mixer considered as a part of a back up system. Another deviation is low water flow; this is a common problem that can be attributed to clogged inlet pipes, faulty or out-of-order pumps, or sediments accumulating at the base of the tank. This may consequently lead to inadequate water supply to the downstream processes and even system shutoffs. Such measures implemented in safeguarding this process include the flow meters with alarms, proper inspection and cleaning schedule scheduling standby pumps. Also, high levels of chemicals may result from over proportioning coagulants or pH adjustors making the amount to contaminate downstream processes and even the boilers. Feedback control, concentration monitoring in the automated dosing system, and training to the operating personnel are the essential measures required.

Sand Filter: One more possible deviation could be high pressure drop across the sand filter, which may be due to sand clogging as a result of high particulate load. This would mean a lowered water flow to ‘next steps’ or filter clogging therefore damaging the filter. They include differential pressure measuring gadgets, back washing of filter, and observing the efficiency of the clarifiers located upstream. Low effective frequency of filtration can be caused by channeling in the sand bed, insufficient backwashing, or deterioration of filter media through physical and chemical processes which decrease turbidity of filtered water and reduce the efficiency of IX or RO units. This can be overcome by daily, weekly and monthly inspection and proper replacement of the filtering material, correct back washing techniques and regular online turbidity monitoring.

Degasifier: One possible deviation in the degasifier is high levels of dissolved gases in the output water could occur due to low stripping air flow rate, poor packing material, or short contact time. This may result in corrosion of other downstream equipment and reduction in efficiency in IX & RO processes. Some of measure include flow meters and alarms for stripping air, packing material should be maintained often, the design of WWT should allow that it will achieve the necessary contact time. Low production flow due to blockages, failure of pumps, etc; is also a problem since restricted water supply affects downstream IX or RO units and the system may need to be shut down. This can be prevented by flow monitoring and alarm system, standby pump, and inspection, and maintenance of this equipment.

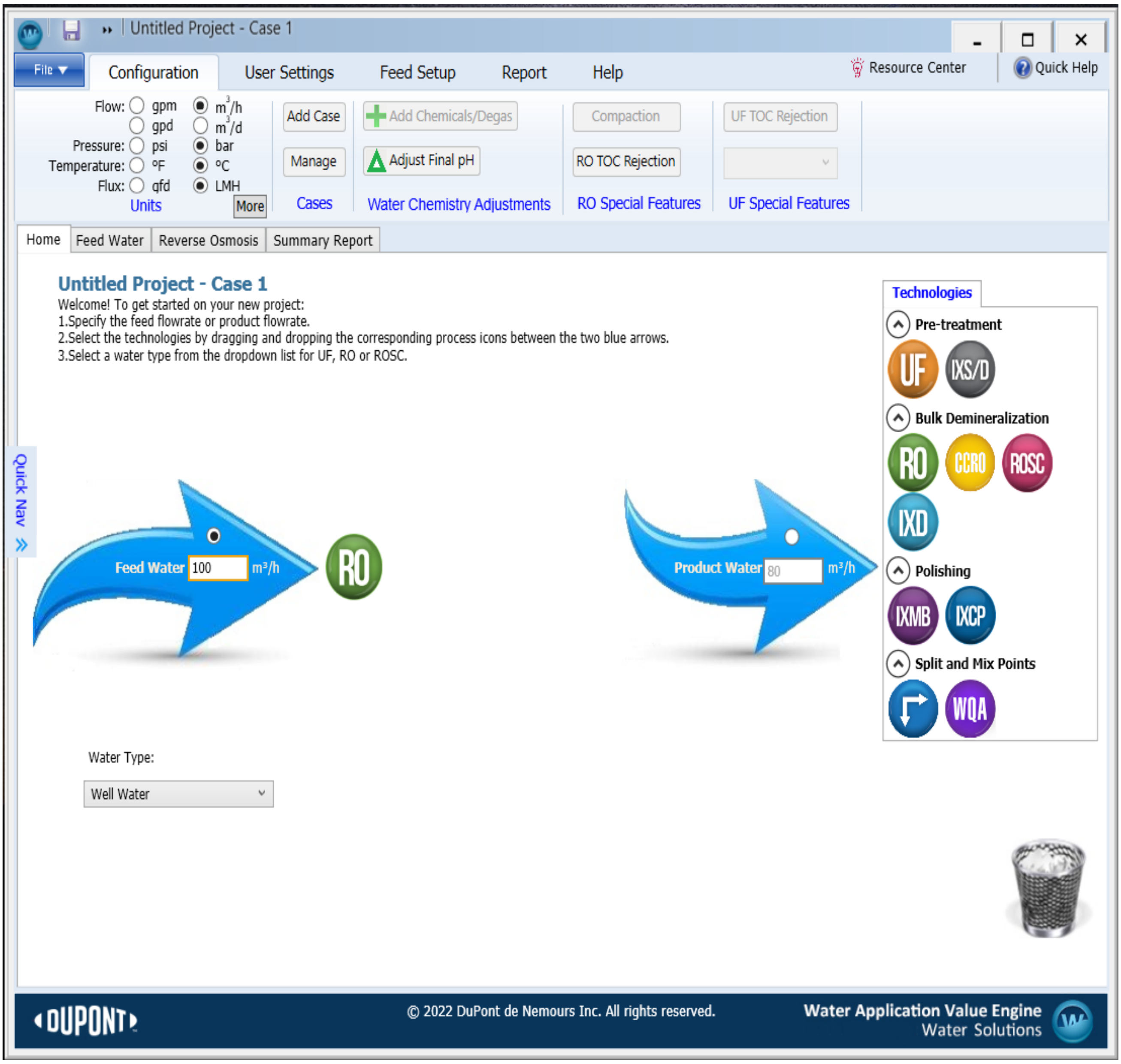
Ion Exchange (IX): In the IX process, the high ion concentration in the out let water may be due to the following reasons such as exhaustion of the resins, channeling in the resin bed or due to improper regeneration process which lead to poor quality of water and further scaling, fouling in the high pressure boilers. Measures include monitoring of water conductivity of the output stream, strict adherence to the right regeneration techniques, and proper replacement of resins as per laid down schedule . Another issue is resin fouling due to heavy sediment content, organic matter or flow of microorganisms that affects the flow rate and makes the system costlier to maintain. Other measures must be employed such as the use of clarifiers and sand filters before the water enters the pipework, giving biocides in the water system, and continuity inspection and cleaning programs.

Reverse Osmosis (RO): High salt rejection in RO systems may occur as a result of membrane foulants, scaling, biofouling and/or incorrect process conditions causing increased operating pressure, increased energy consumption and poor permeate quality. Some practical measures include clarification, sand filtration, degasification, anti-scalant addition, and cleaning or Changing of membrane. Waste water could be produced owing to low water recovery caused by high feed water salinity, membrane damage, or improper system design; this leads to increased costs of operation and reduced efficiency of a desalination system. Implementing correct design and operational procedures, biannual checks on performance, and routine maintenance to minimize these incurrence.

CHAPTER 12

SIMULATION FOR RO AND IX ON DUPONT'S WAVE

We conducted a simulation analysis on both RO and IX. Using Duponts Wave to produce a simulation we obtained following results:



Flow: ○ gpm ● m³/h ○ gpd ○ m³/d
Pressure: ○ psi ● bar
Temperature: ○ °F ● °C
Flux: ○ gfd ● LMH

Untitled Project - Case 1

Welcome! To get started on your new project:

1.Specify the feed flowrate or product flowrate.

2.Select the technologies by dragging and dropping the corresponding process icons between the two blue arrows.

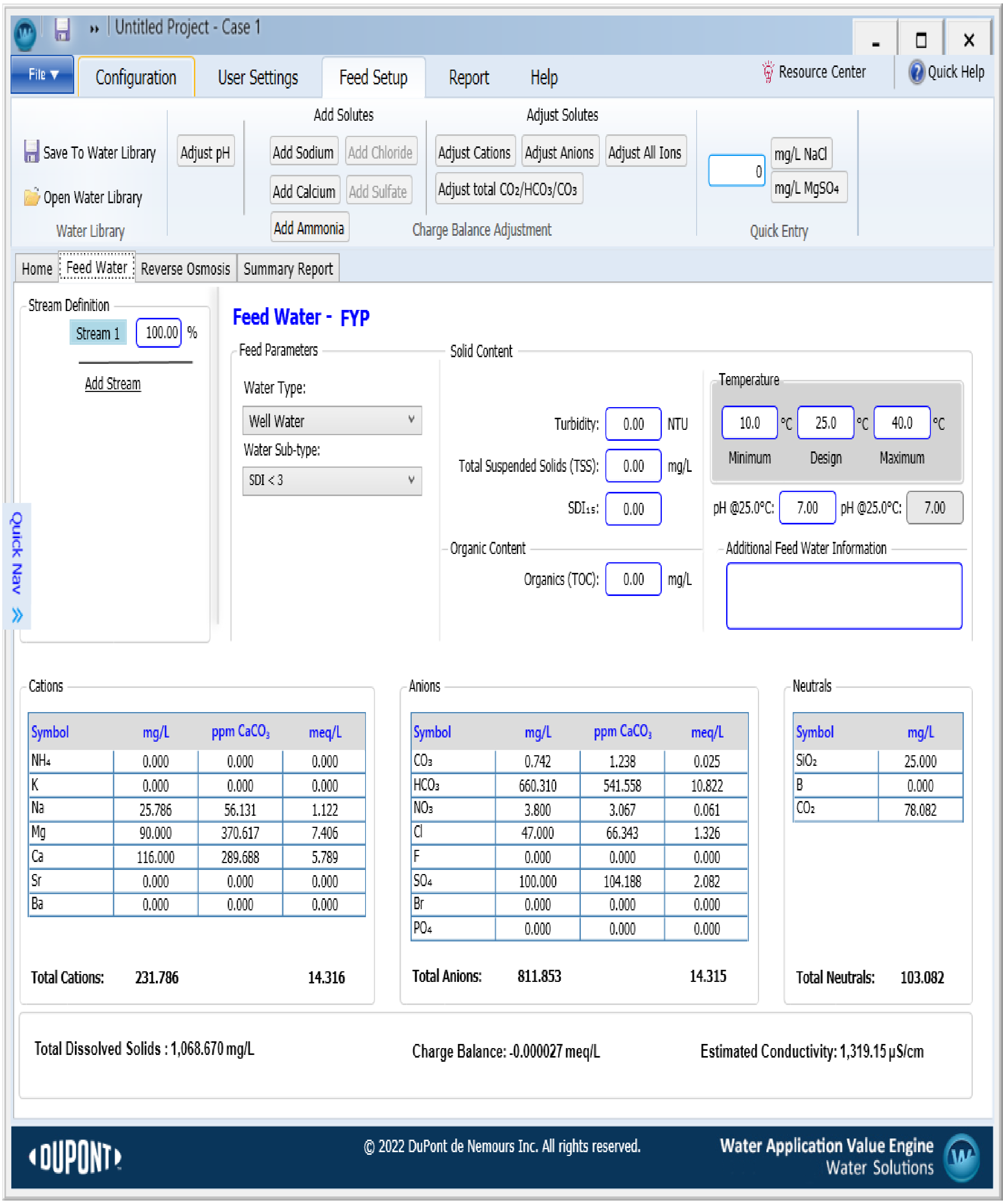
3.Select a water type from the dropdown list for UF, RO or ROSC.

Feed Water 100 m³/h

Product Water 80 m³/h

Water Type: Well Water

Figure 13 Dupont wave



Stream Definition

Stream 1: 100.00 %

Feed Water - FYP

Feed Parameters

Water Type: Well Water

Water Sub-type: SDI < 3

Solid Content

Turbidity: 0.00 NTU

Total Suspended Solids (TSS): 0.00 mg/L

SDI_{15}: 0.00

Temperature

Minimum	Design	Maximum
10.0 °C	25.0 °C	40.0 °C

pH @25.0°C: 7.00

pH @25.0°C: 7.00

Organic Content

Organics (TOC): 0.00 mg/L

Additional Feed Water Information

Cations

Symbol	mg/L	ppm $CaCO_3$	meq/L
NH_4	0.000	0.000	0.000
K	0.000	0.000	0.000
Na	25.786	56.131	1.122
Mg	90.000	370.617	7.406
Ca	116.000	289.688	5.789
Sr	0.000	0.000	0.000
Ba	0.000	0.000	0.000

Total Cations: 231.786 14.316

Anions

Symbol	mg/L	ppm $CaCO_3$	meq/L
CO_3	0.742	1.238	0.025
HCO_3	660.310	541.558	10.822
NO_3	3.800	3.067	0.061
Cl	47.000	66.343	1.326
F	0.000	0.000	0.000
SO_4	100.000	104.188	2.082
Br	0.000	0.000	0.000
PO_4	0.000	0.000	0.000

Total Anions: 811.853 14.315

Neutrals

Symbol	mg/L
SiO_2	25.000
B	0.000
CO_2	78.082

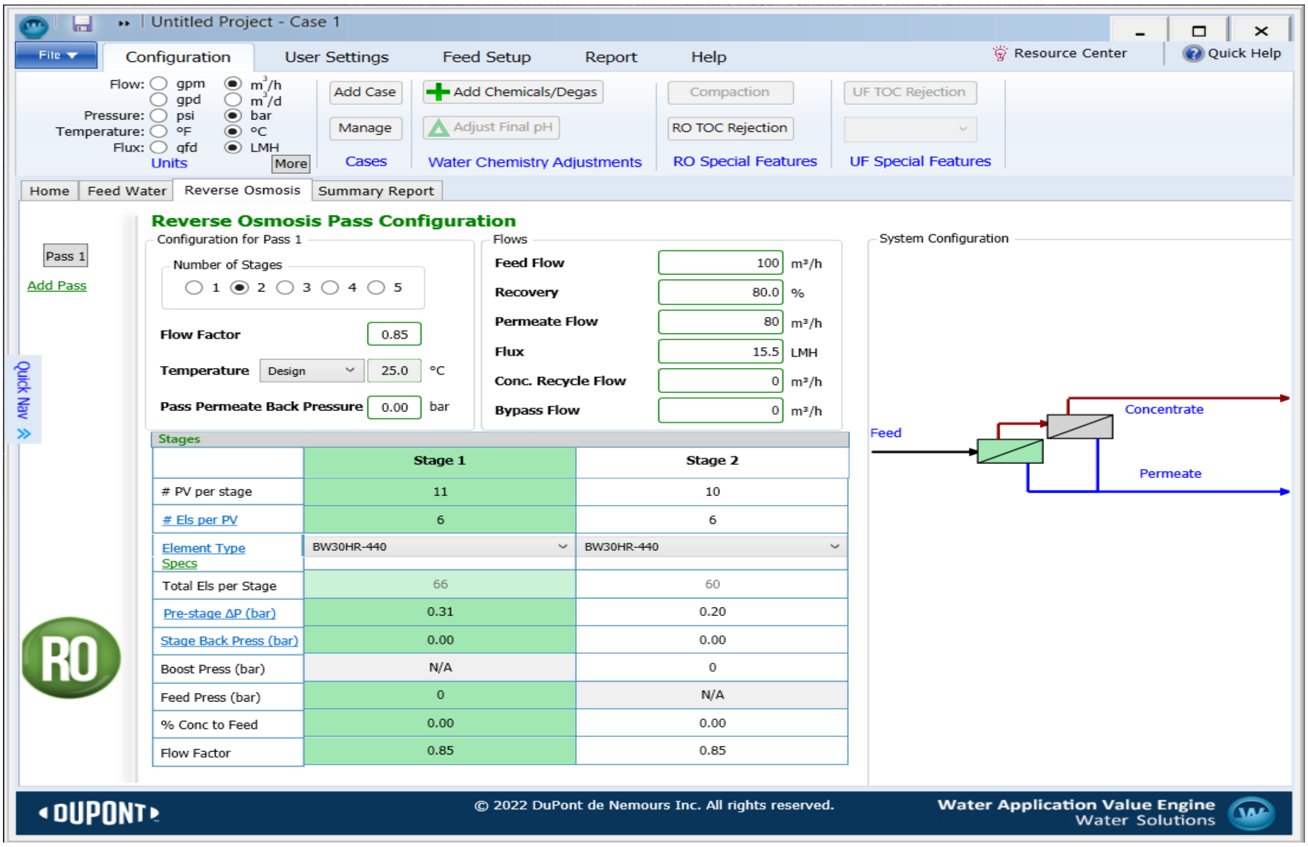
Total Neutrals: 103.082

Total Dissolved Solids : 1,068.670 mg/L

Charge Balance: -0.000027 meq/L

Estimated Conductivity: 1,319.15 µS/cm

Figure 14 Data on Dupont Wave



Flow: ○ gpm ○ gpd ● m³/h ○ m³/d
Pressure: ○ psi ● bar
Temperature: ○ °F ● °C
Flux: ○ qfd ● LMH

Reverse Osmosis Pass Configuration

Configuration for Pass 1

Number of Stages: ○ 1 ● 2 ○ 3 ○ 4 ○ 5

Flow Factor: 0.85

Temperature: Design 25.0 °C

Pass Permeate Back Pressure: 0.00 bar

Flows

Feed Flow: 100 m³/h

Recovery: 80.0 %

Permeate Flow: 80 m³/h

Flux: 15.5 LMH

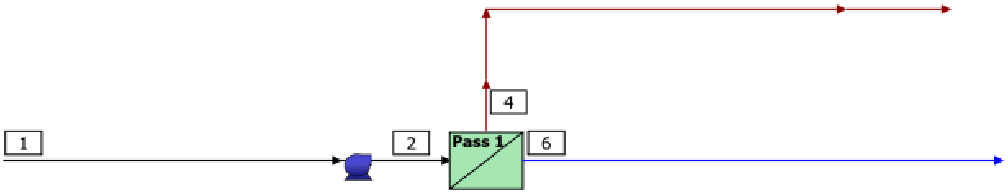
Conc. Recycle Flow: 0 m³/h

Bypass Flow: 0 m³/h

Stages

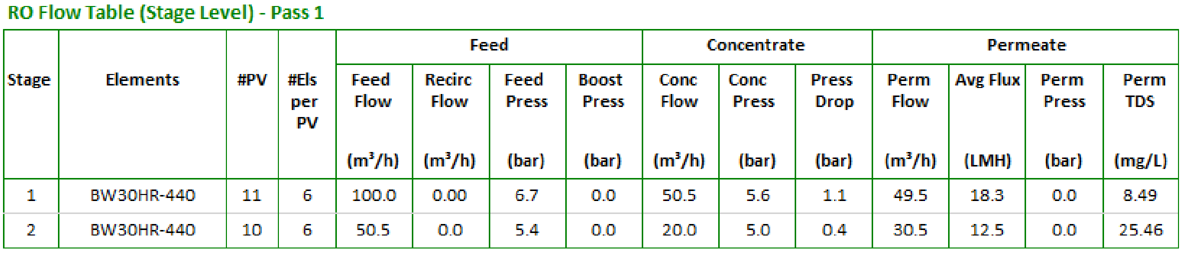
	Stage 1	Stage 2
# PV per stage	11	10
# Els per PV	6	6
Element Type Specs	BW30HR-440	BW30HR-440
Total Els per Stage	66	60
Pre-stage ΔP (bar)	0.31	0.20
Stage Back Press (bar)	0.00	0.00
Boost Press (bar)	N/A	0
Feed Press (bar)	0	N/A
% Conc to Feed	0.00	0.00
Flow Factor	0.85	0.85

RO System Flow Diagram



#	Description	Flow (m³/h)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to RO System	100.0	1,069	0.0
2	Net Feed to Pass 1	100.0	1,069	7.0
4	Total Concentrate from Pass 1	20.0	5,265	5.0
6	Net Product from RO System	80.0	14.89	0.0

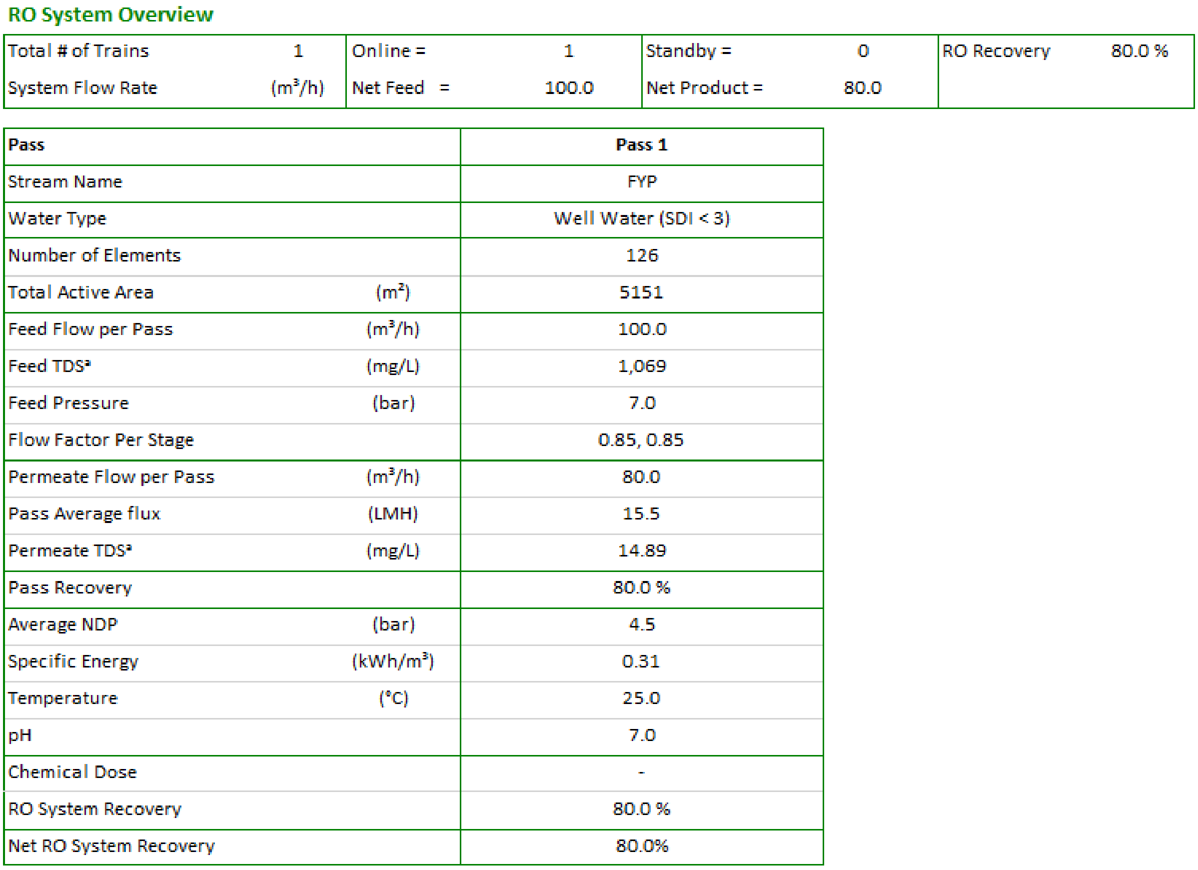
Figure 15 Flow Diagram On Dupont



RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow (m^3/h)	Recirc Flow (m^3/h)	Feed Press (bar)	Boost Press (bar)	Conc Flow (m^3/h)	Conc Press (bar)	Press Drop (bar)	Perm Flow (m^3/h)	Avg Flux (LMH)	Perm Press (bar)	Perm TDS (mg/L)
1	BW30HR-440	11	6	100.0	0.00	6.7	0.0	50.5	5.6	1.1	49.5	18.3	0.0	8.49
2	BW30HR-440	10	6	50.5	0.0	5.4	0.0	20.0	5.0	0.4	30.5	12.5	0.0	25.46

Figure 16 Pass parameters for RO



RO System Overview

Total # of Trains	1	Online =	1	Standby =	0	RO Recovery	80.0 %
System Flow Rate	(m^3/h)	Net Feed =	100.0	Net Product =	80.0		

Pass		Pass 1
Stream Name		FYP
Water Type		Well Water (SDI < 3)
Number of Elements		126
Total Active Area	(m^2)	5151
Feed Flow per Pass	(m^3/h)	100.0
Feed TDS[a]	(mg/L)	1,069
Feed Pressure	(bar)	7.0
Flow Factor Per Stage		0.85, 0.85
Permeate Flow per Pass	(m^3/h)	80.0
Pass Average flux	(LMH)	15.5
Permeate TDS[a]	(mg/L)	14.89
Pass Recovery		80.0 %
Average NDP	(bar)	4.5
Specific Energy	(kWh/m^3)	0.31
Temperature	(°C)	25.0
pH		7.0
Chemical Dose		-
RO System Recovery		80.0 %
Net RO System Recovery		80.0%

RO Solute Concentrations - Pass 1

Concentrations (mg/L as ion)						
		Concentrate		**Permeate**		
	Feed	**Stage1**	**Stage2**	**Stage1**	**Stage2**	**Total**
NH_4^+	0.00	0.00	0.00	0.00	0.00	0.00
K^+	0.00	0.00	0.00	0.00	0.00	0.00
Na^+	25.79	49.59	118.4	1.47	4.56	2.65
Mg^{+2}	90.00	177.9	448.5	0.21	0.68	0.39
Ca^{+2}	116.0	229.3	577.9	0.30	0.98	0.56
Sr^{+2}	0.00	0.00	0.00	0.00	0.00	0.00
Ba^{+2}	0.00	0.00	0.00	0.00	0.00	0.00
CO_3^{-2}	0.74	3.24	23.88	0.00	0.00	0.00
HCO_3^-	660.3	1,298	3,221	5.89	17.21	10.13
NO_3^-	3.80	7.49	18.76	0.03	0.10	0.06
F^-	0.00	0.00	0.00	0.00	0.00	0.00
Cl^-	47.00	92.87	234.0	0.15	0.48	0.27
Br^{-1}	0.00	0.00	0.00	0.00	0.00	0.00
SO_4^{-2}	100.0	197.8	499.1	0.13	0.44	0.25
PO_4^{-3}	0.00	0.00	0.00	0.00	0.00	0.00
SiO_2	25.00	49.18	122.7	0.31	1.00	0.57
Boron	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	78.08	79.64	87.52	77.58	82.12	79.35
TDS[a]	1,069	2,105	5,265	8.49	25.46	14.89
Cond. µS/cm	1,319	2,461	5,589	13	31	19
pH	7.0	7.2	7.5	5.1	5.5	5.3

CHAPTER 13

RESULTS

Comparing results of water quality parameters of reverse osmosis and ion exchange treatment it can be concluded that both methods can provide a similar level of water treatment according to the requirements to the water suitable for use in High-Pressure Boilers. Past research findings have shown that RO and IO systems generate efficiency in lowering TDS, conductivity, and specific ions like hardness and silica to achieve regulatory standards. Consequently, as pertains to the achievement of water quality goals there is not a significant amount of difference between the two processes since the nature of contaminants targeted for removal may slightly differ.

The LOLR comparative analysis revealed that one of the primary differences in operating costs between RO and IO systems is the operating cost. The operating costs differ in terms of energy consumption and usage of chemicals between the two systems in general, with RO systems being more favorable than the IO systems. As the present work has shown, RO systems require low levels of energy, particularly when water sources contain elevated levels of salts; thus, the energy cost for the operation of the system will be substantially lower in the long run. Moreover, high chemical utilization is observed in RO systems than in IO systems, where chemicals referred to as regenerants regenerates resins, contributing to functional costs. Due to the higher unit cost of operations, the adoption of IO systems makes the use of RO as a profitable model for demineralized water production for high-pressure boilers.

Both RO and IO systems share much in demand for space and infrastructures needed to establish such systems for operations and installation. RO systems are made up of membrane unit, high pressure pump, pre-treatment unit and control instruments while IO system is made up of ion exchange vessels, regeneration assets, flow meter and analyzer. These two processes are flexible to accommodate different space requirements and organization and operations characteristics, primarily with concerns to their scalability, modularity, and compatibility with existing structures.

In both RO and IO systems, reliability and maintenance and downtime importance are much similar though challenges difference where it is crucial to follow the right operation as well as maintenance that will enable enhancement of the systems performance and durability. The membrane in a RO system may foul or scale on the surface, or even deteriorate slowly, so that the system must be cleaned and/or the membrane replaced from time to time. Likewise, the IO systems need regeneration of resins to restore ion exchange and associated capacity. But it should be noted that there are corresponding maintenance processes for both systems: while the differences between cases of downtime and frequencies of routine maintenance are low if everything is monitored and performed correctly.

The environmental impact of RO and IO systems, including energy consumption and waste generation, is comparable, with both processes aiming to minimize resource consumption and environmental footprint. In terms of energy efficiency, RO systems use less energy than IO systems in average creating outcomes to lesser carbon discharge and hence less environmental degradation. It is important to note that IO systems often produce waste brine during regeneration, however adequate disposal and treatment steps can help lessen harming the environment. In conclusion, it is necessary to underline that both processes aim at making the operations effective while preserving and prioritizing the environmental concerns global improvement perspectives.

Concerning flexibility, RO, and IO both have the prospects for altering the feedwater qualities, its rates, and systems' functionality. Polymerization and depolymerization of RO systems is possible because of modularity; and this means that the demand of water treatment at any given time is met since modularity allows for changes to be made to meet the new demands as they emerge. Similarly, IO systems may include more than one resin vessel or treatment trains where the kind and characteristics of feedwater or the production rate may demand changes in process. While it is impossible to overemphasize the importance of scalability and flexibility concerns, the difference in costing between traditional open-roller and new-generation ios systems arrests another key different of a technological option and implementation.

13.1 Limitations:

While the comparative analysis provided valuable insights into the performance, efficiency, and economic viability of reverse osmosis (RO) and ion exchange (IO) processes for demineralized water production in high-pressure boiler applications, several limitations should be considered: Despite the fact that some comparative analysis helped to identify the peculiarities of the effects, efficiency, and profitability of the used methods of reverse osmosis and ion exchange for obtaining demineralized water in the conditions of the high-pressure boiler, there are some limitations to Their application:

Assumption of RO Efficiency: By applying hypothesis H2, our study expected that for any given flow rate, the efficiency of RO systems would be higher, and the cost of operation lower than that of IO systems. It should be noted, however, that productivity can differ depending on the specifics of the feedwater and the configuration and conditions of the system used. Explorations may deviate slightly from our assumptions resulting to the need to corroborate through experimental and field research.

Sensitivity to Feedwater Quality: It is also important to take into consideration the quality of the feed water in terms of its TDS, hardness, silica, or any other contaminants that tend to impact on the performance of both RO and IO systems. It is imperative to note that the feedwater compositions and treatment objectives analysed represent average conditions while deviations in feedwater quality may positively or negatively impact the effectiveness of the treatment and performance of the water treatment plant system. Future analysis should extend these efforts by further challenging each of the developed processes with various feedwater conditions, to better understand their performance characteristics.

Complexity of Cost Analysis: Cost analysis primarily includes the costs of investing in capital equipment, day to day expenses, cost of maintaining the developed product throughout its lifespan and many other associated costs. However, it is critical to point out that operating cost is not the sole area which can differ between RO and IO systems; it is also important to take into consideration factors contributing to the overall cost of these systems such as engineering and installation costs which are influenced by many factors. Variability analysis and network sensitivity analysis may help to pinpoint the most influential costs and evaluate how variability affects cost results.

Generalization of Findings: The findings that has been used in the research are the information gathered from the similar works, prints, and reports. Despite the steps taken to review a broad range of sources and literature, it is important to note that some of the discussed findings should be taken with pin when applied to other applications or contexts. It is thus relevant to pay attention to peculiarities of design and development of the system, actual working conditions, as well as pertinent laws and regulations, which might vary depending on the specific study site; the nature of these factors might impact generality of the outcomes yielded.

Scope of Study: The prime concern of this research was to evaluate the efficiency and cost grounds for utilizing RO and IO processes in producing demineralized water for high-pressure boilers. Nevertheless, these outages represent typical water treatment procedures: it is important to note though that the ever-evolving list of other, easier, or more innovative methods such an electro-deionization (EDI) or membrane distillation were not taken into account. It could be beneficial to suggest more approaches and technologies for treatment in future investigations to get a broader picture of the current possibilities and to determine the applicability of the mentioned technologies to various situations.

13.2 Discussion

The discussion section reflects on the findings presented in the results and limitations sections, providing insights into the implications, significance, and areas for further research regarding the comparative analysis of reverse osmosis (RO) and ion exchange (IO) processes for demineralized water production in high-pressure boiler applications.

Comparative Analysis of RO and IO Systems

The comparative analysis thus concluded that both the RO and the IO options can successfully achieve the water quality standard that is appropriate for high-pressure boiler feedwater. Although the kinds and amounts of specific contaminants removed at the end was slightly different, overall quality of water treated by both processes was similar. This indicates that both RO and water softening technologies, within the context of IO systems, provide reasonable prospects for producing demineralized water, and contingent on organisational decision-making criteria such as the operational costs of implementing and maintaining both processes.

Major Difference in Operating Costs:

One of the revelations brought about by the analysis carried out in this study was the fact that the operating costs of RO and IO systems are considerably distinct. In terms of operating cost, the results indicated that the costs of the RO systems were comparatively lower than those of the IO systems, chiefly because of the variations in the energy and the chemical consumption. Another disadvantage related to the operational aspects is that IO systems consume a lot of energy during the regeneration of the resin phase and require chemical regenerants, which led to higher operational costs being identified. The reader would readily understand that RO system is cheaper overall than other forms of filtration systems that may be implemented in an industry.

13.3 Implications:

The analysis of the cost of the RO system basically points to the fact that it may be more effective to use the technology than the IO system for demineralized water production especially where use of high-pressure boiler is contemplated and where minimization of operating costs is the paramount concern. But when it comes to the conceptual comparison between RO and IO then the options should cover more aspects that are discussed next: Water quality objectives Feed water characteristics Systems reliability° Scalability. It is for this reason; stakeholders must evaluate the cost-benefit implication of technology investment by comparing initial costs of investing in technology and recurrent costs and determining whether to embrace technology investment or not.

Future Research Directions

Although our study offers insights on how suitable RO is to IO systems and the proportional costs of the former over the latter, future research could consider the following aspects. Future research could explore:

- Verification of the assumptions made based on specific parametric analysis related to the influence of changes of feed water conditions and RO system configuration on its efficiency and operating cost.
- Strategies for efficient use of energy, and chemicals in operating IO systems to enhance the cost proposition of the systems.

- Conducting comparative analysis of the novel water treatment technologies that can be classified under novel water treatment technologies for demineralized water production including Electro-deionization (EDI) and membrane distillation.
- Continuous development and verification of empirically based models of RO and IO systems used in larger scale industrial applications to gauge the systems' reliability, performance, and maintenance needs, over the course of several years.

  By addressing these research gaps and expanding our understanding of water treatment technologies, we can advance sustainable practices and enhance the efficiency and reliability of water treatment systems in high-pressure boiler applications.

CONCLUSION

Therefore, the broad cost consideration clearly demonstrates that Reverse Osmosis (RO) is more competent than Ion Exchange (IX). The major findings based on the analysis of the material balance indicate that there were no significant differences in the operational factors between the two technologies for each unit process. However, the cost analysis provided a clear indication that RO systems have several financial advantages. Although the capital cost of RO systems is higher than that of other water purification technologies, their long-term running costs are significantly lower. This is primarily due to the fact that RO systems require extraordinarily little maintenance and have a much longer lifespan compared to other systems. The reduced maintenance requirements stem from the robust design of RO systems, which minimizes downtime and extends operational efficiency over time. Additionally, the longer lifespan of RO systems means that the frequency of replacements and associated costs are reduced. This long-term cost efficiency is a critical factor in the overall assessment of water purification technologies. The financial benefits of RO systems are further enhanced by their ability to produce higher quality purified water, making them a safer and more reliable option. Consequently, from both an economic and operational standpoint, RO systems prove to be a more advantageous choice compared to IX systems. Moreover, RO systems offer better purified water quality because they have the capability to eliminate slightly larger varieties of the impurities, thus being more safe and secure. Most importantly, the use of chemical regenerants in RO systems has been minimized which signifies even more reduction in emissions and more operating cost. This difference translates to, half a million dollars, in overall cost elaborating the cost–effectiveness of RO systems. With respect to both, the economic and actual operational implementation, RO systems have been found to be much more advantageous and economical in comparison to the IX systems.

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