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RESEARCH ARTICLE

ASPEN PLUS CONCEPTUAL DESIGN OF BASIC RAW HARD WATER TREATMENT AND SOFTENING OPERATION

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ABSTRACT

Hard water can cause scaling concerns in pipes, turbines, boilers, and heat exchangers used in mining, oil and gas, and industrial applications. It also interferes with nearly every housekeeping chore, from laundry and dishwashing to bathing and personal hygiene. ENRTL-SR and PITZER property models in Aspen Plus V8.8 were chosen during the modelling and simulation of soft water production from a hypothesized hard water stream containing sand. Findings show that, under normal conditions, about 3 m3 of soft pure water can be generated from approximately 40 m3 of raw water using right unit configuration and treatment solvent proportion. Drawbacks which would have address several limitations faced during the simulation, as concluded, can be solved using suggested alternative software tools. Water treatment scientist should try to simulate the same process using Aspen Plus utilizing real data from an existing water treatment facility to correctly test for effectiveness of the software tool. Modification of several existing water treatment plants across the globe to soften water produced is recommended, given its suitability for both domestic and industrial use.

KEYWORDS

Water treatment, PITZER model, Hard water, Contaminated water, Water quality standards

1. INTRODUCTION

Water is mainly classified into natural waters (e.g., rain, sea, spring, lake, river and ocean), underground water (borehole and well) and treated water (distilled water, pipe borne water and chlorinated water), also used as solvent. It exists in liquid, solid or vapor form, being the most abundant (71% of the earth crust) substance known and is colorless, odorless and tasteless, with boiling and freezing points of 100°C and 0°C, respectively. It is neutral to litmus paper and as a test for water, it turns white anhydrous copper (II) tetraoxosulphate (VI) blue and blue cobalt (II) chloride, pink. Provision of safe and clean drinking water to communities has been a great challenge to the government and water treatment industries. Poor water quality is a threat to the health of people in most developing countries (WHO, 2022). Around 780 million people do not have access to clean and safe water and around 2.5 billion people do not have proper sanitation.

As a result, around 6-8 million people die each year due to water related diseases and disasters. Generally, raw (contaminated) water contains ions, color, offensive smell, chemical, biological bacteria, high pH, industrial waste, and debris and may likely be hard and turbid (Spellman, 2013). Treated water is defined as water free of those contaminants and hence is drinkable. Usually, a combination of the processes, such as desalination, flocculation, coagulation, sedimentation, filtration, membrane filtration, ultrafiltration, nanofiltration, reverse osmosis, ozonation and disinfection is used to produce treated drinking water (Aziz and Mustafa, 2019; Caratar et al., 2020; Kaleta and Puszkarewicz, 2019; Karimi et al., 2011). The choice of treatment operations depends on the quality and variability of the raw water source and the treatment objectives, which may vary for industrial applications as opposed to municipal needs (Limphitakphong et al., 2016; WHO, 2022).

Hard water is formed due to the presence of chlorides, sulphates and bicarbonates of calcium and magnesium in dissolved form in water or when water (such as river water, sea water and tap water) percolates through deposits of calcium and magnesium minerals (Dubey, 2022; Wurts, 1993). A traditional measure of the ability of water to react with soap or a measure of divalent ions (magnesium, calcium and/or iron) in water is termed 'water hardness' and is commonly expressed as mg $CaCO_3$/L. In essence, water hardness is customarily measured by chemical titration in mg/L or ppm, which are equivalent units. Water containing $CaCO_3$ at concentration < 60 mg/L = soft; 60-120 mg/L = moderately hard; 120-180 mg/L = hard and; >180 mg/L = very hard (Akram and Fazal-ur-Rehman, 2018; Kalash et al., 2015; Wurts, 1993).

Hard water affects the cleaning action of soap during laundry by forming insoluble scum with soap (Abeliotis et al., 2015). Hardness of water is damaging to the boilers and hot water pipes, as salt deposition occurs, which may lessen their effectiveness. Because it leaves a scaly residue on a container when it is boiled (Boyd, 2000). There is no grave health implication ascribed to taking hard water, except for its ability to change

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the pH balance of human skin. Instead, it serves as dietary supplement due to the presence of magnesium and calcium, also helping in teeth and bones strengthening (Dubey, 2022). Magnesium in water (Table 1) have positive effects on thrombocytes, smooth muscles, cardiac muscles cells, and in the activation of over 300 enzymes in addition to being a party to several metabolic processes (Czekala et al., 2011).

Table 1: Water Quality Standards (Dubey, 2022; NEC, 2018; Ranganathan and Suresh, 2011)

Parameter	Existing Standard
pH Color	8.5-9.2 ≤ 5 Hazen units
Taste	Agreeable
Odor	Unobjectable
Turbidity	≤ 1.5 NTU
Total Dissolved Solid (TDS)	500 mg/L
Total Suspended Solid (TSS)	25 mg/L
Total Hardness as $CaCO_3$ (Max)	200 mg/L
Surfactants	0.1 mg/L
Total Coliforms & E-coli (no. /100mL)	Absent
Biochemical Oxygen Demand (BOD)	6 mg/L
Chemical Oxygen Demand (COD)	10 mg/L
Conductivity	800 μs/cm
Sulphates	25 mg/L
Chloride	50 mg/L
Nitrate	10 mg/L
Fluoride	1 mg/L
Phosphates	0.5 mg/L
Iron (Fe)	≤ 0.2 mg/L
Manganese (Mn)	≤ 0.05 mg/L
Aluminum (Al)	≤ 0.10 mg/L
Magnesium (Mg)	50 mg/L
Calcium (Ca)	75 mg/L
Sodium (Na)	< 800 mg/L
Lead (Pb)	0.02 mg/L
Zinc (Zn)	0.02 mg/L
Copper (Cu)	0.05 mg/L
Free residual chlorine (Cl)	0.5-1.5 mg/L
Dissolved oxygen (O_2)	6 mg/L
Ammonia (NH_3)	0.05 mg/L

Methods of measuring the concentrations of impurities (e.g., metallic and non-metallic elements) in water displayed in Table 1 and their standards, are described in (FSI, 1999; Deshpande, 2010). To model any water treatment operation, most or some of the parameters in Table 1 must be reported. In addition, a group researchers describes a FORTRAN based calculator development in Aspen Plus software to evaluate water electrical conductivity and Langelier Saturation Index (LSI) (Matino et al., 2014). In-depth literature search has shown that, there is still none in existence, a simulated process to rid water of its hardness, besides the simulation carried out by (Usman et al., 2023). Though, had previously highlighted the use of the electrolysis technique to remove water hardness (Agostinho et al., 2012). Bulta and Michael on the other hand, expatiated on water hardness agents removal test (Bulta and Michael, 2019).

Softwares with features that supports wastewater treatment modelling and simulation are SourceTM, Aspen HYSYS, Aspen Plus, BioWin, GPS-X, STOAT, SSSP, WEST, EFOR and AQUASIM (Amrutha and Haseena, 2020; Komulainen and Johansen, 2021; Perez, 2014). SourceTM model is built in the ExtendSIM® model platform, which is an object-oriented platform designed to run time-series computations, also having several customized blocks for wastewater treatment (Perez, 2014). GPS-X modeling tool from Hatch Hydromantis covers wastewater treatment, sludge treatment, biogas production, biogas refining and liquefaction, while WEST modeling tool from DHI covers units operations in general wastewater treatment plant (WWTP) processing, wastewater treatment, sludge treatment and biogas production (Komulainen and Johansen, 2021). Perez states that BioWin, WEST and GPS-X have chemical species limitations and are incapable of producing a system-wide mass balance while Aspen Plus and HYSYS requires additional work to customize for wastewater process (Perez, 2014). Using the sewage treatment operation analysis over time (STOAT), Issa produced a design to optimize a WWTP (Issa, 2019). Design calculation of many units in water treatment plant (WTP) including primary clarifier, aeration tank, secondary clarifier, chlorination chamber, gravity thickener, anaerobic sludge digester and belt process filter using GPS-X were previously carried out by (Sakib 2022). Above all, Aspen Plus is the most commonly used software to model water treatment to enhance its quality (Juntunen et al., 2012; Roy, 2019).

In the literature, Aspen Plus simulation formerly conducted, entails either the recovery of some chemicals or the production of pure water from contaminated water. Modelling, simulation and optimization of water treatment instances using Aspen Plus or HYSYS includes: industrial spent caustic wastewater treatment by wet oxidation technique; models for sedimentation and biological reaction kinetics, common to wastewater treatment; a small-scale solar desalination plant characterized by 3 stages including feed pretreatment, structure and desalination technique and the final permeate and retentate outputs; design of organic wastewater treatment process that uses sulphuric acid (H2SO4) for pH adjustment after selecting the UNIFAC physical property method and; steady state adsorption-based treatment process for the removal of polycyclic aromatic hydrocarbons (PAHs) from sediments and seawater using electrolyte-NRTL thermodynamic model (Chandraseager et al., 2019; Sajjad and Rasul, 2015; Tian et al., 2017; Meramo-Hurtado et al., 2020).

In contrast, harmful chemical removal/recovery instances includes: ammonia (NH3), CO2 and hydrogen sulphide (H2S) removal from sour wastewater using 2 strippers; organic acid pollutant removal from industrial wastewater using RadFrac, heater and split block by selecting the NRTL physical property model and; methane production from a beer waste water treatment (Nabgan et al., 2016; Zeng et al., 2022; Abera, 2021). Since no existing study is available regarding Aspen Plus simulation of hard water treatment, we move to set the following objectives: one, to select an appropriate property model for a hard water treatment modelling and simulation in Aspen Plus; two, use a conceptualized compositions of hard water chemicals to represent the source (contaminated raw hard water) for the treatment process, based on literature composition assessment; three, line up relevant unit operations that will mimic conventional treatment stages using a specified feed stream operating conditions; four, generate the simulation result and run sensitivity test to optimize production; and five, carryout few basic calculations on some expert-defined water treatment property set. With this, modelling and simulation of the reverse osmosis, nanofiltration or membrane filtration, distillation, ultrafiltration, electromagnetic method, chemical precipitation and chemical exchange techniques (Appendix A), among others to soften hard water can be examined in the same manner (Chemil et al., 2021; Nabulsi and Al-Abbadi, 2014; Padarev and Peneva, 2018; Sowgath and Mujtaba, 2017).

2. Methodology

Aspen Plus version 8.8 was used to model the production of clean water from raw and hard water, using the fundamental knowledge described in (Al-Malah, 2016). The contaminated raw water that was fed to the plant contains sand (taken as SiO_2) and other chemicals that characterizes it as hard water. Tank model in Aspen Plus was used to represent or model the aeration chamber and purified water storage reservoir. Mixers were used to thoroughly mix treatment chemicals as well as sludge.

2.1 Process Selection

In Aspen Plus V8.8, 'Chemical Simulation with Metric Units' was chosen as the basic unit in which the stream properties would be reported. It is clearly a chemical process, where a symmetric electrolyte NRTL model with Redlich-Kwong equation of state and Henry's law for electrolyte systems under symmetric reference state for all components (ENRTL-SR) was selected as the base property method for this simulation. ASME 1967 steam table correlations (STEAM-TA) was chosen as the free-water method option. Because pH is a very important parameter to track in every stage of water treatment, PITZER model was selected as the 'Reference' property method to accurately predict the pH of the streams.

Other models like the Electrolyte NRTL-Redlich-Kwong (NRTL-RK), Universal Quasi-Chemical Activity Coefficient-Redlich-Kwong (UNIQAC-RK), Specific Ion Interaction Theory (SIT), AQUEOUS model and PHRQ (PHreeQC) were tried too, in order to obtain the best pH prediction.

Stream/mixture density, viscosity, surface tension, pH, thermal conductivity, mass & mole concentrations of components in a mixture/stream and mass & mole flow of chlorine atoms, are additional property sets in Aspen Plus that were added to the TXPORT physical property set selected as part of stream result report (for solid, liquid, vapor and free-water valid phases) (Meramo-Hurtado et al., 2020).

2.2 Unit and Feed Specification

Entire components or compounds that characterize the water treatment plant are listed in Table 2, in which their solubility and appearance are shown. The knowledge of the chemical formula and phases/form of the components that characterize the simulation was used to select valid phases for inputs of specified streams.

Table 2: Physical and Chemical Properties of Component Feed

Chemical	Formula	Boiling point (°C)	Molecular weight (kg/mol)	Solubility	Appearance (Form)
Raw Hard Water					
Calcium sulphate	CaSO4	163	172.17	0.26 g/100 mL (at 25°C)	White powder
Magnesium sulphate	MgSO4	330	120.366	700 g/1L (at 25°C)	Colorless crystalline powder
Calcium carbonate	CaCO3	899	100.0869	0.013 g/L (at 25°C)	White odorless powder or colorless crystals
Magnesium carbonate	MgCO3	333.6	84.3139	0.0139 g/100 mL (at 25°C)	White powder
Calcium chloride	CaCl2	1935	110.98	74.5 g/100 mL (at 20°C)	Solid white
Magnesium chloride	MgCl2	1412	95.211	54.3 g/100 mL (at 20°C)	White or colorless crystalline solid
Water	H2O	100	18	-	Colorless
Sand (silicon oxide)	SiO2	2230	60.08	Insoluble	Transparent solid (whitish yellow)
Treatment Chemicals					
Aluminum sulphate	Al2(SO4)3	101.111	342.15	36.4 g/100 mL (at 20°C)	White crystalline solid or colorless liquid
Calcium hydroxide	Ca(OH)2	2850	74.093	0.185 g/100 mL (at 25°C)	White powder
Sodium hypochlorite	NaOCl	101	74.44	29.3 g/100 mL (at 0°C)	Pale greenish yellow dilute solution
Atmospheric Air					
Carbon dioxide	CO2	-78.46°C	44.01	0.1449 g/100 mL (at 25°C)	Colorless gas
Nitrogen	N2	-195.8°C	28.0134	0.015 g/L (at 20°C)	Colorless gas
Oxygen	O2	-183°C	31.999	0.00122 mol/dm3 (at 25°C)	Colorless gas
Argon	Ar	-185.8°C	39.948	62 mg/L (at 20°C)	Colorless gas

As shown in Table 2, the feeds to the process are divided into three, namely, raw hard water feed stream, treatment chemicals and atmospheric air. A stream tagged RAWH2O-A was used to represent the contaminated hard water mixture containing sand, water and other minerals (calcium and magnesium salts). The treatment chemicals consist of Al2(SO4)3 for coagulation, Ca(OH)2 for pH adjustment and NaOCl for disinfection, fed at 25°C and 1 atm through 'ALUM', 'LIME' and 'NAOCL' streams respectively. S-H2O (Table 3) was tagged service water stream. It is a clean water that was used to dilute or dissolve lime before feeding it as slurry for pH adjustment.

Table 3: Feed Streams Specifications

Stream	**Flow in**	**Valid Phase**	**Stream Condition**
AIR	100 kmol/h	Vapor	20°C & 1 atm
RAWH2O-A	1×10^6 L/day	Liquid-FreeWater	25°C & 1 atm
S-H2O	100000 L/day	Liquid	25°C & 1 atm
ALUM	50,000 L/day	Liquid	25°C & 1 atm
LIME	50,000 L/day	Liquid	25°C & 1 atm
NAOCL	50 kg/h	Liquid	25°C & 1 atm

As specified in Aspen Plus for stream 'AIR', mole fractions of O_2, Ar, N_2 and CO_2 are 0.2095, 0.0092, 0.7809 and 0.004 respectively – a typical composition of air at ambient temperature. Mass fraction of species in RAWH2O-A stream were specified and are precisely 0.5 H_2O, 0.05 $CaCO_3$, 0.05 $MgCO_3$, 0.01 $CaSO_4$, 0.01 $MgSO_4$, 0.025 $CaCl_2$, 0.025 $MgCl_2$ and 0.33 SiO_2. These weight percents was conceptualized in this research, since there is no range or exact amount in which the chemicals in hard water can be found. In essence, the number of chemicals as well as their concentrations vary in a typical hard water, because not all elements of hard water give it its characteristic hardness. The presence of one or two hard water chemicals is enough to call it hard water. For example, a group researcher previously prepared an artificial hard water by mixing 288 mg $CaCl_2$, 220 mg $MgSO_4.7H_2O$ and 390 mg $MaHCO_3$ in 1 dm^3 of distilled water (Hettiarachchi et al., 2017). On the other hand, reports the chemical composition for the preparation of various categories of hard water (Ahn et al., 2018). Except for the FILTER unit, all other unit operations in this work were initialized by specifying the unit temperature and pressure, as shown in Table 4.

Table 4: Unit Inputs and Expected Calculations

No.	Unit	Input	Valid Phases	Expected Measured Variable
1.	AERATOR	T = 25°C P = 1 atm	Liquid-FreeWater	(1) Outlet Temperature (2) Outlet Pressure (3) Vapor Fraction (4) Heat Duty (5) Net Duty (6) 1st Liquid/Total Liquid
2.	DECANTER	T = 25°C P = 1 atm	Vapor-liquid-FreeWater	
3.	FILTER	FSSO = 1 FLLO = 1 SS = 0.8 OFF = 0.001 OFT = 25°C OFP = 1 atm	Vapor-liquid	(1) FSSO (2) FLLO (3) SLLO (4) LLSO (5) Heat Duty
4.	MIXER-1	TE = 25°C P = 1 atm	Vapor-liquid	(1) Outlet Temperature (2) Outlet Pressure (3) Vapor Fraction (4) 1st Liquid/Total Liquid
5.	MIXER-2	TE = 25°C P = 1 atm	Liquid-FreeWater	
6.	MIXER-3	P = 1 atm	Vapor-liquid-FreeWater	
7.	RESERVOIR	P = 0 bar	-	

T = temperature, FSSO = fraction of solids to solid outlet, FLLO = fraction of liquid to liquid outlet, SS = separation sharpness, OFF = offset of fines, OFT = outlet flash temperature, OFP = outlet flash pressure, SLLO = solid load of liquid outlet, LLSO = liquid load of solid outlet and TE = temperature estimate

After specifying all feed and unit requirements, the modelled flow diagram was run, which converges with no apparent warning or error in the simulation carried out using Aspen Plus. Error tolerance and maximum iterations specified for all 7 units in Table 3 were respectively 10^{-4} and 30.

2.3 Overall Process Description

A water treatment process simulation, consisting of 7 process units, 6 input streams and 3 exit streams was modelled using Aspen Plus V.8.8. The raw feed (RAWH2O-A) as described above, was charged to a tank called AERATOR. An AIR stream was channeled to the AERATOR to contact with the dirty water to reduce its possible odor characteristics. LIME is mixed with pure water (S-H2O) in MIXER-2 to form a lime slurry (L-SLURRY) exit stream. Aerated water (RAWH2O-B) or exit of the AERATOR tank, a separate ALUM feed stream and the L-SLURRY stream were brought together as mixed liquid solution in MIXER-1. MIXER-1 exit or COG-RH2O is a coagulated raw hard water, with presumably the right pH, dissolved oxygen (air) to go into the clarification/sedimentation process unit. 'Flash2' in Aspen Plus model palette (named DECANTER), was used to represent a simple decantation process; with vapor, liquid and free-water outputs (Thermo-012, 2012; Anwar, 2011). Air was exited through the vapor stream of the DECANTER (as ODOR-AIR).

Sand and all mineral constituents of COG-RH2O is expected to exit as the liquid stream or heavy settled flocs through the DECANT stream. Clear water (CLR-H2O) was channeled as FreeWater from the DECANTER to a FILTER. A SOLID stream is expected to exit smaller/negligible volume of solids trapped in the FILTER. Second FILTER exit stream or LIQUID contains filtered water and was sent to another tank named RESERVOIR. A disinfectant chemical via NAOCL feed stream was fed to the reservoir tank, as chlorination is the most commonly used disinfection process according to (WHO, 2017). The resulting stream from the tank is PURE-H2O with residual chlorine disinfectant which is not detrimental to human and animals, if consumed. The DECANT and SOLID streams are byproducts of the DECANTER and FILTER respectively and was mixed in MIXER-3 to be disposed off as SLUDGE wastewater stream.

2.4 Sensitivity Analysis

Sensitivity analysis affords operators of mathematical and simulation models with tools to appreciate the reliance of the model output on the model input, and to explore how imperative each model input is, in defining its output. Some of these input parameters and variables may be unknown, unspecified, or defined with a large imprecision range. Inputs include engineering or operating variables, variables that describe field conditions, and variables that include unknown or partially known model parameters (Saltelli, 2002). In view of that, several sensitivity analysis sets were defined under the 'Model Analysis Tool' in Aspen Plus, where the input block conditions in Table 4 as well as input flows in Table 3 were manipulated against the expected output results. In that order; input variables were varied between a specified range under the 'Vary' tab, parameter to measure was selected in the 'Define' tab and the display type of the expected outcome is selected under the 'Tabulate' tab. The simulation was re-run to see if it converges. All sensitivity results obtained were plotted using ORIGIN 2018 statistical and analytical software.

2.5 Chlorine Consumption Rate

Using Equation 1 given by Sakib, daily consumption of chlorine (DCC) (kg/day), was computed (Sakib, 2022).

$$DCC = \frac{Q_A \times C_{Cl,\ a}}{1000} \tag{1}$$

Where, Q_A = average flowrate for each clarifier (MLD) and $C_{Cl,\ a}$ = assumed average chlorine dosage (mg/L).

The reference disinfectant in this work (i.e., NaOCl) will be used to solve for DCC.

2.6 Calcium and Magnesium Concentration

To convert total hardness in terms of mg CaCO3/L to mg Calcium/L, Equation 2 given was used (Akram and Fazal-ur-Rehman, 2018):

Total hardness (mg CaCO3/L) = 0.4 × Calcium hardness (mg Calcium/L) (2)

Magnesium hardness was then computed according to Equation (3) (Hettiarachchi et al., 2017; Shareef et al., 2015).

Magnesium hardness (mg Mg/L) = Total hardness – Calcium hardness (3)

An alternative form of Equation (3) is presented as Equation (4), as obtained in (Koskela, 2016):

[CaCO3] = 2.5 [Ca] + 4.1 [Mg] (4)

where, [CaCO3] = concentration of CaCO3 (mg/L), [Ca] = calcium concentration (mg/L) and [Mg] = magnesium concentration (mg/L).

It is worthy of note that practical estimate of calcium amount can be carried out using AAS, ICP and EDTA titrimetric methods, while magnesium amounts are estimated by AAS, ICP and gravimetric method (Deshpande, 2010). This study only employed Equations 2 and 3 in the determination of the amounts of the water hardness chemicals.

2.7 Percent Removal

Removal rate of hardness, R (%), was determined using Equation (5) given by (Kalash et al., 2015; Tang et al., 2021);

$$R = \frac{C_{before\ softening} - C_{after\ softening}}{C_{before\ softening}} \times 100 \tag{5}$$

where, $C_{before\ softening}$ = feed concentration (ppm) and $C_{after\ softening}$ = effluent concentration (ppm).

3. Results and Discussion

3.1 Process Model

As explained in the methodology, Figure 1 is the overall process flow diagram derived from the interpretation of the process description. This system was able to model the aerator, chemical mixing tanks, decanter, filter and reservoir, in the order in which it is mentioned.

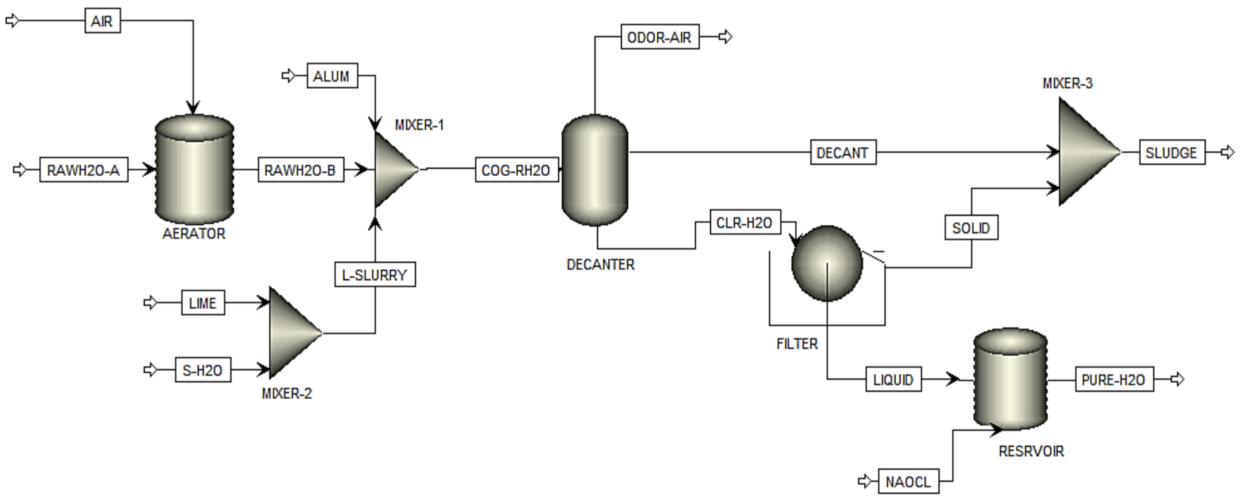

Figure 1: Sandy Hard Water Treatment Process Flow Diagram Modeled in Aspen Plus

Since no heavy contaminants such as sticks, leather, fish, leaves and/or debris of foreign matter present in the raw hard water, the need to have a screening section or chamber is eliminated. MIXER-1 and MIXER-2, as shown in Figure 1, try to mimic typical chemical mixers; especially those found in Mada Water Works, as described by (Abubakar et al., 2022). However, in this work, NaOCl requires no mixing and is fed directly to the filtered water stored in the RESERVOIR unit. Since majority of clarifiers are open basins, an air removal stream (ODOR-AIR) illustrates the elimination of odor. Except for this research, another demonstration of the removal of gaseous component from contaminated water is in the simulation carried out by where H2S, CO2 and NH3 in sour wastewater were removed using 2 strippers in Aspen Hysys V8.8 (Nabgan et al., 2016). This design also ensures that no solid is trapped by the FILTER whose feed is a FreeWater and so points to a 100% efficient filtration process. Such efficiency value is very high compared to conventional filter systems with efficiencies around 90-99+% and lower (Bulta and Michael, 2019). According to a study efficiency of wastewater treatment schemes differs and relies on the wastewater condition and system design (Limphitakphong et al., 2016).

3.2 Materials Flows

Six essential input streams and 3 required outlet streams is contained in this design, as depicted in Table 5.

Table 5: Total Feed Flowrates and Output Flow Results

S/No.	Feed Stream	Flow rate (m^3/h)	S/No.	Outlet Stream	Flow rate (m^3/h)
1.	AIR	2404.23	1.	ODOR-AIR	2441.01
2.	RAWH2O-A	41.667	2.	SLUDGE	40.912
3.	LIME	2.083	3.	PURE-H2O	3.053
4.	S-H2O	4.167			
5.	ALUM	2.083			
6.	NAOCL	0.088			

About 41.667 m^3/h (1000.008 m^3/day) of raw hard water was treated using the scheme shown in Figure 1, resulting in 3.053 m^3/h (73.272 m^3/day) of purified water. In mass flowrates equivalent, more sludge (9517.97 kg/h) is discharged as waste stream. A 25.0748% decrease in the sludge weight is equivalent to 7131.36 kg/h of raw hard water fed ab initio, which produces 7750.88 kg/h of pure water stream (PURE-H2O). This is because, sand and mineral compounds in stream RAWH2O-A, together make up 50% of the contaminated raw hard water. The designed capacity in this work (73.272 m^3/day of clean water), may be categorized as a small-scale plant for a very small population. Previous surface water (source: Greater-Zan River) treatment plant design for a population of 200,000 people in Erbil City, Iraq, has a discharge capacity of only 60,000 m^3/day (Aziz and Mustafa, 2019). Higher than this, are 429,000 m^3/day secondary treatment wastewater treatment plant (WWTP), Zenien, and the 150,000 m^3/day 6th October tertiary WWTP, both in Cairo, Egypt (Al-Dosary et al., 2015). Detailed summary results generated from Aspen Plus are depicted in Tables 6-10.

Table 6: Summary of Property Set Calculated by Aspen Plus

	AIR	RAWH2O-A	LIME	S-H2O	RAWH2O-B	L-SLURRY	ALUM	COG-RH2O
Temperature (C)	20	25	25	25	25	25	25	11.1
Pressure (bar)	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013
Vapor Frac	1	0	0	0	0	0	0	0.164
Mole Flow (kmol/h)	100	249.48	6.957	230.63	349.48	237.587	15.816	602.882
Mass Flow (kg/h)	2896.46	7131.359	515.455	4154.866	10027.82	4670.322	5411.349	20109.49
Volume Flow (m^3/h)	2404.228	41.667	2.083	4.167	45.09	6.25	2.083	2360.363
Enthalpy (Gcal/h)	-0.007	-24.58	-1.063	-15.745	-24.791	-16.808	-11.228	-52.827
Density (kg/m^3)	1.205	171.153	247.419	997.168	222.397	747.255	2597.448	355.04
Density (mol/L)	0.042	5.988	3.339	55.351	7.751	38.014	7.591	10.367
Viscosity (Ns/m^2)	-	-	0.045	0.001	-	-	< 0.001	1.392
Surface Ten (N/m)	< 0.001	-	0.067	0.073	-	-	0.017	0.092
MASSFLCL (kg/h)	-	-	-	0	246.677	0	0	246.677
MOLEFLCL (kmol/h)	-	-	-	0	6.958	0	0	6.958

Table 6: Summary of Property Set Calculated by Aspen Plus

	ODOR-AIR	CLR-H2O	DECANT	SOLID	SLUDGE	LIQUID	NAOCL	PURE-H2O
Temperature (C)	25	25	25	-	25	25	25	25
Pressure (bar)	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013
Vapor Frac	1	0	0	-	< 0.001	0	0	0
Mole Flow (kmol/h)	99.823	427.464	75.596	0	75.596	22.507	0.672	23.179
Mass Flow (kg/h)	2890.64	7700.881	9517.969	0	9517.969	7700.881	50	7750.881
Volume Flow (m^3/h)	2441.006	7.723	40.912	0	40.912	2.965	0.088	3.053
Enthalpy (Gcal/h)	-0.006	-29.182	-23.431	-	-23.431	-15.978	-0.005	-15.983
Density (kg/m^3)	1.184	997.168	232.642	-	232.642	2597.448	565.122	2538.556
Density (mol/L)	0.041	55.351	1.848	-	1.848	7.591	7.591	7.591
Viscosity (Ns/m^2)	-	0.001	2.35E+17	-	2.35E+17	< 0.001	< 0.001	< 0.001
Surface Ten (N/m)	< 0.001	0.072	0.189	-	0.189	0.017	0.017	0.017
MASSFLCL (kg/h)	< 0.001	246.677	-	246.677	< 0.001	23.813	23.813	-
MOLEFLCL (kmol/h)	< 0.001	6.958	-	6.958	< 0.001	0.672	0.672	-

Table 7: Mass Flow of All Components in the Respective Streams of the Plant

Mass Flow (kg/h)	AIR	RAWH2O-A	LIME	S-H2O	RAWH2O-B	L-SLURRY	ALUM	COG-RH2O
ALUMI-01	-	-	-	-	-	-	5411.349	5411.349
H2O	-	3565.68	-	4154.866	3565.68	4154.866	-	7720.546
CACO3	-	356.568	-	-	356.568	-	-	356.568
MGCO3	-	356.568	-	-	356.568	-	-	356.568
CASO4	-	71.314	-	-	71.314	-	-	71.314
MGSO4	-	71.314	-	-	71.314	-	-	71.314
CACL2	-	178.284	-	-	178.284	-	-	178.284
MGCL2	-	178.284	-	-	178.284	-	-	178.284
NAOCL	-	-	-	-	-	-	-	-
CA(OH)2	-	-	515.455	-	-	515.455	-	515.455
SIO2	-	2353.349	-	-	2353.349	-	-	2353.349
O2	670.375	-	-	-	670.375	-	-	670.375
ARGON	36.752	-	-	-	36.752	-	-	36.752
N2	2187.573	-	-	-	2187.573	-	-	2187.573
CO2	1.76	-	-	-	1.76	-	-	1.76
	ODOR-AIR	**CLR-H2O**	**DECANT**	**SOLID**	**SLUDGE**	**LIQUID**	**NAOCL**	**PURE-H2O**
ALUMI-01	trace	-	5411.349	-	5411.349	-	-	-
H2O	0.789	7700.881	18.876	-	18.876	7700.881	-	7700.881
CACO3	trace	-	356.568	-	356.568	-	-	-
MGCO3	trace	-	356.568	-	356.568	-	-	-
CASO4	trace	-	71.314	-	71.314	-	-	-
MGSO4	trace	-	71.314	-	71.314	-	-	-
CACL2	trace	-	178.284	-	178.284	-	-	-
MGCL2	trace	-	1.78E+02	-	1.78E+02	-	-	-
NAOCL		-	-	-	-	-	50	50
CA(OH)2	trace	-	515.455	-	515.455	-	-	-
SIO2	trace	-	2353.349	-	2353.349	-	-	-
O2	667.519	-	2.855	-	2.855	-	-	-
ARGON	36.611	-	0.141	-	0.141	-	-	-
N2	2183.995	-	3.578	-	3.578	-	-	-
CO2	1.726	-	0.035	-	0.035	-	-	-

Table 8: Volume Flow of All Components in the Respective Streams of the Plant

Liq Vol 60F (m^3/h)	AIR	RAWH2O-A	LIME	S-H2O	RAWH2O-B	L-SLURRY	ALUM	COG-RH2O
ALUMI-01	-	-	-	-	-	-	-	-
H2O	-	3.573	-	4.163	3.573	4.163	-	7.735
CACO3	-	1.065	-	-	1.065	-	-	1.065
MGCO3	-	1.264	-	-	1.264	-	-	1.264
CASO4	-	0.157	-	-	0.157	-	-	0.157
MGSO4	-	-	-	-		-	-	-
CACL2	-	0.074	-	-	0.074	-	-	0.074
MGCL2	-	0.563	-	-	0.563	-	-	0.563
NAOCL	-	-	-	-	-	-	-	-
CA(OH)2	-	-	2.079	-	-	2.079	-	2.079
SIO2	-	0.6	-	-	0.6	-	-	0.6
O2	1.122	-	-	-	1.122	-	-	1.122
ARGON	0.049	-	-	-	0.049	-	-	0.049
N2	4.182	-	-	-	4.182	-	-	4.182
CO2	0.002	-	-	-	0.002	-	-	0.002
	ODOR-AIR	**CLR-H2O**	**DECANT**	**SOLID**	**SLUDGE**	**LIQUID**	**NAOCL**	**PURE-H2O**
ALUMI-01	-	-	-	-	-	-	-	-
H2O	0.001	7.716	0.019	-	0.019	-	-	-
CACO3	trace	-	1.065	-	1.065	-	-	-
MGCO3	trace	-	1.264	-	1.264	-	-	-
CASO4	trace	-	0.157	-	0.157	-	-	-
MGSO4	-	-	-	-	-	-	-	-
CACL2	trace	-	0.074	-	0.074	-	-	-
MGCL2	trace	-	5.63E-01	-	5.63E-01	-	-	-
NAOCL	-	-	-	-	-	-	-	-
CA(OH)2	trace	-	2.079	-	2.079	-	-	-
SIO2	trace	-	0.6	-	0.6	-	-	-
O2	1.117	-	0.005	-	0.005	-	-	-
ARGON	0.049	-	< 0.001	-	< 0.001	-	-	-
N2	4.175	-	0.007	-	0.007	-	-	-
CO2	0.002	-	< 0.001	-	< 0.001	-	-	-

Table 9: Mass Concentration of All Components in All 16 Streams of the Plant

Mass Conc (kg/m^3)	AIR	RAWH2O-A	LIME	S-H2O	RAWH2O-B	L-SLURRY	ALUM	COG-RH2O
ALUMI-01	-	-	-	-	-	-	2597.448	111.37
H2O	-	85.576	-	997.168	79.08	664.782	-	158.481
CACO3	-	8.558	-	-	7.908	-	-	7.338
MGCO3	-	8.558	-	-	7.908	-	-	7.338
CASO4	-	1.712	-	-	1.582	-	-	1.468
MGSO4	-	1.712	-	-	1.582	-	-	1.468
CACL2	-	4.279	-	-	3.954	-	-	3.669
MGCL2	-	4.279	-	-	3.954	-	-	3.669
NAOCL	-	-	-	-	-		-	-
CA(OH)2	-	-	247.419	-	-	82.473	-	10.608
SIO2	-	56.48	-	-	52.192	-	-	48.434
O2	-	-	-	-	14.868	-	-	0.517
ARGON	-	-	-	-	0.815	-	-	0.026
N2	-	-	-	-	48.516	-	-	0.648
CO2	-	-	-	-	0.039	-	-	0.005

Table 9: Mass Concentration of All Components in All 16 Streams of the Plant

	ODOR-AIR	CLR-H2O	DECANT	SOLID	SLUDGE	LIQUID	NAOCL	PURE-H2O
ALUMI-01	-	-	132.267	-	132.267	-	-	-
H2O	-	997.168	0.461	-	0.461	2597.448	-	2522.18
CACO3	-	-	8.715	-	8.715	-	-	-
MGCO3	-	-	8.715	-	8.715	-	-	-
CASO4	-	-	1.743	-	1.743	-	-	-
MGSO4	-	-	1.743	-	1.743	-	-	-
CACL2	-	-	4.358	-	4.358	-	-	-
MGCL2	-	-	4.36E+00	-	4.36E+00	-	-	-
NAOCL	-	-	-	-	-	-	565.122	16.376
CA(OH)2	-	-	12.599	-	12.599	-	-	-
SIO2	-	-	57.522	-	57.522	-	-	-
O2	-	-	0.07	-	0.07	-	-	-
ARGON	-	-	0.003	-	0.003	-	-	-
N2	-	-	0.087	-	0.087	-	-	-
CO2	-	-	0.001	-	0.001	-	-	-

Table 10: Thermal Conductivity of All Components in All 16 Streams of the Water Treatment Plant

K (Watt/m-K)	AIR	RAWH2O-A	LIME	S-H2O	RAWH2O-B	L-SLURRY	ALUM	COG-RH2O
ALUMI-01	-	-	-	-	-	-	0.067	0.07
H2O	-	0.606	-	0.606	0.606	0.606	-	0.586
CACO3	-	0.112	-	-	0.112	-	-	0.113
MGCO3	-	0.122	-	-	0.122	-	-	0.123
CASO4	-	0.096	-	-	0.096	-	-	0.097
MGSO4	-	0.114	-	-	0.114	-	-	0.118
CACL2	-	0.17	-	-	0.17	-	-	0.171
MGCL2	-	0.338	-	-	0.338	-	-	0.34
NAOCL	-	-	-	-	-	-	-	-
CA(OH)2	-	-	0.13	-	-	0.13	-	0.131
SIO2	-	2	-	-	2	-	-	2
O2	-	-	-	-	0.061	-	-	0.061
ARGON	-	-	-	-	0.04	-	-	0.04
N2	-	-	-	-	0.054	-	-	0.054
CO2	-	-	-	-	0.078	-	-	0.094
	ODOR-AIR	**CLR-H2O**	**DECANT**	**SOLID**	**SLUDGE**	**LIQUID**	**NAOCL**	**PURE-H2O**
ALUMI-01	-	-	0.067	-	0.067	-	-	-
H2O	-	0.607	0.606	-	0.606	0.067	-	0.067
CACO3	-	-	0.112	-	0.112	-	-	-
MGCO3	-	-	0.122	-	0.122	-	-	-
CASO4	-	-	0.096	-	0.096	-	-	-
MGSO4	-	-	0.114	-	0.114	-	-	-
CACL2	-	-	0.17	-	0.17	-	-	-
MGCL2	-	-	3.38E-01	-	3.38E-01	-	-	-
NAOCL	-	-	-	-	-	-	0.145	0.145
CA(OH)2	-	-	0.13	-	0.13	-	-	-
SIO2	-	-	2	-	2	-	-	-
O2	-	-	0.061	-	0.061	-	-	-
ARGON	-	-	0.04	-	0.04	-	-	-
N2	-	-	0.054	-	0.054	-	-	-
CO2	-	-	0.078	-	0.078	-	-	-

Mass and mole flow of chlorine atoms (MASSFL CL & MOLEFL CL) is 246.677 kg/h in RAWH2O-B, COG-RH2O and SOLID streams; < 0.001 kg/h in the SLUDGE and; 23.813 kg/h in both LIQUID and NAOCL streams (Table 6). In concentration equivalent, values reported here are significantly lower than standards in Table 1. Sodium hypochlorite gives the purified water its chlorine content, which is capable of lasting for about 24 hours only, forming less active hypochlorite ions. Its target is to eliminate E. coli and cyanotoxins from the water, whose presence can be traced to fecal contamination of water. A ratio of NAOCL:LIQUID stream or 50/7700.881 = 0.0065, which falls below the ratio acceptable (1:100) to disinfect water. In this work, NaOCl is used deliberately as the presence of bacteria in water cannot be modelled in Aspen Plus.

Due to low volume of water (0.019 m^3/h) in the SLUDGE stream, a very high viscosity of 2.35×10^{17} Ns/m^2 is too high when compared to 0.00239-0.03 Ns/m^2 (2.39-30 cP) reported by Komesli & Gokcay (2014) and 0.04-0.11 Ns/m^2 for municipal sewage sludge reported by (Wolski, 2021). This will pose serious discharge issues at the end of every treatment process. Though, such SLUDGE stream with high viscous property will be very easy to dewater, as it has only 18.876 kg/h (0.197%) water (Table 7); and may be channeled to growing crops. The SLUDGE is rich in minerals that characterized the original hard water fed. A total of 2.058 m^3/h of mineral compounds (Table 8) constituting 35.28% of the entire SLUDGE stream can serve as organic fertilizer, comparable to digestate from anaerobic digestion process. As obtained in Table 9, the presence of 8.558 kg/m^3 (8558 mg/L) of $CaCO_3$ in RAWH2O-A shows that the feedstock to the treatment plant is a hard water.

Alternatively, using a conversion factor of 0.4 (Equation 2), calcium hardness of the water used is equal to 3423.2 mg Calcium/L. Based on literature categorization, the raw water fed to the system is very hard as $CaCO_3$ concentration in it is >180 mg/L. Conductivity in water (Table 10) is a measure of the amount of dissolved substances (TDS) in the water and that water's ability to pass electricity. Inorganic dissolved solids include, ions that carry a negative charge such as sulfate, nitrate, chloride and phosphate anions and those that carry a positive charge, such as sodium, calcium, aluminum, magnesium and iron cations. Basically, due to the ability of dissolved salts and inorganic chemicals to conduct electrical current. Conductivity increases as salinity increases or the more the impurities in the water, the higher its conductivity. In view of that, RAWH2O-A, RAWH2O-B, COG-RH2O, DECANT and SLUDGE streams have the greatest ability to pass current, as they possess large composition of dissolved salts, as shown in Table 10.

3.3 Response Analysis Outcome

The sensitivity analysis carried out can be divided into 'Block' and 'Stream' sensitivity runs, following the specifications in Tables 3 and 4. Figure 3 shows the assessment result of few input flow values that was manipulated in the course of the Aspen Plus sensitivity analysis just described. A simple increase in the raw hard water stream mass flowrate (RAWH2O-A) from 7000-1000 kg/h, correspondingly increase the SLUDGE and PURE-H2O stream mass flows as evidenced in Figure 3a.

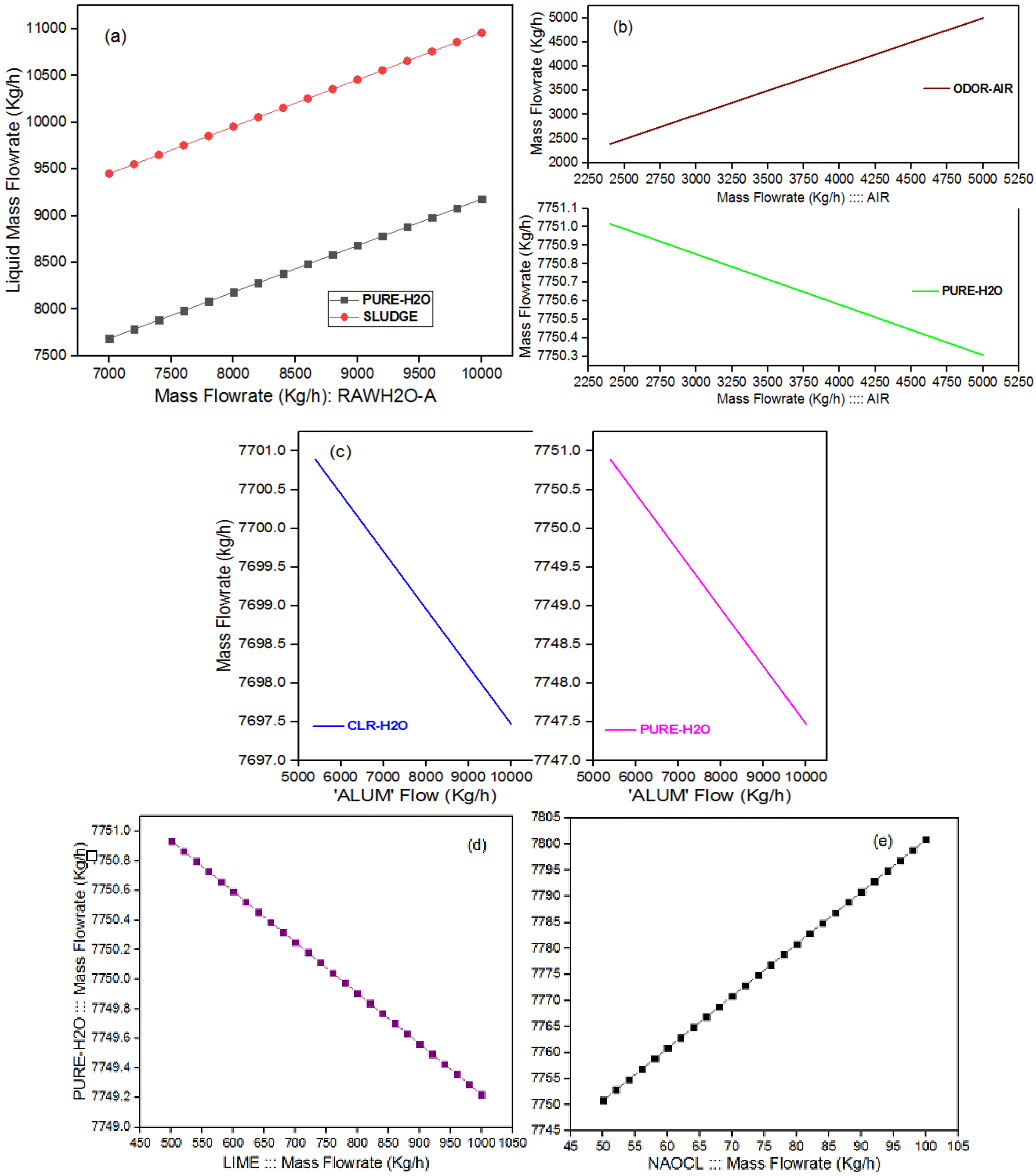

Figure 3: Feed Flow Manipulation Effect on Product Flow

It appears that the PURE-H2O stream mass flow is higher than the RAWH2O-A mass/volume flow specified over every step of the manipulation range. This is due to the addition of service water (S-H2O) via MIXER-2, which is already clean water, and so adds to the volume/mass of the purified water stream. Removal of the S-H2O stream or complete elimination/removal of MIXER-2 may give a lower treated water volume. This is just by the way, as S-H2O stream plus LIME allows for control of the pH of the raw water (RAWH2O-B), since the desirable amount of $Ca(OH)_2$ needed to neutralize the unclean water cannot be known. In Figure 3a, the SLUDGE weight (9452-10959 kg/h) is dependent on the mass flows of ALUM and LIME feed streams.

As observed in Figure 3b, the higher the AIR stream amount (as manipulated: 2400-5000 kg/h), the lower will be the weight of the ODOR-AIR stream, simply because, it oxidizes some of the metallic minerals supplied by the treatment chemicals, also eliminating the odor inherent in the coagulated (COG-RH2O) stream – in addition to some, finding their way through the SLUDGE stream (i.e., ODOR-AIR < AIR stream flow). Same way, the AIR stream weight if increased may react with the chemicals, thereby reducing the mass of the PURE-H2O stream (see Figure 3b: 7751.02-7750.31 kg/h). Example is the formation of calcium and magnesium bicarbonates [$Ca(HCO_3)_2$ & $Mg(HCO_3)_2$], when $CaCO_3$ or $MgCO_3$, CO_2 and H_2O mixes. There is high chance of the process reversing because at normal atmospheric pressure, $Ca(HCO_3)_2$ decomposes into $CaCO_3$, H_2O and CO_2 at temperatures above 50°C.

When alum is added to water, it undergoes a chemical reaction known as flocculation. Flocculation is a process where the alum reacts with impurities and suspended particles in the water, causing them to clump together and form larger particles called flocs (Abubakar et al., 2022; Aziz and Mustafa, 2019). These flocs are easier to remove through filtration or sedimentation processes, resulting in clearer water (CLR-H2O). During flocculation, the mass of the treated water does not decrease with an increase in the mass of ALUM. In fact, the total mass of the water and alum mixture will increase slightly due to the addition of the alum (check weight of COG-RH2O stream).

However, Figure 3c shows otherwise simply because, the DECANTER does separate the coagulated stream into 3 outlet streams (one of which is CLR-H2O = PURE-H2O). DECANT and ODOR-AIR streams does carry along with them, significant volume of the feed, leaving a clear water. It may also be attributed to the addition of S-H2O stream. Certain reactions between LIME and impurities in the water may lead to the formation of solid precipitates. These precipitates can settle at the bottom of the container, resulting in a decrease in the mass of the treated water, as shown in Figure 3d. Obviously, higher volume of treated water (7751-7801 kg/h) will require proportionately high amount of NaOCl (50-100 kg/h) to disinfect as shown in Figure 3e.

Some blocks responded to changes in temperature and pressure of the system, as shown in Figure 4.

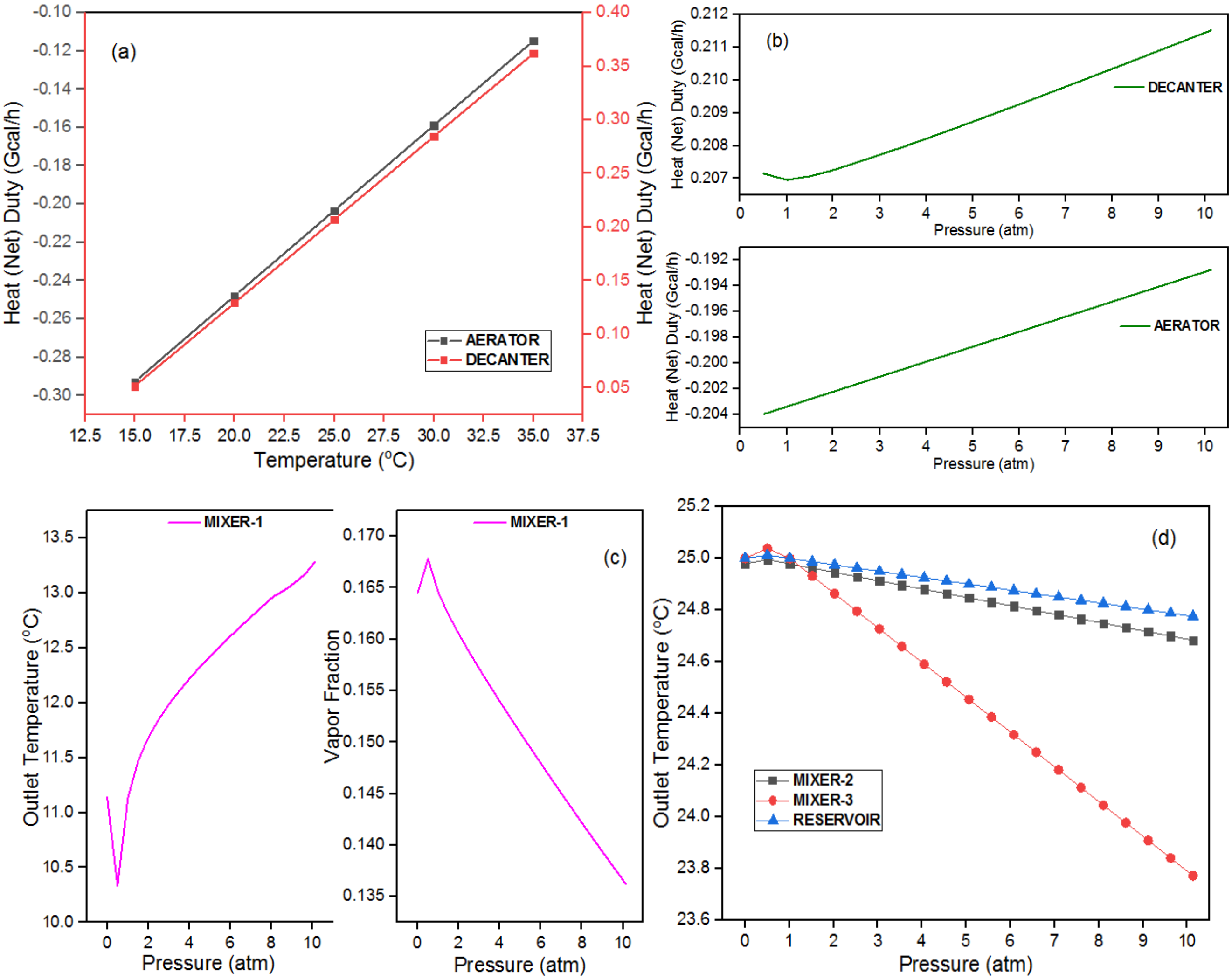

Figure 4: Changes in Input Block Conditions with Performance and Exit Parameters

In Figure 4a, higher heat duty could raise the temperature of the air or gas being introduced into the system, which can impact the overall temperature of the AERATOR. In the DECANTER, higher heat duty can influence the separation process by affecting the properties of the liquid phases being separated. For example, increasing the temperature can change the density, viscosity, or phase behavior of the liquids, thereby impacting the efficiency of the separation. In Figure 4b, the heat duty involves heating an air stream, the increase in temperature may cause the air to expand, leading to an increase in pressure within the aerator. High duty could indirectly affect pressure by altering the properties of the fluids being separated using a decanter. For instance, temperature changes can influence the vapor pressure or viscosity of the liquids, which might impact the pressure required for effective separation. Effect of pressure change on the outlet temperature of MIXER-1 (Figure 4c) may be as a result of the changes in fluid properties of the stream. In the same Figure, pressure changes (0-10 atm) can influence the boiling points, dew points, or bubble points of the components in the mixture, which can, in turn, alter the vapor fraction. Fluid properties may be attributed to possible changes in the outlet temperatures in MIXER-2, MIXER-3 and the RESERVOIR with change in pressure (Figure 4d).

3.4 Sodium Hypochlorite Requirement

In Table 9, C_(Cl, a) = NaOCl mass concentration = 565.122 kg/m3 or 565122 mg/L while in Table 6, Q_A = 2360.363 m3/h = 56.6487 MLD. If plugged into Equation (1), DCC will be equal to 32013.4266 kg/day. Hence daily consumption of NaOCl by the treatment plant is approximately 32 000 kg. The equation helped in knowing the daily feed requirement of NaOCl to the plant to be charged in subsequent plant run instead of relying on the initial guessed amount of 50 kg. It also avoids overfeeding the reservoir tank with chlorine, as the computed value is within the acceptable range.

3.5 Hardness Computation and Removal Rate

This research goal was to remove a total of 3423.2 mg Calcium/L and 5134.8 mg Magnesium/L equivalent to 8558 mg CaCO3/L hardness concentrations initially present in the RAWH2O-A feed stream of the plant. Successfully, the entire CaCO3 concentration in the water was removed as no amount was detected in the outlet stream. This is because 8715 mg/L of CaCO3 got discarded via the SLUDGE stream. Hence, hardness concentration after treatment (C_(after softening)=0 mg/L) obtained herein corresponds with 100% removal in this simulation. In reality, this removal rate will be difficult to achieve, but CaCO3 concentration of as low as 200 mg/L still present in the purified stream for instance, is still okay and within WHO standard. Such outcome matched a removal rate of 97.66% which is still desirable.

4. Conclusion

Hard water containing 8558 mg $CaCO_3$/L and made of 33% sand was successfully modelled using Aspen Plus V8.8 by choosing the ENRTL-SR and PITZER reference property model. A 41.667 m^3/h feedstock containing 50% water was treated using $Al_2(SO_4)_3$, $Ca(OH)_2$ and NaOCl. Using different unit operations arranged successively starting from aerator, mixer, decanter, filter and lastly storage tank, 3.053 m^3/h of purified water stream was generated. It was discovered that the removal of MIXER-2 and the need for service water supply will still enable the achievement of the desired goal, since $Ca(OH)_2$ can be fed in liquid form. Analysis has shown that increasing the feed flow will prompt a corresponding need to raise the amount of treatment chemicals required for the operation. Block properties such as temperature, pressure and temperature-estimate play insignificant role in enhancing production, as they are best suited if kept at ambient conditions. Notwithstanding the scope covered in this study, some observable limitations should be addressed in future works:

1. In this study, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ were not defined and tracked in Aspen Plus, but are assumed present, since they can easily be formed along the process stages and at the same time decompose back to the original reactant.

2. Effect of block conditions on the treated water should be tested in future studies, as the results of this work's sensitivity studies did not point to any optimal value in which the process may be kept.

3. In the decanter, coagulation and flocculation are assumed a joint process in which sand and other solid metallic compounds are expected to settle. Sticks and other debris or heavier impurities wasn't modelled.

4. Concentration of H^+ and OH^- ions in the streams are too low to compute the streams pH using all the property methods enumerated in the methodology. Therefore, the effect of pH cannot be stated.

Setting up a water treatment facility to remove hard water alone is not an advisable venture since hard water poses no serious health challenge if present in low amount, which is often the case. However, setting up an objective to generate soft water, right from the beginning, from contaminated/raw water (say, river, lake or stream water) may be desired for specific industrial application. Since the above drawbacks, as many as they are, expose the weaknesses of Aspen Plus in simulating water treatment plant operations, several other software with complete capabilities should be targeted. This research still achieves a 100% removal of $CaCO_3$ using Aspen Plus above the requirement to always ensure that the hardness chemical must not exceed 200 mg/L WHO standard for drinking water.

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