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Application of CSTR design thickness models for optimum production of Magnesium Chloride from neutralization reaction of Magnesium Oxide and Hydrochloric Acid

Wosu Chimene Omeke*, Ekokoje Aghogho Becky
Department of Chemical Engineering, Federal University Otuoke, Bayelsa State, Nigeria

Abstract
Based on the economic importance of magnesium chloride for both industrial and domestic applications, this article have showed that apart from the use of various extraction technologies for magnesium chloride production, the economic viable product can also be produced via neutralization reaction between naturally occurring magnesium oxide and hydrochloric acid in a continuous stirred tank reactor (CSTR). The CSTR design models were developed from the first principle of mass and energy balance and simulated using MATLAB R2023a version to obtain the CSTR design specification and the relationship between the fractional conversion of the feed materials and the functional parameters of the reactor. At a maximum fractional conversion of 0.9, the CSTR volume, height, diameter, space time, space velocity, quantity of heat generated as well as the quantity of heat generated per unit volume of the reactor were obtained as 18.417m^3, 4.544m, 2.272m, 3.611sec., 0.277sec^{-1}., 3372.750J/s, and 183.134J/m^{3}s respectively. In a bid to ensure continuous production, sustainability and improve the lifespan of the reaction media, the research also considered the design or specification of the CSTR thickness for stainless steel material for construction type (304). The model results showed that a thickness of 4.272mm should be recommended for the reactor body (cylindrical) and head (standard ellipsoidal) in order to mitigate the impact or effect of corrosion during operation and shutdown. Also, the design of the CSTR agitator height and diameter were obtained as 4.044m and 1.272m respectively. This article showed that the design and thickness specification of the CSTR is crucial for optimum, continuous and sustainability of magnesium chloride production.

Keywords: CSTR, thickness design magnesium chloride, neutralization reaction, MATLAB

Introduction

The design of chemical process and equipment such as the continuous stirred tank reactor (CSTR) play a vital role in the production of pharmaceuticals and useful chemicals such as magnesium chloride in chemical industries [24,8]. For effective and optimum production of magnesium chloride from the neutralization reaction of magnesium oxide and hydrochloric acid in a CSTR, the design of the reacting media (CSTR sizing and thickness specification) is essential and must be incorporate the following factors or principles such as uncontrollable cost (overall cost of materials and its properties such as compatibility, resistance to corrosion, rust or stains during reaction, oxidative resistance, conductivity or ability to control heat, thickness, weld ability complexity, fabrication) and controllable cost such as cost of operation and production [27,24]. The production of magnesium chloride and process sustainability is very crucial in process industries because of its substantial benefits as a dust controlling agent in road construction, drying agent, catalyst support for Ziegler Natta catalyst, production of petrochemicals, plastics, reagents and pharmaceuticals [4 ,27, 17]. Based on the above, the design and thickness consideration of the CSTR (neutralization reaction media) becomes very necessary for optimum production and sustainability. The choice of CSTR as the reaction media is based on its design configuration and ability to facilitate continuous operation, improve mass transfer performance particularly in multiphase systems, scalability simplicity since mixing is independent on pumping rate and its ability to effectively handle solids and slurries when compared to other reactors as a result of external agitation by the configured impellers [8, 27]. The flow chemistry of the CSTR enhance efficiency, sustainability and has attracted global interest as a key for chemical industries to reach net zero with the proven ability to minimize cost and energy consumption [25, 15, 23, 6]. Researchers in the past and recent past have showcased the economic viability of magnesium chloride as well as the various techniques for its extraction or production and thus; [16] stated that magnesium chloride can be produced from sea water which is mainly characterized by Na^+, K^+, Mg^+, Cl^- and SO_4^- using preferential salt separation technique which was tested using both batch and continuous method. [11] stated that mixed brines can be purified using hydrogen chloride to produce magnesium chloride and highlighted the negative impact of discharging brines to seawater on aquatic lives and land body. generally, magnesium chloride and its constituents can be obtained from sea water [13, 2, 7, 9, 18, 14]. The CSTR design just like other process equipment design is achieved by integrating the conservation principle of material to obtain the reactor size specification [26, 32, 30, 28, 29].

The effect of brine on aquatic lives and the financial challenges it imposes during treatment or pre-treatment was also emphasized by [22, 3]. In 2019, [19] researched on comparative assessment of zero liquid discharge (ZLD) and minimal liquid discharge techniques to minimize the negative impact associated with brine on the environment. About 99% of fresh water was recovered using both the ZLD and MLD techniques. These techniques can be seen as a waste to wealth program since the recovered fresh water can be applied in cooling systems and domestically for cooking, washing and cleaning while the solid waste is recycled [10] . Minerals such as Na, Mg, Ca, Ba, Li, K, Al, S, Si, Fe, Sn, Mn, Mo, Zn, Ni, Co, Cr, Cu, V, Ti, Cd, Pb, Au, Th, U etc are found in sea water and can be applied in the production of plastics, pharmaceuticals and petrochemicals

[5, 21]. Apart from seawater waste magnesite powder can be recycled and processed to produce high quality magnesium and magnesium compound [12]. The magnesite can be applied as a raw material in the production of glass, cement, sugar, iron-steel, paint, ink, pharmaceuticals and alkaline refactory products since it is composed of 47.6% MgO and impurities such as S_1O_2, Fe, and Ca [1].

To ensure continuous and sustainable process for magnesium chloride production in a CSTR, this article considered the design of a CSTR and its thickness analysis to ensure steady and sustainable production as well as improvement of the CSTR equipment lifespan. When considering thickness design or specification of the equipment, the material for fabrication and its mechanical strength is considered as the most common requirement [24]. Generally, for equipment (CSTR) fabrication, metallic materials be it ferrous or non-ferrous are mostly utilized [27]. In this research, the stainless steel which is a ferrous metal is used as the material for the CSTR thickness design and its properties such as design temperature, design pressure, design stress, welded joint efficiency, corrosion allowance, design loads, and minimum practical wall thickness must be put into consideration.

Materials and Methods

The materials used in this research are the raw materials or reactant feed such as magnesium oxide and hydrochloride acid. The simulation tool and software used are laptop and MATLAB R2023a version and the research data were obtained from literatures, derived or calculated data and thermodynamic data. The research methodology is both quantitative and the analytical and the procedures adopted are;

1. Development of the reaction rate kinetics
2. Application of the conservation law of mass and energy balance in development of the CSTR design models and temperature effect model.
3. Design of the CSTR agitator
4. Application of the CSTR mechanical design models for thickness determination
5. Constant density

1. Development of the Reaction Rate Kinetics

The reaction rate kinetics of this research can be developed from the elementary reaction of the process. The chemistry of the process involves neutralization reaction in equation (1)

$$MgO + 2HCl \xrightarrow{k_1} MgCl_2 + H_2O \quad (1)$$

The Third order irreversible neutralization reaction can be expressed symbolically as;

$$A + 2B \xrightarrow{k_1} C + D \quad (2)$$

The rate law of the neutralization can be expressed as a function of feed rate depletion and kinetic parameters as follows;

$$-r_A = K_o e^{-E/RT} C_{Ao}{}^3 (1 - x_A)(m - 2x_A)^2 \quad (3)$$

2. Development of CSTR Design and Energy Balance Models

Consider the schematic representation of a continuous stirred tank reactor with feed and product streams

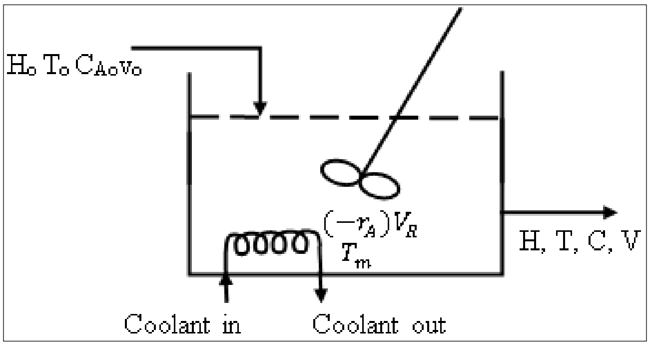

Fig 1: CSTR with Mass and Heat Effect

The design models of the CSTR for volume, height, diameter, space time and space velocity can be obtained by applying the principle of material balance stated as follows

$$\begin{bmatrix}\text{Rate of}\\ \text{accumulation}\\ \text{of material}\\ \text{within the}\\ \text{volume}\end{bmatrix} = \begin{bmatrix}\text{Rate of}\\ \text{input of}\\ \text{feed into}\\ \text{the volume}\end{bmatrix} - \begin{bmatrix}\text{Rate of}\\ \text{outflow of}\\ \text{feed from}\\ \text{the voume}\end{bmatrix} - \begin{bmatrix}\text{Rate of}\\ \text{depletion of}\\ \text{feed due to}\\ \text{chemical}\\ \text{reaction}\end{bmatrix} \quad (4)$$

The terms in equation (4) can be defined, applied and simplified at steady state process operation to yield the design models for CSTR volume, height, diameter, space time and space velocity as;

$$V_R = \frac{F_{Ao} x_A}{K_o e^{-E/RT} C_{Ao}{}^3 (1 - x_A)(m - 2x_A)^2} \quad (5)$$

$$H_R = \left[\frac{16 F_{Ao} x_A}{\pi K_o e^{-E/RT} C_{Ao}{}^3 (1 - x_A)(m - 2x_A)^2}\right]^{\frac{1}{3}} \quad (6)$$

$$D_R = \frac{\left[\frac{16 F_{Ao} x_A}{\pi K_o e^{-E/RT} C_{Ao}{}^3 (1 - x_A)(m - 2x_A)^2}\right]^{\frac{1}{3}}}{2} \quad (7)$$

$$\tau_{CSTR} = \frac{x_A}{K_o e^{-E/RT} C_{Ao}{}^3 (1 - x_A)(m - 2x_A)^2} \quad (8)$$

$$S_V = \frac{K_o e^{-E/RT} C_{Ao}{}^3 (1 - x_A)(m - 2x_A)^2}{x_A} \quad (9)$$

The quantity of heat generated and the quantity of heat generated per unit volume of the reactor during the neutralization reaction are given as;

$$Q = \Delta H_R F_{Ao} x_A \quad (10)$$

$$q = \frac{\Delta H_R F_{Ao} x_A}{V_R} \quad (11)$$

3. Design of the CSTR Agitator

Usually, a clearance is allowed between the stirrer blade and the reactor height.

The length of the stirrer can be expressed mathematically as given by [31].

$$L_{st} = H_R - C \quad (12)$$

$$D_{st} = D_R - 2C \quad (13)$$

4. Design of the CSTR Thickness

To design or specify the CSTR thickness for optimum production of magnesium chloride from neutralization reaction between magnesium oxide and hydrochloric acid, the material for construction and properties such as design temperature, design pressure, design stress, welded joint efficiency, corrosion allowance, design loads and minimum practical wall thickness must be put into consideration [31].

4.1. Material for construction

In this article, the CSTR material for construction is the stainless steel with grade (304). The strength and quality of stainless steel is capable of withstanding corrosion issues that may arise during the neutralization reaction since it constitute 18% and 8% minimum amount of chromium (Cr) and nickel (Ni) respectively. The properties will guarantee stable austenitic structure and good weld-ability without post-weld annealing when welding thin sections. [31] presented the chemical and mechanical constituent of the stainless-steel grade (304) type.

4.2. Design Temperature

Usually, temperature rise during reaction greatly affect the reaction media and material for construction. In order to prevent any uncertainty, the maximum allowable design stress conventionally is usually well below the material temperature.

4.3. Design Pressure

For any equipment design such as the CSTR, conventionally, the design must be made in such a way that it will overcome the maximum allowable pressure that will be exerted during the process operation. Usually, the design pressure is reasonably expected to be about 5 to 10% higher than the operating pressure [31]. This will help mitigate extraneous actions during minor disturbance. Also, the design pressure should constitute the fluid pressure.

4.4. Design Stress

The maximum allowable stress that will be exerted on the CSTR also called the normal design strength is very important as well as the use of a standard or suitable stress factor that will regulate the effect of loading, uncertainty, material quality, design techniques and operation in a bid to ensure optimum yield and safe operation of the process [31].

4.5. Welded Joint Efficiency

The lifespan of equipment such as the CSTR also depends on the type of welds, its quality and the type of welded joint used. The above factors can be taken into consideration by mere visual inspection and the use of radiography. In the design of equipment like the CSTR, the butt joint is conventionally used under ASME BPV code sec. VII D1 [20].

4.6. Corrosion Allowance

One major concern facing the lifespan of process equipment is the effect of corrosion during operation or shutdown. In a bid to ensure sustainability and improve equipment lifespan, standard or accurate corrosion allowance must be considered during equipment design or specification before the fabrication stage. The corrosion allowance usually depends on the material for construction to be used, nature of reactant species or processes involved as well as past experiences from similar processes. For CSTR fabrication with stainless steel material type (304), a corrosion allowance of 4.00mm is conventionally used [20].

4.7. Design Load

In the operation of the CSTR, both internal and external loads which could be seen as major or minor loads are bound to occur and the CSTR should be designed in such a way that it will be capable enough to overcome any load (internal or external) forces that could arise. The major loads are the noticeable static loads, design pressure, total vessel weight and reactant components in it as well as wind loads and seismic loads while the minor loads are loads from shock, local stresses from support or connecting pipes and structures within, coefficient of expansion of the materials, stress due to temperature and pressure changes as well as bending moment must be put into consideration to improve functionality and lifespan of the CSTR during operation or shutdown.

4.8. Minimum Practical Wall Thickness

Conventionally, for an equipment design and fabrication, a minimum thickness allowance is essential in order to improve the equipment rigidity, manage stresses from equipment weight and external loads connected with it. Usually, the thickness of reacting vessels such as the CSTR greatly depends on its diameter as well as corrosion allowance of 2mm [31]. Table 1 presents the actual standard for reactor thickness.

Table 1: Minimum Practical Wall Thickness

Reactor Diameter (m)	Minimum Thickness (mm)
1	5
1 to 2	7
2 to 2.5	9
2.5 to 3.0	10
3.0 to 3.5	12

Consider the thickness design hypothetical schematic of the CSTR in figure 2 for magnesium chloride production with feed and product streams as well as the reactor operating parameters such as temperature (T), pressure (P) and diameter (D_R).

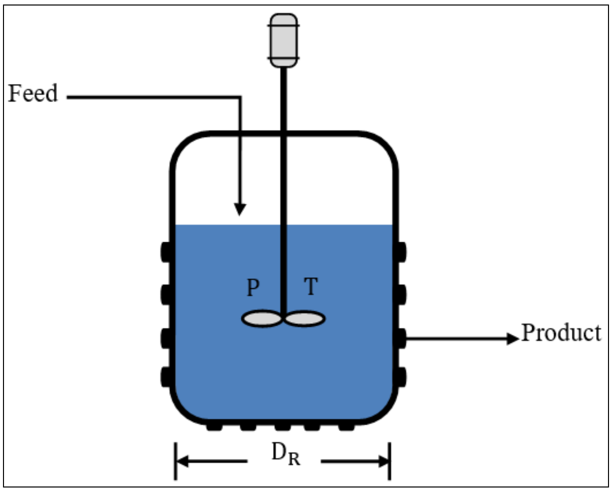

Fig 2: Mechanical Design of the CSTR

The CSTR thickness design models to be applied for determination of the reactor column body (cylindrical) and head (torispherical, standard ellipsoidal and flat) head are presented in equation (14), (15), (16), (17), (18) and (19) by [32] as;

Reactor Column Body (Cylindrical)

$$e = \frac{P_i D_i}{2JF - P_i} \quad (14)$$

Reactor Column Head (Torispherical)

$$e = \frac{P_i D_i C_s}{2JF - P_i(C_s - 0.2)} \quad (15)$$

$$C_s = \frac{1}{4}\left[3 + \sqrt{\frac{R_i}{R_k}}\right] \quad (16)$$

Reactor Column Head (Standard Ellipsoidal)

$$e = \frac{P_i D_i}{2JF - 0.2P_i} \quad (17)$$

Reactor Column Head (Flat)

$$e = c_p D_c \sqrt{\frac{P_i}{F}} \quad (18)$$

The total thickness of the reactor's body and heads as shown in equation (14), (15), (17) and (18) is given as

$$\text{Thickness } (t) = e + \text{corrosion allowance.} \quad (19)$$

5. Data for Evaluation

The data for the simulation of the design models and evaluation of the thickness models is presented in Table 2.

Table 2

Data	Values	Description	References
V_o	0.01194m^3/s	Initial volume flow rate of reactants	[27]
C_{A0}	0.0419mol/m^3	Limiting reactant connection	[27]
F_{A0}	4.998x10^{-4}mol/s	Initial molar flow rate	[27]
X_A	0.90	Fractional conversion	[27]
T_o	291.15k	Initial feed temperature	[4]
T	301.15k	Operating temperature of reactor	[4]
T_c	296.15k	Coolant temperature of reactor	[4]
K_1	0.06835^{-1}	Rate constant	[4]
$-r_A$	6.1 x 10^{-5}mol/m^{3}s	Reaction rate	[4]
ΔH_R	56722.99kj	Change in enthalpy of reaction	[4]
T_D	42.04^{o}C	Reactor design temperature	Calculated
P	1.36bar	Reactor operating pressure	Calculated
F	165N/mm^2	Stress factor	[24]
J	1 (Dimensionless)	Welded joint efficiency	[24]
C_s	1.771 (Dimensionless)	Stress concentration	Calculated
P_i	0.0396N/mm^2	Design pressure	Calculated
R_k	136.32mm	Knukle	Calculated
R_C	2272mm		Calculated
C_p	0.4(Dimensionless)	Full face gasket	[24]

Results and Discussion

The results and discussion of the CSTR design, the relationship between the fractional conversion and process functional parameters as well as the thickness design or specification of the reactor is presented in this section.

1. CSTR Design Results

The design results of the CSTR for the production of magnesium chloride is presented in table 7.

Table 3: Design Results of CSTR Design Volume, Height, Diameter, Space Time, Space Velocity and Quantity of Heat generated Per Unit Volume of the Reactor at various Fractional Conversion and Operating Temperature

X_A	T(K)	V_R(m^3)	H_R(m)	D_R (m)	τ_{CSTR} (s)	S_V(s^{-1})	Q(J/s)	q(J/m^{3}s)
0.10	291.36	0.025	0.505	0.252	0.005	201.875	374.750	14833.830
0.20	291..36	0.064	0.688	0.344	0.013	79.753	749.500	11720.560
0.30	291.36	0.125	0.861	0.431	0.025	40.707	1124.250	8973.550
0.40	291.36	0.227	1.050	0.525	0.045	22.431	1499.000	6592.813

0.50	291.36	0.409	1.277	0.639	0.080	12.461	1873.750	4578.342
0.60	291.36	0.767	1.575	0.738	0.151	6.646	2245.500	2930.139
0.70	291.36	1.592	2.009	1.004	0.312	3.204	2623.250	1648.203
0.80	291.36	4.093	2.752	1.376	0.803	1.246	2998.000	732.535
0.90	291.36	18.417	4.544	2.272	3.611	0.277	3372.750	183.134

Table 3 is tabular presentation of the design result of the CSTR where neutralization reaction between magnesium oxide and hydrochloric acid occur for the production of magnesium chloride. The CSTR design or size specification was obtained from the simulation of the performance models of the reactor using MATLAB R2024a version at constant temperature of 291.36k and fractional conversion of 0.1 to 0.9. At maximum conversion of 0.9, the optimum value of the CSTR functional parameters such as volume, height, diameter, space time, space velocity, quantity of heat generated as well as the quantity of heat generated per unit volume of the reactor was 18.417m^3, 4.544m, 2.272m, 3.611s, 0.277s^{-1}, 3372.750J/s and 183.134J/m^{3}s respectively.

1.1. Profile of CSTR Volume (V_R), Height (H_R), Diameter (D_R) and Fractional Conversion (X_A)

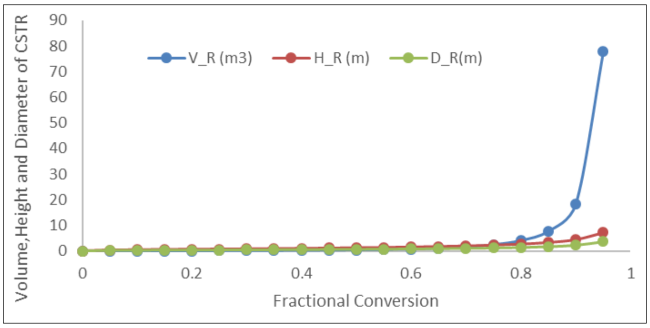

Fig 3: Graph of CSTR volume (V_R), Height (H_R), Diameter (D_R) and fractional conversion (X_A)

Figure 3 showed the behavior of CSTR functional parameters (volume, height and diameter) with an increase in fractional conversion of the reactant feed material during magnesium chloride production from the neutralization reaction of magnesium oxide and hydrochloric acid. The profile was obtained from MATLAB simulation of the CSTR design models developed from the conversion law of materials. According to the profile, the design quantities (V_R, H_R and D_R) displayed an exponential increase as the fractional conversion increases and at a maximum conversion of 0.9, the volume, height and the CSTR diameter stood at 18.417m^3, 4.544m and 2.272m respectively.

1.2. Profile of CSTR Residence Time (T) and Fractional Conversion

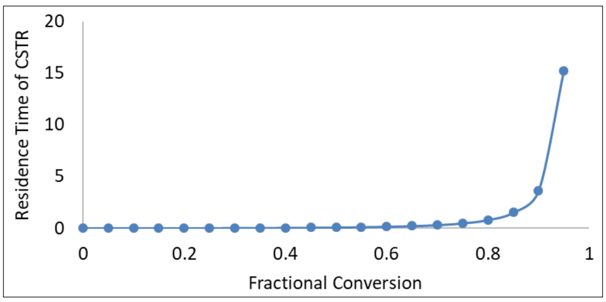

Fig 4: Graph of Residence Time (τ) and Fractional Conversion (X_A)

Figure 4 clearly showed that there is an exponential increase in the fractional conversion as the time spent by feed materials (reactant) increases in the reactor. The significance of this is that more yield of the target product increases as the conversion of feed increases with time (space time). At a fractional conversion of 0.1, 0.5 and 0.9, the residence time spent by fluid element in the reactor was 0.005 sec, 0.080sec and 3.611 sec respectively.

1.3. Profile of Space Velocity (S_V) and Fractional Conversion (X_A)

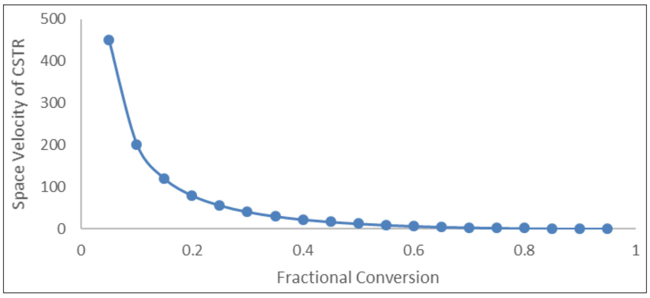

Fig 5: Graph of Space Velocity (S_V) and Fractional Conversion (X_A)

Figure 5 clearly demonstrate the mathematical correlation between the space time (residence time) and the space velocity. The space velocity is defined as the reciprocal of space time. It is the time used to process a unit volume of the feed at inlet condition. According to figure 4, the space velocity decreases exponentially as the fractional conversion increases. The significance of this is that more conversion of the feed material or more yield of the target product (magnesium chloride) will be produced at least value of the space velocity. At space velocity of 201.875sec^{-1}, 12.461sec^{-1} and 0.277sec^{-1}, the volume of the reactor which depends on the yield of target product (magnesium chloride) were 0.025m^3, 0.409m^3 and 18.417m^3 respectively.

1.4. Profile of Quantity of Heat (Q), Quantity of Heat Generated per unit Volume (q) and Fractional Conversion (X_A)

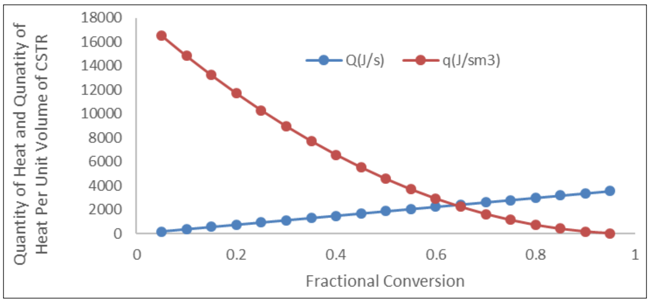

Fig 6: Graph of Quantity of Heat (Q), Quantity of Heat Generated per unit volume (q) and Fractional Conversion (X_A)

Figure 6 is a graphical representation of the relationship between the Quantity of heat generated, Quantity of heat generated per unit volume of the CSTR and fractional conversion. The Quantity of heat generated is the amount of heat generated during the process (neutralization reaction) while the Quantity of heat generated per unit volume of the reactor is the amount of heat generated during the process divided by the reactor volume. According to the plot, and the definition above, the Quantity of heat generated increases linearly as, the fractional conversion or reactor volume increases while the Quantity of heat generated per unit volume of the reactor demonstrated an exponential decrease as the fractional conversion and reactor volume increases. At maximum fractional conversion of 0.9, the values of the Quantity of heat generated and the quantity of heat generated per unit volume of the reactor was 3372.750J/s and 183.134J/m^{3}s respectively.

2. CSTR Agitator Design

The design or specification of the CSTR Agitator is presented in table 8.

Table 4: CSTR agitator design

CSTR Agitator Parameter	Specification (Unit)
Height of Agitator	4.044m
Diameter of Agitator	1.272m

Table 4 represents the design or size of specification of the CSTR agitator height and diameter. The CSTR agitator is responsible for ensuring uniform mixture of the reactant species to attain uniform composition of the content both at the inlet and outlet stream during the neutralization reaction. The design of the CSTR agitator in terms of height and diameter is dependent on the reactor height and diameter as well as minimum practical allowance or clearance of 0.5. The height and diameter of the CSTR stirrer was obtained as 4.044m and 1.272m using a clearance of 0.5m and 1m respectively.

3. Design of the CSTR thickness

The thickness design or specification of the CSTR is presented in table 5.

Table 5: Design of the CSTR Thickness

Thickness Parameter	Specification (Unit)
Column Body	-
Cylindrical	4.272mm
Column Head Doomed	-
Torispherical	4.483mm
Ellipsoidal	4.272mm
Flat	18.079mm

Table 5 present the thickness design or specification of the CSTR column body and head obtained from the application of the thickness design models. According to the table, a column body (cylindrical body) of 4.272mm thickness was obtained while various thicknesses were obtained for the column head (torispherical, ellipsoidal and flat head) using various models. For the purpose of economics, efficiency and uniformity, a thickness of 4.272mm for the cylindrical body and column head (ellipsoidal) is recommended as the thickness for CSTR construction using stainless steel material type (304) as the material for construction. The thickness was obtained by considering certain factors such as material type for construction, operating temperature and pressure, column diameter, design load, stresses, corrosion allowance welded joint efficiency, etc. The above factors were considered in a bid of ensuring sustainability and improve the lifespan of the CSTR for continuous operation and production of magnesium chloride.

Conclusion

The research considered the use of first the principle of mass and energy balance in the development of the CSTR design models for magnesium chloride production via neutralization reaction between magnesium oxide and hydrochloric acid. The design models were simulated using MATLAB R2023a version at various fractional conversions and operating condition of the reactor. The behavior of the profile showing the relationship between the fractional conversion and functional parameters of the reactor showed that the CSTR is suitable for optimum production of magnesium chloride. At a maximum conversion of 0.9, the volume, height, diameter, space time, space velocity, quantity of heat generated as well as the quantity of heat generated per unit volume of the reactor were 18.417m^3, 4.544m, 2.272m, 3.611sec., 0.277sec.$^{-1}$, 3372.750J/s and 183.134J/m^{3}s respectively. The CSTR thickness specification was determined for stainless steel material for construction type (304) as 4.272mm for both cylindrical column body and standard ellipsoidal head. This will ensure continuous production, sustainability and improve the lifespan of the equipment by mitigating the impact or effect of corrosion. The design specification of the CSTR agitator height and diameter was obtained as 4.044m and 1.272m respectively using a clearance of 0.5m. The research showed that apart from the use of various extraction processes for magnesium chloride production, naturally occurring magnesium oxide could react with hydrochloric acid in a CSTR for the production of magnesium chloride which is very vital for domestic and industrial applications.

Table 6: Nomenclature

Symbol	Definition	Unit
A	Magnesium oxide	-
B	Hydrochloric acid	-
C	Magnesium chloride	-
D	Water	-
K_1	Kinetic rate constant	s^{-1}
$-r_A$	Depletion rate of the limiting reactant	mol/m^3/s
C_A	Concentration of reactant specie A	mol/m^3
C_B	Concentration of reactant specie B	mol/m^3
t	Reaction time	S
C_{AO}	Initial concentration of specie A	mol/m^3
C_{BO}	Initial concentration of specie B	mol/m^3

m	Mole ratio of initial concentration of species	Dimensionless
K_o	Arrhenius or pre-exponential constant	s^{-1}
E	Activation energy	KJ/kmol
T	Operating temperature	K
R	Gas constant	j/molk
F_{AO}	Initial molar flow rate of feed	mol/s
V_R	Volume of the reactor	m^3
H_R	Height of the reactor	M
D_R	Diameter of the reactor	M
$_A$	Fractional conversion of specie A	Dimensionless
Q	Quantity of heat generated	J/s
q	Quantity of heat per unit reactor volume	J/m^3s
ΔH_R	Heat of reactor	KJ/mol
$n\tau$	Space time	S
S_V	Space velocity	s^{-1}
v_o	Initial volumetric flow rate	m^3/s
C_p	Specific heat capacity	J/molK
A_C	Area of heat exchange	m^2
U	Heat transfer coefficient	W/m^2K
T_o	Feed initial temperature	K
T_c	Coolant temperature	K
ρ_i	Density of species	Kg/m^3
L_{st}	Length of stirrer	M
C	Clearance	M
D_{st}	Diameter of the stirrer	M
e	Minimum thickness	Mm
Pi	Design pressure	N/mm^2
Di	Column diameter	M
J	Welded joint efficiency	N/mm
F	Design stress factor	Dimensionless
C_s	Stress concentration factor	Dimensionless
C_p	Full face gasket (0.4)	Dimensionless
D_c	Bolt circle diameter	Mm

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