

# Production of Magnesium Chloride from Seawater using CSTR

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**Abstract:** The study was carried out to examine the production of magnesium chloride from seawater in a continuous stirred tank reactor (CSTR). To achieve this, the necessary functional parameters were determined such as the space time, space velocity, heat generated per unit volume, fractional conversion, reactor volume, reactor height and diameter and rate expression. The result obtained revealed that space time value of 921s, space velocity value of  $0.0011 \text{ s}^{-1}$ , heat generated per unit volume  $3.46 \text{ kW/L}$ , fractional conversion 0.9, reactor volume  $3.69 \text{ L}$ , reactor height  $2.66 \text{ dm}$ , reactor diameter  $1.33 \text{ dm}$  and rate expression  $6.1 \times 10^{-5} \text{ mol/s.L}$  as well as the operational temperature is  $301.15 \text{ K}$ . Experimental data was obtained which was used in this computation of the functional parameters as presented in this research work. The study demonstrated the usefulness of magnesium chloride production from seawater using continuous stirred tank reactor (CSTR).

**Keywords:** Design, CSTR, Production, Magnesium Chloride and Seawater

## 1. Introduction

The exploitation of seawater for minerals appears to have garnered less attention in comparison to efforts put in search for crude oil in various on- and off- shore fields around the world. However, the sea in addition to supporting marine flora and fauna is also a sink to numerous minerals or salts of economic value from weathering. Minerals found in seawater (brines) include salts of 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. ([1] [2]).

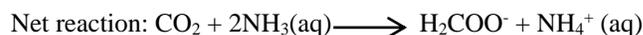
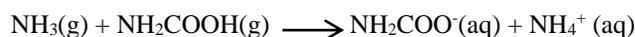
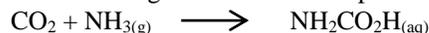
Magnesium and calcium chlorides rank second and third respectively to sodium chloride in terms of relative abundance in seawater. Ca and Mg chlorides find applications in road construction as dust control agents, road de-icing, drying agents (hygroscopic), etc. However, there is renewed interest in  $\text{MgCl}_2$  because of its applications as catalyst support for Ziegler Natta catalyst (used in the petrochemicals/plastic industries for the production of Polyethylene or polypropylene products), Grignard reagents, borates and carnallites. This translates to added commercial value [3]-[7].

Magnesium is nothing short of a miracle mineral in its healing effect on a wide range of diseases as well as in its ability to rejuvenate the aging body. We know that it is essential for many enzyme catalysed reactions, especially in regard to cellular energy production, for the health of the brain and

nervous system and also for healthy teeth and bones. The first prominent researcher to investigate and promote the antibiotic effects of magnesium was a French Surgeon, Pro. Pierre Delbet MD. In 1915 he was looking for a solution to cleanse wounds of soldiers, because he found that traditionally used antiseptics actually damaged tissues and encouraged infections instead of preventing them.

Highly-saline water (NaCl) was the main source for the series of chemical reactions following for production of  $\text{MgCl}$  and other products. The passing over of  $\text{CO}_2$  gas into NaCl solution to get bicarbonate and Ammonical solution i.e. the conversion of  $\text{Na}^+$  and  $\text{Cl}^-$  to produce give  $\text{NaHCO}_3$  and  $\text{NH}_4\text{Cl}$ . More than 80% NaCl was achieved for saturated brine. This process has led to the production of partially desalted water and other valuable products (soda Ash and  $\text{NH}_4\text{Cl}$ ).

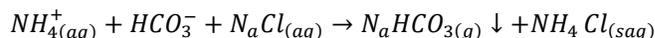
The main stages for the reaction process were



Secondary reactions will be given



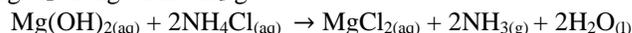
The production formation reactions:



The precipitation of  $\text{NaHCO}_3$  leaves  $\text{NH}_4\text{Cl}$  in solution.

The calculation of bicarbonate at  $160^\circ\text{C} - 230^\circ\text{C}$  gives the  $\text{H}_2\text{O}$  and  $\text{CO}_2$  as products.

$2\text{NaHCO}_3(\text{g}) \rightarrow \text{Na}_2\text{CO}_3(\text{s}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$  part of the partially desalinated water containing  $\text{NH}_4\text{Cl}$  is added differently to Magnesium hydroxide ( $\text{MgCOH}_2$ ) forming  $\text{MgCl}_2$  along with  $\text{NH}_3$  gas.



The research is aimed to develop a design equation of a continuous stirred tank reactor (CSTR) used for the production

of Magnesium chloride from salt water (Brine) and to achieve it, the step wise procedures will be followed to: develop the kinetic model for the process, apply the principle of conservation of mass in the development of the design equations and use the developed equation to estimate functional parameters such as: Volume of reactor ( $V_R$ ), Space time ( $\tau$ ), Space velocity ( $S_v$ ) and Heat generated per unit volume, and incorporate the developed kinetic model into the design equations.

The research will be bordered on the design of a continuous stirred tank reactor for the production of magnesium chloride from salt water is undertaken, effect and design of other process vessels and separators is completely neglected.

Many Authors worked on these areas and some of the reviews are: [8] researched on LCA magnesium production. Sea oceans are inexhaustible source of Mg. Thus the work experimentally carryout shows that about one pound of Mg was produced from each hundred gallons of sea water; many other sources researched on the presence of Mg in sea-water. Through series of experimental analysis carried out, it was found out that sea ocean contain inexhaustible source of Mg and different methods can be used to obtain products of Mg compounds.

[9]-[12] worked on dual-purpose chemical desalination process. Series of chemical reactions were carried out for the removal and extraction of NaCl from sea-water used for production of valuable products through electrolysis method; [13] worked on chemical desalting of saline water using Ammonia and  $\text{CO}_2$ ; Brines currently serve as major commercial sources of magnesium and its products. For instance, major exporters like Norway, United States of America and Union of Soviet Socialist Republic, mined Mg from brines ([1], [14]); Hydrated magnesium chloride,  $\text{MgCl}_2 \cdot x\text{H}_2\text{O}$ , exists as  $\text{MgCl}_2 \cdot 12\text{H}_2\text{O}$  in seawater (0.55%) and in other hydrated forms,  $\text{MgCl}_2 \cdot x(\text{H}_2\text{O})$ , where  $x = 1, 2, 4, 6, 8$  and  $12$  due to its hygroscopic nature [15]; Hexa-hydrate,  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ , on the other hand is the stable form at room temperature. Production of anhydrous or high purity grades and crystal modifications of magnesium chloride have also been reported [16]; conventional method used for the extraction of  $\text{MgCl}_2$  from seawater is by the Dow method. This method exploits the low solubility of the precursor, magnesium hydroxide compared to that of calcium hydroxide since solubility of the salts of negative ions increases down the group; a litre of seawater is said to contain over 1.0g of magnesium ions [17]. However, it could be less with brackish water due to possible river-brackish water mix; no available report on the magnesium chloride content of Nigerian waters despite similar report in North Africa [18]; and investigates the presence, and production of magnesium chloride using a continuous stirred tank Reactor obtained from brine; Magnesium was discovered about the same time as aluminum. Sir Humphrey Davy, the British (Cornish) chemist, first isolated aluminum in 1807 and identified magnesium in 1808.

## 2. Materials and Methods

### A. Materials

The primary raw material needed for this process is Seawater: Seawater currently serves as major commercial sources of magnesium and various salts. Magnesium chloride can further be extracted from the sea water by the Dow method.

The equipment used to conduct this study were, 10L dry plastic container, conical flask of 0.25L, 2L beaker, triple function conductivity meter Siemens D5000 Diffractometer, funnel, Water bath, micro sieve, volumetric flasks of 0.25L and 0.5L.

### B. Methods

#### 1) Collection and concentration of brackish water

Brackish water samples from selected location namely: Opobo in Opobo/Nkoro local government area in Rivers state of Nigeria were collected in a 10L dry plastic container each, prewashed with detergent and rinsed with de-ionized water. All samples were collected at high tide at the location. This was done because salinity is usually higher at high tides than at low tides. The 10 L was heated at  $100^\circ\text{C}$  in a clean 20 L steel pot and later transferred to a 2 L beaker where it was finally reduced to 1 L saturated salt solution through evaporation.

#### 2) Precipitation of $\text{Mg}(\text{OH})_2$ and crystallization of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$

The precipitation of  $\text{Mg}(\text{OH})_2$  precipitates was done by the reaction of 200 mL of a 11.2g (0.2M) CaO with 200 mL of the saturated brackish (brine) water to form white gelatinous precipitates of  $\text{Mg}(\text{OH})_2$ . The reaction was allowed for a day for proper aging before separation by decantation of the clear supernatant. The precipitate was further heated to remove any remaining supernatant liquid present (but not to dryness).

The recovered  $\text{Mg}(\text{OH})_2$  precipitate was reacted with (dissolved in) 200mL of 1M HCl to form the magnesium chloride solution. Evaporation helps the solution and crystallized the hydrated magnesium chloride salt,  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ .

To record the pH, conductivity and salinity of the salt solutions, the triple function conductivity meter was used. Highest yield sample was chosen for X-ray diffraction characterization (on a Siemens D5000 Diffractometer) while X-ray fluorescence analyses were done for only two samples due to cost.

The Dow method gives  $\text{MgCl}_2$  through [19] extraction from seawater by the precipitation of the  $\text{Mg}(\text{OH})_2$  firstly by slurring it with calcinated dolomite and then converting it to  $\text{MgCl}_2$  by reacting it with HCl.

#### 3) The electrolytic process

The electrolytic process is used for the conversion of  $\text{MgCl}_2$  into magnesium metal using fused electrolysis of magnesium chloride. The process involves two stages: production of pure magnesium chloride from sea water or brine; and electrolysis of fused magnesium chloride.

- Production of pure magnesium chloride from sea

water:

Magnesium chloride is also extracted from salt brines which contains about 10% magnesium chloride. The magnesium chloride at these sources still contains significant amount of water and must be dried in order to make the magnesium chloride anhydrous before it can be electrolyzed to give magnesium metal. As explain earlier, Dow method is the conventional method used to extract magnesium chloride then passed through fused magnesium chloride electrolysis to obtain magnesium metal.

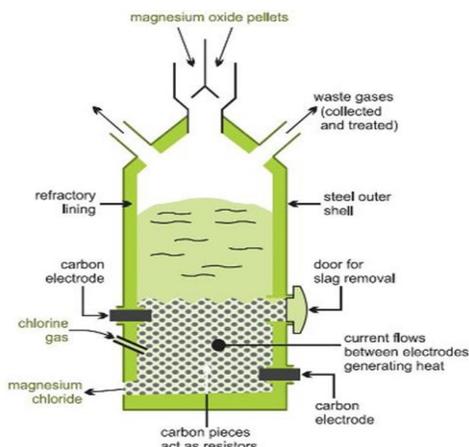
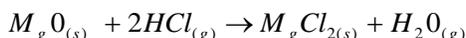
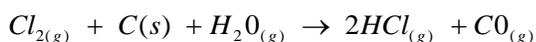
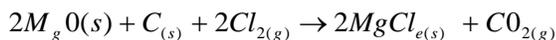
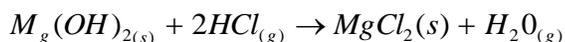


Fig. 1. Production of magnesium chloride from magnesium Oxide [17]

The several chemical reactions taking place the conversion from the Figure 1 above,



The magnesium chloride-rich brines are the source of magnesium; the solution brine is treated for removal of various impurities and the remaining magnesium chloride solution concentrated by evaporation in several stages. The last stage of dehydration has to be carried out in the presence of hydrogen chloride gas to avoid hydrolysis of the magnesium chloride [20].



• *The electrolysis of fused magnesium chloride*

The resulting anhydrous magnesium chloride is fed continuously into electrolytic cells which are hot enough to melt it. On electrolysis, magnesium metal and chlorine gas are produced respectively at the cathode and anode as shown below (Figure 2).

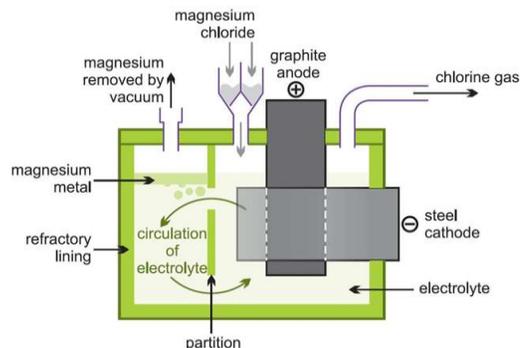
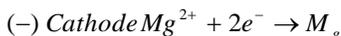
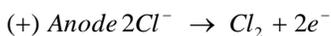


Fig. 2. Electrolysis of fused magnesium chloride to obtain magnesium metal [17]

C. *Development of Design Equation*

The design equation of any chemical engineering system is derived by material and energy balance method of the system. In developing the design equations, the mass balance and the reaction equation kinetics would be derived.

1) *Mass Balance*

The principle of mass balance is based on the theory that mass can neither be created nor destroyed (principle of conservation of mass). For mass balance about an element of volume of a reactor, the conservation principle can be expressed thus:

$$\begin{aligned} & \left( \begin{array}{l} \text{Rate of accumulation} \\ \text{of mass within the reactor} \end{array} \right) \\ & = \left( \begin{array}{l} \text{Rate of inflow} \\ \text{of mass into the} \\ \text{reactor} \end{array} \right) \\ & - \left( \begin{array}{l} \text{Rate of outflow} \\ \text{mass from the reactor} \end{array} \right) \\ & + \left( \begin{array}{l} \text{Rate of formation} \\ \text{of mass due to chemical} \\ \text{reaction} \end{array} \right) \end{aligned}$$

Mathematical Expression for the Component Mass Balance of equation (1) gives:

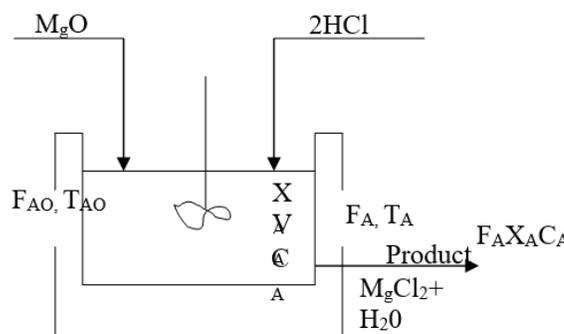


Fig. 3. Schematic representation of a CSTR showing two feed stream and a product stream

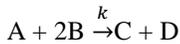
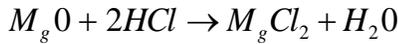
The reaction of magnesium oxide and hydrochloric acid in a CSTR to gives,

$$V_R = \frac{C_{A0} V_0 \alpha_A}{(r_p)} \quad (2)$$

Design Equation for Reactor Parameter

Rate Equation

For a typical irreversible third order reaction of the type



The corresponding rate equation can be expressed as:

$$\frac{-dC_A}{dt} = (-r_A) = k_1 C_A C_B^2 \quad (3)$$

Where A = Magnesium oxide

B = Hydrogen chloride

C = Magnesium chloride

D = Water

$$(-r_A) = k_1 C_{A0}^3 (1 - \alpha_A) (M - 2\alpha_A)^2 \quad (4)$$

Substitute equation (4) into (2) the volume of the reactor will be expressed as

$$V_R = \frac{F_{A0} \alpha_A}{k_1 C_{A0}^3 (1 - \alpha_A) (M - 2\alpha_A)^2} \quad (5)$$

Height of the Reactor  $H_R$

Considering the cylindrical tank reactor, the volume is given by

$$H_R = \frac{F_{A0} \alpha_A}{\pi R^2 [k_1 C_{A0}^3 (1 - \alpha_A) (M - 2\alpha_A)^2]} \quad (6)$$

Space Time ( $\tau$ )

Space time is the time required to process one reactor volume of feed measured at specific condition. Its unit is in time (secs)

$$\tau = \frac{\text{Volume of reactor } (V_R)}{\text{Volumetric flow rate of A } (f_v)}$$

$$\tau = \frac{F_{A0} \alpha_A}{V_0 [k_1 C_{A0}^3 (1 - \alpha_A) (M - 2\alpha_A)^2]} \quad (7)$$

Space Velocity ( $S_v$ )

$$S_v = \frac{F_{A0} \alpha_A}{V_0 [k_1 C_{A0}^3 (1 - \alpha_A) (M - 2\alpha_A)^2]} \quad (8)$$

Heat Generated Per Unit Volume of the Reactor

$$q = \frac{F_{A0} \alpha_A (\Delta H_R) (r_p)}{F_{A0} \alpha_A} = (\Delta H_R) (r_p) \quad (9)$$

2) Energy balance

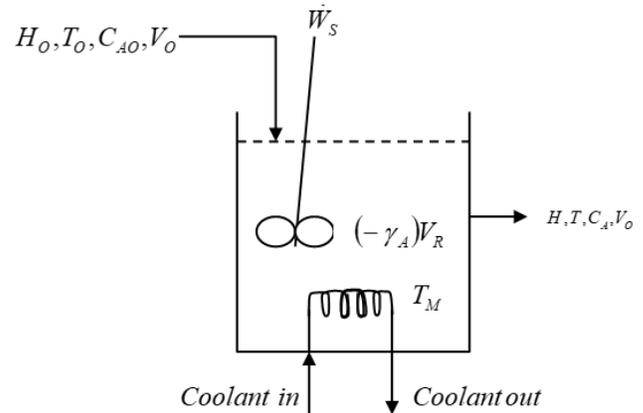


Fig. 4. CSTR in Steady State Operation with Heat Effect

The Energy Balance for the Non-isothermal Continuous Stirred Tank reactor (CSTR) can be obtained using the general principle of conservation of energy which is given as:

$$\begin{aligned} & \left( \begin{array}{l} \text{Rate of accumulation} \\ \text{of energy within the reactor} \end{array} \right) \\ &= \left( \begin{array}{l} \text{Rate of inflow} \\ \text{of energy into the} \\ \text{reactor} \end{array} \right) \\ &- \left( \begin{array}{l} \text{Rate of outflow} \\ \text{energy from the reactor} \end{array} \right) \\ &+ \left( \begin{array}{l} \text{Rate of formation} \\ \text{of energy due to chemical} \\ \text{reaction} \end{array} \right) \\ &- \left( \begin{array}{l} \text{Rate of removal} \\ \text{of energy} \end{array} \right) \\ &+ \left( \begin{array}{l} \text{Shaft work done} \\ \text{by the stirrer} \end{array} \right) \end{aligned} \quad (10)$$

Analyses of equation (10) mathematically for 1 mol of heat gives the energy model as given in equation (11)

$$T - T_o = \tau \frac{(\Delta H_R) (r_A)}{\rho C_p} - \frac{U A_c (T - T_c)}{\rho v_o C_p} \quad (11)$$

D. Experimental Determination of the Rate Constant, (k)

The experiment carried out, the formation of Magnesium Chloride in the continuous stirred tank reactor was measured in terms of moles in volume of the reactor amount. The concentration of the  $MgCl_2$  was recorded with time, in hours.

$$\text{number of moles} = \frac{\text{Mass given (reacted)}}{\text{Molar mass of salt}}$$

$$\text{Molar mass of salt } (MgCl_2) = 24 + (35.5 \times 2) = 94g/mol$$

$$n = \frac{\text{mass}}{94} \text{ mol} \tag{12}$$

$$C = \frac{n}{V}$$

$$M(C) = \frac{\text{moles}}{V} \tag{13}$$

The reaction order theoretically was determined and tested and then found out that the order (n) of the reaction  $MgO + 2HCl \longrightarrow MgCl_2$ : was first order; the rate of reaction was dependent on the amount of  $MgO$  (Magnesium oxide) present in the reactor and that has reacted.

$$(-r_i) = \frac{-dC_A}{d\tau} = kC_A^n \tag{14}$$

$$n = 1$$

$$(-r_A) = kC_A^n \tag{15}$$

$$\ln(-r_A) = n \ln \left( \frac{-\Delta C_A}{\Delta \tau} \right) = \ln \left[ \frac{\Delta C_A}{\Delta \tau} \right] = n \ln C_A + \ln k \tag{16}$$

Plot of  $\ln \left( \frac{-\Delta C_A}{\Delta \tau} \right)$  versus  $\ln C_A$  will be carried out and the intercept will give the rate constant, k while n while n will be known as the slope of the plot obtained.

MS. Excel will be used for the plot and intercept and the equation of the line calculated to discuss the tables.

3. Results and Discussion

The production of 2tons/day of Magnesium Chloride was carried using electrolysis of brine and design models were developed and simulated using excel program and the simulated results are tabulated and figures plotted and discussed below.

A. Results and Discussions

Table 1  
Formation of Magnesium Chloride Concentration (M) with Time (hr)

Time (hr)	Concentration of $MgCl_2$
2	0.008
3	0.012
5	0.035
8	0.068
9	0.072
10	0.088

The experimental work was based on the formation of magnesium chloride ion i.e. crystallization of  $MgCl_2 \cdot 6H_2O$  in the solution was noted and concentration of the magnesium chloride in mol per litre was recorded and shown in Table 1.

The change in concentration in concentration with time plotted against concentration gives a straight line which the slope was determined and equates to the rate constant calculated.

Table 2  
Summary of the Results for Rate Constant, k determination

Time (hr)	Conc.	$\Delta C_A$	$\Delta \tau$	$\Delta C_A / \Delta \tau$	$\ln \left[ \frac{-\Delta C_A}{\Delta \tau} \right]$
2	0.008		1		
3	0.012	0.004	2	0.004	5.52
5	0.035	0.023	3	0.0115	4.47
8	0.068	0.033	1	0.011	4.51
9	0.072	0.004	1	0.044	3.12
10	0.088	0.016		0.016	4.14

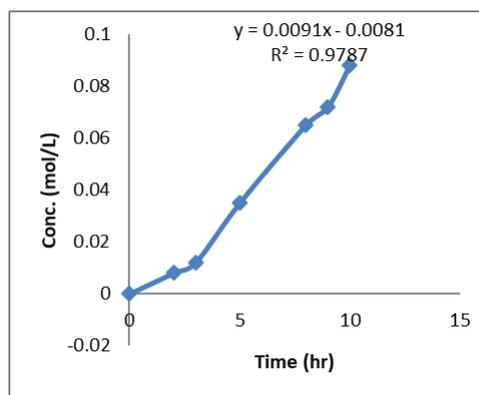


Fig. 4. Graph of Concentration of  $MgCl_2$  versus Time

Figure 4 demonstrate the relationship between the concentrations of the  $MgCl_2$  formation and time. The equation of the line is given as  $y = 0.0091x - 0.0081$  with the squared root of the best fit given as  $R^2 = 0.9787$  for the concentration of  $MgCl_2$  as  $R^2 = 0.9787$  for the concentration of  $MgCl_2$  formed. The order of the equation is  $n = 1$  (one) i.e. first order and the slope of the straight line equation is 0.0091 while the intercept of the straight line equation is  $- 0.0081$ . The value of  $R^2 = 0.9787$  revealed that the reliability of the equation is good and gives correct relationship to obtain the rate expression and the rate constant subsequently obtained. The slope of the equation i.e. 0.0091 gives the rate expression for the formation of the  $MgCl_2$  in the continuous stirred tank reactor, i.e.

$\frac{\Delta C_A}{\Delta \tau} = (r_p) = \text{rate of formation of } MgCl_2 = \text{slope obtained from the plot (Figure 4)}$ .

Figure 5 depicts the relationship between the natural log of the ratio of change of concentration to time which decreases with concentration of the reactants (i.e.  $MgO$  and  $HCl$ ) in the continuous stirred tank reactor (CSTR). The equation of the straight line as expressed as  $y = 21.192 x + 5.5048$  and the square root of the best fit given as  $R^2 = 0.5641$  indicates that the process is of order 1 and is reliable to calculate the rate constant, k for the reaction occurring in the CSTR to give  $MgCl_2$ . As shown in section 3, the intercept of the straight line equation given as 5.5048 gives  $\ln k$  which can be used to obtained the rate constant i.e.  $k = e^{5.5048} = 245.87 \text{ hr}^{-1} = 0.0683s^{-1}$ . This rate constant is vital in the design of the reaction and also for the

determination of the functional parameters of the CSTR.

i.e.  $(r_p) = KC_A^n : n = 1: k = 0.0683s^{-1}$ , hence  $(r_p) = 0.0683 C_{A0} (1-\alpha_A)$

Since the rate expression is the driving force of the reactor,  $V_R, S_v, T, H_R, D$  and  $T$  can be obtained from their corresponding equations.

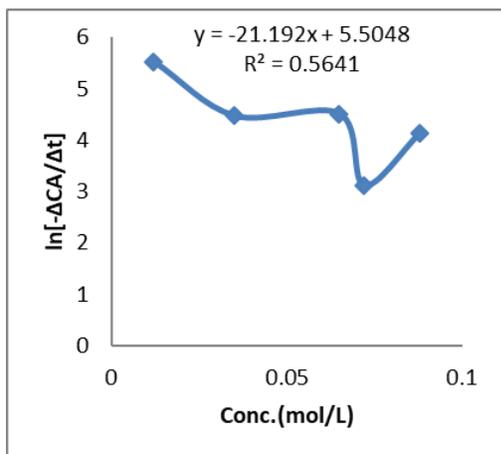


Fig. 5. Graph of Linearize Rate of Reaction versus Concentration

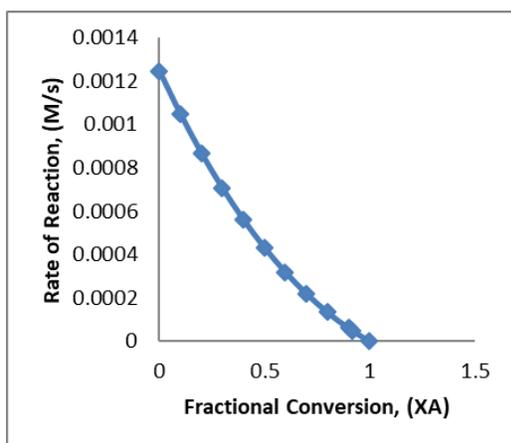


Fig. 6. Plots of Rate of Reaction,  $(r_p)$  versus Fractional Conversion

As shown above, in Figure 6, depicts the variation of rate of reaction,  $r_p$  with fractional conversion and the rate generally is at exponential decrease with conversion. Initially, at conversion of 0, the rate is 0.0012 M/s and decreases to 0M/s exponentially at increasing fractional conversion from 0 to 1. This indicates that lower rates will give a better results and hence more crystallization of the salt i.e.  $MgCl_2 \cdot 6H_2O$ .

Figure 7 depicts the profile of volume of reactor with fractional conversion  $\alpha_A$ . The plot shows that the volume of reaction is a function of the fractional conversion and is at exponential increase with fractional conversion. At lower rates which occur at conversion of 0.9, the reactor volume is highest and is 4.8L. This means that crystallization of the salt varies with fractional conversion and becomes highest at larger volume of 4.8L and at lower rates of the formation of the ions in solution.

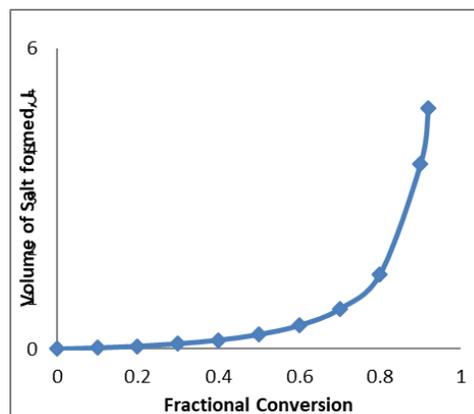


Fig. 7. Graph of Volume of Reaction versus Fractional Conversion

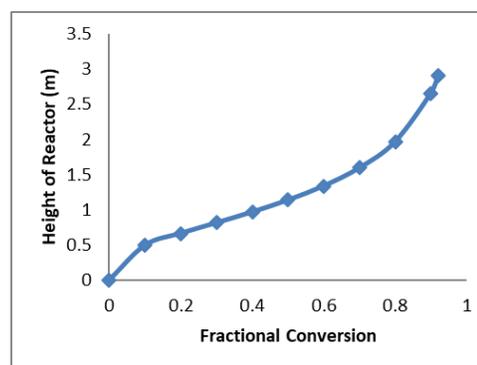


Fig. 8. Graph of Height of Reaction versus Fractional Conversion

Similarly, to Figure 7, Figure 8 is the variation of height of Reactor with fractional conversion. There is an exponential increase of height of reactor with fractional conversion  $\alpha_A$  to a point when  $\alpha_A = 0.92$ . initially; the height of the reactor is 0m at conversion of 0 and increases exponentially to 2.9m at conversion of 0.92. The results show that the increase in height is as a result of volume increment due to lower rates at that conversion.

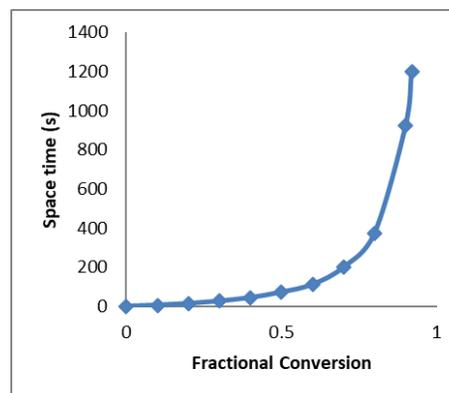


Fig. 9. Graph of Space Time versus Fractional Conversion

Figure 9 shows the variation of space time against fractional conversion. Like in the same manner with Figure 4.4, the space time of the reactor increases with fractional conversion. The

increase is in exponentially such that  $\tau_{max} = 1200$  secs at  $\alpha_A = 0.92$ . The higher space time a value is due to the higher volume obtained and also the higher conversion rates which produces lower rates of crystallization of the salt.

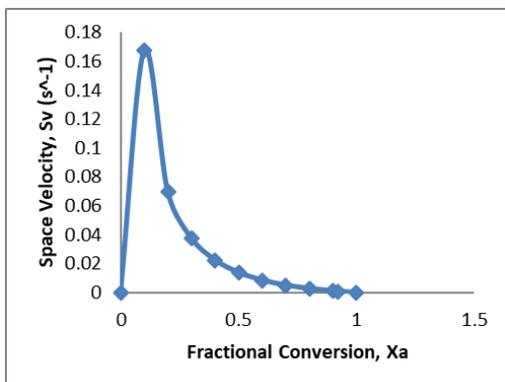


Fig. 10. Profile of Space Velocity versus Fractional Conversion

Figure 10 shows the profile of space velocity with fractional conversion.

There is a spontaneous increase of space velocity from  $S_v = 0$  to  $S_v = 0.17s^{-1}$  when  $\alpha_A = 0$  to  $\alpha_A = 0.15$  from then, space velocity decreases exponentially to zero as fractional conversion increases to 1.

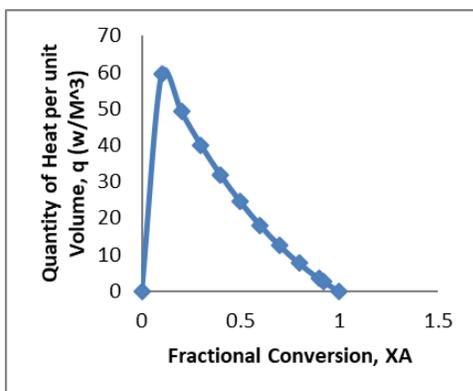


Fig. 11. Profile of Quantity of Heat per unit Volume of Reactor versus Fractional Conversion

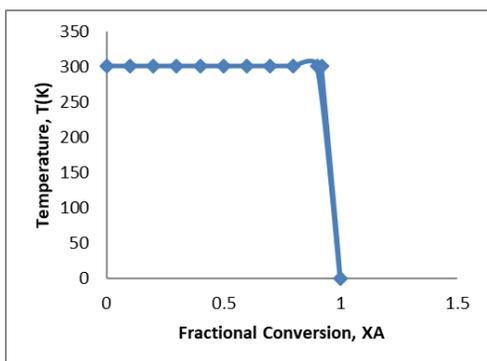


Fig. 12. Temperature Profile versus Fractional Conversion

Figure 11 depicts the profile of quantity of heat generated per

unit volume varying with fractional conversion.

Almost similar to figure 10, there is a sudden increase in  $q$  from 0 to  $60 W/m^3$  when  $\alpha_A = 0$  to  $0.15$  and then  $q$  drops almost linearly to  $0 W/m^3$  as  $\alpha_A$  increases from  $0.15$  to  $1.0$ .

Figure 12 shows the variation of temperature with fractional conversion from the figure, there is quasi – steady state temperature profile with fractional conversion from  $\alpha_A = 0$  to  $0.9$  and then drops to zero ( $0 K$ ) when  $\alpha_A = 1$ .

#### 4. Conclusion

The design for the production of 2 tons per day of Magnesium chloride,  $MgCl_2$  from brine using continuous stirred tank reactor was developed.

The principle of mass and energy balances for the design models generation was applied. Thermodynamic data and literature values were used for the calculation and simulations of the design models to obtain functional parameters values of CSTR and Temperature values.

Table 2 shows the displayed results of the functional parameters and temperature of the reactor (CSTR).

#### Nomenclature

Symbol	Meaning	Unit
NaCl	Sodium Chloride	
$MgCl_2$	Magnesium Chloride	
$C_{AO}$	Initial Concentration	mol/L
$(-r_p)$	Rate of Production of $MgCl_2$	mol/L.s
$V_R$	Volume of the Reactor	L
$\alpha_A$	Fractional Conversion	%
$\tau$	Space Time	s
$F_{A0}$	Initial Molar FlowRate	mol/s
$H_R$	Height of the Reactor	m
$S_v$	Space velocity	$s^{-1}$
$\Delta H_R$	Heat of Reactor	KJ/mol
$\delta$	Density	$kg/m^3$
$T_0$	Initial Temperature	K
$C_p$	Specific Heat Capacity	KJ/KgK
$U$	Overall Heat Transfer coefficient	$W/m^2C$
$W_s$	Shaft Work	W
$A_c$	Area of Coolant	$m^2$
$G_w$	Mass Flow Rate of Coolant	Kg/s
$C_{pw}$	Specific Heat Capacity of Coolant	KJ/KgK
$q$	Heat Generated per unit Volume	KW/L

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