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Design of Heat Exchenger for Production of N –doped ZnO Nanoparticle Through Basic Calculation with Microsoft Excel Application

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Abstract:
The aim of this study is to create heat exchanger (HE) design for N-doped ZnO nanoparticle synthesis in manufacture schale through basic calculation using Microsoft Excel™ . This one-pass shell and tube type HE is simply design for synthesis N-doped ZnO nanoparticle. The specification of HE equipment are shell length 4.8768 m, shell diameter 0.4826 m, tube outer diameter 0.0254 m, and thickness 0.00488 m and fluid used is oil for hot fluid and water for cold fluid. The calculations are done manually using the Microsoft Excel™ application. The results represent that the design of shell and tube HE is single-pass shell and tube exhibits laminar flow, with an effective value of 95,16% with NTU value 150 Thus, HE using a single pass shell and tube does fill-up the requirements and standards, in terms of effectiveness yet not include the calculation of correction factor. However, the results of this analysis can be used as learning materials in the heat exchanger (HE) design process performance analysis, and operating mechanism.

Keywords: Heat Exchanger, Synthesis of N-doped ZnO, Effectiveness, Shell

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1. Introduction

Heat exchanger is defined as a process that takes place between two fluids at different temperatures and separated by a solid wall. It is widely used in various engineering applications, such as in air conditioning and space heating, waste heat recovery, power generation, and processing [1]. One of the application of the heat exchanger is for manufacture of ZnO nanoparticles.

Metal oxides have exhibited good photocatalytic activities under sunlight and have been used to degrade poisonous organic dyes to non-poisonous forms. [2] Recently, the degradation of pollutants was carried out with unique semiconductor metal oxide nanoparticles which include TiO_2, ZnO, WO_3, In_2O_3 and SnO_2. [3]-[7] Among these, ZnO showed superior properties, including an absorption range within the visible region, high photo-stability, good sensor abilities, light-emitting diodes, and solar light harvesting. The photocatalytic performance of ZnO was not effective for the degradation of organic dyes due to an extensive

band gap (3.37 eV) and the recombination of electron–hole pairs.[8]

ZnO nanoparticles have been modied with different dopants consisting of N and S atoms for enhancing the photocatalytic oxidation of organic dyes under UV light irradiation.[9],[10]. Nitrogen-doped ZnO nanoparticles in the form of nanorods and nanowires have been used for water splitting applications Nowadays, N-doping on ZnO nanoparticles has been conducted using various methods such as thermal evaporation [11], pyrolysis [12] and thermal nitridation [13] with ammonia as a nitrogen source precursor.

Hydrothermal methods have exhibited better advantages such as simple processes, lower temperature demands, eco-friendliness and better time control. This method was also used to prepare different morphologies of ZnO nanoparticles such as nanorods, nanotowers, nanotubes, nanoowers and nanovolcanoes as reported previously [14]. The size-controlling agent ethylenediamine was applied for the synthesis of various sizes of ZnO nanoparticles like nanorods and nanoowers with hydrothermal methods at low temperatures [15].

Several studies on the design of heat exchanger (HE) equipment have been done [16-18]. In contrast to the referred studies, we conducted analysis and evaluation of the processes. Therefore, the aim of this study is to create heat exchanger (HE) design for N-doped ZnO nanoparticle synthesis though hydrothermal method in manufacture schale through basic calculation using Microsoft Excel. As a model, we used the process for the production of N doped – ZnO nanoparticles that are from zinc acetate ($Zn(CH_3COO)_2$) and hydrazine monohydrate (N_2H_4) and HE with a shell and tube type is designed. Thus, it can be useful as a reference in designing a HE and become a teaching and learning method for the design process, the working mechanism, to the performance of HE

2. Method

2.1. Synthesis of N-ZnO nanoparticle

The specific processing conditions and preparation procedure are shown in Figure 1. The procedure was taken from previous study conduted by Prabakara & Pillay, 2019 [19]. 1 g (1.5 M) of zinc acetate dehydrate was dissolved in 50 ml of water while stirring for 30 minutes and 5 ml of hydrazine monohydrate solution was introduced to obtain a clear solution under constant stirring again for 30 minutes. 1.2 g (3 M) of NaOH solution was slowly added drop wise into the mixture of solution to form a white precipitate at pH 8. The white precipitate was dissolved for 1 h under stirring to obtain a homogeneous solution. The solution was heated at 180ºC for 48h with help of HE that used oil as hot fluid. Afer the heating a white granular solid representing the N- doped ZnO formed at the bottom of the tank [21]. The white granular solid was washed with double distilled water and ethanol several times and dried in an oven at 80ºC for 12 h with help of HE that used water as cold fluid. A schematic diagram of this procedure is shown in Figure 1.

2.2. Mathematical model for designed Heat Exchanger

The hot fluid used is oil, while the cold fluid is water. The hot fluid enters at 180ºC and leaves at 160^{O}C. The assumption used for the fluid characteristics operating in the heat exchanger is shown in Table 1. The incoming hot oil flow rate is 18.94 (kg/s) while the incoming water flow rate is 2.08 (kg/s). in data collection, the Turbular Exchanger Manufacturers Association (TEMA) Standard was used as the reference regarding the specification, while the thermal analysis is in the form of manual calculations using the basic Microsoft Excel™ based on equation 1-27, follow what has been done by [20]. The equations (1 – 27) is for calculation of heat exchanger parameters using basic Microsoft Office™ application are shown in Table 2.

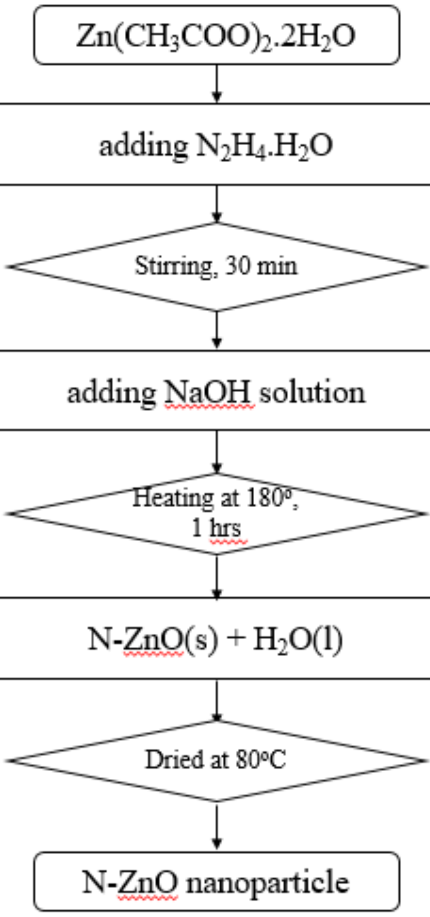

Fig. 1. Schematic diagram of the procedure used for synthesis of N-ZnO nanoparticles.

Table 1. Physical and Thermal Properties of The fluid on Heat Exchanger.

	Shell Side	Tube Side
	Hot fluid (Hot Oil)	Cold fluid (Water)
Inet Temperature, T_{in} (K)	453,15	353,15
Outlet Temperate, T_{out} (K)	433,15	358,15
Fluid Flow Rate (kg/s)	18,94	2,08
Operating Pressure (atm)	1	1
Spesific Heat (kJ/kg.K)	2,19	4,18
Density (kg/m^3)	850	997

Table 2. Calculation of Heat Exchanger Parameters

Section	Parameter	Equation	Eq
Basic parameters	The energy transferred (Q)	$\mathbf{Q_{in} = Q_{out}}$ $\mathbf{m_c \text{ x } Cp_c \text{ x } \Delta T_c = m_h \text{ x } Cp_h \text{ x } \Delta T_h}$ where Q = the energy transferred (Wt) m = the mass flow rate the fluid (kg/s) Cp = the specific heat ΔT = the fluid temperature difference (°C)	(1)
	Logarithmic mean temperature differenced (LMTD)	$\mathbf{LMTD} = \frac{(T_{hi}-T_{Ci})-(T_{ho}-T_{Co})}{In\left(\frac{T_{hi}-T_{ci}}{T_{ho}-T_{co}}\right)}$ Where T_{hi} = temperature of the hot fluid inlet (°C) T_{ho} = temperature of the hot fluid outlet (°C) T_{ci} = temperature of the cold fluid inlet (°C) T_{co} = temperature of the cold fluid outled (°C)	(2)
	Correction Factor	$R = \frac{T_{hi} - T_{ho}}{T_{ci} - T_{Co}}$	(3)
		$P = \frac{T_{hi} - T_{ho}}{T_{ci} - T_{Co}}$	(4)
		$F = \frac{\sqrt{R^2 + 1} ln\left[\frac{1-P}{1-PR}\right]}{T_{ci} - T_{Co}}$ $(R-1)\, ln\left(\frac{2 - P(R + 1 - \sqrt{R^2+1}}{2 - P(R + 1 + \sqrt{R^2+1}}\right)$	(5)
	Heat Transfer Field Area (A)	$A = \frac{Q}{U \text{ x } LTMD}$ Where, Q = Energy transfer (W) LMTD = Logarithmac Mean Temperature Difference U = Overall heat transfer coefficient	(6)
	Number of tube (N)	$N = \frac{A}{\pi \text{ x } D_0 \text{ x } l}$ N = Number of tube A =Heat Transfer Field Area π = 3,14 D_0 = Tube diameter (m) L = Tube length (m)	(7)
	Shell Diameter	$D_S = 0,63\left(\frac{\sqrt{\frac{CL}{CTP}}\, S\,(A \text{ x } PR^2 \text{ x } D_0)}{l}\right)$ Where, D_S = Shell Diameter (m) A = Heat Transfer Field Area (m^2) P, R = Correction factor D_0 = Tube diameter (m) CTP = one tube (0,93); two tube (0,90); three tubes (0,85) CL = 90° and 45° = 1,00; 30° and 60° = 0,8	(8)

Tube	Total Heat Trasfer Surface Area in Tube (a_t)	$$a_t = N_t \frac{a'_n}{n}$$ Where, a_t = total heat transfer surface area in the tube (m^2) Nt = Number of tube a'_n = area of flow in the tube n = number of passes	(9)
	Mass Flow Rate of Water in Tube (G_t)	$$G_t = \frac{m_h}{a_t}$$ Where, G_t = mass flow of water in the tube (kg/m^2s) m_h = mass flow rate of kot fluid (kg/s) a_t = total heat transfer surface area in the tube (m^2)	(10)
	Reynold number (Re_t)	$$Re_t = \frac{di_t \ x \ G_t}{\mu}$$ Where, Re_t = Reynold number in the tube G_t = mass flow of water in the tube (kg/m^2s) di_t = inner tube diameter (m) μ = dynamic viscosity (kg/m.s)	(11)
	Prandtl Number (Pr,t)	$$Pr = \left(\frac{Cp \ x \ \mu}{K}\right)$$ Where, Pr = Prandtl number μ = synamic viscosity of tube liquid (kg/m.s) K = thermal conductivity of the tube material (W/m°C)	(12)
	Nusselt number (Nu,t)	Nu = 0,023 x $Re_t^{0,6}$ x $Pr^{0,33}$	(13)
	Convection Heat Transfer Coefficient in Tube (Nu,t)	$$hi = \frac{Nu \ x \ K}{di_t}$$ Where, hi = convection heat transfer coefficient in the tube (W/m°C) K = thermal conductivity of the tube material (W/m°C) di_t= inner tube diameter (m)	(14)
Shell	Shell flow area (A_S)	$$A_s = \frac{d_s x \ C \ x \ B}{P_t}$$ $$D_b = d_0 \left(\frac{N_t}{k_1}\right)^{\frac{1}{n_1}}$$ Where, d_s = shell diameter (m) C = cleareance (P_t - d_0) B = a shell bundle P_t = tube pitch (1,25 x d_0) (m)	(15)

	Mass Flow Rate of Water in Shell (G_s)	$$G_S = \frac{m_c}{a_s}$$ Where, m_c = the mass flow rate of the cold fluid (kg/s) A_s = the shell flow area (m^2)	(16)
	Equivalent diameter (d_e)	$$d_e = \frac{4\left(\frac{Pt}{2}\ x\ 0,87\ Pt - \frac{1}{2}\pi.\frac{d_o,t}{4}\right)}{\frac{1}{h_i} + \frac{\Delta r}{k} + \frac{1}{h_o}}$$ Where, Pt = tube pitch (1,25 x d_o) (m) π = 3,14 d_o, t = tube diameter (m)	(17)
	Reynold number (Re,s)	$$Re_s = \frac{di_t\ x\ Gs}{\mu}$$ Where, Re_s= Reynold number di_t= inner tube diameter (m) Gs = the mass flow of water in the shell (kg/m^2.s) µ = the dynamic viscosity (kg/m.s)	(18)
	P randtl Number (Pr,s)	$$\text{Pr,s} = \left(\frac{C_p\ x\ \pi}{K}\right)^{\frac{1}{2}}$$ Where, Pr,s = Prandtl number Cp = specific heat capacity (kJ/kg°C) K = thermal conductivity (W/m°C)	(19)
	Nusselt number (Nu,s)	$$Nu_s = 0,023\ x\ Re_s^{0,6} x Pr^{0,33}$$ $Re_s =$ Renold Number Pr = Prandtl number	(20)
	Coviction Heat Tranfer Coefficient (ho)	$$ho = \frac{Nu\ x\ K}{d_e}$$ Where, ho = convection heat transfer coefficient (W/m^2.°C) K = thermal conductivity (W/m°C) d_e= equivalent diameter (m)	(21)
Shell and tube	Actual Overall Heat Transfer Coefficient (U_{act})	$$U_{act} = \frac{1}{\frac{1}{h_i} + \frac{\Delta r}{k} + \frac{1}{h_o}}$$ Where, h_i = inside heat transfer coefficient (W/m^2.°C) h_o = outside heat transfer coefficient (W/m^2.°C) Δr = wall thickness (m) k = thermal conductivity	(22)
Heat rate	Hot Fluid Rate (C_h)	$$C_h = m_h\ x\ Cp_h$$ Where, C_h = hot fluid (W/°C) Cp_h = specific heat capacity (J/kg°C) m_h = mass flow rate of hot fluid (kg/s)	(23)

	Cold Fluid Rate	$\mathbf{C_c = m_c \ x \ Cp_c}$ C_c = cold fluid (W/°C) Cp_c = specific heat capacity (J/kg°C) m_c = mass flow rate of cold fluid (kg/s) $Q_{max} = C_{min}(\boldsymbol{T_{hi} - T_{ci}})$ Where, Q_{max} = maximum heat transfer (W) C_{min} = minimum heat capacity rate (W/°C) $\boldsymbol{T_{hi}}$ = themperature of the hot fluid inlet (°C) $\boldsymbol{T_{ci}}$ = themperature of the cold fluid inlet (°C)	(24)
(Effectiveness	Heat Exchanger Effectiveness ($\boldsymbol{\varepsilon}$)	$\boldsymbol{\varepsilon = \frac{Qact}{Qmax} \ x \ 100\%}$ Where, Q_{act} = actual energy transferred (W) Q_{max} = maximum heat transfer (W)	(25)
	Number of Transfer Unit (NTU)	$\boldsymbol{NTU = \frac{U \ x \ A}{C_{min}}}$ Where, U = overall heat transfer coefficient (W/m^2.°C) A = heat transfer area (m^2) C_{min} = minimum heat capacity rate (W/°C)	(26)
	Foulding factor (Rf)	$\boldsymbol{Rf = \frac{U_a - U_{act}}{U_a \ x \ U_{act}}}$ Where, Rf = foulding factor U_a = overall heat transfer coefficient (W/m^2.°C) U_{act} = actual overall heat transfer coefficient (W/m^2.°C)	(27)

3. Result and Discussion

The principle of the HE design for production of N- doped ZnO nanoparticle is to calculate the difference in temperature T_{hin} and T_{cin}, with a visible effect on the outlet temperature. Through calculation that have been designed using Microsoft Excel application, it is found that the Q value in the shell and tube HE type design is 828435.60 W, with a shell length 4.8768 m, a shell diameter of 990.60 mm, an tube inner diameter is 22.1 mm, and an outer diameter tube is 25.4 mm. The wall thickness, tube leght and tube pitch were 4.88 mm, 4.8768 m; 27,78 mm repectively. The effectiveness of heat exchanger was found to be 95.15 % which indicates the actual heat transfer rate. The total heat exchanger performance is also determined by specific heat of the fluid, density, viscosity and thermal conductivity. The calculation results obtained using Microsoft Excel are shown in Tabel 3.

The HE design model is shown in Fig.2. Synthesis of N-doped ZnO nanoparticle requires heating at 180°C and then drying process which requires lowering temperature to 80°C. Therefore, the hot fluid used is oil and the cold fluid is water. The hot fluid enters at temperature of 180°C and leaves at temperature of 160 °C. The cold fluid enters at 85°C and leaves at 80°C. After that N- doped ZnO nanoparticle is obtained.

Table 3. **Specification of Shell and Tube Heat Exchanger and Operating Condition for Oil and Water Fluid Based on Calculations using Microsoft Excel.**

Description	Type/value
Type of heat exchanger	Single tube pass, type E shell and tube heat exchanger
Oil inlet temperature (°C)	180
Oil outlet temperature (°C)	160
Water inlet temperature (°C)	75
Water outlet temperature (°C)	80
Tube outside diameter, do (mm)	25.4
Tube inner diameter, di (mm)	22.10
Pitch, (mm)	31.75
Total tube number, N	6094,60
Total Heat Transfer Surface Area in Tube (m^2)	0.297
Mass Flow Rate of Fluid in Tube ($kg/m^2.s$)	212.84
Reynold Number in Tube	0.144
Prandtl Number in Tube	59535
Nusselt Number in Tube	0.50
Tube layout	Triangular square
Shell inner diameter, Ds (mm)	31.75
Shell thickness, ds (mm)	4.88
Total Heat Transfer Surface Area in shell (m^2)	0.3925
Mass Flow Rate of Fluid in shell ($kg/m^2.s$)	225,42
Reynold Number in Shell	4441.24
Prandtl Number in Shell	7016.25
Nusselt Number in Shell	772.34
Baffle type	Single-segmental
Baffle spacing, B (mm)	220,4
Initial Heat Transfer Rate (W)	828435.60
Logarithmic Mean Temperature Difference (°C)	10.82
Area of Heat Transfer (m^2)	596.31
Oil mass flow rate (kg/s)	18.94
Water mass flow rate (kg/s)	2.08
Oil heat rate (W/K)	41,421.78
Water heat rate (W/K)	8,706.25
HE Effectiveness (%)	95.15
Number of Transfer Unit	150.06

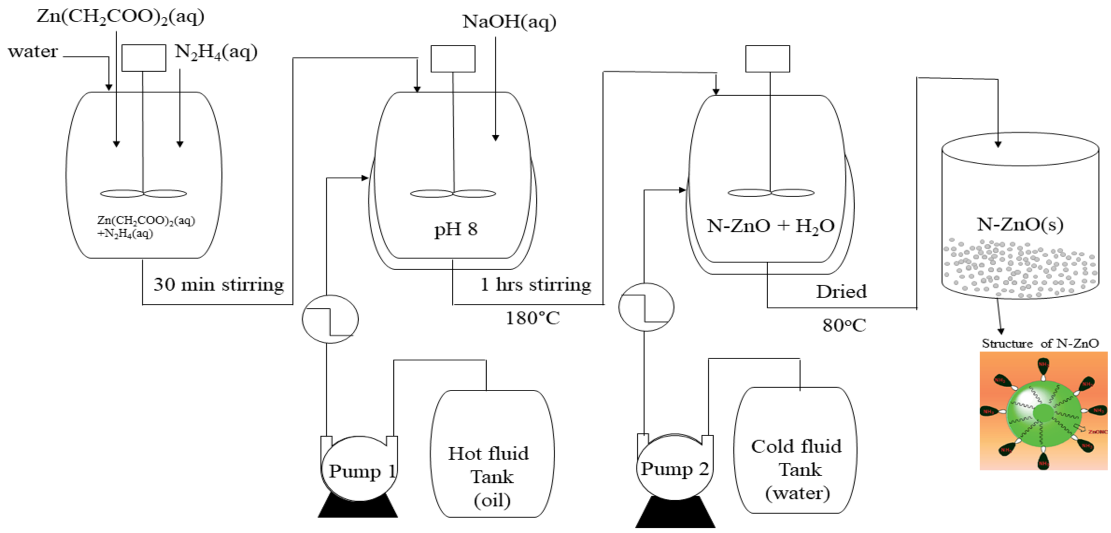

Fig. 2. Process Flow Diagram on Producing N doped -ZnO Nanoparticle

Therefore, this heat exchanger with shell and tube one meets the requirements and standards based on effectiveness, but without the calculation of fouling factor.

Conclusion

In conclusion, the calculation for specification of heat exchanger design for production of N –doped ZnO nanoparticle through basic calculation with Microsoft Excel Application obtained shell length, shell diameter, inner tube diameter, outer tube diameter, wall thickness, and tube pitch 4.8768 m, 990.60 mm, 0.0221 m,0.0254 m, 0.00488 m, 27.78 mm, respectively. Based on the calculation performed through Microsoft Excel, the result show that the heat exchanger design on the shell and tube that fits is a laminar flow type, with an effectiveness of 95.15%. This HE designs has a high effectiveness so it is considered effective for use. This result is very important to maximize the efficiency of the shell and tube heat exchanger. Therefore, the results of the analysis lead to information that will help optimize the single-pass shell-and-tube HE models for production of N doped – ZnO nanoparticle.

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