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Computational Calculation on the Shell and Tube-Type Heat Exchanger for Lanthanum Oxide (La_2O_3) Nanoparticle Production Process for Energy-Related Material Application

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ABSTRACT

This paper introduced a design of a heat exchanger to get an optimum heat transfer enhancement technique that can be used for the production of lanthanum oxide (La_2O_3). The shell and tube type was selected since this type is one of the effective types for making excellent heat transfer, which was then compared to the Tubular Exchanger Manufacturers Association (TEMA) standard to obtain the dimensional specifications of the heat exchanger device. Several parameters were calculated to evaluate the performance of the designed heat exchanger. Numerical calculation obtained from the heat exchanger containing 138 tubes can be used to maintain the temperature in the reactor (prospective temperature can change from 40 to 60°C with rapid heating) using heating liquid (controlling by transferring heat from 100 to 70°C) with the effective value of 96%. This study can be used as a reference for supporting information in the current issue of the need for the large production of La_2O_3 particles.

1. INTRODUCTION

Lanthanum (La) is a rare earth element, one of the seventeen f-electropositive metallic elements. Lanthanum forms a stable lanthanum oxide (La_2O_3) that can be formulated into nanoparticles. La_2O_3, which is sold commercially at about 1-3 USD/kg, has been widely applied in large fields of uses, such as catalysts [1], superconductors [2], flue gas convectors [3], and hydrogen storage materials [4]. La_2O_3 is also used as the blood-brain barrier that is a serious barrier to promising therapeutic compounds [5, 6]. This excellent usage creates the condition that La_2O_3 is put on the list as one of the crucial materials for being large-scale produced.

To support large-scale production, a heat exchanger is required. In short, a heat exchanger is a device used for interacting heat processes between two types of fluids [7]. This device has been well-used in pharmaceutical manufacturing and industries, food production, heat dissipation from nuclear reactors [8, 9], power plants, air conditioning processes, cryogenics, alternative fuels, refrigeration, transportation, as well as heat recovery [10]. The need for the design of a heat exchanger has been well-reported. Chu et al. [11] investigated the use of porous media to improve heat and mass transport in energy systems. Nusselt number values were 50% more than laminar flow in channels without porous materials. Maddah et al. [12] looked into the ideal heat exchanger, one that transfers the most heat while producing the least amount of entropy. Jamal and Syahputra [13] conducted a simulation of the system temperature test on a heat exchanger with a feedforward controller type. The control results obtained were relatively better than the feedback control, especially on the response speed in a stable situation. Gasia et al. [14] looked at the effect of forced convection in a cylindrical shell-and-tube heat exchanger with water as the phase change material (PCM) that is circulated during the smelting process. The flow rate in the heat exchanger, efficacy, melting period, and heat transfer rate are all increased by raising the PCM. Several other reports that have been published in the description and application of heat exchangers include magnetite particle [15], revamped chemical plant [16], nano zeolite production [17], and heat exchanger for nanofibril cellulose production [18]. Although many reports showed excellent heat exchangers, research focusing on heat exchange equipment in the La_2O_3 nanoparticle industry is still limited. This becomes the novelty of this study to patch the current condition and can be used as a reference for supporting current issues in the production of La_2O_3 nanoparticles.

Based on our previous studies [19] for the feasibility study in the production of La_2O_3 and the design of a heat exchanger [20-26], the purpose of this study was to introduce our numerical analysis for the design of a shell and tube-type heat exchanger for supporting the production of La_2O_3 nanoparticles.

Figure 1 shows the process flow diagram for the large-scale production of La_2O_3 particles. The production reactor requires a heating device to maintain the temperature at 60°C to mix all the precursors, which is supported by the heat exchanger. To assess the performance of the heat exchanger, we focused the calculations based on the thermal load (*Q*), the logarithmic mean temperature difference (*LTMD*), the heat transfer surface area (*A*), and the number of tubes (*Nt*) of the heat exchanger to obtain standard dimensions in the design.

In this study, we focused on the heat exchanger for supporting the fabrication of La_2O_3. Information regarding the detailed production of the La_2O_3, including agglomeration and purification, is not explained.

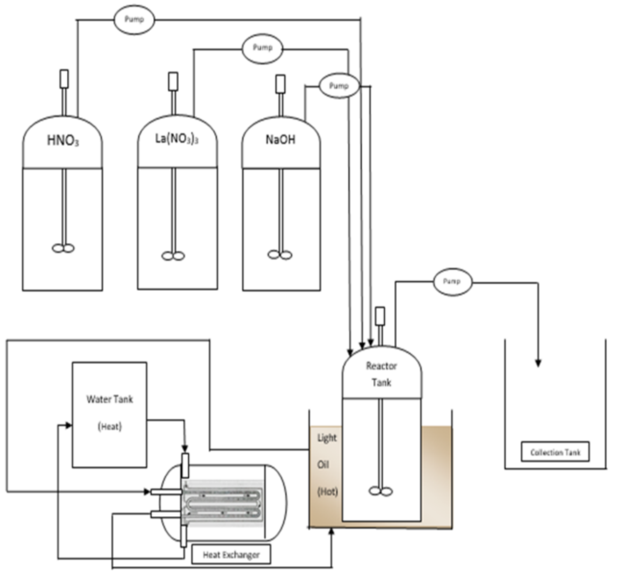

Figure 1. Illustration of lanthanum oxide particles production

2. MATERIALS AND METHODS

This study adopted a shell and tube-type heat exchanger. This type of heat exchange is to make in a wide range of diameters and flow configurations, easy to apply to a wide range of operating pressures and temperatures [27], and easy to adapt to different operating conditions [28]. This heat exchanger was designed based on several parameters from the Standard of Tubular Exchanger Manufacturers Association (TEMA) to obtain data regarding its specifications. Some of these parameters were used to evaluate the heat exchanger's performance design made. Various assumptions were used in designing and estimating heat exchanger performance:

(i) The shell and tube heat exchanger are a form of heat exchanger (two shell pass and four tube pass).
(ii) The material for the heat exchanger design is carbon steel.
(iii) The fluid used is a light oil-water fluid system.
(iv) The flow system in this heat exchanger is a counter-current flow.
(v) On the shell side, the hot fluid is assumed to be present, while on the tube side, the cold fluid is supposed to be present.
(vi) The specifications for the stationary head type (indicating front end), shell (indicating shell type), and rear head (indicating rear end type) of the heat exchanger follow AEW.
(vii) There is no heat leakage during the heat exchange process.
(viii) The overall coefficient (*U*) for light oil-hot and cold-water fluids is 750 W/m^2.°C.
(ix) The orientation of the shell geometry is horizontal.
(x) The baffle type is single-segmental with a perpendicular orientation.
(xi) The pressure assumed during the preparation of the La_2O_3 particle is 2.01 bar.

The dimensions of the heat exchanger were designed using several assumptions. Table 1 shows the dimensions of the heat exchanger according to the TEMA standard, and Table 2 shows the specifications of the fluids acting on the equipment.

3. RESULTS AND DISCUSSION

Evaluation of equipment performance is necessary for designing heat exchangers. The performance of the heat exchanger consists of *Q*, *LTMD*, *A*, and *Nt*. Tables 2 and 3 are used to model the heat exchanger. Based on the assumptions and calculation analysis, the designed heat exchanger follows the specifications in Table 3. The specifications of the equipment used are based on the standards of TEMA. Based on the calculation results, the resulting heat transfer rate is 682,531 W (see Table 3). This heat transfer value is influenced by the fluid flow rate and the number of tubes. The fluid flow rate in the tube needs to be reduced, while it can reduce the heat transfer coefficient. As a compensation, *Nt* must be increased, while it can create a pressure drop at the inlet and outlet of the nozzles. The pressure drop is approximately proportional to the square of the velocity. *Ut* is proportional to the number of tubes per pass [29]. Pressure drop is the loss of pressure that occurs during the passage of a fluid through a heat exchanger. In this study, the value of pressure drop for the tube and shell sides are 2.73 and 0.004 psi, respectively. The pressure drop value shows less than 10 psi, which means the heat exchanger meets the standards [30]. Pressure drop affects the value of the fouling factor which affects the fluid flow rate, where the higher the value pressure drop means resistance or fouling factor value will be greater, with this large fouling value, the friction or resistance in the pipe increases. If the resistance increases, it is necessary to clean the heat exchanger device, thus the performance of the heat exchanger can run optimally thus the heat transfer that occurs takes place optimally.

Other parameters such as *LMTD*, *A*, *Nt* heat transfer area, number of tubes, overall heat exchanger transfer coefficient, correction factor, and the effective values are 16.98℃, 67.2 m^2, 138 pcs, 750 W/m^2 K, and 96%, respectively (see Table 3). The LMTD value needs to be corrected with a correction factor (*Ft*) for shell and tube heat exchangers. Here, (*Ft*) is more than 0.75, which has a value of 14.45, meaning that the economic exchanger can be achieved [29]. If *Ft* is less than 0.75, an economic exchanger design cannot normally be realized. In these cases, an alternative type of exchanger that is closer to true counter-current flow should be considered. The use of two or more shells in series, or multiple shell-side passes, will bring the flow closer to true counter-current flow and should be considered where a temperature cross is likely. The design is shell and tube according to *A* value is more than 200 ft^2, which has a value of 723.25 ft^2 [30]. Reynold's number is more than 2,000, which has a value of 98,963 for the tube and 16,720 for the shell, meaning that both flows are turbulent [29]. The design has a good potential to be developed with an effective value of 96%. Figures 2 and 3 illustrate the tube arrangement and 2D tube layout drawing. This paper was done and focused only on the design of a shell and tube-type heat exchanger. Research regarding heat transfer experiments and further simulations will be done in our further research.

Table 1. Dimensional specifications of heat exchangers based on TEMA standards

Parameters	Specification
Conductivity Material (W/m°C)	53.457
Tube Outer Diameter (m)	0.03
Tube Inner Diameter (m)	0.02
Thickness of pipe joint (m)	0.002
Wall Thickness (m)	0.00211
Tube Length (m)	6.10
Tube arrangements	Triangular
Pitch Tube (m)	0.03
Tube-side passes	Four passes side
Tube Characteristic Angle (°)	30
Shell Inner Diameter (m)	0.89
Baffle Cut	25%

Table 2. Specifications of tube and shell sides

Parameters	The specification in Tube Side	The specification in Shell Side
Inlet Temperature (*T*,in;°C)	40	-
Outlet Temperature (*T*,out;°C)	60	-
Inlet Temperature (*T*,in;°C)	-	100
Outlet Temperature (*T*,out;°C)	-	70
Fluid Flow Rate (kg/s)	2.50	0.85
Density (kg/m^3)	1,105.50	1,527.67
Viscosity (lb/ft.h)	0.11	0.14
Thermal Conductivity (W/m.K)	0.30	0.64
Heat Specific (J/kg.K)	4,185,995	2,949,693
Operating Pressure (bar)	1.379	1.034

Table 3. Performance parameters of heat exchangers designed based on calculations

No	Parameter	Results
1	Initial Heat Transfer Rate (*Q*)	143,730,265 W
2	Logarithmic Mean Temperature Difference (*LMTD*)	16.98°C
3	Assumed Overall Fluid Heat Coefficient of Water (*Ua*)	750 W/m^2.K
4	*R*	1.5
5	*S*	0.67
6	*Ft*	14.45
7	*ΔTm*	904.12°C
8	Area of Heat Transfer (*A*)	67.19 m^2 723.25 ft^2
9	Number of Tube (*Nt*)	138
10	Total Heat Transfer Surface Area in Tube (*at*)	0.01 m^2
11	Mass Flow Rate of Water Fluid in Tube (*Gt*)	205.55 kg/m^2.s
12	Reynold Number in Tube (*Re*, t)	98,963.4
13	Prandtl Number in Tube (*Pr*, t)	1,499.2
14	Nusselt number (*Nu*,t)	255.30
15	Convection Heat Transfer Coefficient in the Tube (*hi*)	214,339 W/m^2.K
16	Baffle Spacing	0.22 m
17	Total Heat Transfer Surface Area in Shell (*as*)	0.04 m^2
18	Mass Flow Rate of Water Fluid in Shell (*Gs*)	21.41 kg/m^2.s
19	Equivalent Diameter in Shell (De)	0.06 m
20	Reynold Number in Shell (Re,s)	16,719.8
21	Prandtl Number in Shell (*Pr*, s)	967.26
22	Nusselt Number in Shell (Nu, s)	76.01
23	Convection Heat Transfer Coefficient in Shell (ho)	168,339 W/m^2.K
24	Overall Heat Transfer Coefficient Actual (*Uact*)	86,696 W/m^2.K
25	Tube Fluid Rate (*Ct*)	10,466,790 W/°C
26	Shell Fluid Rate (*Cs*)	2,495,378 W/°C
27	HE Effectiveness (ε)	96%
28	Number of Transfer Units (*NTU*)	0.02
29	Dirt factor	0.0013 h.ft^2.°F/Btu
30	Pressure Drop (ΔP_{tube})	2.73 psi
31	Pressure Drop (ΔP_{shell})	0.004 psi

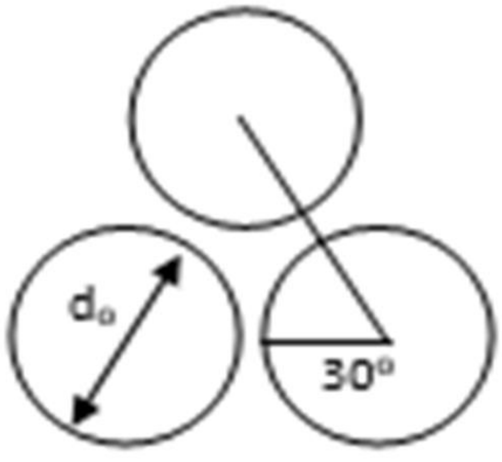

Figure 2. Tube arrangement: Tringular 30°

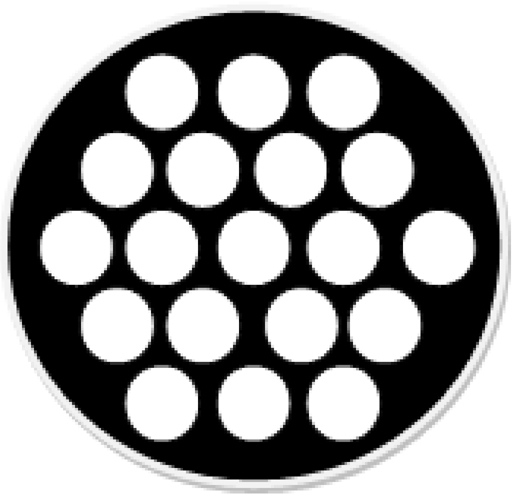

Figure 3. Particles size distribution by granulometry laser

4. CONCLUSION

Based on the above calculation, the heat exchanger design for supporting the production of La_2O_3 nanoparticles, which refers to the TEMA standard, has been successfully designed with several calculations. The design used the shell and tube type (two shell passes-four tube passes) with a total of 138 tubes. The heat transfer rate by the tool is 143,730,265 W with the turbulent flow system. The effectiveness of the heat exchanger design reaches 96%.

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