# Shell and Tube Design

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**Submission date:** 01-Apr-2023 09:55PM (UTC+0700)
**Submission ID:** 2052869943
**File name:** 17_5_16.pdf (523.03K)
**Word count:** 4134
**Character count:** 20462

Journal of Engineering Science and Technology
Vol. 17, No. 5 (2022) 3224 - 3234
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# SHELL AND TUBE HEAT EXCHANGER DESIGN FOR TITANIUM DIOXIDE PARTICLE PRODUCTION PROCESS

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## Abstract

The purpose of this research is to design a shell and tube type heat exchanger (two passes) for application in the titanium dioxide (TiO2) production industry. To design the heat exchanger, the Tubular Exchanger Manufacturers Association (TEMA) standard is used to obtain the dimensional specifications of the device. Several other specifications are also specified, especially the specifications for the working fluid. Then, these parameters are calculated manually using the Microsoft Excel application to evaluate the performance of the designed heat exchanger. The results of the study indicate that the designed heat exchanger has met the standard. The heat exchanger has 29 tubes with an effective value of more than 65%. A high value of tool effectiveness indicates that the heat exchanger has good performance. Hopefully, this planning and design can be used as a reference in a design in a heat exchanger in the future so that it can be more economical, effective, and has high reliability in production activity.

Keywords: Effectiveness, Heat exchanger, Laboratory scale, Performance, Shell and tube.

## 1. Introduction

The heat exchanger acts as a transfer of heat between two fluids. Heat transfer can occur directly, where the fluid is first heated by mixing the heating fluid (without a separator) in the same container. Meanwhile, heat transfer through an indirect process occurs when the heating fluid is not in direct contact with the heating fluid. Thus, the heat transfer process has intermediate media such as pipes, plates, or equipment other [1, 2].

Until now, the heat exchanger system is developing quite rapidly and can be applied in life, especially in the industrial sector such as oil refineries, factories chemical and petrochemical, natural gas industry, refrigeration, and power generation [3, 4].

Sarafraz et al. [5] investigated the thermal performance of a chevron-type flat plate heat exchanger for operating with CuO/water nanofluids. According to their findings, applying constant vibration to the heat exchanger improves the overall system performance. In the absence of vibration, particle contaminants constantly accumulate on the inner wall of the heat exchanger. Indeed, the contaminations cause thermal resistance.

Shirvan et al. [6] have provided a novel model for analysing the sensitivity and efficacy of a twin pipe heat exchanger. Fares et al. [7] also developed a shell and tube heat exchanger model for operating graphene nanofluids. It increases the thermal performance of the vertical shell and tube heat exchanger. It has been mentioned earlier that heat exchangers are very influential in the industry on the success of the whole series of processes because the failure of the operation of this apparatus both due to mechanical or operational failure can lead to cessation of other unit operations [8]. Then, a heat exchanger is required to have good performance; thus, maximum results can be obtained and can fully support other operational units. One of the performance characteristics of a heat exchanger is the effectiveness of the heat exchanger.

In our previous studies, we designed industrial apparatuses [9, 10] as well as analysed and evaluated some trainings, experiments, processes [11-18]. Here, the objective of this study is to focus on the design of a shell and tube-typed heat exchanger for application in titanium dioxide ($TiO_2$) particles production.

Figure 1 shows an illustration of the $TiO_2$ synthesis process on a laboratory scale. Based on Fig. 1, the laboratory-scale $TiO_2$ production process requires a heating device at a temperature of 80°C to mix all the precursors. For the assumption of the production process on an industrial scale, the heater on the laboratory scale is replaced by a heat exchanger.

Therefore, since the design of industrial apparatus evaluation especially a heat exchanger apparatus in the production of $TiO_2$ for industrial applications is still rare, here we evaluated heat exchanger performance for being applied in the $TiO_2$ production. The evaluation was done, in which the focus calculation is based on heat transfer surface area ($A$) that depend on other parameters, namely overall heat transfer coefficient ($U$), thermal load ($Q$), and logarithmic mean temperature difference (LMTD or $\Delta Tlm$) to get the standard dimension of designed heat exchanger apparatus.

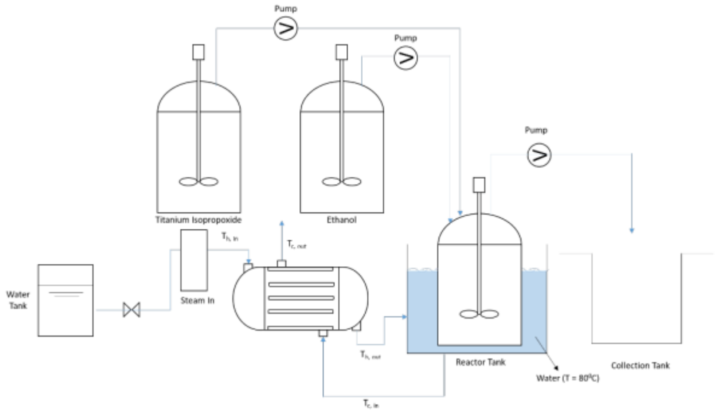

**Fig. 1. Illustration of particles production.**

## 2. Method

The present heat exchanger (i.e. shell and tube type heat exchanger) was designed, based on the Tubular Exchanger Manufacturers Association (TEMA) standard for designing the dimension of apparatus. After designing the dimensions of the equipment according to the standard, the basic performance of the apparatus is evaluated by calculating heat exchanger parameters such as the thermal analysis takes the form of an overall calculation of $U$, LMTD, $Q$, and pressure drop. All parameters are calculated manually using basic Microsoft Office applications that are calculated based on Equations 1-27 in Table 1. Then, the 2D and 3D layouts are obtained by the HTRI application by entering the values that have been calculated manually into the HTRI software. All data were then compared to literature using searching method as reported previously [19, 20].

**Table 1. Heat exchanger parameter calculation.**

| Section | Parameter | Equation | Eq. |
|---|---|---|---|
| **Basic parameters** | The energy transferred ($Q$; $Wt$) | $Q_{in} = Q_{out}$<br>$m_c \times Cp_c \times \Delta T_c = m_h \times Cp_h \times \Delta T_h$<br>where<br>$m$ = the mass flow rate of the fluid (Kg/s)<br>$Cp$ = the specific heat<br>$\Delta T$ = the fluid temperature difference (°C). | (1) |
| | Logarithmic mean temperature differenced ($LMTD$) | $LMTD = \dfrac{(T_{hi} - Tc_i) - (T_{ho} - Tc_o)}{ln\dfrac{(T_{hi} - Tc_i)}{(T_{ho} - Tc_o)}}$<br>where<br>$T_{hi}$ = temperature of the hot fluid inlet (°C)<br>$T_{ho}$ = temperature of the hot fluid outlet (°C)<br>$Tc_i$ = temperature of the cold fluid inlet (°C)<br>$Tc_o$ = temperature of the cold fluid outlet (°C) | (2) |
| | Correction factor ($F$) | $R = \dfrac{T_{hi} - T_{ho}}{T_{co} - T_{ci}}$ | (3)<br>(4) |

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| | | $P = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}$<br>$F = \frac{\sqrt{R^2+1}\ln[\frac{1-P}{1-PR}]}{(R-1)\ln(\frac{2-P(R+1-\sqrt{R^2+1}}{2-P(R+1+\sqrt{R^2+1}})}$ | (5) |
| | Heat Transfer Field Area (*A;* m²) | $A = \frac{Q}{U \times LTMD}$ | (6) |
| | Number of Tubes (*N*) | $N = \frac{A}{\pi \times D_o \times l}$<br>where<br>$\pi$ = 3.14<br>$D_o$= tube diameter (m)<br>$l$ = tube length (m). | (7) |
| | Shell Diameter (*D<sub>s</sub>; m*) | $D_s = 0.63(\frac{\sqrt{\frac{CL}{CTP} \times ((A \times (PR)^2 \times D_o}}{l})^{\frac{1}{2}}$<br>where<br>P, R = the correction factor<br>$D_o$ = tube diameter (m).<br>For CTP value (one tube pass = 0,93; two tube pass = 0,90; and three tube pass = 0,85) and CL value (90° and 45° = 1,00; and 30° and 60° = 0,87). | (8) |
| **Tube** | Surface Area of Total Heat Transfer in Tube ($a_t$; m²) | $a_t = N_t \frac{a'_t}{n}$<br>where<br>$N_t$ = the number of tubes<br>$a'_t$ = the flow area in the tube (m²)<br>$n$ = the number of passes. | (9) |
| | Mass Flow Rate of Water in Tube (*Gt*; kg/m²s) | $Gt = \frac{m_h}{a_t}$<br>where<br>$m_h$ = the mass flow rate of the hot fluid (kg/s)<br>$a_t$ = the flow area tube (m² | (10) |
| | Reynold number in tube (Re, *t*) | $Re_t = \frac{di_t \times Gt}{\mu}$<br>where<br>$di_t$ = the inner tube diameter (m),<br>$Gt$ = the mass flow of water in the tube (m²)<br>$\mu$ = the dynamic viscosity (Kg/ms). | (11) |
| | Prandtl Number (Pr, *t*) | $Pr = (\frac{C_p \times \mu}{K})^{\frac{1}{2}}$<br>where<br>*Pr* = Prandtl number<br>*Cp* = the specific heat of the fluid in the tube<br>$\mu$ = the dynamic viscosity of the fluid in the tube (Kg/ms)<br>*K* = the thermal conductivity of the tube material (W/m°C). | (12) |
| | Nusselt number (Nu, *t*) | $Nu = 0.023 \times {Re_t}^{0.6} \times Pr^{0.33}$ | (13) |
| | Inside coefficient ($h_i$) | $hi = \frac{Nu \times K}{d_i,t}$ | (14) |

| | | | |
|---|---|---|---|
| | | where<br>$hi$ = the convection heat transfer coefficient in the tube (W/m$^2$°C)<br>$K$ = the thermal conductivity of the material (W/m°C)<br>$d_i, t$ = the inner tube diameter (m). | |
| **Shell** | Shell flow area ($A_s$) | $$A_s = \frac{d_s \times C \times B}{P_t}$$<br>$$D_b = d_o(\frac{N_t}{k_1})^{\frac{1}{n_1}}$$<br>where<br>$d_s$ = shell diameter (m)<br>$C$ = clearance ($P_t$-$d_o$)<br>$B$ = a shell bundle<br>$P_t$ = tube pitch (1.25× $d_o$) (m). | (15)<br>(16) |
| | Mass Flow Rate of Water in Shell ($Gs$) | $$Gs = \frac{m_c}{a_s}$$<br>where<br>$m_c$ = the mass flow rate of the cold fluid (Kg/s)<br>$A_s$ = the shell flow area (m$^2$). | (17) |
| | Equivalent diameter ($d_e$) | $$d_e = \frac{4(\frac{Pt}{2} \times 0.87\, Pt - \frac{1}{2}\pi \frac{d_{o,t}}{4})}{\frac{1}{2}\pi d_{o,t}}$$<br>where<br>$P_t$ = tube pitch (1.25× $d_o$) (m)<br>π = 3.14<br>$d_{o,t}$ = tube outside diameter (m). | (18) |
| | Reynold number in shell ($Re_{,s}$) | $$Re_s = \frac{di_t \times Gt}{\mu}$$<br>where<br>$di_s$ = inner tube diameter (m)<br>$Gs$ = the mass flow of water in the shell (Kg/m$^2$s)<br>$\mu$ = the dynamic viscosity (kg/ms). | (19) |
| | Prandtl Number in shell (Pr, $s$) | $$Pr = (\frac{C_p \times \mu}{K})^{\frac{1}{2}}$$<br>where<br>$Cp$ = specific heat capacity (kJ/kg°C)<br>$\mu$ = dynamic fluid viscosity (kg/ms)<br>$K$ = thermal conductivity (W/m°C). | (19) |
| | Nusselt number in shell (Nu, $s$) | $$Nu_s = 0.023 \times Re_s^{\,0.6} \times Pr^{0.33}$$ | (20) |
| | Convection Heat Transfer Coefficient ($ho$) | $$ho = \frac{Nu \times K}{d_e}$$<br>where<br>$ho$ = convection heat transfer coefficient (W/m$^2$°C)<br>$K$ = thermal conductivity (W/m°C)<br>$d_e$ = equivalent diameter (m). | (21) |
| **Shell and Tube** | Actual Overall Heat Transfer Coefficient ($U_{act}$) | $$U_{act} = \frac{1}{\frac{1}{h_i} + \frac{\Delta r}{k} + \frac{1}{h_o}}$$<br>where<br>$hi$ = inside heat transfer coefficient (W/m$^2$°C) | (22) |

| | | | |
|---|---|---|---|
| | | $ho$ = outside heat transfer coefficient (W/m$^2$°C),<br>$\Delta r$= wall thickness (m)<br>$k$ = thermal conductivity(W/m°C) | |
| **Heat rate** | Hot Fluid Rate ($C_h$; W/°C) | $C_h = m_h . Cp_h$<br>where<br>$Cp_h$ = specific heat capacity (J/kg°C)<br>$m_h$ = mass flow rate of hot fluid (kg/s). | (23) |
| | Cold Fluid Rate ($C_C$; W/°C) and Maximum Heat Transfer ($Q_{max}$; W) | $C_C = m_c . Cp_c$<br>where<br>$Cp_h$ = specific heat capacity (J/kg°C),<br>$m_c$ = mass flow rate of cold fluid (kg/s).<br>$Q_{max} = C_{min}\left(T_{h,i} - T_{c,i}\right)$<br>where<br>$C_{min}$ = minimum heat capacity rate (W/°C)<br>$T_{h,i}$ = temperature of the hot fluid inlet (°C)<br>$T_{c,i}$ = temperature of the cold fluid inlet (°C). | (24) |
| **Effectiveness** | Heat Exchanger Effectiveness ($\varepsilon$) | $\varepsilon = \frac{Qact}{Qmax} \times 100\%$<br>where<br>$Q_{act}$ = actual energy transferred (W)<br>$Q_{max}$ = maximum heat transfer (W) | (25) |
| | Number of Transfer Unit ($NTU$) | $NTU = \frac{U \times A}{C_{min}}$<br>where<br>$C_{min}$ = minimum heat capacity rate (W/°C). | (26) |
| | Fouling factor ($Rf$) | $Rf = \frac{U_a - U_{act}}{U_a \times U_{act}}$<br>where<br>$Rf$ = fouling factor<br>$U_a$ = overall heat transfer coefficient (W/m$^2$°C)<br>$U_{act}$ = actual overall heat transfer coefficient (W/m$^2$°C) | (27) |

## 3. Results and Discussion

Several assumptions are used to design and estimate the performance of the apparatus heat exchanger, including:

(i) The type of heat exchanger is a shell and tube with two-pass process.

(ii) The material used for the design of the heat exchanger is carbon steel

(iii) The fluid used is a water-water fluid system.

(iv) The flow system in this heat exchanger is a counter-current flow

(v) The cold fluid is assumed to be on the tube side and the hot fluid is assumed to be on the shell side and.

(vi) The specifications for the type of stationary head (indicating the front end), shell (indicating the shell type), and rear head (indicating the rear-end type) of the heat exchanger respectively are AEW

(vii) Assuming there is no heat leak during the heat exchange process

(viii) Overall coefficient (U) for hot and cold fluids water is 800 W/m2°C

(ix) The orientation of the shell geometry is horizontal

(x) The baffle type is single segmental with orientation perpendicular

The dimensions of the designed apparatus heat exchanger follow several assumptions. Table 2 shows the dimensions of the heat exchanger apparatus according to the TEMA standard.

The design of the heat exchanger is needed to evaluate the performance of the apparatus. The performance of the apparatus heat exchanger includes *Q*, *LMTD*, *A*, and *Nt* of the heat exchanger. The data used to the heat exchanger model have been defined as in Tables 2 and 3 which respectively show the apparatus dimension specifications and fluid specifications. According to the analysis, the designed heat exchanger and its specifications is presented in Table 3. The dimension specifications of the apparatus refer to the TEMA standards. Figures 2-4 illustrate the 2-dimensional tube layout drawing (Fig. 2(a)), 3-dimensional bundle layout (Fig. 2(b)), exchanger drawing (Fig. 3), and setting plan (Fig. 4).Table 2 presents the specifications of the fluid acting on the apparatus.

**Table 2. Dimensional specifications of the heat exchanger apparatus based on the TEMA standard.**

| Parameters | Specifications |
|---|---|
| **Conductivity Material (W/m°C)** | 206 |
| **Tube Diameter (m)** | 0.016 |
| **Wall Thickness (m)** | 0.0012 |
| **Tube Length (m)** | 1.83 |
| **Tube arrangements** | Triangular |
| **Pitch Tube (m)** | 0.0064 |
| **Tube-side passes** | 2 pass |
| **Tube Characteristic Angle (°)** | 30 |
| **Shell Diameter (m)** | 0.15 |
| **Baffle Cut** | 20% |
| **Baffle Spacing (m)** | 0.0675 |

**Table 3. Specifications of hot and cold fluids**

| Parameters | Specifications | |
|---|---|---|
| | Shell side | Tube side |
| **Inlet Temperature ($T_{h,in}$; °C)** | 90 | - |
| **Outlet Temperature ($T_{h,in}$; °C)** | 50 | - |
| **Inlet Temperature ($T_{c,in}$; °C)** | - | 30 |
| **Outlet Temperature ($T_{c,in}$; °C)** | - | 80 |
| **Fluid Flow Rate (kg/s)** | 0.003 | 0.001 |
| **Density (kg/m$^3$)** | 971.82 | 992.22 |
| **Viscosity (Nm/s$^2$)** | 0.315 | 0.798 |
| **Thermal Conductivity (W/m.K)** | 679.1 | 630.5 |
| **Heat Specific (kJ/kg. K)** | 4.1785 | 4.2159 |
| **Operating Pressure (bar)** | 1.013 | 1.013 |

Based on the assumptions in Tables 2 and 3, Table 4 shows the results of calculations to evaluate the performance of the designed apparatus heat exchanger. According to the results, the heat transfer rate is 669.12 W (Table 3). Several parameters such as LMTD, surface area, number of tubes, overall heat exchanger transfer coefficient, and the effective value of the designed heat exchanger were 58°C, 14,224 m$^2$, 29 pcs, 34.696 W/m$^2$.K, and 66.67%, respectively (see Table 3). The high overall heat exchanger transfer coefficient value indicates the easier it is for heat to move from the hot fluid to the cold fluid [21]. The effectiveness of the successfully designed heat exchanger apparatus is more than 60%. The resulting effectiveness value measures the amount of heat carried, the value is large if the temperature difference between the input and output is large. Therefore, the effectiveness of the heat exchanger is directly proportional to the magnitude of the temperature difference [22]. The fluid flow on the tube side shows turbulent flow. Meanwhile, the fluid flow on the shell side shows laminar flow. Fluid flow is determined by the Reynolds value (*Re*). If the value of *Re* is larger than 2300, the fluid flow follows the turbulent flow. On the other hand, if $Re < 2300$, the fluid flow follows laminar flow [23]. Although the effective value is good, some parameters still do not meet the standards, namely the fouling resistance value. Here, the fouling resistance value still exceeds the permissible standard value. Based on the TEMA standard, the fouling resistance value for water fluid is 0.0002 °C.m$^2$/W.

**Table 4. Performance parameters of heat exchangers designed based on calculations.**

| No. | Parameter | Results |
|---|---|---|
| 1 | **Initial Heat Transfer Rate ($Q$)** | 669.12 W |
| 2 | **Logarithmic Mean Temperature Difference ($LMTD$)** | 58°C |
| 3 | **Assumed Overall Fluid Heat Coefficient of Water ($U_a$)** | 1000 W/m$^2$.K |
| 4 | **Area of Heat Transfer ($A$)** | 14.224 m$^2$ |
| 5 | **Number of Tube ($Nt$)** | 29 |
| 6 | **Total Heat Transfer Surface Area in Tube ($a_t$)** | 3.594 m$^2$ |
| 7 | **Mass Flow Rate of Water Fluid in Tube ($Gt$)** | 0.00166 kg/m$^2$.s |
| 8 | **Reynold Number in Tube (Re, $t$)** | 25070.82 |
| 9 | **Prandtl Number in Tube (Pr, $t$)** | 5.326 |
| 10 | **Nusselt Number in Tube (Nu, $t$)** | 17.416 |
| 11 | **Convection Heat Transfer Coefficient in the Tube ($h_i$)** | 512.714 W/m$^2$.K |
| 12 | **Bundle Shell ($Db$)** | 6.867 m |
| 13 | **Total Heat Transfer Surface Area in Shell ($a_s$)** | 0.00174 m$^2$ |
| 14 | **Mass Flow Rate of Water Fluid in Shell ($Gs$)** | 2.293 kg/m$^2$.s |
| 15 | **Equivalent Diameter ($De$)** | 0.126 m |
| 16 | **Reynold Number in Shell (Re, $s$)** | 921.580 |
| 17 | **Prandtl Number in Shell (Pr, $s$)** | 1.966 |
| 18 | **Nusselt Number in Shell (Nu, $s$)** | 8.326 |
| 19 | **Convection Heat Transfer Coefficient in Shell ($h_o$)** | 44.068 W/m$^2$.K |
| 20 | **Overall Heat Transfer Coefficient Actual ($U_{act}$)** | 34.696 W/m$^2$.K |
| 21 | **HE Effectiveness ($\varepsilon$)** | 66.67% |
| 22 | **Number of Transfer Unit ($NTU$)** | 29.50 |
| 23 | **Fouling Resistance** | 0.027 °C.m$^2$/W |

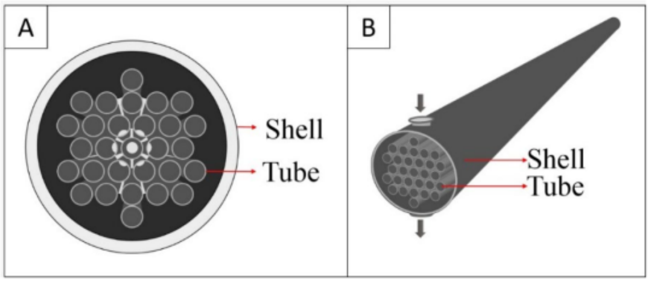

**Figure 2. 2D tube layout (a) and 3D bundle layout (b).**

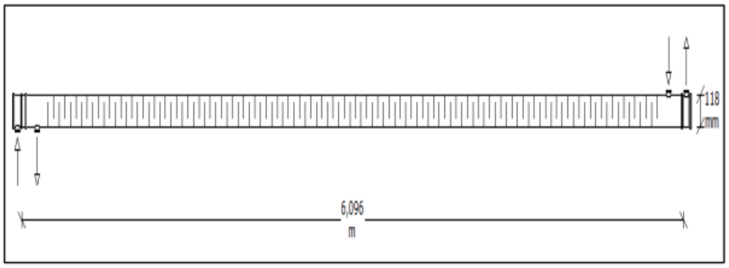

**Fig. 3. Exchanger drawing.**

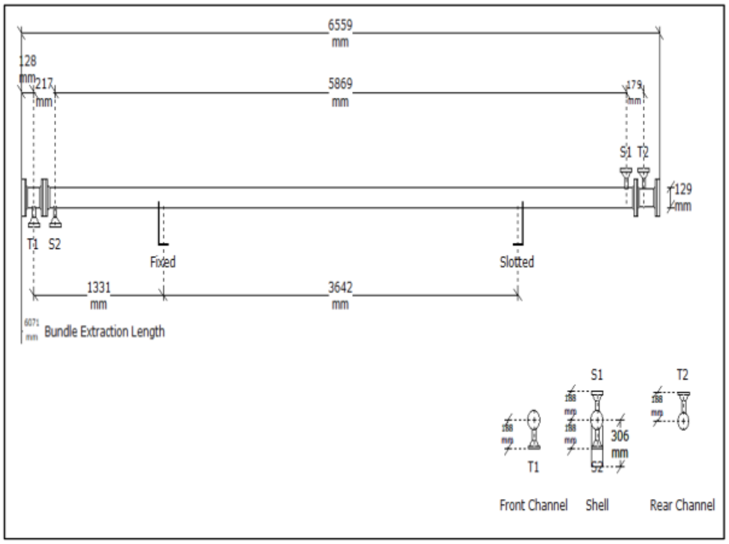

**Fig. 4. Setting plan.**

Here, a little background information on how to design a heat exchanger would be good to include to demonstrate the need for the current design. Recent advances in heat exchanger systems are concerned with various aspects of the system design and modeling/simulation process and their impact on performance.

## 4. Conclusion

Based on the TEMA standard-based design, the heat exchanger with the shell and tube type with two-pass process operated with the number of the tube as much as 29 pcs. The heat transfer rate is 669.12 W with the turbulent flow on the tube side and laminar flow on the shell side. The effectiveness of the heat exchanger reaches more than 65%. Therefore, the heat exchanger designed has good performance. Standard parameters for designing apparatus heat exchangers are needed to obtain good apparatus performance and meet the basic requirements of the apparatus, for example by meeting the rules of the TEMA standard for dimensions and geometries (such as fluid temperature, flow rate, flow regulation, heat exchanger material, tube length, diameter shell and tube, and the number of tubes and baffles).

## Acknowledgments

This study was supported by RISTEK BRIN (Grant: Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT)) and Bangdos Universitas Pendidikan Indonesia.

### References

1. Liu, F.; Ma, J.; Feng, X.; and Wang, Y. (2018). Simultaneous integrated design for heat exchanger network and cooling water system. *Applied Thermal Engineering*, 128 (2018), 1510-1519.
2. Chew, K.H.; Klemeš, J.J.; Alwi, S.R.W.; and Manan, Z.A. (2015). Process modifications to maximise energy savings in total site heat integration. *Applied Thermal Engineering*, 78 (2015), 731-739.
3. Chen, J.; Liu, Y.; Lu, X.; Ji, X.; and Wang, C. 2019. Designing HE for enhancing heat transfer of slurries in biogas plants. *Energy Procedia*, 158 (2019), 1288-1293.
4. Oh, C.H.; Kim, E.S.; and Patterson, M. 2010. Design option of heat exchanger for the next generation nuclear plant. *Journal of Engineering for Gas Turbines and Power*, 132(3), 1-9.
5. Sarafraz, M.M.; Nikkhah, V.; Madani, S.A.; Jafarian, M.; and Hormozi, F. (2017). Low-frequency vibration for fouling mitigation and intensification of thermal performance of a plate heat exchanger working with CuO/water nanofluid. *Applied Thermal Engineering*, 121, 388-399.
6. Shirvan, K.M.; Mamourian, M.; Mirzakhanlari, S.; and Ellahi, R. (2017). Numerical investigation of heat exchanger effectiveness in a double pipe heat exchanger filled with nanofluid: a sensitivity analysis by response surface methodology. *Powder Technology*, 313 (2017), 99-111.
7. Fares, M.; Mohammad, A. M.; and Mohammed, A. S. (2020). Heat transfer analysis of a shell and tube heat exchanger operated with graphene nanofluids. *Case Studies in Thermal Engineering*, 18 (2020), 100584.
8. Chen, J.; Liu, Y.; Lu, X.; Ji, X.; and Wang, C. (2019). Designing HE for enhancing heat transfer of slurries in biogas plants. *Energy Procedia*. 158: 1288-1293.
9. Nandiyanto, A.B.D.; Andika, R.; Aziz, M.; and Riza, L.S. (2018). Working volume and milling time on the product size/morphology, product yield, and electricity consumption in the ball-milling process of organic material. *Indonesian Journal of Science and Technology*, 3(2), 82-94.
10. Sukmafitri, A.; Ragadhita, R.; and Nandiyanto, A.B.D. (2020). Disk rotation speed and diameter of impactor in disk mill on particle size distribution from rice husk. *Journal of Engineering Science and Technology*, 15(3), 1698-1704.
11. Nandiyanto, A. B. D.; Oktiani, R.; and Ragadhita, R. (2019). How to read and interpret FTIR spectroscope of organic material. *Indonesian Journal of Science and Technology*, 4(1), 97-118.

12. Ragadhita, R.; and Nandiyanto, A.B.D. How to calculate adsorption isotherms of particles using two-parameter monolayer adsorption models and equations. *Indonesian Journal of Science and Technology*, 6(1), 205-234.
13. Gunawan, R.; and Nandiyanto, A.B.D. How to Read and Interpret 1H-NMR and 13C-NMR Spectrums. *Indonesian Journal of Science and Technology*, 6(2), 267-298.
14. Yolanda, Y.D.; and Nandiyanto, A.B.D. (2022). How to read and calculate diameter size from electron microscopy images. *ASEAN Journal of Science and Engineering Education*, 2(1), 11-36.
15. Pratiwi, R.A.; Nandiyanto, A.B.D. (2022). How to read and interpret uv-vis spectrophotometric results in determining the structure of chemical compounds. *Indonesian Journal of Educational Research and Technology*, 2(1), 1-20.
16. Nugraha, A.; Nandiyanto, A.B.D. (2021). How to read and interpret GC/MS spectra. *Indonesian Journal of Multidiciplinary Research*, 1(2), 171-206.
17. Fatimah, S.; Ragadhita, R.; Al Husaeni, D.F. and Nandiyanto, A.B.D. (2022). How to calculate crystallite size from x-ray diffraction (XRD) using scherrer method. *ASEAN Journal of Science and Engineering*, 2(1), 65-76.
18. Putri, S.R.; Hofifah, S.N.; Girsang, G.C.S.; and Nandiyanto, A.B.D. (2022). How to identify misconception using certainty of response index (cri): a study case of mathematical chemistry subject by experimental demonstration of adsorption, *Indonesian Journal of Multidiciplinary Research*, 2(1), 143-158.
19. Azizah, N.N.; Maryanti, R.; and Nandiyanto, A.B.D. (2021). How to search and manage references with a specific referencing style using google scholar: from step-by-step processing for users to the practical examples in the referencing education. *Indonesian Journal of Multidiciplinary Research*, 1(2), 267-294.
20. Husaeni, D.F.A. and Nandiyanto, A.B.D. (2022). Bibliometric using Vosviewer with publish or perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post covid-19 pandemic. *ASEAN Journal of Science and Engineering*, 2(1), 19-46
21. Singh, S.K.; and Sarkar, J. (2020). Improving hydrothermal performance of hybrid nanofluid in double tube heat exchanger using tapered wire coil turbulator. *Advanced Powder Technology*, 31(5), 2092-2100.
22. Sreedhar Rao, B.; Keerthana Reddy, C.; Meena, P.; and Kishore Kumar, S. (2020). Thermal performance of corrugated plate heat exchanger using ethylene glycol as test fluid. *Journal of Mechanical and Energy Engineering*, 44(4), 167-172
23. Hasanpour, A.; Farhadi, M.; and Sedighi, K. (2014). A review study on twisted tape inserts on turbulent flow heat exchangers: The overall enhancement ratio criteria. *International Communications in Heat and Mass Transfer*, 55, 53-62.

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# Shell and Tube Design

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11