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HEAT EXCHANGER DESIGN FOR THE GOLD NANOPARTICLES PRODUCTION IN INDUSTRIAL SCALE

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ABSTRACT

This study aims to analyze heat exchanger designs in the production of gold nanoparticles (AuNPs) by the biosynthesis method using Sargassum horneri (SH) extract. The simple design of this heat exchanger (HE) uses the shell and tube type, the one-pass tube, and the fluids are water. Other specifications for a HE design are the tube length is 4.267 m, the shell diameter is 254 mm, the outer tube diameter is 22.225 mm, the inner tube diameter is 21.184 mm, the wall thickness is 2.1082 mm, and the pitch tube is 31.75 mm. Based on manual calculations using Microsoft Excel software, the results show that this design has laminar flow as indicated by the Reynolds value. In addition, the HE designs has an effectiveness value of 98.98% with an NTU value of 11.50. In this study, the HE designs results have a high effectiveness value, suitable for consideration in manufacturing gold nanoparticles with SH extract on an industrial scale. In addition, this heat exchanger design analysis can be utilized as a model for learning how to design heat exchangers, how it works, and how to analyze the performance of heat exchangers.
***Keywords**: heat exchanger designs, gold nanoparticles, shell and tube, Sargassum horneri.*

Abstrak

Penelitian ini bertujuan untuk menganalisis desain heat exchanger dalam produksi nanopartikel emas (AuNPs) dengan metode biosintesis menggunakan ekstrak *Sargassum horneri* (SH). Desain sederhana dari *heat exchanger* (HE) ini menggunakan tipe *shell and tube*, *one pass tube*, dan fluidanya adalah air. Spesifikasi lain untuk desain HE adalah panjang tube 4.267 m, diameter shell 254 mm, diameter tube luar 22.225 mm, diameter tube dalam 21.184 mm, tebal dinding 2.1082 mm, dan pitch tube 31.75 mm. Berdasarkan perhitungan manual menggunakan aplikasi Microsoft Excel, diperoleh hasil bahwa rancangan ini memiliki aliran laminar yang ditunjukkan dengan nilai Reynolds. Selain itu, desain HE memiliki nilai keefektifan sebesar 98,98% dengan nilai NTU sebesar 11,50. Pada penelitian ini, hasil desain HE memiliki nilai efektifitas yang tinggi, cocok untuk pertimbangan dalam pembuatan nanopartikel emas dengan ekstrak SH pada skala industri. Selain itu, analisis desain alat penukar kalor ini dapat dimanfaatkan sebagai model untuk mempelajari cara merancang alat penukar kalor, cara kerjanya, dan cara menganalisis kinerja alat penukar kalor.
Kata Kunci: desain penukar panas, nanopartikel emas, shell and tube, *Sargassum horneri.*

1. INTRODUCTION

Transfer of heat energy in two flows with different temperatures is the capability of a device called a heat exchanger. Heat exchangers are highly used in industry as an important part of a production process in recovering heat. Heat exchangers are essential components in processing, power production, power generation, transportation, refrigeration, electronics, chemical industries, food industries, and manufacturing [1-2].

Shell and tube is one of the HE types. As its name suggests, this type consists of a shell (a large cylindrical reservoir) at high pressure and there are tubes inside it. This exchanger utilizes two fluids, where one fluid is permitted to flow in the tube and the other flows outside the tube. The cold fluid flows through the tubes and the hot one flows on the tubes that inside the shell [2-3].

Our previous studies have used this design of heat exchanger for the production of carbon particles [4], titanium dioxide particles [5], graphene oxide nanoparticles [5], cellulose nanofibril production [6], ZnO nanoparticles [7], and so on. Other studies have also been carried out to design heat exchanger that has a type of shell and tube [8], designs with optimization using the CFD and Tagauchi methods [9], the particle swarm method [10], the Falcon algorithms method [11-12], and others. So, the existence of this heat exchanger can be utilized in the production process of nanoparticle materials, including gold nanoparticles (AuNPs).

Gold nanoparticles are incredibly desirable for a wide range of technological applications due to their adjustable properties, which are determined by the size and shape of the constituent particles [13]. Gold nanoparticles are getting more attention because of their excellent plasmonic properties, ease to synthesize, ability to functionalize with different materials for the desired purpose, low toxicity, high biocompatibility, and easy access to their nano-dimensions [14].

Based on these advantages, gold nanoparticles are widely used as catalysts [6–8], biosensors [9-10], X-ray imaging [20], drug delivery [21], bioelectric devices [22], and so on. Currently, many researchers have developed gold nanoparticle synthesis. There are various techniques for carrying out the synthesis of AuNPs by dividing them into chemical, physical, and biological techniques [23]. In biological techniques, especially gold nanoparticle biosynthesis, plants can replace the use of hazardous chemicals commonly used in synthesizing AuNPs. Therefore, this technique is considered to be able to reduce the negative impact caused by the release of gold nanoparticles into the environment [24].

Several studies have carried out the biosynthesis of gold nanoparticles using *Citrus limetta* Risso peels [25], *Tecoma capensis* [26], *Ceiba pentandra* leaves [27], *Punica granatum* peels [28] *Gracilaria crassa* leaves [24], *Sargassum horneri* [16], *Dittrichia viscosa* [29], *Annona muricata* leaves [30], Galaxaura elongata [30], *Musa acuminata* colla flowers [31], *Persea americana* fruit peel [32], etc.

The biosynthesis process for gold nanoparticles will be more useful if they are produced extracellularly using plants or their extracts, and controlled according to their size, dispersion and shape. The plants used can also be increased for the large-scale synthesis of nanoparticle materials [33]. As a model for the heat exchanger design, in this study, we use the process of producing gold nanoparticles with biological techniques or biosynthesis using *Sargassum horneri* (SH) extract which has been done before [16].

The type of HE chosen in this design is the shell and tube types. The heat exchanger selection represents significant importance in the design of the heat recovery system. It is essential to design the type of HE with the maximum degree of compactness concerning process parameters such as temperature, process fluid composition, proximity to impurities, and potential operational problems [34]. This study was made with the hope that HE designs can be utilized as a model for learning how to design heat exchangers, how it works, and how to analyze the performance of heat exchangers.

2. METHODOLOGY

The gold nanoparticle synthesis method in this study was carried out based on the method that has been carried out by [16]. In the manufacture of gold nanoparticles only a few materials are needed, such as *Sargassum horneri* extract, ethanol, hydrogen tetrachloroaurate(III)trihydrate, $HAuCl_4.3H_2O$. Besides that, the design of the heat exchanger for SH-AuNPs, begins with selecting cold and hot fluids. In this study, water was used as cold and hot fluids.

Water is a type of fluid most often used as a fluid in heat exchangers on an industrial scale. This is because water has a high specific heat, is widely available, and is cheap [2]. In designing a heat exchanger, some data is needed, such as data on the inlet temperature of the water fluid and also data on the outlet temperature of the water fluid, the physical and thermal properties of the two fluids, including thermal conductivity, viscosity, specific heat, and fluid density. The design of the heat exchanger in this study used a water fluid inlet temperature of 80ºC and a water fluid outlet temperature of 20ºC. These two temperatures were chosen because they were adjusted to the synthesis method carried out by Song, et al. (2022) [16]. Thus, the physical and thermal properties of the two fluids are also adjusted to the two water fluid temperatures [35-36], as shown in **Table 1**. This data collection directs to the standard of the Tubular Exchanger Manufacturers Association (TEMA) used as a design reference. In the TEMA standard, not all calculations need to be performed, but several parameter values are assuming the desired size variation [37].

The specification of heat exchanger design shown in **Table 2**. The HE designs has a few specifications, namely a shell and tube type with one pass tube, temperature inlet and outlet of tube and shell, length is 4.267 m, inner tube diameter is 21.184 mm, inner shell diameter is 254 mm, and baffle spacing is 56 mm, as shown in **Figure 1**.

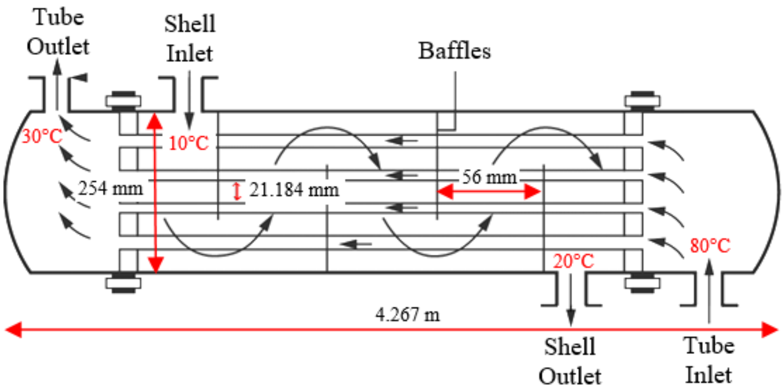

Figure 1. A heat exchanger designs of shell and tube types [38].

2.1. Gold Nanoparticle Synthesis

The gold nanoparticle biosynthesis process is shown in **Figure 2**, while **Figure 3** shows a process flow of the biosynthesis process. The biosynthesis of gold nanoparticles was initiated by adding 1 mL of filtered SH extract (2 mg/mL) to a solution of $HAuCl_4.3H_2O$ [1 M], then incubated in water for 15 minutes at 80°C and continued by cooling the colloidal tube for 5 minutes. The biosynthesis of gold nanoparticles can be successful if the suspension changes color to dark purple. The detailed procedure for preparing SH extract was described in previous studies [16].

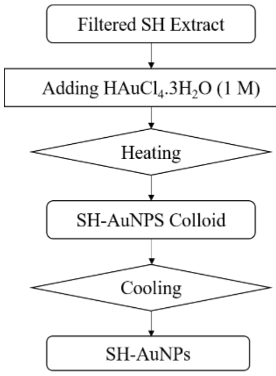

Figure 2. Schematic diagram of the gold nanoparticles biosynthesis.

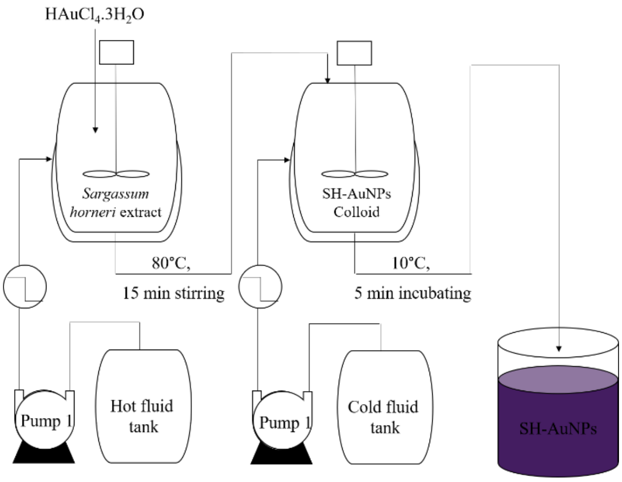

Figure 3. Process flow diagram of SH-AuNPs manufacturing.

3. THE MATHEMATICAL MODEL ON HEAT EXCHANGER DESIGNS

The fluid characteristics assumptions used in the heat exchanger are presented in Table 1. These assumptions are helpful for designing shell and tube heat exchangers. The types of hot and cold fluids in this design are water with an inlet temperature of hot fluids is 80°C with an outlet temperature of 30°C, and an inlet temperature of cold fluids is 10°C with an outlet temperature of 20°C. Based on the temperature data of the two fluids, the temperature difference between the two is significantly different. So that the design of this heat exchanger has a relatively large effectiveness value because the effectiveness value of a heat exchanger is directly proportional to the magnitude of the temperature difference between the two fluids (ΔTLMTD) [39]. The inlet water flow rate for the hot fluid is 3.05 (kg/s), while the cold fluid inlet flow rate is 2.2 (kg/s). The process of collecting thermal analysis specification data was carried out by manual calculation using the Microsoft Excel application based on equations 1-15 [4]. The heat exchange parameters are calculated according to **Table 2**.

Basic parameters calculation for heat exchanger shows by equation 1-4. To measure the energy transferred (Q), some variables need to be determined, as mentioned below.

$$Q_{in} = Q_{out}$$
$$m_c \times Cp_c \times \Delta T_c = m_h \times Cp_h \times \Delta T_h \quad (1)$$

Q is energy transferred (W)
m is the mass flow rate of the fluid (Kg/s)
C_p is the specific heat
ΔT is the fluid temperature difference (°C)

To calculate the Logarithmic mean temperature differenced (LMTD) the result has to be determined by:
$$LMTD = \frac{(T_{hi}-T_{Ci})(T_{ho}-T_{Co})}{ln\frac{(T_{hi}-T_{Ci})}{(T_{ho}-T_{Co})}} \quad (2)$$

T_{hi} is the hot fluid inlet temperature (°C)
T_{ho} is the hot fluid outlet temperature (°C)
T_{Ci} is the cold fluid inlet temperature (°C)
T_{Co} is the cold fluid outlet temperature (°C)

To measure the heat transfer field area (A), it has to be determined using below equation.
$$A = \frac{Q}{U_d \times \Delta T_{LMTD}} \quad (3)$$

Q is energy transferred (W)
U_d is the overall heat transfer coefficient
ΔT_{LMTD} is the logarithmic mean temperature difference (F)

To determine the Number of tube (Nt) use the eq. 4.
$$Nt = \frac{A}{L \times a''} \quad (4)$$

A is the heat transfer area (ft^2)
L is the length of tuber
a" is the outer surface area (ft/ft^2)

Shell and Tube parameters calculation for heat exchanger shows by equation 1-4. To calculate the surface are of heat transfer in tube (a_t), it can be determined by this equation below.
$$a_{s,t} = N_{s,t}\frac{a'_{s,t}}{n} \quad (5)$$

a'_t is the flow area in the tube (m^2)
n is the passes number

The result of a'_t will use to calculate mass flow rate of water in tube (G_t).
$$G_{s,t} = \frac{m_{h,c}}{a_{s,t}} \quad (6)$$

These two values were needed to calculate the Reynolds number. The Reynolds number can be determined by using Eq. 7, where μ is the fluid dynamic viscosity in the tube.

$$Re_{s,t} = \frac{di_{s,t} \times G_{s,t}}{\mu} \quad (7)$$

Prandtl Number (Pr) in the tube can be determined by using Eq. 8, where K is the thermal conductivity of the tube material.

$$Pr = \left(\frac{C_p \times \mu}{K}\right)^{\frac{1}{2}} \quad (8)$$

The value of Reynolds number and Prandtl number was used to determine the Nusselt number (Nu).

$$Nu = 0.023 \times Re_{s,t}^{0.6} \times Pr^{0.33} \quad (9)$$

Actual Overall Heat Transfer Coefficient (U_{act}) can be determined by using eq. 10.

$$U_{act} = \frac{1}{\frac{1}{h_i} + \frac{\Delta r}{k} + \frac{1}{h_o}} \quad (10)$$

h_i is coefficient of inside heat transfer
h_o is coefficient of outside heat transfer
Δr is wall thickness

To measure the hot and cold fluid rate, it has to be determined using the eq. 11 as mentioned below.

$$C_h = m_h Cp_h \quad (11)$$

C_h is hot fluid rate (W/K)
Cp_h is the specific heat capacity (J/Kg K)
m_h is hot fluid mass flow rate (Kg/s)

This calculation also applied to calculate the cold fluid rate.

$$C_c = m_c Cp_c \quad (12)$$

C_c is cold fluid rate (W/K)
Cp_c is the specific heat capacity (J/Kg K)
m_c is cold fluid mass flow rate (Kg/s)

Number of heat transfer units, NTU can be determined by using Eq. 13.

$$NTU = \frac{U \times A}{C_{min}} \quad (13)$$

Heat exchanger effectiveness, ε can be determined by using Eq. 14.

$$\varepsilon = \frac{Q_{act}}{Q_{max}} \times 100\%$$

$$Q_{max} = C_{min}(T_{hi} - T_{ci}) \quad (14)$$

Q_{act} is actual energy transferred
T_{hi} is the hot fluid inlet temperature
T_{ci} is the cold fluid inlet temperature

Heat exchanger fouling factor can be determined by using Eq. 15.

$$Rf = \frac{U_a - U_{act}}{U_a \times U_{act}} \quad (15)$$

Rf is the fouling factor
U_a is the coefficient of overall heat transfer (W/m^2.°C)
U_{act} is the coefficient of actual overall heat transfer (W/m^2.°C)

Table 1. Physical and thermal properties of the fluid.

Parameters	Hot Fluid water at 80°C	Cold fluid water at 10°C

Thermal conductivity, λ ($W/m^2 \cdot K$)	0.671	0.585
Viscosity, v (mm^2/s^{-1})	0.000339	0.00131
Heat Specific, c_p (J/kg·K)	4193	4195
Density, ρ (g/l)	971.6	999.2

4. RESULTS AND DISCUSSION

In the biosynthesis of nanoparticles, it is necessary to have a reduction reaction and the formation of metal salts by the nanoparticles to be made; in this case, the SH extract acts as a capping agent and reducing agent for the reduction reaction during the formation of gold nanoparticles, based on the characterization that has been carried out [7]. According to them, to reduce the size of the nanoparticles as well as increase their dispersion, synthesis must be carried out by biosynthetic techniques, one of which is using algae. In addition, control of synthesis time and temperature is also required [30].

Assuming the heat exchanger operates on the production of SH-AuNPs, is shown by the calculation results from equations 1-15 using the data obtained from [35], which has been adjusted for cold and hot water fluid, shown in **Table 2**. The HE design concept calculates the different temperatures between the inlet temperatures of the two fluids and sees how it affects the outlet temperature between them [4].

Based on the calculation results, the Q value of HE designs is 639432.5 W with the Reynolds number on the tube as 2183.98. Cause the Reynolds number in this design shows a number less than 2300, so the flow type in the shell of this HE designs is laminar flow [40]. The design of HE specifications are shell and tube type, one pass tube type, tube layout is triangular (30°), baffle type is single-segmental, and other specifications are shown in **Table 2** based on calculation results using Microsoft Excel.

In addition, with the number of NTU operating conditions is 31.79, this HE effectiveness is high when the hot fluid inlet temperature is 80°C with the outlet temperature is 30°C, and the cold fluid inlet temperature is 10°C with the outlet temperature is 20°C. The effectiveness of this HE is determined by Eq. 14, and the result of this heat exchanger effectiveness is 98.98%.

The fouling factor affects the decrease in HE performance depending on the flow rate. The TEMA standard allowable fouling factor for liquid water as fluids is 0.0002 [41], while the fouling factor value in this study was 0.0017. Therefore, the HE designs with the shell and tube type in this study doesn't fulfill the requirements and standards, but the effectiveness of this HE designs is quite good mathematically and can be considered for gold nanoparticle production in an industrial scale. Besides that, this HE designs analysis can be utilized as a model for learning how to design heat exchangers, how it works, and how to analyze the performance of heat exchangers.

Tabel 2. Specification of heat exchanger designs and operating condition for water fluid based on calculation result.

Description	**Type/value**
Heat exchanger type	Shell and tube
Tube type	One pass
Hot fluid (water) inlet temperature (°C)	80
Hot fluid (water) outlet temperature (°C)	30
Cold fluid (water) inlet temperature (°C)	10
Cold fluid (water) outlet temperature (°C)	20
Tube outside diameter, OD (mm)	22.225
Tube inner diameter, ID (mm)	21.184
Pitch tube (mm)	31.75
Length (m)	4.267
Wall thickness (mm)	2.1082
Total tube number, N	495
Total heat transfer surface area in tube (m^2)	0.2978
Mass flow rate of fluid in tube ($kg/m^2.s$)	34.95
Reynold Number in Tube	2183.98
Prandtl Number in Tube	2.118
Tube layout	Triangular
Shell inner diameter, Ds (mm)	254
Total heat transfer surface area in shell (m^2)	0.03136
Mass flow rate of fluid in shell ($kg/m^2.s$)	70.15
Reynold Number in Shell	1059259.704
Prandtl Number in Shell	9.394
Nusselt Number in Shell	4370.234

Baffle type	Single-segmental
Baffle spacing, B (mm)	56
Initial Heat Transfer Rate (W)	639432.5
Logarithmic Mean Temperature Difference (Δ_{LMTD}) (°C)	24.8534
Area of Heat Transfer (m^2)	147.545
Water mass flow rate in tube (kg/s)	3.05
Water mass flow rate in shell (kg/s)	2.2
Water heat rate in tube (W/K)	11000
Water heat rate in shell (W/K)	7920
Overall Heat Transfer Coefficient	174.37507
Actual Overall Heat Transfer Coefficient	132.95556
Number of Transfer Unit	11.50
HE Effectiveness (%)	98.98
Fouling Factor ($W/m^2.K$)	0.001786545

5. CONCLUSION

In conclusion, based on the calculations performed through Microsoft Excel, the appropriate heat exchanger design results are laminar flow type, with an effectiveness of 98.98% and an NTU of 11.50. Although the HE effectiveness value is high (98.98%) and the fouling factor of this heat exchanger designs does not meet the TEMA standard, but the analysis result on this heat exchanger design can provide an initial reference in optimizing the HE models with shell and tube type, and the base fluid is water for producing gold nanoparticles in industrial scale. Moreover, this HE designs can be utilized as a model for learning how to design heat exchangers, how it works, and how to analyze the performance of heat exchangers.

REFERENCES

[1] J. Zhang, X. Zhu, M. E. Mondejar, and F. Haglind, "A review of heat transfer enhancement techniques in plate heat exchangers," *Renew. Sustain. Energy Rev.*, vol. 101, pp. 305–328, 2019, doi: 10.1016/j.rser.2018.11.017.

[2] A. Hajatzadeh Pordanjani, S. Aghakhani, M. Afrand, B. Mahmoudi, O. Mahian, and S. Wongwises, "An updated review on application of nanofluids in heat exchangers for saving energy," *Energy Convers. Manag.*, vol. 198, no. April, p. 111886, 2019, doi: 10.1016/j.enconman.2019.111886.

[3] S. Muthukrishnan, H. Krishnaswamy, S. Thanikodi, D. Sundaresan, and V. Venkatraman, "Support vector machine for modelling and simulation of heat exchangers," *Therm. Sci.*, vol. 24, no. 1PartB, pp. 499–503, 2020, doi: 10.2298/TSCI190419398M.

[4] A. B. D. Nandiyanto, S. R. Putri, R. Ragadhita, and T. Kurniawan, "Design of Heat Exchanger for the Production of Carbon Particles," *J. Eng. Sci. Technol.*, vol. 17, no. 4, pp. 2788–2798, 2022.

[5] A. B. D. Nandiyanto, R. Ragadhita, and T. Kurniawan, "Shell and Tube Heat Exchanger Design for Titanium Dioxide Particle Production Process," *J. Eng. Sci. Technol.*, vol. 17, no. 5, pp. 3224–3234, 2022.

[6] H. Nur Purnamasari, T. Kurniawan, and A. Bayu Dani Nandiyanto, "Design of Shell and Tube Type Heat Exchanger for Nanofibril Cellulose Production Process," *Int. J. Res. Appl. Technol.*, vol. 1, no. 2, pp. 318–329, 2021, doi: 10.34010/injuratech.v1i2.6410.

[7] A. R. Salsabila, A. Bayu, D. Nandiyanto, M. Fiandini, R. Ragadhita, and T. Kurniawan, "Heat Exchanger Design for Producing ZnO Nanoparticles using Pomegranate Fruit Peels Extract," vol. 02, no. 01, pp. 12–21, 2022.

[8] J. P. Fanaritis and J. W. Bevevino, "Designing Shell-and-Tube Heat Exchangers.," *Chem. Eng. (New York)*, vol. 83, no. 14, pp. 62–71, 1976.

[9] N. Biçer, T. Engin, H. Yas, E. Büyükkaya, A. Aydın, and A. Topuz, "Design optimization of a shell-and-tube heat exchanger with novel three-zonal baffle by using CFD and taguchi method," *Int. J. Therm. Sci.*, vol. 155, no. April, 2020.

[10] V. K. Patel and R. V. Rao, "Design optimization of shell-and-tube heat exchanger using particle swarm optimization technique," *Appl. Therm. Eng.*, vol. 30, no. 11–12, pp. 1417–1425, 2010, doi: 10.1016/j.applthermaleng.2010.03.001.

[11] A. L. H. Costa and E. M. Queiroz, "Design optimization of shell-and-tube heat exchangers," *Appl. Therm. Eng.*, vol. 28, no. 14–15, pp. 1798–1805, 2008, doi: 10.1016/j.applthermaleng.2007.11.009.

[12] E. H. de Vasconcelos Segundo, V. C. Mariani, and L. dos S. Coelho, "Design of heat exchangers using Falcon Optimization Algorithm," *Appl. Therm. Eng.*, vol. 156, no. April, pp. 119–144, 2019,

doi: 10.1016/j.applthermaleng.2019.04.038.

[13] K. Cruse *et al.*, "Text-mined dataset of gold nanoparticle synthesis procedures, morphologies, and size entities," *Sci. Data*, vol. 9, no. 1, pp. 1–12, 2022, doi: 10.1038/s41597-022-01321-6.

[14] M. Yari and N. Javanmardi, "Multifunctional Gold nanoparticle : as novel agents for cancer treatment," *J. Adv. Appl. NanoBio-Technologies*, vol. 3, no. 2, pp. 43–48, 2022.

[15] M. Abbas, H. H. Susapto, and C. A. E. Hauser, "Synthesis and Organization of Gold-Peptide Nanoparticles for Catalytic Activities," *ACS Omega*, vol. 7, no. 2, pp. 2082–2090, 2022, doi: 10.1021/acsomega.1c05546.

[16] W. C. Song, B. Kim, S. Y. Park, G. Park, and J. W. Oh, "Biosynthesis of silver and gold nanoparticles using Sargassum horneri extract as catalyst for industrial dye degradation," *Arab. J. Chem.*, vol. 15, no. 9, p. 104056, 2022, doi: 10.1016/j.arabjc.2022.104056.

[17] T. D. Tran, M. T. T. Nguyen, H. V. Le, D. N. Nguyen, Q. D. Truong, and P. D. Tran, "Gold nanoparticles as an outstanding catalyst for the hydrogen evolution reaction," *Chem. Commun.*, vol. 54, no. 27, pp. 3363–3366, 2018, doi: 10.1039/c8cc00038g.

[18] X. Lu, X. Dong, K. Zhang, X. Han, X. Fang, and Y. Zhang, "A gold nanorods-based fluorescent biosensor for the detection of hepatitis B virus DNA based on fluorescence resonance energy transfer," *Analyst*, vol. 138, no. 2, pp. 642–650, 2013, doi: 10.1039/c2an36099c.

[19] D. Lin, R. G. Pillai, W. E. Lee, and A. B. Jemere, "An impedimetric biosensor for E. coli O157:H7 based on the use of self-assembled gold nanoparticles and protein G," *Microchim. Acta*, vol. 186, no. 3, pp. 1–9, 2019, doi: 10.1007/s00604-019-3282-3.

[20] M. A. MacKey, M. R. K. Ali, L. A. Austin, R. D. Near, and M. A. El-Sayed, "The most effective gold nanorod size for plasmonic photothermal therapy: Theory and in vitro experiments," *J. Phys. Chem. B*, vol. 118, no. 5, pp. 1319–1326, 2014, doi: 10.1021/jp409298f.

[21] J. Cheng, Y. J. Gu, S. H. Cheng, and W. T. Wong, "Surface functionalized gold nanoparticles for drug delivery," *J. Biomed. Nanotechnol.*, vol. 9, no. 8, pp. 1362–1369, 2013, doi: 10.1166/jbn.2013.1536.

[22] J. Im *et al.*, "Functionalized Gold Nanoparticles with a Cohesion Enhancer for Robust Flexible Electrodes," *ACS Appl. Nano Mater.*, vol. 5, no. 5, pp. 6708–6716, 2022, doi: 10.1021/acsanm.2c00742.

[23] K. Nejati, M. Dadashpour, T. Gharibi, H. Mellatyar, and A. Akbarzadeh, "Biomedical Applications of Functionalized Gold Nanoparticles: A Review," *J. Clust. Sci.*, vol. 33, no. 1, 2022, doi: 10.1007/s10876-020-01955-9.

[24] C. Kamaraj *et al.*, "Green synthesis of gold nanoparticles using Gracilaria crassa leaf extract and their ecotoxicological potential: Issues to be considered," *Environ. Res.*, vol. 213, 2022, doi: 10.1016/j.envres.2022.113711.

[25] M. Sivakavinesan *et al.*, "Citrus limetta Risso peel mediated green synthesis of gold nanoparticles and its antioxidant and catalytic activity," *J. King Saud Univ. - Sci.*, vol. 34, no. 7, p. 102235, 2022, doi: 10.1016/j.jksus.2022.102235.

[26] M. Hosny, M. Fawzy, Y. A. El-Badry, E. E. Hussein, and A. S. Eltaweil, "Plant-assisted synthesis of gold nanoparticles for photocatalytic, anticancer, and antioxidant applications," *J. Saudi Chem. Soc.*, vol. 26, no. 2, p. 101419, 2022, doi: 10.1016/j.jscs.2022.101419.

[27] A. Aji, D. Oktafiani, A. Yuniarto, and A. K. Amin, "Biosynthesis of gold nanoparticles using Kapok (Ceiba pentandra) leaf aqueous extract and investigating their antioxidant activity," *J. Mol. Struct.*, vol. 1270, no. August, p. 133906, 2022, doi: 10.1016/j.molstruc.2022.133906.

[28] N. Ahmad, S. Sharma, and R. Rai, "Rapid green synthesis of silver and gold nanoparticles using peels of Punica granatum," *Adv. Mater. Lett.*, vol. 3, no. 5, pp. 376–380, 2012, doi: 10.5185/amlett.2012.6357.

[29] S. Ayyoub *et al.*, "Biosynthesis of gold nanoparticles using leaf extract of Dittrichia viscosa and in vivo assessment of its anti-diabetic efficacy," *Drug Deliv. Transl. Res.*, vol. 12, no. 12, pp. 2993–2999, 2022, doi: 10.1007/s13346-022-01163-0.

[30] A. Folorunso *et al.*, "Biosynthesis, characterization and antimicrobial activity of gold nanoparticles from leaf extracts of Annona muricata," *J. Nanostructure Chem.*, vol. 9, no. 2, pp. 111–117, 2019, doi: 10.1007/s40097-019-0301-1.

[31] S. Valsalam, P. Agastian, G. A. Esmail, A. K. M. Ghilan, N. A. Al-Dhabi, and M. V. Arasu, "Biosynthesis of silver and gold nanoparticles using Musa acuminata colla flower and its pharmaceutical activity against bacteria and anticancer efficacy," *J. Photochem. Photobiol. B Biol.*, vol. 201, p. 111670, 2019, doi: 10.1016/j.jphotobiol.2019.111670.

[32] A. E. Adebayo *et al.*, "Biosynthesis of silver, gold and silver–gold alloy nanoparticles using Persea

americana fruit peel aqueous extract for their biomedical properties," *Nanotechnol. Environ. Eng.*, vol. 4, no. 1, 2019, doi: 10.1007/s41204-019-0060-8.

[33] V. Kumar and S. K. Yadav, "Plant-mediated synthesis of silver and gold nanoparticles and their applications," *J. Chem. Technol. Biotechnol.*, vol. 84, no. 2, pp. 151–157, 2009, doi: 10.1002/jctb.2023.

[34] P. Stehlík, "Conventional versus specific types of heat exchangers in the case of polluted flue gas as the process fluid - A review," *Appl. Therm. Eng.*, vol. 31, no. 1, pp. 1–13, 2011, doi: 10.1016/j.applthermaleng.2010.06.013.

[35] A. M. Flynn, T. Akashige, and L. Theodore, *Kern's Process Heat Transfer Second Edition*. Beverly: Scrivener Publishing, 2019.

[36] C. L. Yaws, *Chemical Properties Handbook*. New York: The McGraw-Hill Company, 1999.

[37] D. Indriati, A. Bayu, D. Nandiyanto, M. Fiandini, R. Ragadhita, and T. Kurniawan, "Shell and tube heat exchanger design for production graphene oxide nanoparticles from agricultural waste," vol. 4, no. 2, pp. 206–216, 2022.

[38] B. Zohuri, *Compact heat exchangers: Selection, application, design and evaluation*. 2016. doi: 10.1007/978-3-319-29835-1.

[39] S. R. Battula, K. R. Chittireddy, M. Pullurwar, and K. K. Sriramoju, "Thermal performance of corrugated plate heat exchanger using ethylene glycol as test fluid," *J. Mech. Energy Eng.*, vol. 4, no. 2, pp. 167–172, 2020, doi: 10.30464/jmee.2020.4.2.167.

[40] O. Evju, "Computational hemodynamics in cerebral aneurysms : Robustness of rupture risk indicators under different model assumptions," 2016.

[41] A. Bayu *et al.*, "Design of heat exchanger for the production of synthesis silica," pp. 1–13, doi: 10.36909/jer.ASSEEE.16033.