Development of Decision Support System for Design Analysis of Gasifier Reactor's Heat Exchanger

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ORIGINAL RESEARCH

Abstract— The design of a heat exchanger, a device that transfers thermal heat energy between two fluids or more that are in thermal contact, presents some level of difficulty and requires a complex design. The sensitivity of the design to changes in system and operating parameters makes the design or redesign challenging. A quick and dependable computer-based tool was used to automatically design shell and tube heat exchangers, and this tool was created using MATLAB programming software to optimize the design parameters, minimize computation time, and maximize efficiency. From the result obtained, the result of the decision support system correlates with the documentation manual at 0.9954, and computation time was reduced by 91.72% for full data processing and 98.33% to 99.41 for the iteration process. The associated delay observed in the manual method is majorly in the area of computation, not input, as in the case of the Decision Support System. This study serves a critical purpose in advancing the efficiency and reliability of thermal systems. By automating the design process and optimizing key parameters, this research significantly enhances the precision and speed of engineering decisions.

Keywords— Heat Exchanger, Decision Support System, Operating Parameters. computation time.

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1 INTRODUCTION

The wide-ranging challenges experienced by the Nigerian power sector have kept it from achieving commercial growth. Many industries, organisations and institutions have resulted to other sources of power supply such as the use of fossil fuel powered electricity generators and heavy-duty diesel generators to meet up their daily power need. These generators heavily rely on fuel (petrol and diesel) to power the engines for generation of power, which according to (Mbachu et al 2022) are both economically and environmentally unfriendly.

The enhancement of citizen's lives is one of the significant economic and social advantages that have grown as a result of technological breakthroughs in the areas of manufacturing, services, and trade. This development has also provoked numerous side effects such as massive generation of urban solid waste which has triggered global concern on its sustainable disposal management (Kwak, T et al 2006,) Adesina et al. 2024). Investigated the Effects of Increased Thermal Generation by Unit Commitment Optimization in Hydrothermal Power Systems Using Lagrange Algorithm. While (Cengel 2003) studied heat transfer in a practical approach. (Inayat, et al 2022) gave 10-Recent progress in biomass air gasification using moving and fixed bed gasifiers, (Kasali, 2024).

Integrated fairness in current consumption of end devices in time-slotted LoRa-based wireless sensor network. Efforts to protect the environment from the adverse effects of urban solid waste littering have resulted in the development of various technologies for managing such waste. These technologies include incineration, biogas generation, and gasification. Furthermore, "Miscellany" provides a framework for establishing a standard safety protocol under OSHA, promoting optimal safety standards in the industry to safeguard lives. (Omoyi et al 2022). Modeling of Biomass Gasification: From Thermodynamics to Process Simulations. Energies was done by (Marcantonio et al. 2023).

Gasification converts organic materials into a gas form known as syngas or producer gas, whose major constituents are CO, H_2, with traces of CO_2, N_2 and CH_4 and has contaminants such as tar, particles of dust etc, depending on the composition of the organic compound (Wang 2010), (Molino et al 2016). According to (Kumar and Shukla 2016) cyclone separator can be employed in purging the gas of these contaminants. Most often, raw materials with high calorific values like plastic, and polymers are used to create energy-rich gases. This high temperature pyrolysis process is anaerobic and generates heat with calorific value as high as 36MJ/Nm^3. It is used for generation of heat and electricity using a variety of machinery such as steam generators; gas turbines; and boilers for steam generators. (Ranjan et all 2024)

The produced gas is usually cooled using shell and tube heat exchangers, which was described in (Dubey et al 2014) as a device that can transfer thermal heat energy between two or more fluids that are in thermal contact but have different temperatures. (Marzouk, et al 2023). Provided a comprehensive review of methods of heat transfer enhancement in shell and tube heat exchangers. In the same vein, (Samson, et al 2024). Designed and Implemented a Sensor-Based Machine Overheat Protection System with Alarm Notification. Due to the variety of components to be processed, whose operation are within a wide range of pressures, temperatures, chemical compatibility, flow rates, its design is usually customized to suit specific working conditions of the

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Section C- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
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system to which the exchanger is incorporated (Bell et al 2004). As a result of excellent heat transfer, ease of maintenance, simplicity of construction as well as compact size, shell and tube heat exchangers are usually adopted as heat exchanger in preheating feed water, evaporators, turbine coolers and condensers etc. Figure 1 shows a clearly labelled diagram of the heat exchanger.

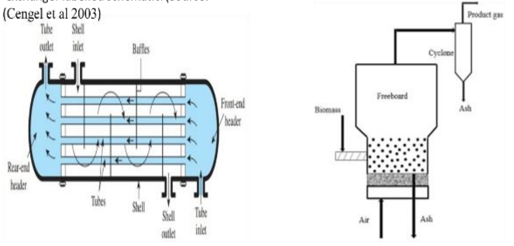


Figure 1a: A standard shell and tube heat exchanger labelled schematic. (Source: (Cengel et al 2003)

Figure 1b: The gasification process (source: Inayat et al. (Inayat et al 2022)

Figure 1: Shows a clearly labelled diagram of the heat exchanger.

2 MATERIALS AND METHODS

The decision support system for designing a shell and tube heat exchanger was created using the MATLAB integrated development environment. This system considers tube geometrics, materials selection, fluid allocation, and mechanical and thermal design factors.

The outside diameter of the tube was chosen to be 1″ (25.4 mm) for ease of cleaning and fouling prevention. The tube thickness was selected based on area to volume density and hoop stress. The length of tube was determined balancing mechanical cleaning and installation space, leading to a 12.5 cm length.

The tube pitch was spaced properly to prevent leaky joints, and a 60° layout was chosen for greater heat transfer. Material selections for different parts were made based on considerations such as strength, corrosion resistance, and thermal conductivity.

The design analysis involved calculating the energy heat load, log mean temperature, shell diameter, shell and tube thickness, number of tubes, pressure drop, and overall heat transfer coefficient.

The geometry of the external diameter of the tube was arbitrarily taken as 1″ (25.4 mm) as a result of the ease of mechanical cleaning and fouling. The tube thickness selection is based on the area to volume density and also, the developed hoop stressed is due to the passage of fluid through it. During the determination of the length of tube, there was a concession between overhead and relief of mechanical anti-fouling cleaning, also bearing in mind the space installation. Thus, 12.5 cm of length was adopted. The distance between the centre-to-centre distances between adjoining tubes, known as tube pitch, were properly spaced to avoid leaky joints occurring in the tube sheet. The pitch ratio is in the range of 1.25< PT/do < 1.5 according to the study by (Hossie 2018). Also, the angle between the pitches of the tubes is characterized by the tube layout. For a greater heat transfer a 60° layout was considered, just as in (Vikram, et al 2017) (Popa, G.2019).

3 DESIGN ANALYSIS USING MATLAB ± PROGRAMS

The decision support system was developed on MATLAB platform. The developed system has the capacity to run series of iteration and for different sizes of heat exchanger by changing the parameters. It provides higher accuracy and computation speed than manual design. Figure 3 shows the graphic user interface for the no phase design platform, while figure 4 and figure 5 shows that of the phase change design and the reboiler design platforms.

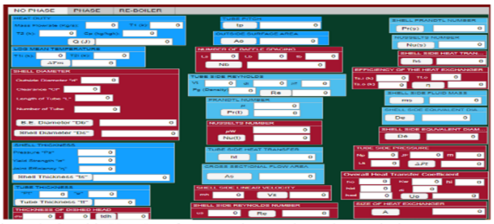


Figure 3. Graphic User Interface snapshot no phase change design

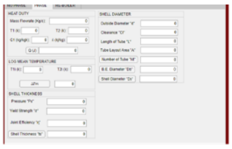
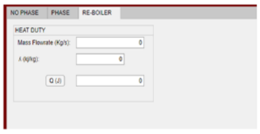


Figure 4: Graphic User Interface snapshot of phase change design


NO PHASE | PHASE | RE-BOILER

HEAT DUTY

Mass Flowrate (Kg/s): 0

λ (kj/kg): 0

Q (J) 0

Figure 5: Graphic User Interface snapshot for the re-boiler design

The following design specifics were inputted in the decision support system for a shell and tube heat exchanger design. The details of the design problem are contained in Table 1

Table 1: Parameter of a sample design problem

S/No	Particulars	Value	Unit
1	Mass flow rate	5.519	kg/s
2	Inlet tube side temperature	100	°C
3	Outlet tube side temperature	74	°C
4	Inlet shell side fluid temperature	25	°C
5	Outlet shell side fluid temperature	52	°C
6	Heat capacity of fluid	4.186	kg/kg
7	Heat capacity of condensate	2257	kj/kg
8	Latent heat of vaporization	40.65	kj/kg
9	Outside diameter	25.4	Mm
10	Inside diameter	22.58	Mm
11	Length	0.125	M
12	Clearance	56	
13	Number of tubes	24	NOS
14	Pressure inside shell	40	MPa

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15	Yield strength of shell material	215	MPa
16	Allowable design stress	79	Mpa

These parameters were keyed into the decision support system and the results were obtained as shown in Table 2 in the result and discussion section. The manual computation was done using the corresponding equations and the result was used to validate the result of the decision support system.

4 RESULTS AND DISCUSSIONS

The results of the computations, both manual computation and that of the Decision Support System, are presented in Table 2. The two arrays of data correlated strongly at a correlation coefficient of 0.9954. The average processing time of the data (inputting, computation, and display) is about six (6) minutes, and the iteration takes 5 to 30 seconds depending on the number of parameters, whose value is changed, and the associated delay is majorly in the area of inputting the data. The manual method takes an average of 55 minutes to 1.5 hours to process the data, and the iteration takes 5 minutes to 85 minutes depending on the number of parameters, whose value is changed and the location of the parameter along the processing flow line. Existing research highlights several limitations and time-consuming aspects of manual data processing. For instance, manual data entry is often described as labour-intensive and prone to human error, which can significantly slow down the process. (Insightvity.2023). Also, the associated delay is majorly in the area of computation not inputting as in the case of the Decision Support System. There is about 91.72% reduction in data processing time and 98.33% to 99.41 reduction in iteration time.

Table 2: Compared output of the manual and decision support system computation for the heat exchanger design

S/N	Equations	Manual	Result from the Decision Support System
1	Heat duty	600.6J	600.6J
2	LMTD	48.54^{0}C	48.5^{0}C
3	Shell bundle diameter	201.28mm	201.30mm
4	Shell diameter	257.28mm	257.3mm
5	Shell thickness	14.70mm	14.70mm
6	Tube thickness	1.409mm	1.41mm
7	Thickness of dished header	6.608mm	6.608mm
8	Tube pitch	31.75mm	31,75mm
9	Tube surface area	239.42m^2	239.40m^2
10	No of baffle spacing	1.2236m	1.2230m
11	Tube side Reynolds number	53024	53024
12	Tube Prandtl number	7.86	7.856
13	Nusselt number	282.93	282.9
14	Tube side heat transfer	137.64W/m^2 ^{0}C	137.0W/m^2 ^{0}C
15	Cross sectional area	40212m^2	39831.36m^2
16	Shell side linear velocity	0.0435m/s	0.07031m/s
17	Shell side Reynolds number	1119	1415
18	Shell side Prandtl number	7.86	7.86
19	Shell Nusselt number	12.29	12 3
20	Shell heat side transfer	62.64W/m^2 ^{0}C	62.0W/m^2 ^{0}C
21	Efficiency	64%	64%
22	Shell side hot fluid	5.5182kg/kgk	5.5182kg/kg
23	Shell side equivalent (square pitch)	140.51mm	140.50mm
24	Shell side equivalent (triangular pitch)	118.27mm	118.3mm
25	Tube side pressure	49083.27pa	62523.7pa
26	Overall heat transfer	110*10^{-6}	110*10^{-6}
27	Heat absorbed area	112848m^2	111959.06m^2

5 Conclusion and Recommendation

From the analysis of the results, it was established that the programming is more convenient and faster method in decision design analysis. It is recommended for use in decision design of heat of heat exchanger in schools and industries for the production of various shell and tube heat exchangers. Incorporating artificial intelligence techniques, especially in the area suggesting possible values as drop down, will optimize the process further.

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