DESIGN AND DEVELOPMENT OF A SUSTAINABLE SHELL AND TUBE HEAT EXCHANGER FOR USE IN A HIGHER INSTITUTION

Abstract

A heat exchanger can be defined as a thermofluid device that is used to transfer heat between two media, from a heat sink and to a heat source. This heat transfer is driven by the temperature differential between the former and the latter. The purpose of this work is to design, fabricate and test a shell and tube type heat exchanger which students can use to learn the basic principles of a heat exchanger. The heat exchanger was fabricated using gas wielding technique. It has two circuits – a hot water circuit and a cold water circuit. Two 1500kw heaters serve as the source of heat for the hot water circuit which circulates under gravity when heated. The cold water circuit has an 0.55kw (5HP) centrifugal pump which effects water circulation. A digital thermometer was used to measure the temperature of fluids at specific intervals. The temperature of the cold water circuit increased on the average at 2.3^{o}C while that of the hot water increased at 7^{o}C. The LMTD was computed to be 4.690^{o} C. while the effectiveness of the heat exchanger was 0.790. The results obtained from this work, was captured succinctly by (Salby, 1999): The second law of thermodynamics is inspired by the observation that the quantity q/T (q is heat content and T is temperature) is independent of path under reversible conditions. One of the several statements of the second law, the Clausius inequality, has the consequences that pertain to the direction of thermodynamic processes: first, heat must be rejected to the environment somewhere during a cycle; second, under reversible conditions, more heat is exchanged at high temperature than at low temperature; and third, irreversibility reduces the net heat absorbed during a cycle. The first consequence precludes the possibility of a process that converts heat from a single source entirely into work: a perpetual motion machine of the second kind. The second consequence implies that net work is performed by the system during a cycle if heat is absorbed at high temperatures and rejected at low temperatures. The third consequence implies that irreversibility reduces the net work performed by the system, in the case of a heat engine, and increases the net work that must be performed on the system, in the case of a refrigerator.

Keywords: Shell and tube heat exchanger, performance analysis, mass flow rate, separation between baffles, pressure drop and heat transfer coefficient.

1. Introduction

A heat exchanger can be defined as a thermofluid device that is used to transfer heat between two media, from a heat sink and to a heat source. This heat transfer is driven by the temperature differential between the former and the latter. Heat exchangers are essential elements in a wide range of systems, including the human body, automobiles, computers, power plants, and comfort heating/cooling equipment (Selbaş et. al., 2006). Shell and tube heat exchangers are gaining special importance in boilers, oil coolers, condensers, preheaters. They are also widely used in process applications as well as refrigeration and air conditioning industry The robustness and medium weight shape of Shell and Tube heat The exchangers make them very suitable for high pressure operations. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air conditioning systems in a home, to chemical processing and energy production in large plants Heat exchanger may be classified according to the following main criteria: 1. Recuperators and Regenerators; 2. Transfer process: Direct contact and Indirect contact; 3. Geometry of construction: tubes, plates and extended surfaces; 4. Heat transfer mechanisms: single phase and two phase; 5. Flow arrangements: parallel, counter and cross flows (Banu et. al., 2022). A primary goal in heat exchanger design is the estimation of the minimum heat transfer area required for a given heat service, as this determines the overall cost of the heat exchanger. However, there is no concrete objective function that can be expressed explicitly as a function of the design variables, and in fact many discrete combinations of the design variables are possible (Selbaş et. al., 2006).

(Raja et. al., 2022) investigated the effect of CuO / water Nano fluids on the enhancement of heat transfer inside a shell and tube heat exchanger at variable inlet temperature. Two different concentrations of 0.2% and 0.4% by volume concentration prepared by single step method has been used at various inlet temperature. The experimental setup consists of multi tube shell and tube heat exchanger with counter flow arrangement. Observation shows that there is significant increase in heat transfer with the increase in volume concentration of Nano particles. By maintaining a constant mass flow rate of 0.0456 kg/sec in both cold and hot side, heat transfer coefficient increases by 18%.

(Marzouk et. al., 2022) presented a numerical model of a shell and tube heat exchanger to analyze six different configurations of baffles to increase the performance of thermal parameters and hydraulic parameters. Baffle configurations include conventional single segment (CSS), staggered single segment (SSS), flower segment (FS), hybrid segment (HS), circular ring baffle (CR), and circular ring with holes (CRH) baffles.). The characteristics of the water flow field, pressure drop and heat transfer performance, including effectiveness (ε) and heat transfer coefficient (h), are studied with a variation of the recharge numbers of 10500 to 38500 to analyze the best performance. The efficiency and heat transfer coefficient increase with increasing Reynolds numbers. The results of the HS configuration are the highest shell side pressure loss, while the thermal influence of HS and CR on the increase in heat exchanger performance is more significant compared to other configurations for all test cases. . Compared to the CSS and SSS baffle configurations, the dead spaces and recirculation zones are disappearing in the FS and HS configurations, where the RCH completely exceeds the dead zones. The maximum values of the efficiency and heat transfer coefficient of STHX are achieved in the case of the CRH type with an improvement of about 166% and 142% respectively, compared to the CSS baffle. The CRH achieved lower friction losses than the hybrids and annular baffles where the shell side pressure drop for HS was the highest value. RCH pressure drop heat transfer coefficients are approximately 138% higher than other configurations.

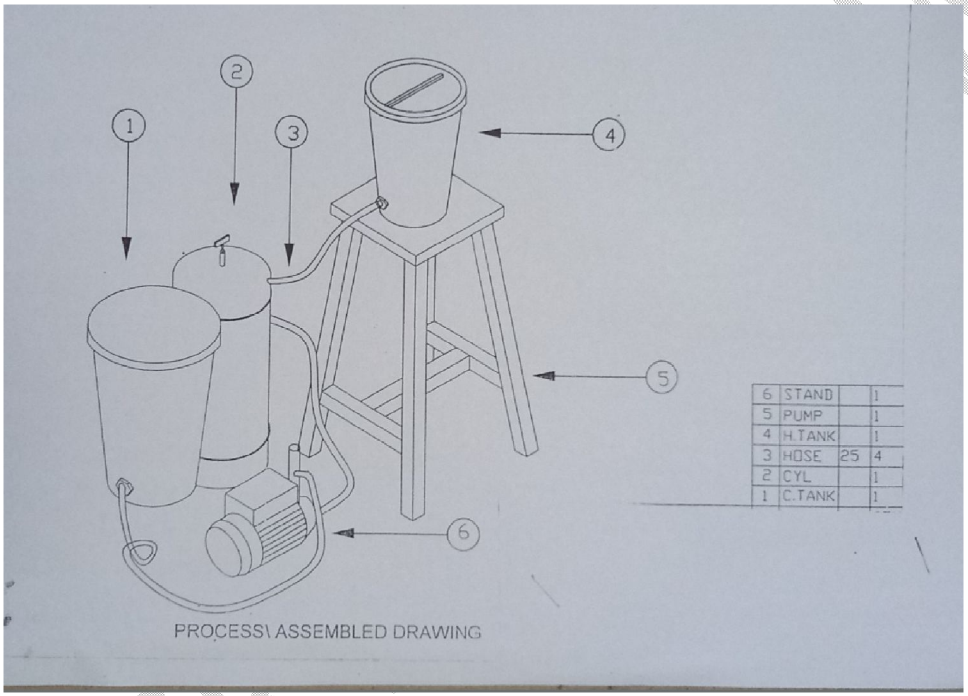
(Vinayak et. al., 2022) presented the experimental and numerical investigations on the efficiency of a small shell and tube heat exchanger for different combinations of refrigerants. A numerical investigation is performed using a commercial computational tool, Fluent, to analyze the heat transfer characteristics for the selected refrigerant combinations. The coolant combinations used consist of ethylene glycol (EG) and deionized water (DW) with varying percentages of the former. Consequently, a combination of ethylene glycol (EG) and deionized water was used, namely 60EG:40DW, 30EG:70DW and 20EG:80DW. EG and DW base fluids were used to compare heat transfer characteristics, respectively, with the selected refrigerant combination. For numerical investigations, CAD model of counterflow heat exchanger with 0 degree inclined baffles; with cold liquid flowing through the shell at a rate of 0.3 kg/s while hot liquid flows through the copper tubes at a flow rate of 0.3 kg/s. Different combinations of shell and tube liquid are analyzed for identical initial and boundary conditions, keeping all other Fluent parameters the same. Temperature contours are generated for all five cases. The temperature distribution for different shell and tube liquid combinations is compared to assess the effectiveness of heat exchange. Improved heat exchange with higher temperature difference between shell/tube inlet and outlet is ensured, and the respective combination of shell and tube fluid is selected for industrial refrigeration applications. The results of the CFD approach are validated with the experimental results and the results are acceptable. From the results it is found that the combination 60EG:40DW showed better heat transfer characteristics compared to other combinations used. Among the different coolant combinations, 60EG:40DW showed higher heat transfer, as indicated by the higher temperature difference in the shell and tube sections, followed by other combinations compared to pure ethylene glycol. Shell and tube outlet temperatures with 60EG:40DW increased by 227% and 105% respectively compared to pure EG, due to improved heat exchange. Heat transfer rate, heat transfer coefficient with 60EG:40DW increased compared to pure EG.

(Selbaş et. al., 2006) successfully applied genetic algorithms (GA) for the optimal design of the shell and tube heat exchanger by varying the design variables: tube outer diameter, tube layout, number of tube passes, tube diameter. casing exterior, baffle spacing. and deflector cut. The LMTD method is used to determine the heat transfer area for a given design configuration.

(Kumar et. al., 2021) extended the application to automotive Heat. In this work, iteration based mathematical model to solve for analytical thermo-hydraulic performance estimation of a typical heat exchanger is adopted with Log Mean Temperature Difference (LMTD) method by incorporating the variation in properties of fluids during each iteration, since the overall thermal resistance ratio between targeted & calculated Heat Rejection Rate (HRR) has to be converged to unity to solve for the actual thermal performance of the heat exchanger. This condition ensures convergence and there is no deviation between the two adjacent iterations in terms of HRR value. Additionally, the above condition ensures that deviation between analytical value calculated by Effectiveness-NTU (∊-NTU) method and experimental data will be reduced significantly due to the proposed iterative LMTD approach adopted in this work. Along with iterative LMTD methodology, ∊-NTU method is adopted for last iteration to cross-verify the obtained value of the HRR for same operating conditions. In order to evaluate heat transfer coefficients for air and coolant side, standard correlations are used from well-established and validated literature data. For coolant side pressure drop calculations, network solution methodology is adopted where fluid flow behavior in each segment of heat exchanger is studied in detail and analytical relationships are used to predict net pressure drop in entire heat exchanger. In our mathematical model, louvered fin effects on heat transfer is taken into account by adopting colburn approach and the geometrical effects of internal fins on flow channels is also included. Experimental validations tests are carried out to compare with the analytical results of HRR, Coolant Side Pressure Drop (CSPD) and Air Side Pressure Drop (ASPD) across heat exchanger. A good agreement is found between experimental and analytical results which validates the accuracy of present mathematical model and methodology, the maximum deviation for HRC is 4% on higher side, for CSPD and ASPD it is 15.4%,8.7% on higher side respectively.

Students studying mechanical engineering are required to have a theoretical and practical understanding of the working principles of heat exchangers, this is because, after their mostly theoretical knowledge they acquire from the classroom, they would definitely work with heat exchangers. The national board for technical education, NBTE, curriculum 2001 recommended that polytechnics running mechanical engineering programmes should have heat exchangers in their laboratory. Unfortunately, there is no heat exchanger in the department of mechanical engineering, delta state polytechnic, Otefe-Ogha. This work, therefore, sets out to design and fabrication a tube and shell heat exchanger to help in the teaching of students.

2. Materials and methods



6	STAND		1
5	PUMP		1
4	H.TANK		1
3	HOSE	25	4
2	CYL		1
1	C.TANK		1

Figure 1: process/assembly drawing of heat exchanger

2.1 Working principles of the heat exchanger

In the developed shell and tube heat exchanger, heat is generated by electric heaters from 2 to 1500 watts immersed in a 30 liter container of water. The hot water produced is allowed to flow by gravity into steel tubes (50 in number) and is discharged through an outlet valve back into the 30 liter hot water container. This completes the hot water circuit. In the cold water circuit, the cold water is stored in a 60 liter water tank. A 0.55kw centrifugal pump (0.5hp flow rate 1.8m3/h at 33m head) sucks the water from the 60 liter container and discharges it into the casing through the casing inlet. The cold water is discharged from the housing through the outlet and returns back to the 60 liter container, thus completing the cold water circuit. The heat of the hot water in the steel tube is extracted by the cold water through the conduction process. A digital thermometer is used to measure the temperature of the hot water in the hot water container and the hot water at the point of discharge. The same measurement applies to cold water temperature. It will be noted that the temperature of the hot water at the point of discharge is lower than the temperature of the hot water in the container, while the temperature of the cold water in the container will increase with time. Bleed valves help ensure that air is removed from the system.

2.2 Design of shell and tube heat exchanger

The energy conservation equation for a exchanger having an arbitrary flow arrangement is, The oil mass flow rate is calculated using the energy balance. Equation

$$Q_h = \dot{m}_h C_{ph}(T_{h1} - T_{h2}) \qquad (1)$$

$$Q_c = \dot{m}_c C_{pc}(T_{c2} - T_{c1}) \qquad (2)$$

Heat loss due to heat transfer from the hot water to the cold water is 5-10%

$$Q_c = 0.9Q_h \qquad (3)$$

The selected flow arrangement is of the counterflow type and accordingly LMTD for this stage is F=0.95)

$$\Delta T_m = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln\frac{(T_{h1} - T_{c2})}{(T_{h2} - T_{c1})}} \qquad (4)$$

$$\Delta T_m = \frac{(46.7 - 37.2) - (39.2 - 37.4)}{\ln\frac{(46.7 - 37.2)}{(39.2 - 37.4)}}$$

$$= 4.690^o C$$

To solve certain heat exchanger problems, engineers often use a log mean temperature difference (LMTD), which is used to determine the temperature driving force for heat transfer in heat exchangers. LMTD is introduced due to the fact that the temperature change that takes place in the heat exchanger from inlet to outlet is not linear (Kumar et. al., 2021; Cui et. al., 2014; Li et. al., 2017).

The rate of heat transfer between the cold and hot water is given by

$$Q_{act} = UA\Delta T_m \qquad (5)$$

ΔT_m is the log mean temperature difference

The total surface area of the heat exchanger is calculated, thus

$$A = \frac{Q_{act}}{U\Delta T_m} \qquad (6)$$

Computation of Effectiveness of Heat Exchanger

Effectiveness of Heat Exchanger was computed thus

$$\varepsilon = 2\left\{1 + C + \sqrt{1 + C^2 \frac{1 + exp\left[-NTU\sqrt{1 + C^2}\right]}{1 - exp\left[-NTU\sqrt{1 + C^2}\right]}}\right\}^{-1} \qquad (7)$$

$$\varepsilon = \frac{Q_{actual}}{Q_{max}} \qquad (8)$$

$$\varepsilon = \frac{\dot{m}_h C_{ph}(t_1^h - t_2^h)}{\dot{m}_h C_{ph}(t_1^h - t_1^c)} \qquad (9)$$

$$\varepsilon = \frac{46.7 - 39.2}{46.7 - 37.2}$$

$$\varepsilon = 0.790$$

List 1: input parameters

s.no	Input parameters	Value	Unit
1	Shell thickness	1.5	mm
2	Diameter of heat exchanger	257.8	mm
3	Diameter of steel tubes	12	mm
4	Number of tubes	50	-
5	Length of tube	435	mm
6	Circumference of the area containing the tubes	810	mm
7	Number of circular plates	2	-
8	Diameter of circular plates	254.8	mm
9	PVC hoses	25	mm
10	Diameter of plastic plates	19.05	mm
11	Back nut diameter	25.4	mm
12	PVC union	19.05	mm
13	Pump rating	0.5 (0.5HP, flowrate of 1.8 m3/hr at a head of 33m)	kW
14	Capacity of cold water container	60	Litres
15	Capacity of hot water container	30	Litres
16	Capacity of electric heats	1500 X 2	W

2.2 Method of fabrication

Two circular steel plates were marked, cut out and grounded to the desired diameter, 50 holes of 12mm diameter were drilled on both plates to house the steel tubes. Fifty pieces of steel tubes of 12 mm diameter and 435 mm long were long were welded to both drilled holes of the 2 steel plates. A steel sheet of 1.5 mm thickness was folded to 257.8 mm diameter and gas wielded, forming a hollow cylinder. The circular steel plate and steel tubes were inserted into the hollow cylinder and wielded into the inner diameter. A gas cylinder was cut and used in covering the howllow cylinder at both ends. Holes were drilled on the exchanger forming the inlets and outlets of the hot and cold water circuits respectively. The water containers of 60 litres and 30 litres were also drilled at the top and bottom respectively serving as sources for the flow of fluid. A PVC hose was connected from the outlet of the hot water container (30 litres) to the hot water inlet of the heat exchanger. Another hose was connected from the hot water outlet, which has a valve (ON/OFF) of the heat exchanger in order to return the hot water back to the hot water container completing the hot water circuit connection. Subsequently, another PVC hose was connected from the outlet of the cold water container (60 litres) to the centrifugal pump which in turn was connected to the inlet of the cold water in the heat exchanger. Another hose was connected from the outlet of the cold water in the heat exchanger back to the 60 litres cold water container.

2.3 Performance evaluation

A systematic methodology was applied to evaluate how well the shell and tube heat exchanger performed. Results for the evaluation are as shown in tables 1 and 2; and The hot water container (30 litres) was filled with water to the level of 25 litres and the water was allowed to flow through the PVC hose into the tubes side of the heat exchanger and the valve (ON/OFF) at the outlet of the hot water in the heat exchanger was closed to enable the water to be trapped in the heat exchanger and the temperature was noted. Two water heaters of 1500 kW were inserted into the hot water container and they were switched on and the water was heated to a desired and the value was noted. After heating to a desired temperature, the valve was opened allowing the hot water to flow cycle. The cold water was filled with water to a level of 50 litres and the temperature noted. The pump was switched on allowing the water to be forced through the shell of the heat exchanger and over the outside of the steel tubes. The hot water will transfer heat via the inner wall of the steel tubes to the cold water and the temperature was noted at the cold water outlet of the heat exchanger. Two different performance evaluation were carried out.

3.0 Results and discussions

Results from the tests and performance evaluation show that at time, t, the temperatures at the inlet and outlet of the system were the same at 29.8^{o}C. As heating process goes on, there was temperature increment for the cold water and hot water circuit. On close observation, the temperature of the cold water system increased at a mean rate of 2.3 ^{o}C, while that of the hot water circuit increased at a mean temperature of 70 ^{o}C.

3.1 Log mean temperature difference (LMTD)

The Log mean temperature difference (LMTD) of $4.690^{o}C$ was obtained. The authors acknowledged that the LMTD value is quite low. Possible reason for this low value could be due to heat losses resulting from both hot and cold water circuits, since they weren't lagged.

In the case of heat exchangers, the temperature difference between the hot and cold fluid varies continuously along HX. Here, the arithmetic mean difference will give an error in the heat transfer value. Therefore, the logarithmic mean is considered for fewer errors in the answers.

3.2 Effectiveness of Heat Exchanger

Results also show that The Effectiveness of Heat Exchanger was obtained as 0.790. The result is slightly in disagreement with (Mogaji et. al., 2019). Falls within the range of heat exchanger effectiveness: for shell and tube heat exchanger with n = 3, the effectiveness is 0.56. There was 0.41 % increase or percentage deviation from (Mogaji et. al., 2019). Intuitively, the result from the present study was closer to fluid heat exchanger effectiveness of (Mogaji et. al., 2019) reported the same value for flow arrangements: cross flow for methanol, 0.76; parallel flow for methanol was 0.71.

Table 1: first performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger

Clock time	Cold water circuit			Hot water circuit		
	Inlet temp. oC	Outlet temp. oC	Δ_t (deg C)	Inlet temp. oC	Outlet temp. oC	Δ_t (deg C)
10.29	29.8	29.8	0	29.8	29.8	0
11.23	29.8	34.2	4.4	43.5	35.8	7.7
11.44	36.8	39	2.2	45.2	39.4	5.8
12.01	36	37.2	1.2	43	38.4	4.6
12.20	35.5	36.3	0.8	43	36.4	6.6
12.36	37.2	39.4	2.0	46.7	37.4	9.3
12.55	34.7	37.4	2.7	47.1	39.0	8.1
01.13	36.5	39.8	3.3	46.2	39.8	7.2
1.37	36.0	37.8	1.8	43.7	38.5	5.2
2.0	37.6	40.00	2.40	2.40	40.00	8.10
Mean			2.30			7.00

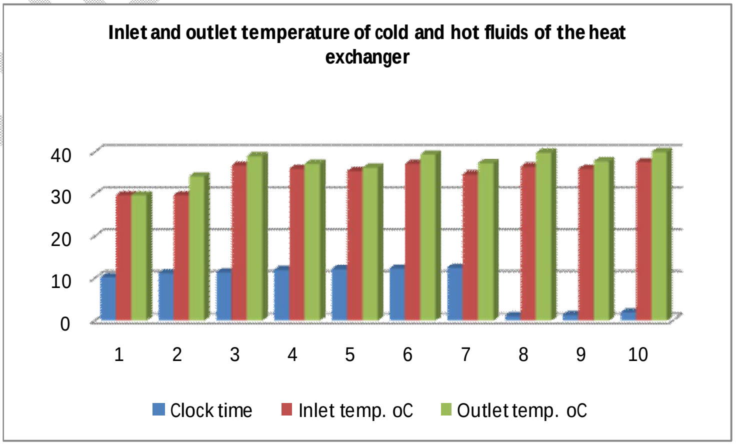


Figure 2: first performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger for cold water circuit

Figure 2 and table 1 show first performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger for cold water circuit. On closer observation, the difference between the inlet temperature and outlet temperatures for the cold water circuit changes as the various entry and exit temperature changes. The highest recorded temperature for the cold water circuit for the inlet temperature was recorded to be 37.6^{O}c; while the lowest recorded temperature for the cold water circuit for inlet temperature was recorded to be 29.8^{O}c. Conversely, the highest recorded temperature for cold water circuit for the outlet temperature was recorded to be 40^{o}c; while the lowest recorded temperature for the cold water circuit for outlet temperature was recorded to be 29.8^{o}c. The highest heat gain occurred at time, t = 2 hours and the temperature differential between the inlet of the cold water circuit and its numerical value was 2.40 ^{o}c, while the lowest heat gain occurred at time, t = 0 hours and the temperature differentials between the inlet of the cold water circuit and its numerical value was 0 ^{o}c.

Also, Figure 2 and table 1 show second performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger for cold water circuit. On closer observation, the difference between the inlet temperature and outlet temperatures for the cold water circuit changes as the various entry and exit temperature changes. The highest recorded temperature for the cold water circuit for the inlet temperature was recorded to be 40^{O}c; while the lowest recorded temperature for the cold water circuit for inlet temperature was recorded to be 32.8^{O}c. Conversely, the highest recorded temperature for cold water circuit for the outlet temperature was recorded to be 40.9^{o}c; while the lowest recorded temperature for the cold water circuit for outlet temperature was recorded to be 34^{o}c. The highest heat gain occurred at time, t = 2.10 hours and 2.22 hours and the temperature differentials between the inlet of the cold water circuit and its numerical value were 2.10 ^{o}c and 2.22 ^{o}c, while the lowest heat gain occurred at time, t = 2.31hours, time, t = 2.52, time, t = 3.01 hours and the temperature differentials between the inlet of the cold water circuit and their numerical values were at -3.1 ^{o}c and -3.1 ^{o}c.

As can be seen from tables 1 and 2, plus figures 2 to 5, the temperature difference between the hot and cold fluid varies continuously along the heat exchanger.

In a heat exchanger, when heat is transferred from a high temperature fluid to a low temperature fluid, the temperature difference between these two fluids changes. As time passes the rate of heat transfer decreases, when we calculate the amount of heat transfer at different times it will not be the same, it varies. It is not feasible to calculate the total heat transferred by taking the readings at different times or the calculation rate at different times. The temperature differentials vary exponentially, not linearly. So we determined a value of LMTD that would give us an average value rate of heat transfer accurately and quickly. We would have obtained the same values by calculating the heat transfer at different times.

(Piyush Jena, 2018) gives reasons, and they are in consonance with results obtained: Heat exchangers are generally cylindrical in nature. In hollow cylinders, temperature profile across the material is logarithmic as can be proved from Fourier's law of conduction. Also, the temperature difference between the two fluids keeps on changing

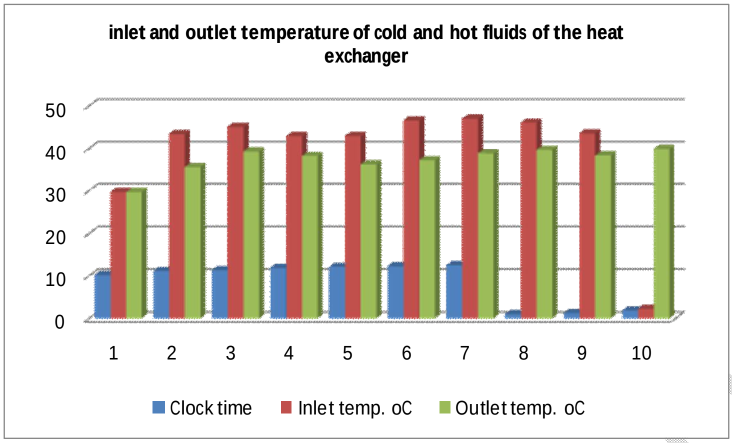


Figure 3: first performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger for hot water circuit.

From figure 3, results show that the inlet temperatures for the hot water circuit were always greater the outlet temperatures, but for the initial temperature at time, t = 0. This is consistent with the principles governing heat transfer, heating and cooling and the second law of thermodynamics. The hot water circuit has to loss heat to attain thermal energy equilibrium between the thermodynamic system and its environment.

Table 2: Second performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger

	Cold H2O circuit			Hot H2O circuit		
Time	inlet temp. (^{o}C)	outlet temp. (^{o}C)	Δ_t (deg C)	inlet temp. (^{o}C)	outlet temp. (^{o}C)	Δ_t (deg C)
1:57	32.8	34.0	1.2	48.4	36.5	-11.9
2:10	33.1	34.9	1.8	50.1	37.2	-12.9
2:22	33.8	35.6	1.8	51.3	38.4	-12.9
2.31	34.5	36.0	1.5	52.6	39.0	-13.9
2.42	35.2	36.7	1.5	53.2	39.8	-13.4
2.52	36.3	37.4	1.1	55.0	41.1	-13.9
3.01	36.5	37.9	1.4	55.8	41.9	-13.9
3:13	37.0	38.3	1.3	56.3	43.1	-13.2
3.24	37.6	38.8	1.2	56.9	43.9	-13.0
3.33	37.9	39.2	1.3	57.5	44.6	-12.9
3.43	38.0	39.5	1.5	57.9	44.9	-13.0
3.53	38.3	39.9	1.6	58.3	55.2	-3.1
4.03	38.9	40.2	1.3	58.9	55.5	-3.4
4:13	40.0	40.9	0.9	59.2	56.1	-3.1

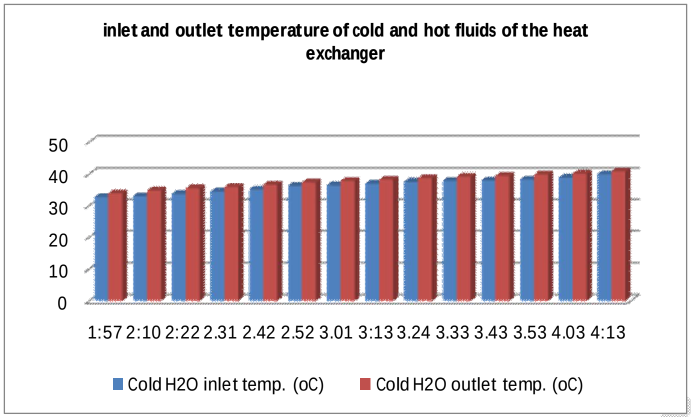


Figure 4: Second performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger Cold H2O circuit

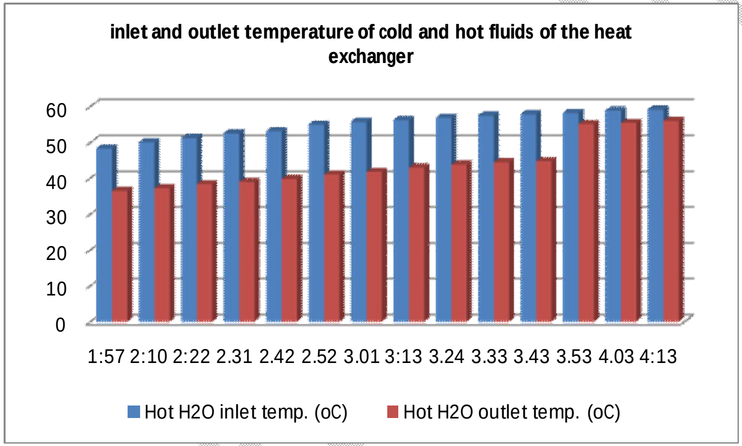


Figure 5: Second performance evaluation for inlet and outlet temperature of cold and hot fluids of the heat exchanger hot H_2O circuit

From figure 5, results show that the inlet temperatures for the hot water circuit were always greater the outlet temperatures, inclusive of the initial temperature at time, t = 0. This is consistent with the principles governing heat transfer, the principles of heating and cooling and the second law of thermodynamics. The hot water circuit has to loss heat to attain thermal energy equilibrium between the thermodynamic system and its environment.

4.0 Conclusions

A shell and tube type heat exchanger was designed and fabricated using locally available materials with the intension that it will be used to teach students the principles of heat exchanger. The heat exchanger was fabricated with gas welding technique, amongst others. It consisted of two circuits – a cold water circuit and a hot water circuit. Only the cold water circuit had a pump to circulate water; the water in the hot water circuit flows under gravity. Performance evaluation was carried out using the fabricated heat exchanger. The cold water circuit increased on the average at a rate of 7.0 ^{o}C on average. The LMTD of the heat exchanger was calculated to be $4.690^{o}C$ while its effectiveness was calculated to be 0.760.

In a heat exchanger, when heat is transferred from a high temperature fluid to a low temperature fluid, the temperature difference between these two fluids changes. As time passes the rate of heat transfer decreases, when we calculate the amount of heat transfer at different times it will not be the same, it varies. It is not feasible to calculate the total heat transferred by taking the readings at different times or the calculation rate at different times. The temperature differentials vary exponentially, not linearly. So we determined a value of LMTD that would give us an average value rate of heat transfer accurately and quickly. We would have obtained the same values by calculating the heat transfer at different times.

The results obtained from this work, was captured succinctly by (Salby, 1999): The second law of thermodynamics is inspired by the observation that the quantity q/T (q is heat content and T is temperature) is independent of path under reversible conditions. One of the several statements of the second law, the Clausius inequality, has the consequences that pertain to the direction of thermodynamic processes: first, heat must be rejected to the environment somewhere during a cycle; second, under reversible conditions, more heat is exchanged at high temperature than at low temperature; and third, irreversibility reduces the net heat absorbed during a cycle. The first consequence precludes the possibility of a process that converts heat from a single source entirely into work: a perpetual motion machine of the second kind. The second consequence implies that net work is performed by the system during a cycle if heat is absorbed at high temperatures and rejected at low temperatures. The third consequence implies that irreversibility reduces the net work performed by the system, in the case of a heat engine, and increases the net work that must be performed on the system, in the case of a refrigerator.

Similarly, (Piyush Jena, 2018) gives reasons, and they are in consonance with results obtained: Heat exchangers are generally cylindrical in nature. In hollow cylinders, temperature profile across the material is logarithmic as can be proved from Fourier's law of conduction. Also, the temperature difference between the two fluids keeps on changing

5.0 Recommendations

The authors recommend that a second centrifugal pump be incorporated for the hot water circuit to facilitate steady flow of fluid since this would improve results of heat exchanger. Lagging of the heat exchanger should be done to reduce the heat loss.

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