HEAR TRANSFER LABORATORY
DEPARTMENT OF MECHANICAL ENGINEERING

Experiment No.8 #: STUDY OF SHELL AND TUBE TYPE HEAT EXCHANGER SYSTEM

OBJECTIVES:

To study a shell and tube heat exchanger.
The experimental setup (Shell and tube heat exchanger), is designed to analyze a typical shell and tube heat exchanger with the following objectives:

(a) To evaluate the rate of heat transfer from hot fluid to cold fluid.
(b) To calculate the LMTD of the shell and tube heat exchanger at different oil/water flow rates.

INTRODUCTION:

Heat exchangers are class of equipment, which facilitate the exchange of heat between two fluids that are at different temperatures. The heat transfer in the heat exchanger is by convection in each fluid and by means of conduction through the walls separating the fluids. The rate of heat transfer between the two fluids at any location in a heat exchanger depends on the magnitude of the temperature gradient between two fluids as well as the velocities and their respective thermo-physical properties. The various types of heat exchangers differ with respect to the mixing chambers – their layouts and whether it allows or forbids the fluids to mix with each other. The different types of heat exchangers commercially used are illustrated in Fig.1

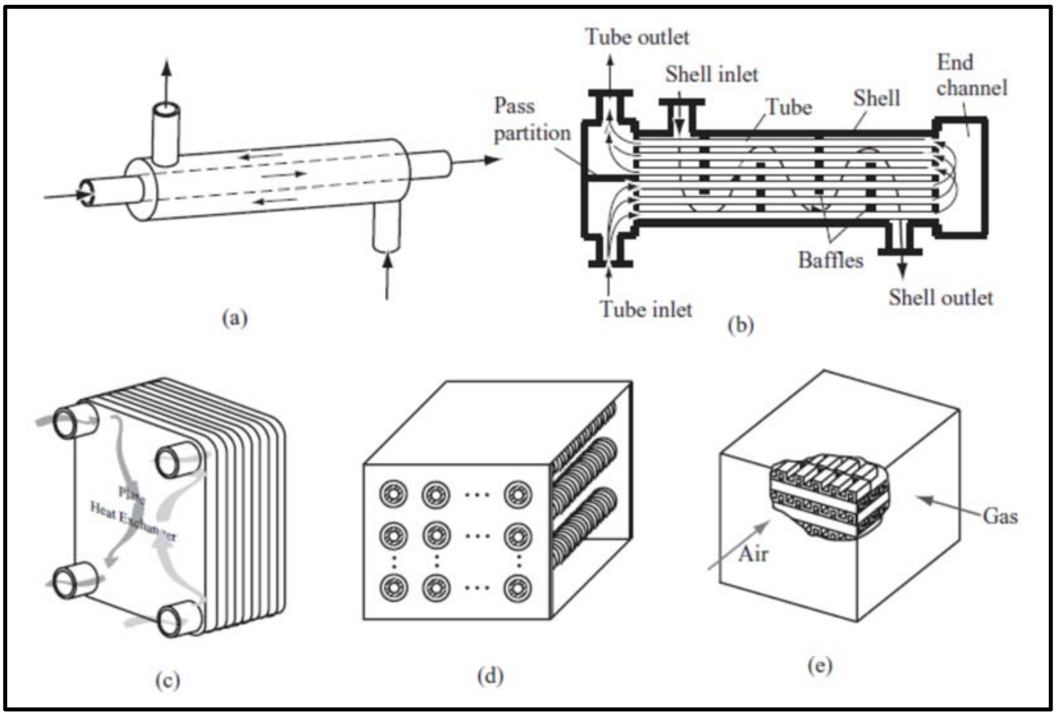

Fig. 1. Types of Heat Exchangers (a) Double Pipe Heat Exchanger, (b) Shell and Tube Heat Exchanger, (c) Brazed Plate type Heat Exchanger, (d) Circular Finned Tube Heat Exchanger, (e) Plate Finned Heat Exchanger

APPARATUS

Description of the experimental set up includes:

Shell and Tube Heat Exchanger:

Shell and tube heat exchanger is oil cooler, wherein the hot oil flowing in the shell is cooled by water flowing in tubes. As seen in the photograph, the heat exchanger was insulated with Armaflex insulation sheet and mounted on a base. The oil is passing through the shell and water through the tubes; accordingly oil and water, inlet and outlet flow connections are done.

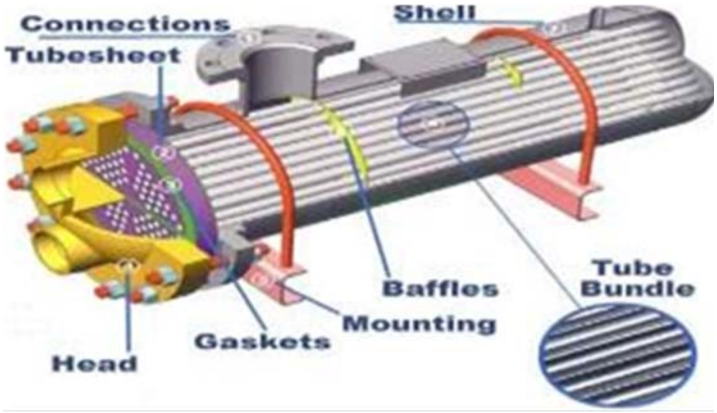

Fig. 2. Experimental set up and cross sectional view of shell and tube heat exchanger

Shell and tube heat exchanger was connected to the respective sumps by ¾″ CPVC pipe, capable of sustaining a nominal working temperature up to 85°C. However, PVC starts to destabilize when the temperature reaches 140°C (284°F), with melting temperature starting around 160°C (320°F). The linear expansion coefficient of rigid PVC is small and has good flame retardancy. Further, to reduce the heat losses to the environment, the oil line was insulated with Nitrile rubber pipe foam insulation (thermal conductivity 0.034 W/m K.

The foam insulation offered excellent flexibility, resistance to water vapour; it was also oil and acid resistant. It also had excellent adhesive and coating receptiveness along with ease of fabrication. The photograph below illustrates (a) the pipe insulators and (b) the sheet insulators. Table 1 gives us the detailed specifications of both, the pipe and the sheet insulators.

Property	**Value**
Density Range	50-60 kg/m3
Temperature Range	-40 to +105°C
Thermal Conductivity	0.034 W/m K (at 0°C)

Oil Bath and Water Sump:

The oil bath used was a 150 lt. stainless steel tank, which was insulated from outside with 10 mm Armaflex insulation sheet. The insulation was done on the lid of the tank too. The tank was fitted with a 6 kW electric heater, connected to an ON-OFF controller and Pt-100 (RTD) thermocouple that was also connected to the controller. The tank had one outlet, going to the oil circulating pump and two inlets, bypass and one inlet from system. The water sump was a 500 lt. Syntex tank, placed slightly away and outside the experiment room, on a raised platform. The coolant water being used was to be circulated at room temperature, therefore there was no need for any insulation here. The schematic in Fig. 3 explains the general piping arrangement from the sumps.

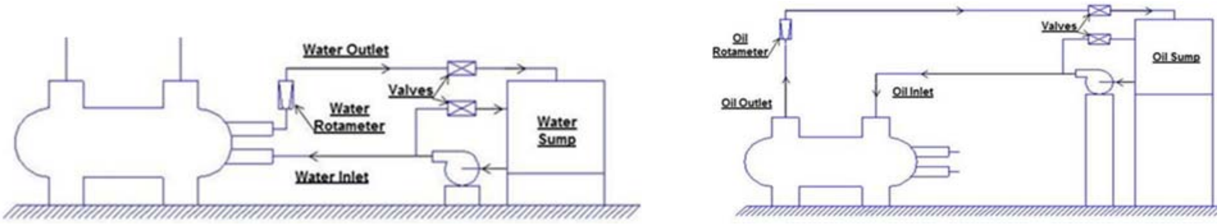

Fig.3. Schematic of (a) Water piping and (b) Oil piping.

ON-OFF Controller:

An ON-OFF controller is used to control the temperature of oil bath. A Selec make controller is connected to 6 kW heater and thermocouple, both inserted in the oil bath. The thermocouple used to sense the oil temperature and accordingly triggers the heater ON or OFF, depending upon the set temperature in the controller. With the help of the ON-OFF controller, we were, by and large, able to achieve constant oil bath temperature (±1°C).

Thermocouples

The inlet and outlet temperatures of oil and water are measured with the help of built-in-house K-type thermocouples with bead diameters ranging between 0.5-0.75 mm. Altogether, four thermocouples were used, two each for oil and water-for their respective inlet temperatures to the heat exchanger and outlet temperatures from the heat exchanger. The thermocouples were connected to the NI-9213 card, which in turn was connected to the computer system where the readings were noted via a Labview interface.

Rotameters

Two rotameters are used in the experiment, one each for the measurement oil flow rate and water flow rate. Both the rotameters are calibrated as per the laid down procedure for corresponding fluid at different operating temperatures. The rotameters belongs to the class of variable area meters, it measures the flow rate of the fluid by allowing the cross-sectional area of the fluid to vary, which inherently causes a measurable effect.

Technical Specification of the experimental set up:

Following is the technical specification of the set up:

Capacity of the heat exchanger (Q)= 3.0 kW

Effective length range	0.5-1.0m (Ensure table mounted)

Standard tube and shell size as:

Tube Material	SS316
Tube OD	9.53 mm
Tube Thickness	0.71 mm
Shell Material	Carbon Steel
Shell OD	114.30 mm
Shell ID	102.26 mm

Shell Dimensions

Material Tube	Cast Steel	
Pattern Tube Pitch		90
	PT	0.012m

Shell ID Shell OD	$D_{i,shell}$	0.102m
Shell Length	$D_{o,shell}$	0.114m
Tube Dimensions	L_s	0.5m
Material	SS316	
Tube Length	L	0.5m
No. of passes		4
Tube OD Tube	D_o	0.00953m
ID Tube Pitch	D_i	0.00811m
Baffle Design	PT	0.0125m
Baffle Thickness Min	t_b	0.005m
Baffle spacing	L_b	0.065m
Nos of Baffles	N_b	5

Assuming properties of the fluids to be constant across the process, the following properties are imperative for the calculation purpose. The oil used for the experimental purpose is hydraulic oil, which is very frequently used for cooling intention in plastic industries. The VG-32 oil is blended from highly refined base stocks with high viscosity index and specially selected anti-oxidant, anti-corrosion, anti-wear, anti-rust and anti-foam additives. VG-32 oil can sustain very high pressure of the system and high speed of the pumps and compatible with the seals normally used in the hydraulic system.

Properties of VG-32 Oil:

Density	-	ρ_o	-	839 kg/m^3
Viscosity	-	μ_o	-	8.5282 mPa-s
Specific Heat	-	C_{po}	-	1968 J/kg K
Thermal Conductivity	-	k_o	-	0.151 W/m K

Properties of Water:

(m)	Density	-	ρ_w	-	1000 kg/m^3
(n)	Viscosity	-	μ_w	-	0.8301 mPa-s
(o)	Specific Heat	-	C_{pw}	-	4187 J/kg K
(p)	Thermal Conductivity	-	k_w	-	0.6049 W/m K
(q)	Fouling Resistance	-	f	-	0.00017 m^2 K/W

Formula to be used:

For hot fluid we have,

Heat capacity of hot fluid: $(mCp)_o$

Similarly for cold fluid we have,

Heat capacity of cold fluid: $(mCp)_w$

Therefore we have the capacity ratio (C) as,

$$C = \frac{C_{\min}}{C_{\max}}$$

$$Q_{\max} = C_{\min}\left(T_{o_{in}} - T_{w_{in}}\right)$$

For heat exchanger effectiveness we have,

$$\varepsilon = \frac{Q}{Q_{max}}$$

Considering a square array of tubes, as illustrated in the Fig. 4 below,

Gap between tubes C^1 = $P_T - D_o$ = 0.00297 m

Cross flow area S_S = $(D_o/ P_T)* C^1 *L_B$ = 0.00158 m^2

Equivalent Diameter D_e = $4(P_T^2 - \pi D_o^2/4)/\pi D_o$= 0.011337 m

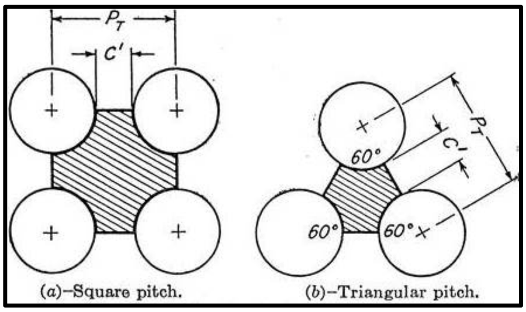

Fig. 4.Typical tube pattern arrangement

Now, for calculating the mass flux, we determine it by,

Mass Flux m_s = m_h/S_s

m_h= mass flow rate of oil (kg/s)

The Reynolds number and Prandtl number are herewith calculated considering the mass flux,

Reynolds Number Re = $m_s* D_e/\mu_{oil}$

Prandtl Number Pr = $C_{p,oil}*\mu_{oil}/k_{oil}$

The shell side heat transfer coefficient is calculated using the Sider-Tate correlation,

$$h = (0.36k/D_e)(\mathrm{Re})^{0.55}(\mathrm{Pr})^{(1/3)}$$

Calculation of the tube side heat transfer coefficient:

The heat exchanger has 24 Nos of tubes and it is a four pass system, therefore in each pass we have 6 Nos of tubes.

Now, the Reynolds Number and Prandtls number are herewith calculated as,

Reynolds Number Re = $\rho_w* v_{tube}*D_i/\mu_w$

Prandtl Number Pr = $C_{p,water}*\mu_w /k_w$

Since, the flow is in intermediate state, that is, it is in transition phase (from laminar to turbulent), and we find Nusselt number by the following correlation.

$$\mathrm{Nu}_m = (1-\chi)\,\mathrm{Nu}_{lam2300} + \chi \mathrm{Nu}_{turb10^4}$$

where,

$\mathrm{Nu}_{lam2300}$ = Nu # for boundary conditions for laminar flow at Re = 2300,

Nu_{turb10^4} = Nu # for turbulent flow and boundary conditions at Re = 10^4,

χ = Intermittency factor

And, $$\chi = \frac{\mathrm{Re}-2300}{10^4-2300}$$

To determine Nu (at Re=2300) and Nu (at Re=10^4) consider,

$\mathrm{Nu}_{lam2300}$ = 3.66 and for Nu_{turb10^4}, consider Dittus-Boelter correlation,

$$\mathrm{Nu}_{turb10^4} = 0.023\,\mathrm{Re}^{\left(4/5\right)}\,\mathrm{Pr}^n$$

Here, $n = 0.4$ for heating, i.e. surface temperature greater than the bulk mean fluid temperature ($T_s > T_m$),

$n = 0.3$ for cooling, i.e. ($T_s < T_m$).

Finally, we have,

$$\mathrm{Nu}_m = \frac{hD_i}{k_w}$$

Based on above calculations:

Shell side (Oil)	$h_o =$	$W/m^2\ K$
Tube side (Water)	$h_w =$	$W/m^2\ K$

Calculation of Overall heat transfer coefficient (U) and number of tubes (N) required. Considering, convective heat transfer inside and outside the tubes and conduction via the tube material, we have

$$UA_s = \left[\frac{1}{(hA)_w} + \frac{\ln\left(R_o/R_i\right)}{2\pi LNK} + \frac{1}{(hA)_o}\right]^{-1}$$

Since tube material is SS316, k = 16 W/m K

$$NTU = -\frac{1}{\sqrt{1+C^2}}\ln\left(\frac{2/\varepsilon - 1 - C - \sqrt{1+C^2}}{2/\varepsilon - 1 - C + \sqrt{1+C^2}}\right)$$

$$NTU = \frac{UA_s}{C_{min}}$$

For standard tube pattern, the nearest adjustable matching configuration should be selected.
Calculation of outlet temperatures of cold and hot fluid streams.

For oil outlet temperature, $T_{o_{out}} = T_{o_i} - \dfrac{Q}{Q_{max}}$

Similarly for water outlet temperature,

$$T_{w_{out}} = T_{w_i} + \frac{Q}{Q_{max}}$$

Calculation of LMTD:

Experimental LMTD = (ΔT_1 - ΔT_2) / ln ($\Delta T_1/\Delta T_2$)
Where:
$\Delta T_1 = T_3 - T_2$
$\Delta T_2 = T_4 - T_1$

Theoretical value of LMTD $= \dfrac{(T_{o_{in}} - T_{w_{out}}) - (T_{o_{out}} - T_{w_{in}})}{\ln\dfrac{(T_{o_{in}} - T_{w_{out}})}{(T_{o_{out}} - T_{w_{in}})}}\ ^oC$

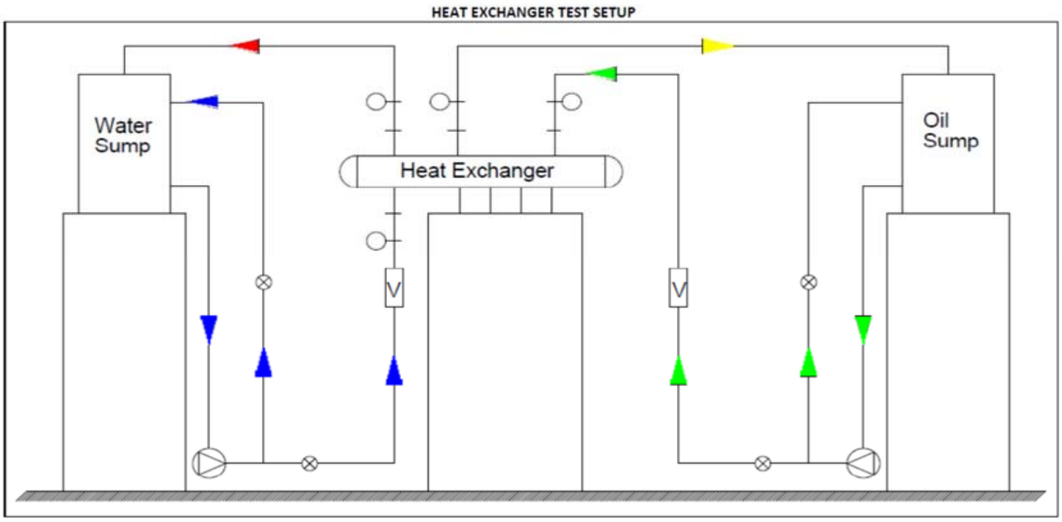

Fig. 5. Schematic of Set-up

PROCEDURE:

We have designed 3 kW single shell and four tube pass heat exchanger in the laboratory. The objective is to determine the effectiveness of a 3 kW system at varied operating conditions. Accordingly, the following tests are to be carried out to find out the variation of LMTD with different water flow, keeping the oil flow constant:

(a) To analyze variation of LMTD by keeping water inlet temperature and oil inlet temperature constant.

The first trial was taken for the increasing inlet water temperature and decreasing inlet oil temperature. For this experiment, only one coil of the 6 kW electric heater was made functional. The 6 kW coil heater had three coils of 2 kW each and all three had separate connections, for this trial we connected only one heater. The temperature on the ON-OFF controller for oil was set at 75°C. The hot oil initially at 75°C entered the shell and tube heat exchanger and cooled oil exited at about 66°C; this oil was then allowed to enter the oil sump. The cooled oil entering the oil sump started reducing the oil temperature entering the shell and tube heat exchanger.

Similarly, the water initially entered the heat exchanger at 30°C and the warmer water exiting the shell and tube heat exchanger was at about 32°C. Likewise the oil, the warmer water too was allowed to flow back in the water sump. The warm water entering the sump started increasing the water inlet temperature. Readings were noted at different flow rates of water. The graph below shows the LMTD (log mean temperature difference) against the water flow rate. The readings were noted when all the temperatures attended steady state for different flow rate of water. Here, the only constant factor was the oil flow rate, otherwise rest all the factors were made to change.

General procedure of operating the experimental set-up

The safety and following the laid down standard operating procedure of the laboratory before starting the experiment was of paramount importance. All the parts, valves, wiring, working of thermocouples, NI-card and Labview software was checked and ensured its proper working. As also, as per the standard operating procedure of laboratory, fire extinguisher for short circuit or oil burning contingencies was catered for.

To start the equipment initially and thus the experiment, the following steps were adhered to. To understand the steps described herewith, refer to Fig. 3, which gives the schematic of piping arrangement of the oil and water circuits respectively.

(a) Ensure sufficient oil and water level in respective sumps and that for oil sump we confirmed that the heater and the RTD were in the oil.

(b) Oil bypass valve i.e. valve-1 was kept open and valve-2 initially was kept closed.

(c) Then we started the pump, we here checked oil is circulating properly without any leakages in the bypass line. Then the valve-2 was gradually opened, to the extent that there was some flow of oil in the heat exchanger exit line. The air plug on the shell was opened and oil was made to overflow for some time and then it was closed.

(d) When we got sure that there were no leakages and entire air from the shell was plugged out, we started the ON-OFF controller.

(e) On switching the controller on, we first set the temperature with the help of buttons on the display device. If the RTD in the oil was showing temperature of oil below that of the set value, the heater turned ON and as the oil started heating and temperature about to reach set value, the heater started turning ON and OFF, and later on the temperature of the oil sump was constant at the set value with (±1°C) variation.

(f) Later with the help of valve-1 and valve-2, we adjusted the flow rate in the rotameter to about 12 LPM, so that after calibration, we got the oil flow rate at 0.164 kg/s.

(g) Refer Fig.3, on similar lines, water circuit was also started. After checking the water level in the tank, the valve-1 was kept open and pump was started. Then the valve-2 was gradually opened, here too after letting the water flow through air plug, the plugs were tightened. We ensured there were no leakages in water line too.

(h) Since, we wanted to use water at ambient temperature; there was no requirement of ON-OFF controller for water tank.

(i) Lastly, before taking the readings of the inlet and outlet temperatures of oil and water, correct and accurate working of the Labview data acquisition interface was ensured.

OBSERVATIONS:

Date:
Batch Number:

S. No	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	Flow rate of oil (LPM)	Flow rate of water (LPM)	Time
1							
2							
3							
4							
5							

PRECAUTIONS:

1. Check the initial temperature in controller before starting the experiments, it must show ambient temperature initially.
2. Insure sufficient amount of oil in the container so that both the heaters are completely immersed in it.
3. Connect all the connections carefully and tightly.
4. Do not touch the water or terminal points after putting the switch in the on position.
5. Wait for sufficient time in to achieve the steady state.
6. After the attainment of steady state condition take necessary readings.

RESULTS:

Plot to be shown: Experimental LMTD Vs water flow rate.

DISCUSSION:

Theoritical LMTD and Experimental LMTD

REFERENCES:

1. W. M. Rohsenow, J. P. Hartnett, and E. N. Ganic, 1985, *"Handbook of Heat Transfer Applications",* McGraw Hill, New York
2. Refer: Frank P. Incopera, 2007., "Fundamentals of Heat and Mass Transfer" pp. 150.
3. Refer: https://en.wikipedia.org/wiki/Rotameter
4. Refer: https://en.wikipedia.org/wiki/List_of_thermal_conductivities