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Heat transfer through fabricated coil type shell in tube heat exchanger

Surakasi Raviteja
ravitejasurakasi@gmail.com
Avanthi Institute of Engineering and Technology, Makavarapalem, Narsipatnam

Gondesi Satya Mahesh Reddy
gsmahesh316@gmail.com
Avanthi Institute of Engineering and Technology, Makavarapalem, Narsipatnam

Raghavendra Santhosh
santoshnani76@gmail.com
Avanthi Institute of Engineering and Technology, Makavarapalem, Narsipatnam

ABSTRACT

Heat transfer enhancement due to the helically coiled heat exchanger is a burning topic in the field of research. But so far, there is no experimental or theoretical analysis of a helically coiled heat exchanger considering fluid-to-fluid heat transfer published, hence intending our work on this subject by using Methanol in water solution as a cold fluid. Methanol (also known as methyl alcohol, carbonyl, wood alcohol, wood naphtha or wood spirits) is a chemical compound with chemical formula CH_3OH. It is the simplest alcohol and is a light, volatile, colourless, flammable, poisonous liquid with a distinctive odour that is somewhat milder and sweeter than ethanol (ethyl alcohol). At room temperature, it is a polar solvent and is used as antifreeze, solvent, and as a denaturant for ethyl alcohol. The Methanol, when prepared a solution with water, can be used as a coolant in the Heat Exchanger (Helically Coiled Heat Exchanger in our case) to take advantage of their improved heat transfer properties which would result in enhanced heat transfer in the helical coil heat exchanger. For this purpose, a solution was prepared with varying proportion of Methanol in water. We used four concentrations of 5%, 10%, 15% and 20% of methanol by volume in 5 litres of water. Water is Polar and Methanol as well. So, when we put methanol in water it gets dissolved and producing intermolecular forces i.e. hydrogen bonding. Various properties such as pH, Electrical Conductivity, Thermal Conductivity, boiling point etc. were tested.

Keywords— *Helical coil heat exchanger, pH thermal conductivity*

1. INTRODUCTION

1.1 Heat exchangers

Heat Exchangers are devices in which heat is transferred between two fluids at different temperatures without any mixing of the fluids. There are two fluids, one is hotter than the other, and they are at different temperatures. Heat is transferred from the hot fluid to the cold fluid; a device in which this happens is called a heat exchanger. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air conditioning systems in a household to chemical processing and power production in large plants.

1.1.1 Applications and uses: The simple design of a shell and tube heat exchanger makes it an ideal cooling solution for a wide variety of applications. One of the most common applications is the cooling of hydraulic fluid and oil in engines, transmissions and hydraulic power packs. With the right choice of materials, they can also be used to cool or heat other mediums, such as swimming pool water or charge air.

1.2. Helically coiled heat exchangers (Shell and tube type)

Process heat transfer with conventional shell and tube heat exchangers is familiar to many engineers in many industries. Their use and performance are well-documented. Helically coiled heat exchangers, although they have been around for many years, are not as well known.

Although various configurations are available, the basic and most common design consists of a helically coiled tube. The tube ends are connected to manifolds, which act as fluid entry and exit locations. The tube bundle is constructed of a number of tubes stacked atop each other, and the entire bundle is placed inside a casing or shell

1.2.1 Advantages offered by helical coil heat exchanger

- Compact size provides a distinct benefit.
- Higher film coefficients (the rate at which heat is transferred through a wall from one fluid to another)

- More effective use of available pressure drop results in inefficient and less-expensive designs.
- True counter-current flow fully utilizes available LMTD (logarithmic mean temperature difference).

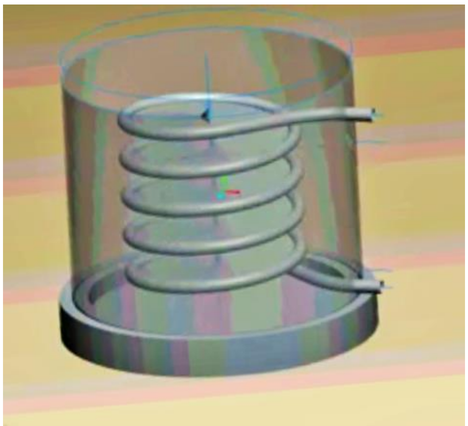

Fig 1: Helical coiled heat exchanger

1.3 Methanol as coolant in heat exchanger

Methanol (also known as methyl alcohol, carbonyl, wood alcohol, wood naphtha or wood spirits) is a chemical compound with chemical formula CH_3OH. It is the simplest alcohol and is a light, volatile, colourless, flammable, poisonous liquid with a distinctive odour that is somewhat milder and sweeter than ethanol (ethyl alcohol). At room temperature, it is a polar solvent and is used as an antifreeze, solvent, fuel, and as a denaturant for ethyl alcohol. It is not popular for machinery but may be found in automotive windshield washer fluid, de-icers, and gasoline additives

1.4 Ethanol as coolant in heat exchanger

Ethanol, also called alcohol, ethyl alcohol, and drinking alcohol, is a chemical compound, a simple alcohol with the chemical formula C_2H_5OH. Its formula can be written also as $CH_3{-}CH_2{-}OH$ or $C_2H_5{-}OH$ (an ethyl group linked to a hydroxyl group) and is often abbreviated as EtOH. Ethanol is a volatile, flammable, colourless liquid with a slight characteristic odour. It is a substance and is the principal type of alcohol found in alcoholic drinks.

2. LITERATURE REVIEW

In the paper presented by Ramchandra K.Patil- Industrial Equipment Co; B.W. Shende- Polychem Ltd; And Prasanta K. Ghosh-Hindustan Antibiotics Ltd. it states that where the pressure drop of one fluid is limited, by setting the velocity of the annulus fluid in an HCHE at about 1m/s, the pressure drop will be low.

While the heat transfer characteristics of double pipe helical heat exchangers are available in the literature, there exists very few published experimental or theoretical analysis of a helically coiled heat exchanger considering fluid-to-fluid heat transfer, which is the subject of the paper “Experimental and CFD estimation of heat transfer in helically coiled heat exchangers” presented by J.S. Jayakumar, S.M. Mahajani, J.C. Mandal, P.K. Vijayan, RohidasBhoi.

The performance of the residual heat removal system, which uses a helically coiled heat exchanger, for various process parameters was investigated by Jayakumar and Grover (1997). The work had been extended to find out the stability of operation of such a system when the barge on which it is mounted is moving (Jayakumar, 1999; Jayakumar et al., 2002).

Heat transfer and flow through a curved tube are comprehensively first reviewed by Berger et al. (1983) and subsequently by Shah and Joshi (1987). The latest review of flow and heat transfer characteristics is provided by Naphon&Wongwises (2006).

3. FABRICATION OF HELICALLY COILED HEAT EXCHANGER

3.1 Selection of material for helical tube

For a better heat exchange from the tube in shell and tube type or helical coil type heat exchanger, the tube material should have good thermal conductivity. The material that we have used for the helical coil is Copper. Copper has the best thermal conductivity property after silver.

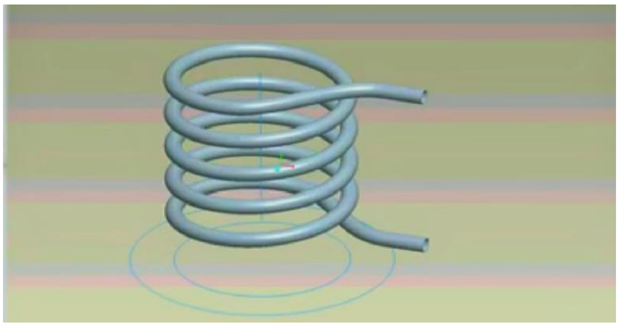

Fig. 2: Design of Helical Coil

3.2 Fabrication of heat exchanger parts by parts

3.2.1 Specifications and construction of helical coil

- The pipe has an inner diameter of 0.8cm
- The coil diameter is 18cm
- The distance between two adjacent turns is called pitch which is of 2cm
- The number of turns made to the coil is 6
- The material used for the making of the helical coil is copper

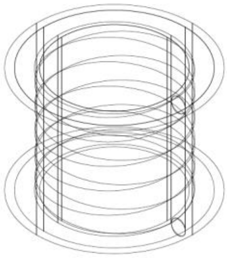

Fig 3: Wire frame design of helical coil

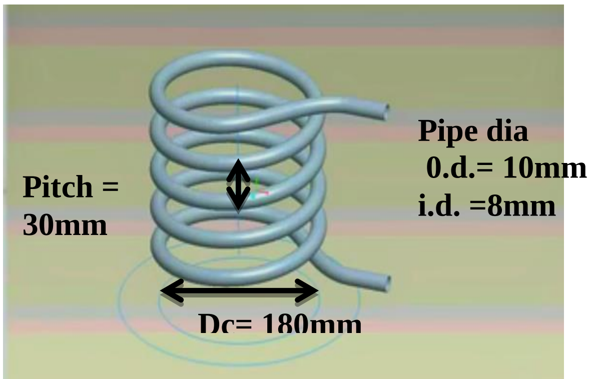

Fig. 4: Dimensions of helical coil

3.2.2 Specifications and construction of cylinders

Inner cylinder

(a) The inner cylinder is of dimensions 30*16cm.
(b) The material used for the making of the inner cylinder is a combination of galvanised iron sheet and mild steel.
(c) The sheet is rolled to the required dimensions and the edges of the cylinder are brazed to prevent leakage of water into the inner cylinder.
(d) Saw dust is used as insulating material and is poured in the inner cylinder.
(e) The top and bottom of inner cylinder are completely closed by using brazing operation.
(f) The inner cylinder is placed in between the helical coil.

Fig. 5: Inner cylinder filled with sawdust

Outer cylinder

(a) The outer cylinder is of dimensions 30*20cm
(b) The material used for making outer cylinder is also a combination of galvanised iron sheet and mild steel
(c) The sheet is rolled to the required dimensions and the edges of the cylinder are brazed to prevent leakage of water outside of the cylinder
(d) The coil is held inside the outer cylinder from a height of 6cm from top and bottom by the means of hooks which are provided inside the cylinder so that the coil stands on the hooks
(e) Inlet and outlet are provided to the cylinder at a height of 3cm from the top and other at a height of 3cm from the bottom
(f) These inlet and outlet are provided to allow the passage of hot water inside the cylinder
(g) The coil is also provided with inlet and outlet to allow cold water to flow inside the coil
(h) Gate valves are provided to the inlets and outlets of the cylinder to regulate the flow inside the coil and cylinder

Fig. 6: Outer and inner cylinder

Fig. 7: Coil inside the outer cylinder

3.3 Assembly of the setup

All the above-mentioned parts were assembled together and few of other components were also added as a supporting part, which facilitated the ease in conducting the practical experiment.

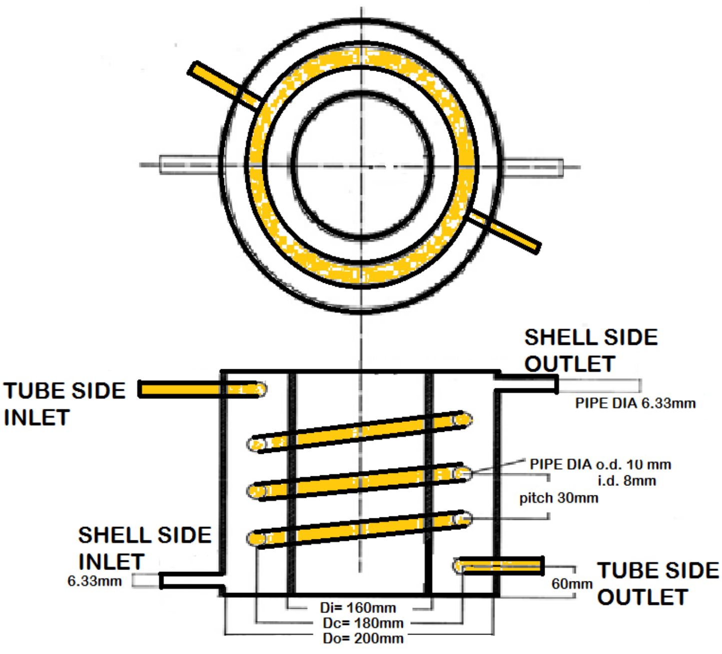

Fig. 8: Sectional view of heat exchanger

Fig. 9: The outlook of HC heat exchanger

The supplementary components are as listed below.

(a) Heater: A heater is an object that emits heat or causes another body to achieve a higher temperature. In a household or domestic setting, heaters are usually appliances whose purpose is to generate heating (i.e. warmth). Other types of heaters are Ovens and Furnaces.

Fig 10: Heater

(b) Submersible pump: A submersible pump (or sub pump, electric submersible pump (ESP) is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump cavitation, Submersible pumps push fluid to the surface as opposed to jet pumps having to pull fluids. Submersibles are more efficient than jet pumps.

Fig. 11: Submersible pump

(c) Laboratory Thermometer: It is the tool used in laboratories to measure temperature with high accuracy. It can be partially or fully immersed in the substance being measured.

Fig. 12: Laboratory thermometer

3.4 Assembly of setup

All the components mentioned above were assembled together as shown below. A tank with an electrical heater is provided to heat the water to be circulated through the shell. The total power of the heater is 1000W. A controller is provided to maintain the temperature of water at the inlet of the test section at the set value. The hot fluid from the tank is pumped through the test section using a submersible pump of 18W and pumping height of 6 ft. The flow rate of the hot fluid is measured manually using a measuring jar. Both inlet and outlet temperatures of the hot fluid are measured by using temperature sensors and the values are available on digital displays. Cooling water from a constant temperature tank is circulated through the tube. Its flow rate, Let and outlet temperatures are measured.

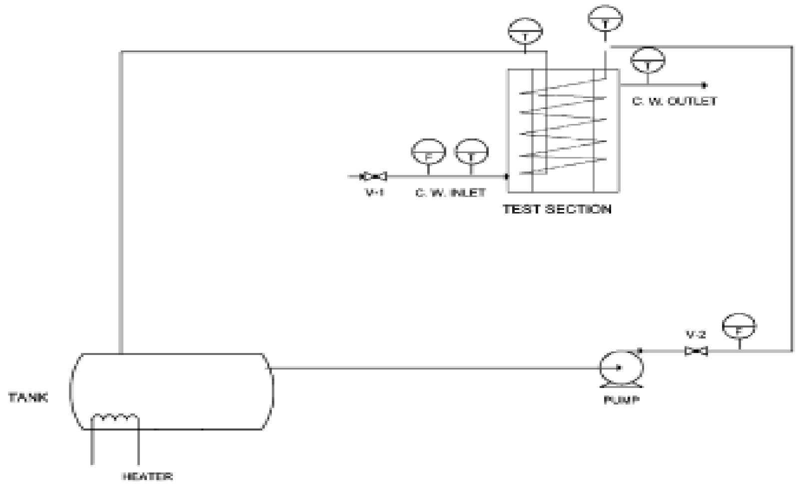

Fig. 13: Line diagram of experimental setup

Fig. 14: Actual experimental setup

4. PREPARATION OF SOLUTIONS

4.1. Preparation of water-water solution

As water is polar solvent 1000 ml of cold water and 1000 ml of hot water are injected into the helically coiled heat exchanger and the values are noted and the rate of heat exchange is calculated.

4.2. Preparation of methanol-water and ethanol-water solution

A solution of Methanol in Water: The Methanol and Ethanol, when prepared a solution with water, can be used as a coolant in the Heat Exchanger (Helically Coiled Heat Exchanger in our case) to take advantage of their improved heat transfer properties which would result in enhanced heat transfer in the helical coil heat exchanger. This is a low-cost antifreeze solution, finding use in refrigeration services and ground source heat pumps. Similar to glycols, this can be inhibited to stop corrosion. This fluid can be used down to -40°C owing to its relatively high rate of heat transfer in this temperature range. Its main disadvantages as a heat transfer fluid are its toxicological considerations. It is considered more harmful than ethylene glycol and consequently has found use only for process applications located outdoors. Also, methanol is a flammable liquid and, as such, introduces a potential fire hazard where it is stored, handled, or used.

4.2.1 Amount of methanol and ethanol added by volume in water: Various concentration of the methanol-water solution was prepared for comparing the thermal properties. We prepared four different concentrations of 25%, 50%, 75% and 100% of methanol by volume in 1 litre of water.

4.2.2 Method of preparation of the solution: Water is Polar and Methanol, Ethanol as well. So, when we put methanol in water it gets dissolved and producing intermolecular forces i.e. hydrogen bonding. Hence it is quite easy to prepare a methanol-water solution, by just pouring the right amount of methanol in water and stirring it gently prepares the solution of our interest.

5. .EXPERIMENT ON THE HELICALLY COILED HEAT EXCHANGER

5.1. Experimental procedure

The present investigation aims at improving the efficiency of a helical heat exchanger using a mixture of water and ethylene glycol solution. It also aims to check the effects of the concentration of methanol in water as a coolant solution.

Steps to follow

Step 1: Initially, the heater is turned on and we wait till the temperature of the hot water reaches 52°C. The RELAY circuit has a temperature controller which is configured so that the maximum temperature of the hot fluid is 52°C. So, if the fluid in the hot reservoir reaches 52°C then the heater circuit is cut off.

Step 2: After the required temperature is attained, the pump in the hot fluid reservoir is turned on and allowed to fill the shell and it waits till it gets filled. As soon as the hot water starts flowing from the top valve, the pump in the cold reservoir is turned on.

Step 3: There are four thermocouples provided at inlet and outlet of hot fluid and also at inlet and outlet off cold fluid.

Step 4: Now the temperatures at inlets and outlets are measured using thermocouples and their values are displayed on the digital display of RELAY circuit temperature controller. This is done with the help of connection of the thermocouple to that controller so at the required point we get the reading of temperature.

Step 5: In this way, the experiment is conducted by adding a different concentration of methanol at different stages in water. At every stage, the temperature is recorded

Step 6: The temperature difference in four different concentrations of methanol in water was noted on the table below.

LET

T_{hi}= Hot fluid inlet temp.
T_{ho}= Hot fluid outlet temp.
T_{ci}= Cold fluid inlet temp.
T_{co}= Cold fluid outlet temp.

Solution		T_{hi} (℃)	T_{ho} (℃)	T_{ci} (℃)	T_{co} (℃)
Hot medium	**Cold medium**				
Water (1000ml)	Water (1000ml)	55	48	30	33
Ethanol (25% sol)	Water (1000ml)	56	45	30	33
Ethanol (50% sol)	Water (1000ml)	56	48	30	36
Ethanol (75% sol)	Water (1000ml)	56	50	30	31
Methanol (25% sol)	Water (1000ml)	56	53	30	31
Methanol (50% sol)	Water (1000ml)	56	50	30	31
Methanol (75% sol)	Water (1000ml)	56	49	30	31
Methanol (100% sol)	Water (1000ml)	56	48	30	31

5.2 Observations

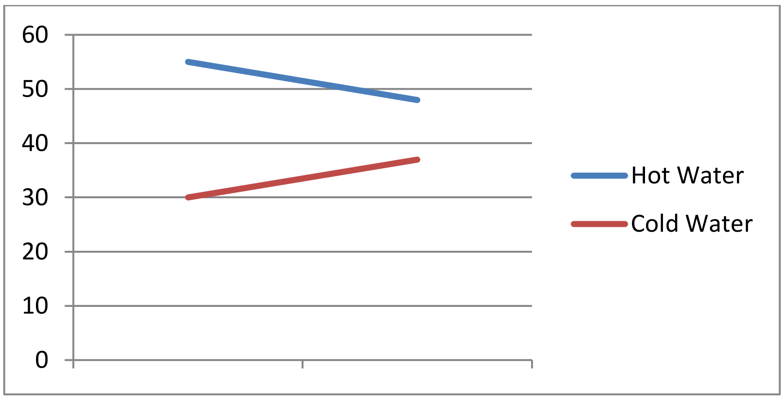

Fig. 15: LMTD graph for just water as both cold and hot fluid (Y- axis as Temperature in ^{0}C)

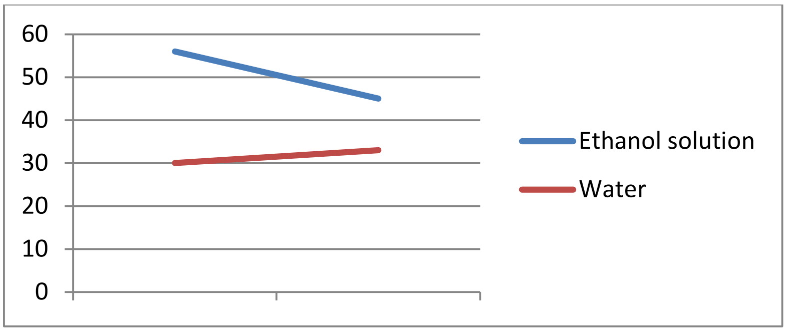

Fig. 16: Temperature change in 25% Ethanol as hot fluid and water as the cold fluid

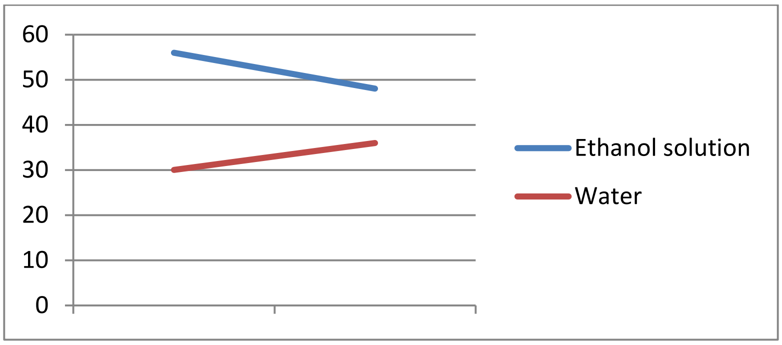

Fig. 17: Temperature change in 50% Ethanol as hot fluid and water as the cold fluid

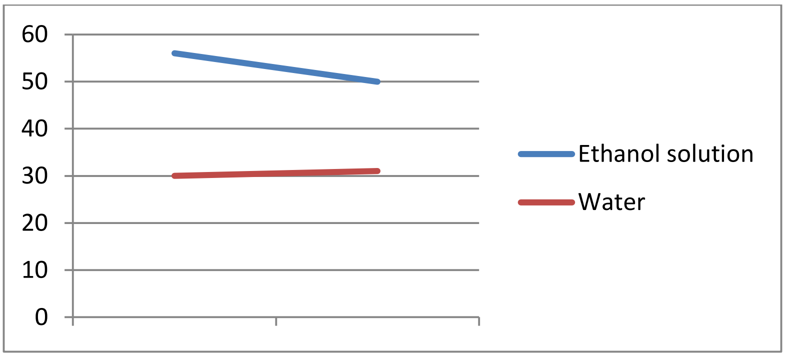

Fig 18: Temperature change in 75% Ethanol as hot fluid and water as the cold fluid

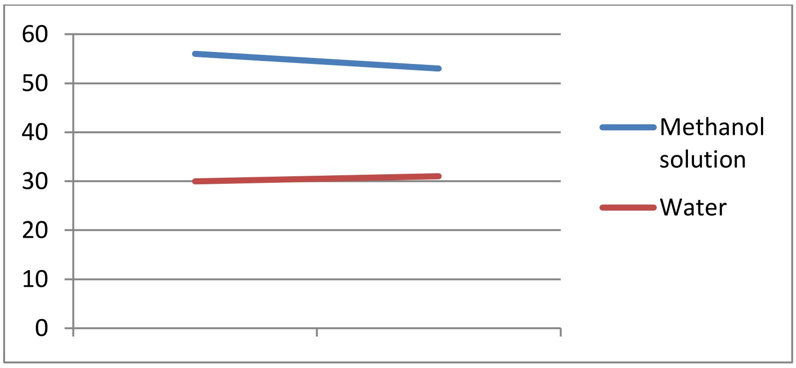

Fig. 19: Temperature change in 25% Methanol as hot fluid and water as the cold fluid

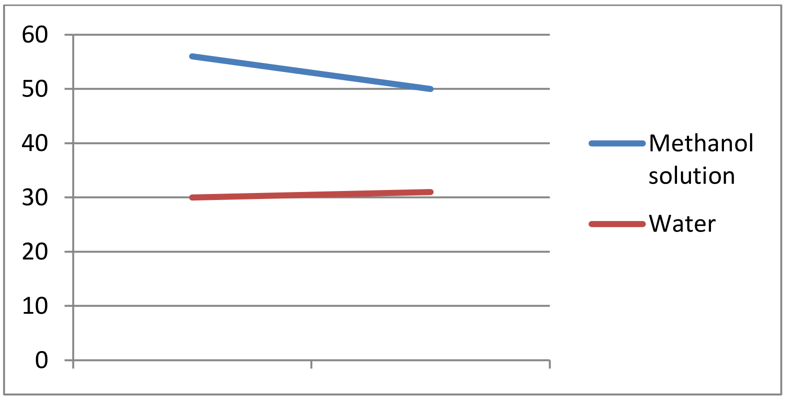

Fig. 20: Temperature change in 50% Methanol as hot fluid and water as the cold fluid

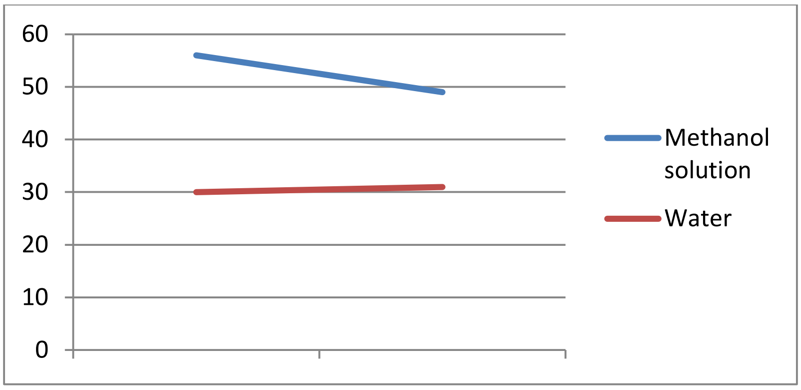

Fig. 21: Temperature change in 75% Methanol as hot fluid and water as the cold fluid

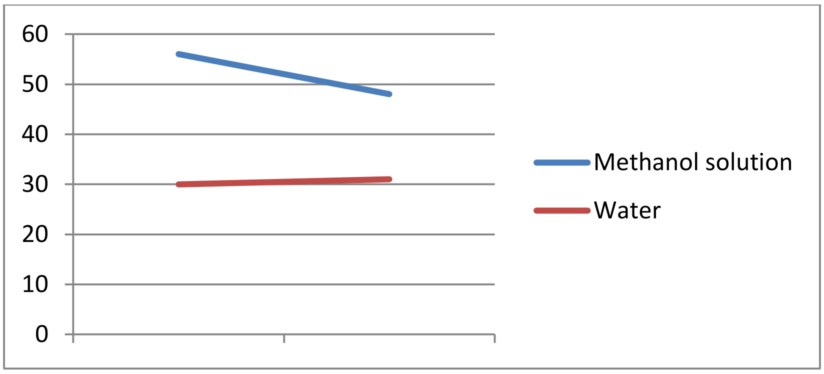

Fig. 22: Temperature change in 100% Methanol as hot fluid and water as the cold fluid

5.3 Formulae

LMTD for counter flow heat exchanger

$$\text{LMTD} = \frac{\Delta Ta - \Delta Tb}{ln(\frac{\Delta Ta}{\Delta Tb})}$$

For counter current flow:

$$\Delta T_a = T_{hi} - T_{co}$$
$$\Delta T_b = T_{ho} - T_{ci}$$

Where,

T_{hi}= Hot fluid inlet temp, T_{ho}= Hot fluid outlet temp, T_{ci}= Cold fluid inlet temp, T_{co}= Cold fluid outlet temp.

$$U = \frac{Q}{A \times LMTD} \text{W/m}^2 - \text{K}$$

Where,

Q = Heat flow rate (W)

A = Area of Heat flow rate (m^2)

Table 1

	Water + water	%Ethanol+ Water			%Methanol+ Water			
		25%	50%	75%	25%	50%	75%	100%
A	1	1	1	1	1	1	1	1
B	1	1	1	1	1	1	1	1
C	1	0.947	0.894	0.841	0.945	0.896	0.844	0.792
D	1	1	1	1	1	1	1	1
E	1	0.947	0.894	0.841	0.945	0.896	0.844	0.792
F	1	1	1	1	1	1	1	1
G	55	56	56	56	56	56	56	56
H	48	45	48	50	53	50	49	48
I	30	30	30	30	30	30	30	30
J	33	33	36	31	31	31	31	31
K	4.18	2.46	2.46	2.46	2.51	2.51	2.51	2.51
L	4.18	4.18	4.18	4.18	4.18	4.18	4.18	4.18
M	19.93	18.72	18.98	22.41	23.99	22.41	21.86	21.31
N	2.701	2.875	2.836	2.402	2.244	2.402	2.462	2.526

Where,

A. The flow rate of oil (L.P.M)
B. The flow rate of water (L.P.M)
C. The density of water (hot) (g/cm^3)
D. The density of water (cold) (g/cm^3)
E. Mass of water (hot) (g)
F. Mass of water (cold) (g)
G. The inlet temperature of hot water (T_{hi}) (J)
H. The outlet temperature of hot water (T_{ho}) (J)
I. The inlet temperature of cold water (T_{ci}) (J)
J. The outlet temperature of cold water (T_{co}) (J)
K. Specific heat of methanol (J/℃)
L. Specific heat of water (J/℃)
M. Logarithmic Mean Temperature Difference (LMTD)
N. Overall heat transfer coefficient (W/m^2-K)

6. CONCLUSION

It is clearly evident that as we increase the concentration of methanol in water the heat transfer capacity enhances, hence it is recommended that despite changing the design and construction of the heat exchanger we should start concentrating on the cooling fluid. Methanol, as in our case, showed a satisfactory result by improving the effectiveness of the helically coiled heat exchanger.

7. FUTURE SCOPE OF WORK

It was clearly evident that not only by changing the design of heat exchanger but also by changing the cooling fluid can drastically increase the heat transfer capability of a heat exchanger (helically coiled heat exchanger in our case). As methanol increased the thermal performance of helically coiled heat exchanger, the heat transfer can be further improved, by adding additives to that, which reduces the chances of corrosion due to the use of methanol.

But as the physical property of methanol does not allow the use of higher concentration of it in the heat exchanger, because it is poisonous in nature, so other coolants such as Ethylene Glycol, Propylene Glycol etc. can also be used.

The use of Nano fluids may prove to be a better option when it comes to heat transfer enhancement properties. Further, the experiment can be conducted on the Nano fluid such as Al_2O_3 and silver Nano fluids

Better exchange of heat in the helically coiled heat exchanger at a higher temperature, and hence can be tested at a higher temperature in future.

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BIOGRAPHY

Surakasi Raviteja
Assistant professor
Department of mechanical engineering
Avanthi Institute of Engineering and Technology, Makavarapalem, Narsipatnam

Talabathula Sankar Raghavendra Santhosh
Student
Mechanical engineering
Avanthi Institute of Engineering and Technology, Makavarapalem, Narsipatnam