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Analysis of Heat Exchanger with Nanofluids

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Abstract - Heat Exchanger has become an essential component of almost every modern industry; in the time when resources are limited and there is tough competition in the market heat exchanger marks special importance.

In this paper the thermal performance analysis of a counter flow heat exchanger is performed by varying the composition of nanofluids used, which is a mixture of coolant and iron particles. An experimental analysis has been performed on counter flow heat exchanger. The volume fraction of coolant varies from 0-2.0% by mass. Experimental results such as heat transfer rates, overall heat transfer coefficient, and heat exchanger effectiveness have been calculated to assessing the performance of heat exchanger. The objective of this project is too determined whether the use of Nanofluids improves the heat exchangers performances and at what percentage of Nanoparticles-coolant mixture the performance of counter flow heat exchanger obtain maximum heat exchange rate and at what percentage deteriorates.

Keywords: Counter Flow Heat exchanger, nanofluids, iron powder, exchanger efficiency &performance.

I. INTRODUCTION

A heat exchanger is the equipment built to efficiently transfer heat from one medium to another without actually mixing the two. The two media may be separated one and another by a solid conducting structure to prevent mixing the two. It is widely used in appliances such as air conditioning, refrigeration, power plants, chemical plants, space heating, natural gas processing, petrochemical plants, petroleum refineries and sewage treatment. The ultimate example of a heat exchanger is found in an internal combustion engine in which a fluid known as engine coolant flows through radiator coils and air flows which past the coils cools the coolant and heats the incoming air.

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other.

Heat exchangers are commonly used in practice in a wide variety of applications, from air conditioning systems in a house to power production applications in large plants

A. Daily life examples of heat exchanger

The various examples of heat exchangers from our daily life are

1. Milk chillers of pasteurizing plant
2. Oil coolers of heat engines
3. Automobile radiators
4. Regenerators
5. Condensers and evaporators in refrigeration plants
6. Condensers and boilers in steam plants
7. Intercoolers and preheaters

In an automobile, fuel and air produce power within the engine through combustion. Only a portion of the generated power actually supplies the automobile with power- the rest is wasted in the form of exhaust and heat. if the excess heat is not removed, the engine temperature becomes too warm which results in overheating and viscosity breakdown of lubricant oil, metal weakening of the overheating engine parts resulting in quicker wear , among other things.

B. Heat Exchanger Classification

Due to the large number of heat exchanger configurations, a classification system was devised based upon the basic operation, construction, heat transfer, and flow arrangements. The following classifications are outlined by J.L. Kakac and Liu in 1998 are:

- Recuperates and regenerators
- Transfer processes; indirect contact or direct contact
- Geometry of construction; plates, tubes and extended surfaces
- Heat transfer mechanism; single phase or two phase flow
- Flow Arrangement; counter flow, parallel flow or cross flow

With the new technology emerging and the systems are becoming more and more compact there is also the need for improvement in the performance and efficiency of the heat exchanger device. The rate of heat exchange is to be increased with many constrains in the path to archive so. There are design constrains, the space is limited, parameters can hardly changed. Then there is material that can help to increase or decrease the heat transfer rate and performance but here also the variable options are limited, as we need strength endurance and reliability too along with the high heat transfer rate. So the parameters left here is the working fluid. Therefore in this report the performance of the heat exchanger is measured by changing the working fluid type. Instead of using the simple working fluid, we have used a special blend of working fluid which contains the iron Nanoparticles circulating along the flow of the fluid. And a study is being done on it. In the past few years the Nanoparticles have come up as a wide possible scope in various fields. In heat exchangers too these are been used. The Nanoparticles of aluminum is been used to decrease the fluids mass flow rate [12] and other such experiments are been conducted too.

C. Methods of heat exchanger analysis

1) *LMTD Method*

The log mean temperature difference (LMTD) is derived in all basic heat transfer texts. It may be written for a parallel flow or counter flow arrangement.

The LMTD has the form:

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \Delta T_2 \Delta T_1}$$

Where,

ΔT_1 and ΔT_2 represent the temperature difference at each end of the heat exchanger, whether parallel flow or counter flow.

The LMTD expression assumes that the overall heat transfer coefficient is constant along the entire flow length of the heat exchanger. If it is not, then an incremental analysis of the heat exchanger is required. The LMTD method is also applicable to cross flow arrangements when used with the cross flow correction factor. The heat transfer rate for a cross flow heat exchanger may be written as:

$$Q = F\ UA\ \Delta T_{LMTD}$$

Where, the factor F is a correction factor, and the log mean temperature deference is based upon the counter flow heat exchanger arrangement. The LMTD method assumes that both inlet and outlet temperatures are known. When this is not the case, the solution to a heat exchanger problem becomes more difficult. And this method becomes less appropriate to find the efficiency of exchanger alternate method based upon heat exchanger electiveness is used for the analysis. If ΔT1 = ΔT2 = ΔT, then the expression for the LMTD reduces simply to ΔT.

NTU Method The effectiveness / number of transfer units (NTU) method was developed to simplify a number of heat exchanger design problems. The heat exchanger effectiveness is defined as the ratio of the actual heat transfer rate to the maximum possible heat transfer rate if there were infinite surface area. The heat exchanger effectiveness depends upon whether the hot fluid or cold fluid is a minimum heat capacity fluid. That is it the fluid which has the lower heat capacity coefficient C =m.Cp. If the cold fluid is the minimum heat capacity fluid then the effectiveness is defined as:

$$E = C_{max}\ (T_{hi} - T_{ho})/C_{min}\ (T_{hi} - T_{ci})$$

Otherwise, if the hot fluid is the minimum heat capacity fluid, then the effectiveness of heat exchanger is defined as:

$$E = C_{max}\ (T_{co} - T_{ci})/C_{min}\ (T_{hi} - T_{ci})$$

We may now define the heat transfer rate as:

$$Q = E C_{min}\ (T_{hi} - T_{ci})$$

With these relations and equations we are now able develop expressions which can relate the heat exchanger effectiveness (E) to another parameter such as the Number of Transfer Units (NTU).

2) *NTU Method*

The Number of Transfer Units (NTU) Method is used to calculate the rate of heat transfer in heat exchangers (especially counter current exchangers) when there is insufficient information to calculate the Log Mean Temperature Difference (LMTD). In heat exchanger analysis, if the fluid inlet and outlet temperatures are specified or can be determined by simple energy balance equation, the use of LMTD method is possible; but when these temperatures are not available The NTU or The Effectiveness method is used.

To define the effectiveness of a heat exchanger we need to find the maximum possible heat transfer that can be hypothetically achieved in a counter-flow heat exchanger of infinite length. Hence one of the fluids will be experiencing the maximum possible temperature difference, which is the difference of $(T_{hi} - T_{ci})$ (The temperature difference between the inlet temperature of the hot stream and the inlet temperature of the cold stream). Then the method proceeds to calculate the heat capacity rates (i.e. mass flow rate (m) multiplied by specific heat) C_h and C_c for the hot and cold fluids respectively, and denoting the smaller one as C_{min}

A quantity

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

is then found, where Q_{max} is the maximum heat that is transferred between the fluids. C_{min} is the lowest heat capacity of the fluid which helps to determine the maximum possible heat transfer in a hypothetically infinite length exchanger, actually temperature change of the other fluid would change more slowly along the heat exchanger length, and it would never actually reach the inlet temperature of the other fluid. The method used at this point is concerned only with the fluid that undergoes the maximum change in temperature.

The *effectiveness (E)*, is the ratio between the actual heat transfer rate and the maximum possible heat transfer rate:

$$E = Q_{act}\ / Q_{max}$$

Where:

$$Q = C_h\ (T_{ho} - T_{hi}) = C_c\ (T_{co} - T_{ci})$$

Effectiveness is dimensionless quantity which lies between 0 and 1. If E is known for a particular heat exchanger, and we know the inlet and outlet conditions of the two flow streams we can calculate the amount of heat being transferred between the fluids by:

$$Q_{act} = E\ C_{min}\ (T_{hi} - T_{ci})$$

For any heat exchanger efficiency, E can be shown as:

$$E = \int (NTU, C_{min}\ / C_{max})$$

For a given geometry, E can be calculated using correlations in terms of the "heat capacity ratio"

$$R = C_{min}\ / C_{max}$$

And the *number of transfer units*, NTU

$$NTU = UA / C_{min}$$

Where, U is the overall heat transfer coefficient and Ais the heat transfer area.
For example, the effectiveness of a parallel flow heat exchanger is calculated with:

$$E = \frac{1 - \exp\ [-NTU\ \ (1+R)\ ]}{1+R}$$

Also, the effectiveness of a counter flow heat exchanger can be calculated with expression:

$$E=\frac{1-\exp\ [-NTU\ \ 1-R\ ]}{1-R\ \exp\ [\ -NTU\ \ 1-R\ ]}$$

For R=1

$$E=NTU/\ (1+NTU)$$

Similar effectiveness relationships can be derived for concentric shell & tube heat exchanger and for other types of heat exchangers. These expressions are differentiated from one to another depending on the various parameters and specifications such as

a) flow type of the heat exchanger like parallel counter or cross one,
b) Number of passes of tubes
c) Type of flow stream i.e. mixed type or unmixed type.

Note that the C_r =0 is a special case in which phase change condensation or evaporation is occurring in the heat exchanger. Here in this special case the heat exchanger's behaviour is independent of the flow arrangement of heat exchanger. Hence the effectiveness is given by:

$$E=1-\exp\ [-NTU]$$

II. METHODOLOGY DEVELOPMENT

The configuration of counter heat exchanger used in analysis is the lab based heat exchanger in which the water is used as cold fluid and oil iron particles mixture is used as hot fluid. The governing equations presented in these sections are those developed for a counter flow heat exchanger. These basic equation are applied for the numerical methodology assuming that fluid is flow one dimensional and unsteady, there is no phase change in exchanger and axial conduction of fluid are neglected. It is considered that the fluid in the tube is perfectly mixed in the tube cross section and external fluid is perfectly unmixed. The energy balance equation for hot and cold fluid is written as

$$dQ = q.\ dA = -C_h\ \Delta T_h\ = -\ C_c\ \Delta T_c$$

The negative sign in this equation are a result of T_h & T_c decreasing with A (these temperature decreases with increases flow length). Also, dQ is heat transfer rate from hot fluid to cold fluid. In general for any isobaric change of state equation should be replaced by

$$dQ= -w\ dh_h = -w\ dh_c$$

Here if the change of state takes place then enthalpy differences is replaced by enthalpies of phase changes which is either enthalpy of evaporation or enthalpy of condensation of the coolant. Here the overall heat transfer rate equation on differential base for a small surface area dA will be given as

$$dQ = U\ (T_h - T_c\ )\ \text{local}\ dA = U\ \Delta T\ da$$

Integrating equations together over the entire heat exchanger surface for specified inlet temperature will result in an expression that will relate all important operating variables and geometric parameter of heat exchanger.

$$Q = \int C\ dT =\ \ C_h\ \ (T_{ho} - T_{hi}\ \ ) = C_c\ \ (T_{co} - T_{ci}\ \ )$$

$$q = \int U.\ \Delta T.\ dA = U.\ A_m . \Delta T_m$$

Numerical solution methodology

The proposed work is based on the governing equations used in this paper. First the mass flow rate and the temperature is measured with the help of oil flow meter and thermocouple respectively. Also find the temperature of oil particles mixture at the inlet and outlet of the heat exchanger. Now, by varying the volume fraction of coolant in mixture determine the parameters again. Now repeat the experiment until the iron particles concentration reaches up to 20% of the total oil particles mixture

S no.	ratio	Hot fluid (oil) (k)		Cold fluid (water) (k)		R	Q_{act}	ε(%)
		T_{Hi}	T_{Ho}	T_{Ci}	T_{Co}			
1	0	120	99	25	35	.47	10.4	22.10
2	.5	120	98.5	25	36	.51	11.4	22.63
3	1.0	120	98.1	25	36.4	.52	11.9	23.05
4	1.5	120	97.5	25	37.1	.53	12.6	23.68
5	2.0	120	98	25	36.5	.52	12.0	23.1

In case of limited access to experimental equipment and related references, we can utilized ε-NTU method to compare the numerical solutions obtained in steady state with the results of this analytical method. The effectiveness (E) of a heat exchanger is defined as the ratio of the actual heat transfer to the maximum heat transfer that could be theoretically obtained in the heat exchanger without any size limitations. The maximum rate heat transfer rate can be expressed by

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

The effectiveness of heat exchanger is given by-

$$E = Q_{act}\ / Q_{max}$$

Where, Q_{act} is the actual heat transfer rate in the heat exchanger Therefore, for a known value of the effectiveness of a heat exchanger, the actual heat transfer can be determined as follows

$$Q_{act} = E\ C_{min}\ (T_{hi} - T_{ci})$$

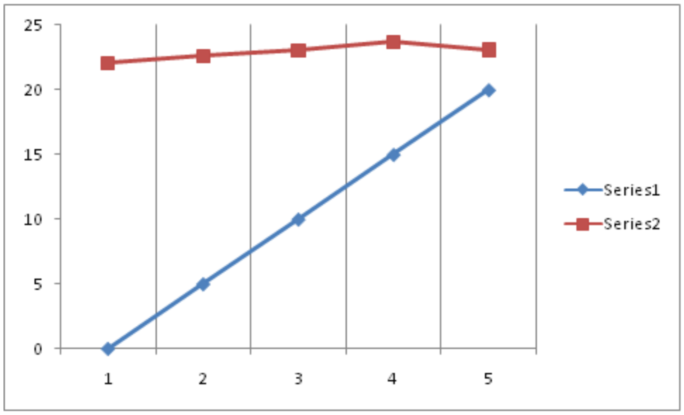
The specification of the iron particles used is that it is fine powdered iron particles of size 7 µm in diameter

The iron particles have high energy absorption and transfer abilities.

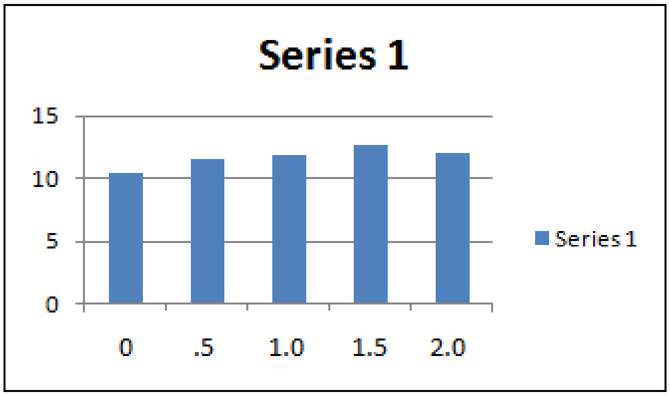
III. RESULT AND DISCUSSION

- During the experiment it was found that the heat transfer rate of the heat exchanger was increased when using the iron particle
- It was seen that for a constant heat transfer rate the mass flow rate of fluids was reduced when using the iron particles mixture
- The overall efficiency of the heat exchanger was more with nanofluids than with normal fluids

Observation Table



Graph 1 Bar graph between efficiency and the mass percent of iron particles (series 1 is ratio & series 2 shows efficiency %)



Graph 2 Graph between the actual heat transfer and mass percent of iron particles

IV. CONCLUSION AND FUTURE SCOPES:

A series of experiments were conducted on a counter flow heat exchanger which was performed by the variation of mass fraction of hot fluid (a mixture of coolant with iron Nanoparticles). The effect of these parameters on outlet temperature and overall heat transfer coefficient and the efficiency of heat exchanger were studied. It was found that when the mass flow rate of cold fluid was increased the outlet temperature of hot fluid was decreased. The heat transfer rate of the heat exchanger increases as the iron particle concentration in the hot fluid was increased, the effectiveness (E) of the heat exchanger also increased but when the concentration exceeds by 1.5% effectiveness decreases because high pumping was required and other circulatory problems.

The use of Nanoparticles other then increasing the efficiency can also serve as clearing the inner unreached part of exchanger by performing as abrasive action, this can be tested on a long run of the heat exchanger. The result on counter flow heat exchanger were positive the same can be tested o other type, shape and size of heat exchangers

V. NOMENCLATURE

Q_{max}	Maximum heat transfer rate
C_{min}	Minimum heat capacity rate
T_{hi}	Inlet temperature of hot fluid
T_{ci}	Inlet temperature of cold fluid
T_{ho}	Outlet temperature of hot fluid
ΔT	Temperature difference
T_{co}	Outlet temperature of cold fluid
ΔT_m	Mean temperature difference
U	Over all heat transfer coefficient
Q_{act}	Actual heat transfer that occurred
A	Area of heat exchanger
A_m	Mean area of heat exchange
NTU	Number of heat transfer units
R	Heat capacity ratio
h	Specific enthalpy

W	Mass flow rate of hot fluid
W	Mass flow rate of cold fluid
E	Heat exchanger efficiency
ΔT_{LMTD}	Log mean temperature difference
ΔT_1	Temperature difference on side 1
ΔT_2	Temperature difference on side 2
c_h	Specific heat capacity of hot fluid
c_c	Specific heat capacity of cold fluid

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