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Enhancement in heat transfer by reducing the diameter of tube in shell and tube heat exchanger

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Abstract:

Heat exchanger is a device which is used to transfer heat between two or more fluids that are at different temperature or in other words heat exchangers are devices which enhance or facilitate the flow of heat and the heat transfer from heat source to heat sink.

Since, their inception there has been a lot of improvement and modification oriented towards performance enhancement and making it an indispensable tool in multifaceted domains of science and technology. ‘Small is Beautiful’ has become a buzz word in the chemical process industry. This has motivated research towards achieving compactness, efficiency and economic viability. The major thrust is into the design of mini and micro heat exchangers which are now in great demand in various chemical process industries including the food industry. Micro channels are of current interest for the use in heat exchanger where very high heat transfer performance is desired. This has provided a new direction in the design of shell and tube heat exchangers.

The present work is an initiation towards gaining fundamental understanding of heat transfer effects in a shell and tube heat exchanger with very small tube diameter. This understanding will be of

paramount importance for designing highly compact and efficient heat exchangers for chemical process industries.

The objective of the present investigation is to study the effect of tube diameter on the heat transfer coefficient of a shell and tube heat exchanger for three fluids namely, Ethylene Glycol, Servotherm Light and Servotherm Medium. Based on the small tube diameter, an affordable micro heat exchanger is constructed for small scale industries where costs play an important role in proper selection of equipments.

Introduction

Due to the current energy crises, research in heat transfer has taken on a new dimension, and efforts are now being made globally to save, recover, use, and generate new energy sources economically.

Hydraulic diameter is used to designate tubes and channels that are smaller than normal tubes and pipes. Mini channels have a hydraulic diameter less than 3mm, whereas regular ducts and tubing have a hydraulic diameter higher than 3mm. The heat transfer area density, or the amount of heat transferred per unit of volume of the exchanger, rises as that of the diameter of the flow channels used in a heat exchanger shrinks [1]. The tube size as well as area density, two connected variables, have an impact on how compacted the heat exchanger is.

Due to improved heat transfer and higher heat flux dissipation, the flow path linked with laminar heat exchangers has now been shrinking in size. High transfer of heat and efficiency can be achieved by using narrower dimensions of the channel, however this is counterbalanced by a greater drop in pressure per unit length of pipe.

Various variables in hydraulic diameter, baffle cut, shelling type, tube pitches, baffle cut, number of tube runs, baffle cut, length of the tube, etc. are among the design choices for tube and shell heat exchangers.

Advantages and Disadvantage of Micro heat exchanger

Large volumes of heat may be transferred using tube and shell heat exchangers, which also offer reliable, reasonably priced designs. They can reduce the need for liquid volume, floor area, as well as weight while still providing significant quantities of functional tube surface. There are several different sizes of tube and shell exchangers. The thermal processes and production techniques are well established and employed by contemporary competitive manufacturers since they are being used in manufacturing for more than 150 years.

The major benefits of shell-and-tube heat exchangers are as follows:

1. The tubes or the shell, in either a horizontal or vertical position, may facilitate the heat transfer for condensation or boiling.
2. A wide variety of pressures and pressure decreases are possible.
3. It is reasonably priced to handle thermal stress concentrations.
4. To address issues with corrosion and other factors, there is a lot of materials plasticity. Various materials can be used to create both the shell as well as the tubes.
5. Fins that extend the heat transfer surface can improve heat transmission.
6. Since the equipment may be disassembled for these tasks, cleaning plus repairs are rather simple.

1. Small diameter tubes gives-

- High heat transfer coefficients
- Low thermal resistance
- High aspect ratios
- Occupy less space.

DISADVANTAGES OF MICRO HEAT EXCHANGER

- High pressure drops
- Complexity in fabrication

Increase in heat exchanger functionality often entails running it at a closer temperatures or with higher duty. The amount of heat recuperation will increase as the temperature gets closer. This restriction causes the coefficient of the total thermal conductivity, U, to rise. The relationship between duty (Q), surface area (A), as well as driving force (T) and the total thermal efficiency.

The following actions should be taken into account when creating a plan to improve heat transfer performances [7] for tube and shell exchangers.

1. Check to see if the exchanger is functioning as it should according to the design.
2. Determine if the pressure decrease is within acceptable bounds.
3. Make sure the fouling variables aren't exaggerated. Exchangers with low velocities are enlarged as a result of excessive fouling factors in the design state. These slow speeds might make the fouling issue worse. Performance improvements for the heat exchanger may be made using more liberal fouling agents and routine cleaning.
4. Take into account employing a straightforward shell-and-tube exchanger that has been enhanced or intensified with fining, tube inserts, altered tubes, or altered baffles.

The current study places special attention on tube heat exchanger with smaller tube diameters in order to make them affordable for small-scale companies, where equipment procurement is highly influenced by equipment prices. The basic objective of a heat exchanger improvement is to always provide a competitive edge over the usage of another heat exchanger.

The experiments have been conducted using Ethylene Glycol, Servotherm Light and Servotherm Medium with different grades. Generally, less viscous fluids generally gives good result as compared to more viscous fluids. This is due to boundary layer thickness, which increases heat transfer resistance results in low heat transfer coefficient. Higher heat transfer rates are affected by thinner boundary layer in developing the region at high Reynolds number.

EXPERIMENT

An experimental investigation is conducted for single-phase flow through micro channels for predicting the thermal behaviour of micro heat exchanger as overall heat transfer coefficient, L.M.T.D, pressure drop.

When conducting an experimental study, it is crucial to take the necessary precautions to determine the Proper Amounts, assess Those Amounts Precisely, and also Most Notably, Conduct the Appropriate Calculations to Analyze the Data. Prior to doing an experimental study, it is crucial to understand which variables need to be quantified. Therefore, a detailed analysis of the physical processes present in the system in issue is required before planning an experimentation.

The experimental setup is includes-

The test section consisting of micro heat

Exchanger, the glass section for flow measurement, a process fluid tank for process fluid, a variable speed centrifugal pump for circulating process fluid and Electronic relay temperature indicator and controller box.

Before running the experiment, one should always check the level of process fluid in hot fluid storage tank by level indicator, otherwise it will not give desired result and moreover it can damage the system. Start the centrifugal pump (TULLU-50) so that process fluid will be in circulation. Allow some time to get steady state condition, and then measure the flow rate in flow meter (glass section) by measuring time required for specified height, marked in the glass section by closing the valve placed at the down of glass section. Once all the above mentioned readings for constant flow rate is noted , change the flow rate, allow some time for system to achieve steady state and take at least 10 different volumetric highest flow rate up to the lowest flow rate.

Experimental approach

The amount of heat lost to the surroundings for the considered configuration must be known in order to build or anticipate the heat exchanger transfer performance [4]. Implementing total energy balancing for cold and hot fluid streams can easily yield characteristics that can be used to calculate the proportion of fluctuations in exchange rates.

Convection correlations may be used to estimate the total heat transfer coefficient, which is computed on the assumption that it is constant throughout the heat exchanger. However, it is useful to have a methodology for estimating the thermal efficiency and heat transfer coefficients or the tube dimensions according with given range of temperature as well as flow configurations when choosing a heat exchanger.
The heat transfer coefficient of process liquid is calculated by assuming that the main resistance to heat transfer is offered by the process liquid. The heat transfer coefficient of water (h_c) was assumed to a very high value (5500 W/m^{2o}C) and the flow rates of cooling water is as high as possible i.e. between 8-12 lit. / min.

$$\frac{1}{h_h} = \frac{1}{U} - \frac{1}{h_c}$$

So by knowing overall heat transfer coefficient (U) and by assuming heat transfer coefficient of cold fluid (h_c), the heat transfer coefficient of hot fluid (h_h) is calculated.

Effect of diameter of tubes on h_h

The objective of the present investigation is to study the effect of tube diameter on the heat transfer coefficient of a shell and tube heat exchanger for three fluids namely, Ethylene Glycol, Servotherm Light and Servotherm Medium with different grades. Thus the present work is an initiation towards gaining fundamental understanding of heat transfer effects in a shell and tube heat exchanger with very small tube diameter. Studies conducted in microchannels [2] and [3] indicate that employing smaller channel dimensions results in high heat transfer performance, although it is accompanied by a higher pressure drop per unit length. Thus, proper balance should be maintained between heat transfer and pressure drop in heat exchanger.

Fig. 1- Assembled Heat Exchanger

In the present content,
Heat exchanger 1 refers to tube diameter 3 mm, Heat exchanger 2 refers to tube diameter 2.4 mm, Heat exchanger 3 refers to tube diameter 1.8 mm.

m (gm/sec.)	$A*\Delta T_{ln}$	$U(W/m^{2o}C)$	h_h $(W/m^{2o}C)$	N_{Re}	NU (Exp)
104.0	1.384	1035.6	1275.8	625.8	10.8
95.7	1.355	992.8	1211.5	575.7	10.3
88.3	1.356	968.5	1175.4	531.2	10.0
82.3	1.341	1066.4	1322.9	495.5	11.2
70.1	1.311	943.6	1139.0	422.1	9.7
60.9	1.298	813.9	955.2	366.2	8.1
46.2	1.255	680.1	776.1	278.1	6.6
37.3	1.239	556.4	619.1	224.6	5.3
31.8	1.166	669.6	762.4	191.6	6.5
21.6	1.116	534.5	592.1	130.2	5.0

Table.1: Summary of results for E.G at 60ºC for H.E-1

Fig. 2- Sets of Heat Exchanger of 3mm, 2.4mm and 1.8mm.

The excerpts of the experimental findings using Ethylene Glycol are tabulated in figure:

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The experimental findings are summarized for Ethylene glycol for all three heat exchangers at 60C in Table 1 to 3.

Table.2: Summary of results for E.G at 60ºC for H.E-2

m (gm/sec.)	$A^*\Delta T_{ln}$	U(W/m^{2o}C)	h_h (W/m^{2o}C)	N_{Re}	NU (Exp)
79.2	1.281	1141.4	1440.3	635.1	9.2
71.2	1.251	1066.4	1322.8	570.9	8.4
63.4	1.252	991.3	1209.3	508.9	7.7
56.3	1.226	935.7	1127.5	451.3	7.2
51.1	1.216	903.0	1080.4	409.8	6.9
43.6	1.206	817.4	960.0	349.8	6.1
35.8	1.201	731.7	844.0	287.5	5.4
31.4	1.183	687.8	786.1	252.1	5.0
24.8	1.142	635.6	718.7	199.4	4.6
22.5	1.109	660.6	750.7	180.8	4.8

E.G.		TEMP	60	ºC	NPR	45.27
m (gm/sec.)	$A^*\Delta T_{ln}$	U(W/m^{2o}C)	h_h (W/m^{2o}C)	N_{Re}	NU (Exp)	
112.9	1.465	849.4	1004.6	543.5	10.7	
107.5	1.435	825.6	971.4	517.4	10.3	
103.8	1.444	812.3	953.0	499.7	10.1	
98.1	1.447	785.2	916.0	472.5	9.7	
90.8	1.420	757.7	878.8	437.0	9.3	
81.1	1.425	705.5	809.3	390.3	8.6	
73.2	1.401	676.7	771.6	352.3	8.2	
64.8	1.385	644.6	730.2	312.0	7.8	
60.0	1.334	632.0	714.1	288.8	7.6	
54.3	1.290	580.5	649.0	261.5	6.9	
42.0	1.293	536.5	594.5	202.0	6.3	
38.1	1.265	522.6	577.5	183.3	6.1	
27.4	1.257	413.8	447.4	131.7	4.8	

Table.3: Summary of results for E.G at 60ºC for H.E-3

The effect of tube diameter on heat transfer coefficient for all three heat exchangers for all three fluids at 60 C is highlighted in figure 3 to 5.

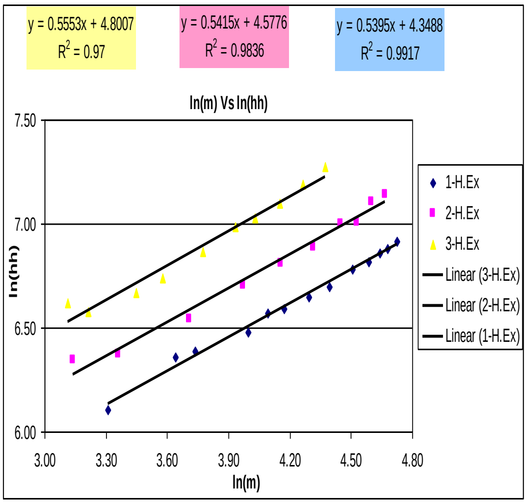

Fig. 3- Effect of tube diameter on HTC for ethylene glycol at 60ºC

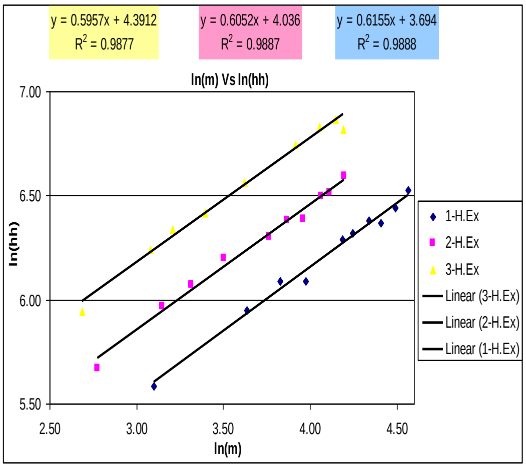

Fig. 4- Effect of tube diameter on HTC for servotherm light at 60ºC

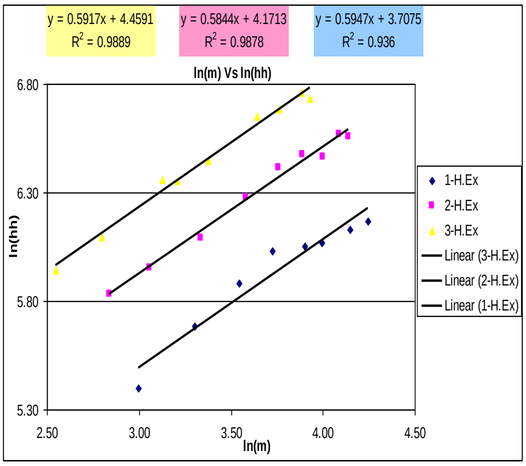

Fig. 5- Effect of tube diameter on HTC for servotherm medium at 60ºC

Above Plot shows mass flow rate verses heat transfer coefficient for tube diameter of 3 mm, 2.4 mm and 1.8 mm with the fluid ethylene glycol at 60ºC.

It is evident from the plot that, the heat transfer coefficient for E.G is comparatively better than other fluids (servotherm light, servotherm medium), due to its property [5] and [6] like viscosity of fluid (μ), and thermal conductivity (k). E.G has highest thermal conductivity and lowest viscosity as compare to other fluids, which in turn results in higher heat transfer coefficient. The trend for other fluids is same as ethylene glycol in all heat exchanger.

Therefore, when viscosity decreases, fluid velocity rises, increasing the heat transfer coefficient.

Further observation reveals that the heat transfer coefficient rises with decreasing tube diameter.

A fluid first undergoes an entry loss as it reaches the core of the heat exchanger owing to a rapid decrease in flow area, followed by a loss from the core itself due to the friction as well as other intrinsic losses, and lastly a loss from abrupt expansion as the fluid leaves the core. Additionally, if the core's density changes as a consequence of cooling or heating, the flow may accelerate or decelerate. Additionally, this results in a general decline in pressure.
Although, it is correct that smaller heat transfer exchangers are produced by larger pressure drops, capital savings are only possible at the price of operational expenses. The most cost-effective pressure drop could only be established by taking into account the link between operational expenses and expenditures.

Heat exchanger designers can take several steps to reduce shell side pressure drop. These include modifying the baffle design increasing the tube pitch, using multiple shells in parallel, reducing the tube length and increasing the nozzle size.

Conclusion

Understanding and quantifying how using large scale passageways affects thermal performance and heat transfer and the ensuing process is difficult in order to improve the equipment performance while reducing size, cost, as well as energy demands Heat exchanger advancement has been moderate despite growing demands on industries to recuperate significant amounts of energy, save costs, and minimize the environmental consequences. Thus, the innovative growth of the heat transfer technology is essential in processing various operations of man-made industries. In this context the effect of different parameter as diameter, temperature, mass flow rate, viscosity of the fluid, on heat transfer is being studied.
Enhancement in the heat transfer is obtained by reducing the diameter of tube in an exchanger.
Lower the viscosity of the fluid, better will the heat transfer coefficient. Decrease in the viscosity of fluid, results in thinner boundary layer, which in turn increases the heat transfer coefficient along with temperature. Ethylene glycol gave best results as compare to other thermal fluids due to its lowest viscosity. This shows that the property of the fluid as viscosity has significant effect on heat transfer characteristics.
Also, by increasing the mass flow rate, the heat transfer coefficient increases.

Heat transfer in heat exchanger of different diameter, experimentally investigated over the range flow rate, with different fluids. Laminar flow is considered in single-phase flow. The resulting high performance heat exchanger leads improved heat transfer coefficient at the cost of pressure drop.

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