Performance Analysis Of Cross Counter Flow Shell And Tube Heat Exchanger By Experimental Investigation & Mathematical Modelling

Parmar Kalpesh D
M. E.(Thermal)*
Rajiv Gandhi Prodyogiki Vishavavidhalaya, Bhopal

Prof. Manoj Chopra
HOD (Mechanical Department))
R.K.D.F. IST,Bhopal

Abstract

Heat exchanger is a Major element as far as heat transfer and energy conservation is concern. There are so many types of heat exchangers available in industry but due to wide range of design possibilities, simple manufacturing, law maintenance cost, counter flow and cross flow heat exchanger extensively used in the petroleum, petrochemical, air conditioning, food storage and other industries. In this paper the mathematical modelling of cross-counter flow heat exchanger is presented. In this paper an attempt is made to analyze the performance of shell and tube type cross counter flow heat exchanger by changing the various parameters like both hot and cold fluid flow rate, direction of fluid flow. After changing the various parameters, the maximum performance obtained. For that the mathematical model of counter flow heat exchanger is adopted and also the analysis of the heat exchanger is carried out.

In this paper, in order to analyze the performance of heat exchanger, one experiment was carried on counter cross flow shell and tube heat exchanger in one chemical laboratory at Rajkot. The performance of heat exchanger is evaluated by changing the various parameters and find out the maximum performance (effectiveness).

Keywords
Cross-counter flow, heat exchanger, Ɛ-NTU method

1. Introduction

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact.

Typical applications [1] involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi-Component fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distil, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner.

In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type or simply recuperators. In contrast, exchanger which there is intermittent heat exchange between hot and cold fluid via thermal energy storage and release to the exchanger surface and matrix are referred to as indirect transfer type or simply regenerator.

Such exchangers usually have a fluid leakage from one stream to another, due to pressure difference and matrix rotation/valve switching. Common examples of heat exchangers are shell and tube exchanger, automobile radiators, condensers, evaporator, air preheaters and cooling towers. If no phase change occurs in any of the fluid in the exchanger it is sometimes referred as a sensible heat exchanger. There could be internal thermal energy sources in the exchanger such as in the electrical heaters and nuclear fuel elements. Combustion and chemical reaction may takes place within the exchanger, such as in electrical heater and nuclear fuel elements. Combustion and chemical reaction may takes place within the exchanger such as in boilers, fire heaters and fluidized bed exchangers. Mechanical devices may be used in some exchangers, such as in scraped surface exchangers, agitated vessels and stirred tank reactors. Heat transfer in the separating wall of recuperator generally takes place by conduction. However, in a heat pipe heat exchanger the heat pipe is not only acts as a separating wall, but also facilitates the transfer of heat by condensation, evaporation and conduction of the working fluid inside the heat pipe. In general, if the fluids are immiscible, the separating wall may be eliminated, and the interface between the fluids replaces a heat transfer surface as in a direct contact heat exchanger.

2. Data Collection

In this paper data of shell & tube cross-counter flow heat exchanger is utilized for analysis. One experiment on shell & tube cross counter flow heat exchanger is performed at Rajkot in one chemical laboratory and data regarding various temperatures are obtained by increasing and decreasing the fluid flow consequently.

3. Classification of Methods

Choosing an appropriate mathematical model or class of models is as much an art as a science. There is no single approach that is 'best' for all situations, but it is possible to lay down some general guidelines.The performance analysis of different cross flow heat exchanger starts from[1],the performance analysis is also carried out by computational model[2], for the detailed design of finned coil has been developed. This programme discretises heat exchangers into tube elements for which the governing equations are solved using local values of temperature, pressure, physical properties and heat transfer coefficients, Innovative way [3]of analyzing the the heat exchanger is by testing of different refrigerant through dynamic simulation of mathematical model of evaporator and condenser in refrigeration.The author proposed a mathematical model of an evaporator based on one-dimension partial differential equations representing mass conservation, and tube wall energy has been formulated. There are some methods [4], for increasing shell-and-tube exchanger performance. The methods consider whether the exchanger is performing correctly to begin with, excess pressure drop capacity in existing exchangers, the re-evaluation of fouling factors and their effect on exchanger calculations, and the use of augmented surfaces and enhanced heat transfer. [7], Counter flow heat exchangers are commonly used in cryogenic systems because of their high effectiveness. In addition to operating and design parameters, the thermal performance of these heat exchangers is strongly governed by various losses such as longitudinal conduction through wall, heat in leak from surrounding, flow misdistribution etc. the numerical model developed earlier is extended to take into consideration the effect of heat in sink and the predictions are compared with the experimental results. The study is further extended to understand quantitative effect of heat in leak and axial conduction parameters on degradation of heat exchanger performance for 300-80 k and 80-20 k temperature range. A new approach[8],for thermal performance calculation of cross flow heat exchanger Effectiveness-number of transfer units (Ɛ-NTU) data for several standard and complex flow arrangements are obtained using this methodology. The results are validated through comparisons with analytical solutions for one pass cross-flow heat exchanger with one to four rows and with approximate series solution for an unmixed heat exchanger obtained in all cases very small errors.

New effectiveness data for some complex configurations are provided. Ɛ-NTUcomputation with a mathematical model for cross flow heat exchanger [10], Describes in the field of Performance evaluation of staggered cross flow heat exchanger under air dust mixture. Performance evaluation of cross flow heat exchanger is also done by [11] ,[12] & ,[13] using MATLAB. Heat exchanger performance is also analyzed by optimization by [14] & [15].Behaviour of cross flow heat exchanger is also analyzed by solid works and FEA [16]. Now the latest analytical technique is performance analysis is computational fluid dynamics (CFD) is utilized by [17].

4. Ɛ-NTU Method

A new numerical methodology [10] for thermal performance calculation in cross-flow heat exchangers is developed. Effectiveness-number of transfer units (Ɛ-NTU) data for several standard and complex flow arrangements are obtained using this methodology. In this paper performance analysis is carried out by changing the various parameters(1)By increasing the cold fluid flow rate (2) By decreasing the cold fluid flow rate (3) By increasing the hot fluid flow rate(4) By decreasing the hot fluid flow rate(5) By changing the direction of fluid(parallel flow instead of counter flow)

5. Mathematical model

The main aim of the present study is to find out the maximum performance for cross counter flow heat exchanger by varying the various parameters. A method based on Ɛ-NTU approach is utilized for the analysis of heat exchanger performance. For that the data of shell & tube cross-counter flow heat exchanger is used. One experiment on cross counter flow shell & tube heat exchanger is performed in laboratory and data of four different temperatures of hot and cold fluid is obtained by changing the various parameters. Here one mathematical model [18] is also utilized for calculation of effectiveness of heatexchanger. The final equation of mathematical model of effectiveness of cross-counter flow heat exchanger

$$\epsilon = \frac{1 - \exp[-NTU(1-C)]}{1 - C\exp[-NTU(1-C)]}$$

6. Result & Discussion

The Ɛ-NTU Method is widely used technique to analyze the performance of cross flow heat exchanger. Here the observation table is presented. Without changer in any parameter the effectiveness of the cross-counter flow heat exchanger is 42.85%

1st case:- If the cold fluid flow rate increased by 10 to 90%

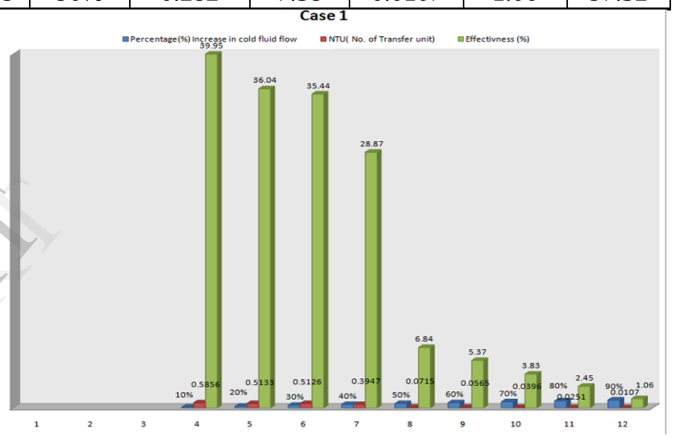
Table:-1

OBSERVATION TABLE FOR SHELL AND TUBE HEAT EXCHANGER						
Sr No.	Hot Water			Cold Water		
	Time for 10Lt of water(minute)	Inlet temp (T_{hi})	Outle temp (T_{h0})	Time for 10 lt of water (minute)	Inlet temp (T_{ci})	Outlet temp (T_{co})
1	3 min.	40	38.22	5.24	26	31.6
2	3 min.	40	38.41	4.67	26	31.05
3	3 min.	40	38.63	4.09	26	30.48
4	3 min.	40	38.85	3.5	26	30.05
5	3 min.	40	39.05	2.91	26	29.5
6	3 min.	40	39.24	2.34	26	28.96
7	3 min.	40	39.46	1.75	26	28.44
8	3 min.	40	39.65	1.17	26	27.93
9	3 min.	40	39.85	0.59	26	27.44

1st case:- Effect on various performance parameter

Table:-2

OBSERVATION TABLE						
Sr. No.	Percentage(%) Increase in Cold Fluid Flow rate	Cold fluid flow in (Kg/s)	Overall Heat Transfer Co-efficient (U) W/m2°C	NTU (No. of Transfer unit)	Effectivness (%)	Percentage decrease in Effectivness (%)
1	10%	0.318	67.13	0.5856	39.95	6.72
2	20%	0.356	62.21	0.5133	36.04	15.85
3	30%	0.0407	54.49	0.5126	35.44	17.25
4	40%	0.0476	47.85	0.3947	28.87	32.59
5	50%	0.0572	40.56	0.0715	6.84	84.00
6	60%	0.0712	33.34	0.0565	5.37	87.46
7	70%	0.952	25.11	0.0396	3.83	91.05
8	80%	0.142	17.01	0.0251	2.45	94.27
9	90%	0.282	7.58	0.0107	1.06	97.52



2nd case:- If the cold fluid flow rate decreased by 10 to 80%

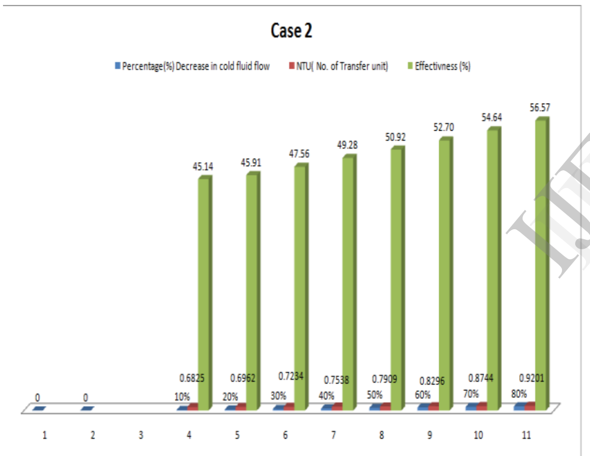
Table:-3

OBSERVATION TABLE FOR SHELL AND TUBE HEAT EXCHANGER						
Sr No.	Hot Water			Cold Water		
	Time for 10Lt of water(minute)	Inlet temp (T_{hi})	Outle temp (T_{h0})	Time for 10lt of water (minute)	Inlet temp (T_{ci})	Outlet temp (T_{co})
1	3 min.	40	38.38	6.41	26	32.32
2	3 min.	40	38.58	6.69	26	32.58
3	3 min.	40	38.77	7.57	26	32.66
4	3 min.	40	38.95	8.16	26	32.90
5	3 min.	40	39.12	8.74	26	33.13
6	3 min.	40	39.31	9.32	26	33.38
7	3 min.	40	39.56	9.92	26	33.65
8	3 min.	40	39.78	10.49	26	33.92

2nd case:- Effect on various performance parameter

Table:-4

OBSERVATION TABLE						
Sr. No.	Percentage(%) Increase in Cold Fluid Flow	Cold fluid flow in (Kg/s)	Overall Heat Transfer Co-efficient (U) W/m2°C	NTU (No. of Transfer unit)	Effectiveness (%)	Percentage increase in Effectiveness (%)
1	10%	0.0260	63.42	0.6825	45.14	5.07
2	20%	0.0249	58.31	0.6962	45.91	7.14
3	30%	0.0220	51.96	0.7234	47.56	10.99
4	40%	0.0202	49.28	0.7538	49.28	15.00
5	50%	0.0190	41.47	0.7909	50.92	18.83
6	60%	0.0178	32.38	0.8296	52.70	22.98
7	70%	0.0168	23.18	0.8744	54.64	27.51
8	80%	0.0158	7.16	0.9201	56.57	32.01



3rd case:- If the hot fluid flow rate increased by 10 to 60%

Table:-5

OBSERVATION TABLE FOR SHELL AND TUBE HEAT EXCHANGER						
Sr No.	Hot Water			Cold Water		
	Time for 10Lt of water(minute)	Inlet temp (Th o)	Outlet mp. (Th0)	Time for 10lt of water (minute)	Inlet temp(Tci)	Outlet temp (Tco)
1	2.7 min.	40	38.20	5.83	26	31.50
2	2.45 min.	40	38.36	5.83	26	31.68
3	2.23 min.	40	38.54	5.83	26	31.86
4	2.0 min.	40	38.78	5.83	26	32.03
5	1.82 min.	40	38.96	5.83	26	32.22
6	1.68 min.	40	39.16	5.83	26	32.41

3rd case:-Effect on various performance parameter

Table:-6

OBSERVATION TABLE						
Sr. No.	Percentage(%) Increase in hot Fluid Flow	Hot fluid flow in (Kg/s)	Overall Heat Transfer Co-efficient (U) W/m2°C	NTU (No. of Transfer unit)	Effectivness (%)	Percentage increase in/Decrease Effectivness (%)
1	10%	0.0617	67.76	0.6266	39.25	8.35(dec.)
2	20%	0.0680	68.46	0.5747	40.56	5.30(dec.)
3	30%	0.0747	68.85	0.5843	41.31	3.54(dec.)
4	40%	0.0833	58.29	0.6139	43.06	0.0537(dec.)
5	50%	0.0915	65.88	0.6368	44.41	3.68(dec.)
6	60%	0.0920	58.32	0.6654	45.78	6.88(dec.)

4th case:- If the hot fluid flow rate Decreased by 10 to 90%

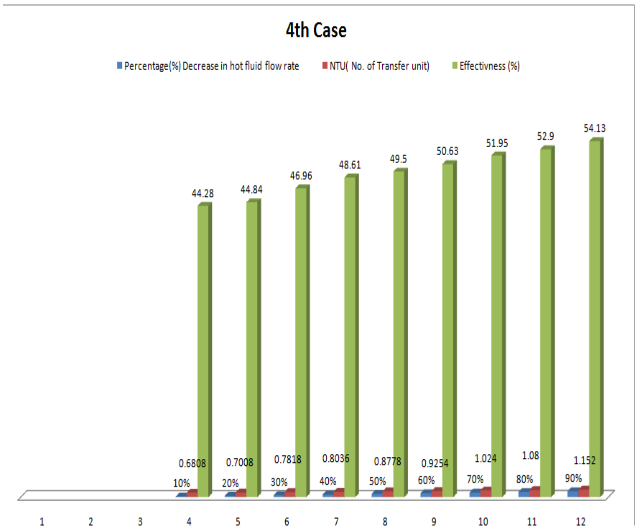
Table:-7

OBSERVATION TABLE FOR SHELL AND TUBE HEAT EXCHANGER						
Sr No.	Hot Water			Cold Water		
	Time for 10Lt of water(minute)	Inlet temp (T_{hi})	Outle temp (T_{ho})	Time for 10lt of water (minute)	Inlet temp (T_{ci})	Outlet temp (T_{co})
1	3.25	40	37.82	5.83	26	32.20
2	3.42	40	37.63	5.83	26	32.38
3	4.00	40	37.44	5.83	26	32.58
4	4.21	40	37.25	5.83	26	32.76
5	4.39	40	37.10	5.83	26	32.93
6	4.56	40	36.91	5.83	26	33.09
7	5.22	40	36.72	5.83	26	33.28
8	5.40	40	36.53	5.83	26	33.44
9	5.58	40	36.34	5.83	26	33.59

4th case:-Effect on various performance parameter

Table:-8

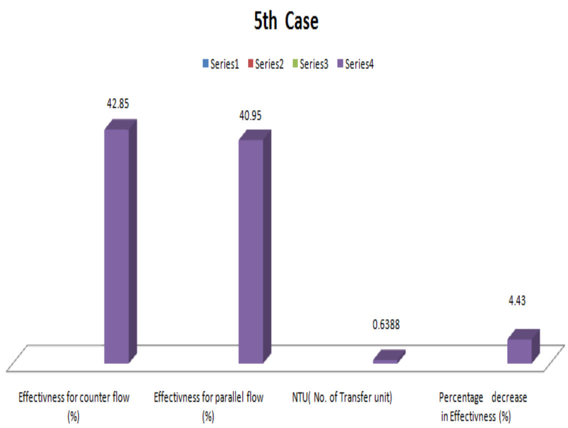
OBSERVATION TABLE						
Sr. No.	Percentage (%) Decrease in hot Fluid Flow rate	Hot fluid flow rate in (Kg/s)	Overall Heat Transfer Co-efficient (U) W/m2°C	NTU (No. of Transfer unit)	Effectiveness (%)	Percentage increase in Effectiveness (%)
1	10%	0.0512	75.44	0.6808	44.28	2.33
2	20%	0.0487	79.31	0.7008	44.84	4.33
3	30%	0.0416	78.67	07818	46.96	8.75
4	40%	0.0395	82.09	0.8036	48.61	11.84
5	50%	0.0379	85.52	0.8778	49.50	13.43
6	60%	0.0365	83.97	0.9254	50.63	15.36
7	70%	0.0319	88.19	1.024	51.95	17.51
8	80%	0.0308	92.04	1.080	52.90	18.99
9	90%	0.0298	95.74	1.152	54.13	20.83



5th case:- By changing the direction of fluid flow

Table:-9

Sr. No.	Effectiveness for counter flow (%)	Effectivness for parallel flow (%)	Overall Heat Transfer Co-efficient (U) W/m2°C	NTU (No. of Transfer unit)	Percentage decrease in Effectivness (%)
1	42.85	40.95	27.22	0.6388	4.43



Discussion:-

1st case:-Increase in the cold fluid flow rate by 10% to 90% we observe that the effectiveness and also NTU will decrease slowly up to 40% and then very fast from 50% to 90%

2nd case:- Decrease in the cold fluid flow rate by 10% to 80% we observe that the effectiveness and also NTU increases continuously.

3rd case:- Increase in the hot fluid flow rate by 10% to 60% we observe that NTU and effectiveness first decreases and then increases gradually.

4th case:- Decrease in the hot fluid flow rate by 10% to 90% we observe that NTU and effectiveness both increases gradually and we obtain the maximum effective by decreasing the hot fluid flow by 90% we get 54.13% effectiveness.

5th case:- By changing the direction of fluid flow(Using parallel flow instead of counter flow arrangement) and keeping the NTU constant the effectiveness will decrease by 4.43%

Above results are explained by Graphs of Ɛ vs.NTU for all the five cases.

7. Conclusion:-

From all above five cases it is concluded that we get the maximum performance (effectiveness) by decreasing the hot fluid flow and keep the cold fluid flow constant for this particular heat exchanger.

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PARMAR KALPESH D. earned his B.E. in Mechanical Engineering from Saurashtra University and Pursuing M.E. in Mechanical (Thermal Engineering) Engineering from Rajiv Gandhi Prodyogiki Vishavidyalaya, Bhopal. He has 8 years field experience, 3.5 years teaching experience and currently he is Assistant Professor in Dr. Subhash Technical Campus, Junagadh, (Gujarat), and INDIA.