ANALYSIS OF HEAT TRANSFER CHARACTERISTICS IN CROSS FLOW PLATE FIN TYPE HEAT EXCHANGER WITH NON-NEWTONIAN FLUIDS

Dr. N. Tamilselvan[1], Sreedharan. K. V[2]

[1]*Associate Professor, Dept. of Mechanical Engineering, Excel Engineering College (Autonomous), Tamil Nadu, India*
[2]*PG Scholar, Dept. of Thermal Engineering, Excel Engineering College (Autonomous), Tamil Nadu, India*

---***---

Abstract - *Cross flow plate fin type heat exchangers use corrugated metal plates to transfer heat energy between two fluids which flow in directions normal to each other. These heat exchangers are compact heat exchangers which provide high heat transfer surface area to volume ratio. Using corrugated sheets on each side of the flat plates, form a thin flow pass for hot and cold fluid streams making it to more compact, high effective and more heat transfer capacity. Due to its compactness, light weight and high heat transfer capacity into small volume, these heat exchangers are widely used in Aerospace, Cryogenics and other mobile units where weight and volume are prime considerations. Certain important parameters which play a vital role in predicting the performance of heat exchangers can be determined through a detailed experimental analysis. These parameters also depend on the types of heat exchangers, types, concentration and flow rates of cold fluids used for heat exchanging purposes. The objective of this analysis is to study the heat transfer characteristics in cross flow plate fin type heat exchanger, using non-Newtonian fluid (Carboxy Methyl Cellulose) as cold fluid. The experimental analysis were conducted using different concentrations (0.01, 0.05 and 0.1%) of cold fluid at different flow rates for determining its effect on heat exchanger parameters such as individual heat transfer coefficient, overall heat transfer coefficient, fin effectiveness, surface effectiveness and heat exchanger effectiveness.*

Key Words: **Overall heat transfer coefficient, Fin effectiveness, Surface effectiveness, Heat exchanger effectiveness, Carboxy Methyl Cellulose.**

1. INTRODUCTION

Cross flow plate fin type heat exchangers provide large heat transfer area in a small space with increased heat transfer efficiency. It consists of corrugated metal plates placed between the flat plates and the structure is joined together by brazing or welding. The corrugated sheets that are sand witched between the plates, serve as fins to give extra heat transfer area and to provide structural support to the flat plates by holding the plates together. Hot and cold fluid streams flow in perpendicular directions along the passages made by corrugations between the parting sheets. Due to its significant inherent advantages with high efficiency and high degree of compactness these heat exchangers play a prominent role in cryogenic and aerospace applications. Aluminium as a light material and having high thermal conductivity is being widely used as an ideal heat exchanger material for these applications. But its use is limited for long time service at higher temperatures, usually to a maximum temperature of 250°C. Heat exchangers used for these applications should have high thermal effectiveness. Therefore it is important to conduct the analysis of heat transfer characteristics in a cross flow plate fin type heat exchanger, using different variety of cold fluids to study its effect on heat exchanger parameters and to find solutions for the limitations encountered in various applications. Review of literatures related to this investigation reveals that, a wide range of non-Newtonian fluids which offer good heat transfer performance were used in the past, as cold fluid for conducting the heat transfer performance studies. Non-Newtonian fluids were seen used in the heat transfer analysis of parallel and counter flow plate heat exchangers. The performance analysis for the present study was conducted experimentally in a cross flow plate fin type heat exchanger using Carboxy Methyl Cellulose (CMC) as non-Newtonian fluid at different concentrations and flow rates. The data obtained from the experiment were used for determining the individual heat transfer coefficient, overall heat transfer coefficient, fin effectiveness, surface effectiveness and heat exchanger effectiveness for the analysis of heat transfer characteristics in cross flow plate fin type heat exchangers.

2. MATERIALS AND METHODS

2.1 Materials for heat exchanger and its construction features

Cross flow plate fin type heat exchanger required for experimental analysis of heat transfer characteristic was constructed by fabrication using Aluminium as its material. The heat exchanger was made of two plates, a strip of corrugated sheet and a flat plate which were folded on both sides, so as to provide an enclosure to the corrugations. Corrugations were joined to the flat plates by welding. Flat plates acts as primary and the corrugations as secondary heat transfer surface. The inlet header joins the inlet face of the heat exchanger core to the inlet supply pipe and the outlet header joins the outlet face of the heat exchanger core to the return pipe of respective fluid streams. The schematic diagram of the heat exchanger is shown in figure 1.

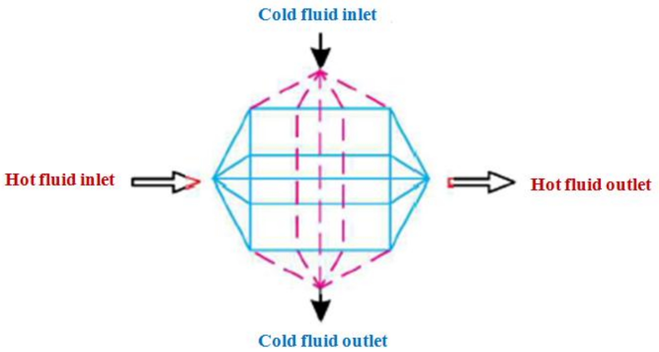

Fig -1: Schematic diagram of cross flow plate fin type heat exchanger

2.2 Materials for cold fluid.

This study considered a non-Newtonian fluid as cold fluid for conducting the experiment in cross flow plate fin type heat exchanger. The base fluid that used in this experimental studies was Carboxyl Methyl Cellulose - CMC ($C_8H_{15}NaO_8$) which is a non-Newtonian fluid having better exchanger effectiveness

2.3 Experimental set up and procedure

Experimental analysis of cross flow plate fin heat exchanger was conducted using Carboxy Methyl Cellulose (CMC) as cold fluid for different flow rates and concentrations as follows:

Initially the boiler was filled with soft water and the electric heater was switched on to produce steam at required quantity and temperature.

The required composition of CMC solution was prepared in a storage vessel at room temperature and atmospheric pressure.

Inlet valve on the cold fluid stream circuit was opened and Water-CMC solution at a concentration 0.01% on volume basis was allowed to pass through the heat exchanger using a centrifugal pump.

After ensuring enough quantity of steam at required temperature that was generated in the boiler, the inlet valve on the hot fluid stream circuit was opened and the steam was allowed to pass through the heat exchanger.

After a steady state has been reached, the flow rate, inlet and outlet temperature of both cold and hot fluids were noted and recorded.

The experiment was repeated for same concentration (0.01%) but for different flow rates of cold fluid. Inlet and outlet temperature of both cold and hot fluids were noted and recorded for each flow rate.

The experiments were repeated for different flow rates and concentrations (0,05% and 0.1%) of Water-CMC solutions.

The data obtained from experimental studies were analyzed using MATLAB software.

The schematic diagram for experimental set up is shown in figure 2.

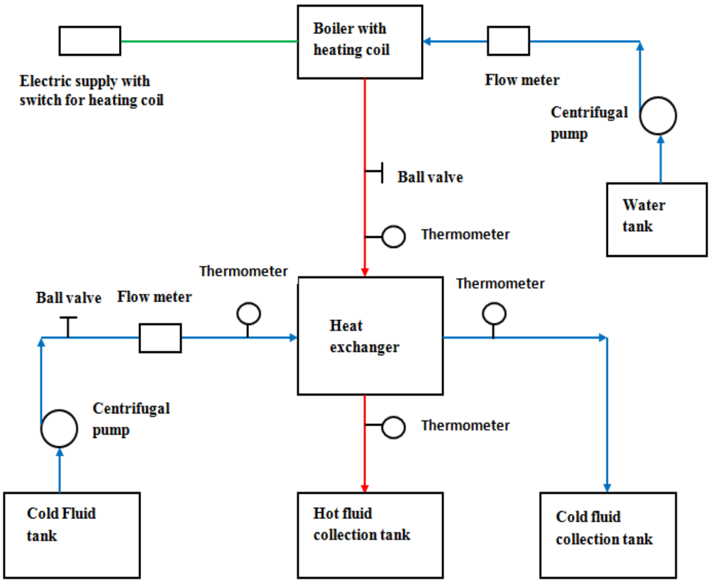

Fig -2: Schematic diagram for experimental set up

2.4 Experimental observations and predictions

The following data collected during experimental analysis for different flow rates and concentrations of Water-CMC system were recorded:

- Temperature of cold fluid before and after the heat exchanger t_1 and t_2 respectively.
- Temperature of hot fluid before and after the heat exchanger T_1 and T_2 respectively.

Following heat exchanger parameters were determined using the collected data, for different flow rates and concentrations of Water-CMC system.:

- Reynolds number for both cold and hot fluids
- Individual heat transfer coefficient for both cold and hot fluids
- Fin effectiveness for both cold and hot fluids
- Surface effectiveness for both cold and hot fluids
- Overall heat transfer coefficient
- Heat exchanger effectiveness
- Capacity ratio
- Number of Transfer Units

The data obtained from experimental analysis and the heat exchanger parameters calculated for different flow rates and concentrations of Water-CMC system are tabulated in table 1, 2 and 3 as shown below.

Table -1: Water –CMC (0.01%)

Cold Fluid (Water-CMC)			Hot Fluid (Water)			Heat Transfer Coefficient			C*	NTU	Fin Effective-ness		Surface Effective-ness		Exchanger Effectiveness
Fluid temperature		Reynolds number	Fluid temperature		Reynolds number	Hot Fluid	Cold Fluid	Over-all			Hot Fluid	Cold Fluid	Hot Fluid	Cold Fluid	
t_1	t_2	N_{Re}	T_1	T_2	N_{Re}	h_h	h_c	U			$\eta_{f,h}$	$\eta_{f,c}$	$\eta_{o,h}$	$\eta_{o,c}$	ε
°C			°C			W/m²K	W/m²K	W/m²K			%	%	%	%	%
30	48.5	4.28	121	90.5	14.156	9.999	8.433	4.571	0.388	0.484	99.87	99.89	99.90	99.92	32.59
30	47.5	5.67	121	89	13.977	9.733	11.185	5.199	0.517	0.413	99.87	99.85	99.91	99.89	29.20
30	47.5	6.24	121	87.5	13.803	9.504	12.304	5.356	0.569	0.386	99.87	99.84	99.91	99.88	27.87
30	47	7.06	121	88	13.861	8.893	13.945	5.423	0.646	0.344	99.88	99.81	99.91	99.87	25.61
30	46.5	7.32	121	87	13.747	8.910	14.465	5.505	0.672	0.336	99.88	99.81	99.91	99.86	25.15
30	45	7.81	121	86.5	13.690	8.751	15.458	5.580	0.724	0.316	99.88	99.79	99.92	99.85	24.02
30	43	8.26	121	85	13.524	8.772	16.393	5.705	0.775	0.302	99.88	99.78	99.92	99.84	23.18

Table -2: Water –CMC (0.05%)

Cold Fluid (Water-CMC)			Hot Fluid (Water)			Heat Transfer Coefficient			C*	NTU	Fin Effective-ness		Surface Effective-ness		Exchanger Effectiveness
Fluid temperature		Reynolds number	Fluid temperature		Reynolds number	Hot Fluid	Cold Fluid	Over-all			Hot Fluid	Cold Fluid	Hot Fluid	Cold Fluid	
t_1	t_2	N_{Re}	T_1	T_2	N_{Re}	h_h	h_c	U			$\eta_{f,h}$	$\eta_{f,c}$	$\eta_{o,h}$	$\eta_{o,c}$	ε
°C			°C			W/m²K	W/m²K	W/m²K			%	%	%	%	%
30	48	4.27	121	90	14.052	10.219	8.411	4.610	0.388	0.488	99.86	99.89	99.90	99.92	32.78
30	47	5.65	121	89	13.977	9.733	11.156	5.193	0.517	0.412	99.87	99.85	99.91	99.89	29.18
30	46.5	6.20	121	88.5	13.919	9.488	12.240	5.339	0.569	0.385	99.87	99.84	99.91	99.88	27.80
30	46	7.02	121	88	13.861	9.272	13.873	5.550	0.646	0.352	99.88	99.81	99.91	99.87	26.05
30	45	7.25	121	87.5	13.804	9.080	14.353	5.554	0.672	0.339	99.88	99.81	99.91	99.86	25.31
30	44.5	7.78	121	86	13.634	8.922	15.418	5.643	0.724	0.320	99.88	99.79	99.91	99.85	24.23
30	44	8.31	121	85.5	13.579	8.929	16.477	5.782	0.775	0.306	99.88	99.78	99.91	99.84	23.41

Table -3: Water –CMC (0.1%)

Cold Fluid (Water-CMC)			Hot Fluid (Water)			Heat Transfer Coefficient			C*	NTU	Fin Effective-ness		Surface Effective-ness		Exchanger Effectiveness
Fluid temperature		Reynolds number	Fluid temperature		Reynolds number	Hot Fluid	Cold Fluid	Over-all			Hot Fluid	Cold Fluid	Hot Fluid	Cold Fluid	
t_1	t_2	N_{Re}	T_1	T_2	N_{Re}	h_h	h_c	U			$\eta_{f,h}$	$\eta_{f,c}$	$\eta_{o,h}$	$\eta_{o,c}$	ε
°C			°C			W/m²K	W/m²K	W/m²K			%	%	%	%	%
30	48.5	4.28	121	88	13.861	10.790	8.433	4.730	0.388	0.500	99.86	99.89	99.90	99.92	33.35
30	48	5.69	121	87	13.747	10.399	11.215	5.390	0.517	0.428	99.86	99.85	99.90	99.89	29.96
30	47.5	6.52	121	86.5	13.690	10.066	12.863	5.640	0.594	0.389	99.87	99.83	99.90	99.88	28.01
30	47	7.06	121	86	13.634	9.781	13.945	5.741	0.646	0.364	99.87	99.81	99.91	99.87	26.71
30	46.5	7.60	121	85.5	13.579	9.535	15.022	5.824	0.698	0.342	99.87	99.80	99.91	99.86	25.50
30	45	8.09	121	85	13.524	9.318	16.010	5.881	0.749	0.322	99.88	99.79	99.91	99.85	24.34
30	44.5	8.34	121	84.5	13.469	9.124	16.519	5.868	0.775	0.310	99.88	99.78	99.91	99.84	23.68

3. RESULTS AND DISCUSSION

3.1 Graphical representation

Based on the results obtained from the analysis of heat transfer characteristics in cross flow plate fin type heat exchanger, for Water-CMC at different compositions, graphs are plotted for relevant heat exchanger parameters. The results are graphically represented for individual heat transfer coefficients, overall heat transfer coefficients, fin temperature effectiveness, surface temperature effectiveness and heat exchanger effectiveness with respect to the Reynolds number of hot and cold fluids.

3.2 Heat transfer coefficient Vs Reynolds number

Charts 1 and 2 shown below are the graphical representation between the Reynolds number and the individual heat transfer coefficient (hot and cold side) for different compositions of CMC to analyze the changes that have been occurred due to the variation in flow rate and composition of non-Newtonian fluid.

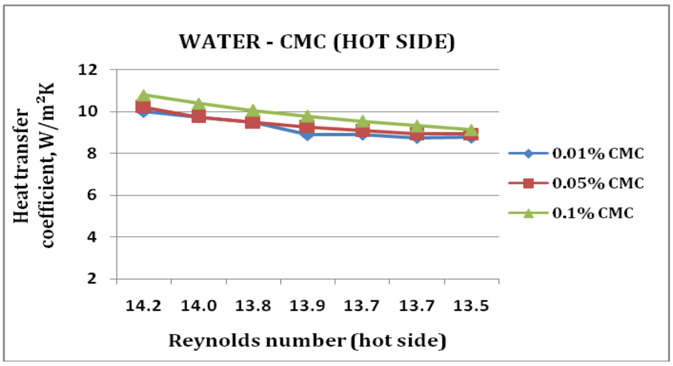

Chart -1: Heat transfer coefficient Vs Reynolds number (hot side) for Water-CMC system

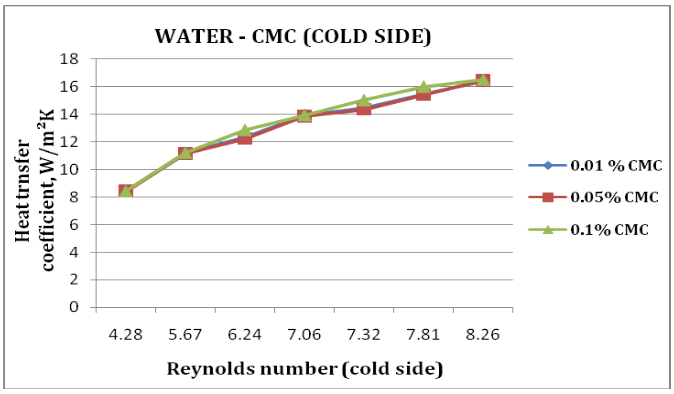

Chart -2: Heat transfer coefficient Vs Reynolds number (cold side) for Water-CMC system

3.3 Overall heat transfer coefficient Vs Reynolds number

Charts 3 and 4 shown below are the graphical representation between the Reynolds number (hot and cold side) and the overall heat transfer coefficient for different compositions of CMC to analyze the changes that have been occurred due to the variation in flow rate and composition of non-Newtonian fluid.

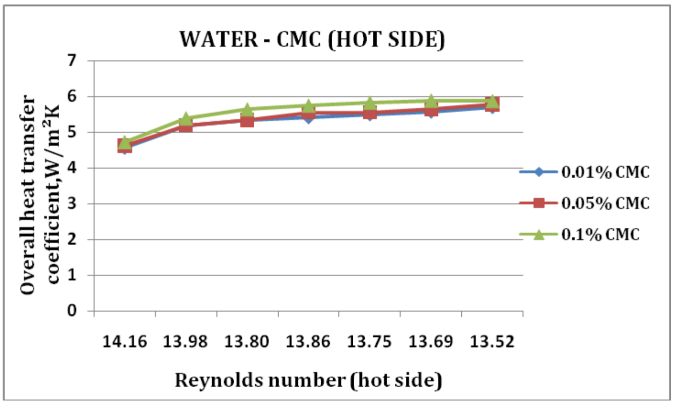

Chart -3: Overall heat transfer coefficient Vs Reynolds number (hot side) for Water-CMC system

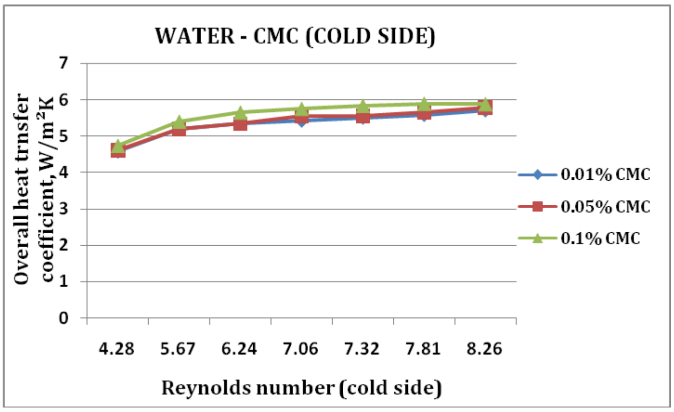

Chart -4: Overall heat transfer coefficient Vs Reynolds number (cold side) for Water-CMC system

3.4 Fin effectiveness Vs Reynolds number

Charts 5 and 6 shown below are the graphical representation between the Reynolds number and fin temperature effectiveness (hot and cold side) for different compositions of CMC to analyze the changes that have been occurred due to the variation in flow rate and composition of non-Newtonian fluid.

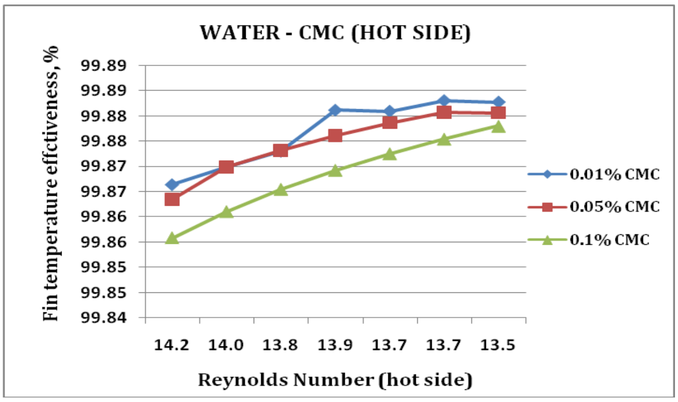

Chart -5: Fin effectiveness Vs Reynolds number (hot side) for Water-CMC system

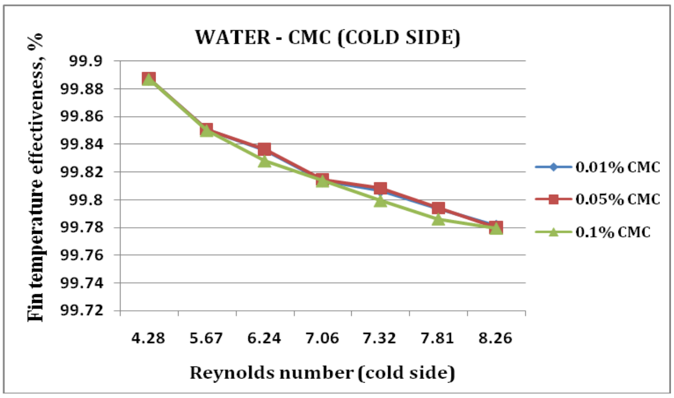

Chart -6: Fin effectiveness Vs Reynolds number (cold side) for Water-CMC system

3.5 Surface effectiveness Vs Reynolds number

Charts 7 and 8 shown below are the graphical representation between the Reynolds number and the surface effectiveness (hot and cold side) for different compositions of CMC to analyze the changes that have been occurred due to the variation in flow rate and composition of non-Newtonian fluid.

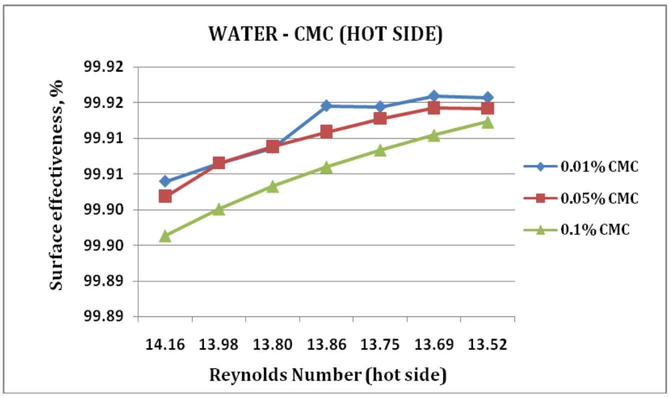

Chart -7: Surface effectiveness Vs Reynolds number (hot side) for Water-CMC system

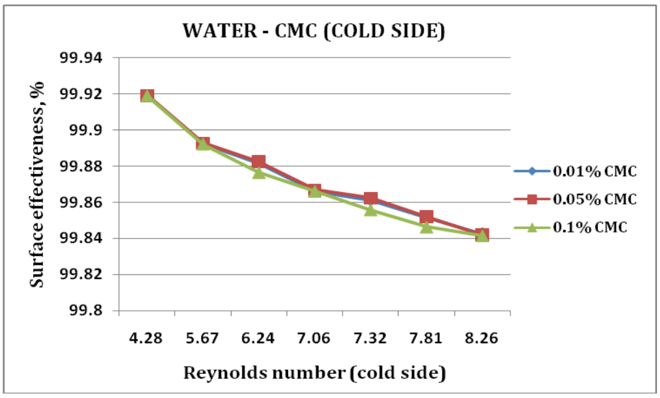

Chart -8: Surface effectiveness Vs Reynolds number (cold side) for Water-CMC system

3.6 Exchanger effectiveness Vs Reynolds number

Charts 9 and 10 shown below are the graphical representation between the Reynolds number (hot and cold side) and the exchanger effectiveness for different compositions of CMC to analyze the changes that have been occurred due to the variation in flow rate and composition of non-Newtonian fluid.

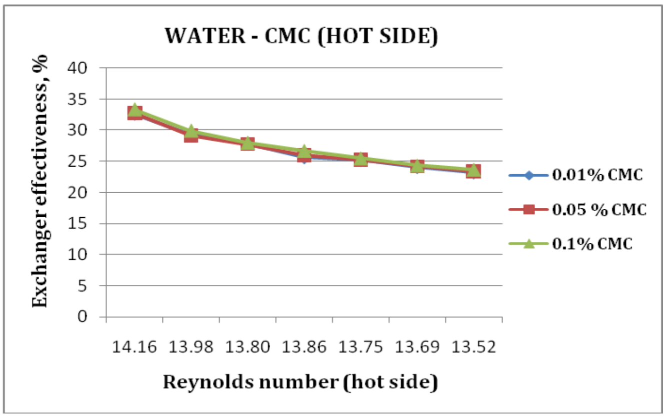

Chart -9: Exchanger effectiveness Vs Reynolds number (hot side) for Water-CMC system

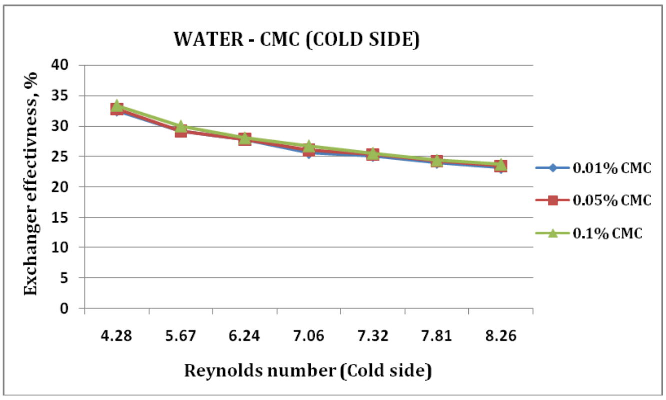

Chart -10: Exchanger effectiveness Vs Reynolds number (cold side) for Water-CMC system

3.7 Result analysis and comparison

From the results of experimental analysis conducted on cross flow plate fin type heat exchanger for various compositions (0.01%, 0.05% and 0.1%) of non Newtonian fluid (Water-CMC system), the following observations are made:

The individual heat transfer coefficient increases with the increase in Reynolds number for different compositions of Water-CMC system (hot side).

The individual heat transfer coefficient increases with the increase in Reynolds number for different composition of Water-CMC system (cold side).

The overall heat transfer coefficient decreases with the increase in Reynolds number for different compositions of Water-CMC system (hot side).

The overall heat transfer coefficient increases with the increase in Reynolds number for different compositions of Water-CMC system (cold side).

The fin effectiveness decreases with the increase in Reynolds number for different compositions of Water-CMC system (hot side).

The fin effectiveness decreases with the increase in Reynolds number for different compositions of Water-CMC system (cold side).

The surface effectiveness decreases with the increase in Reynolds number for different compositions of Water-CMC system (hot side).

The surface effectiveness decreases with the increase in Reynolds number for different compositions of Water-CMC system (cold side).

The exchanger effectiveness increases with the increase in Reynolds number for Water-CMC system (hot side).

The exchanger effectiveness decreases with the increase in Reynolds number for Water-CMC system (cold side).

4. CONCLUSIONS

On the basis of the experiments conducted on cross flow plate fin type heat exchanger with non-Newtonian fluid (Carboxy Methyl Cellulose) as cold fluid, the effect of variation in the flow rate and composition of non-Newtonian fluid on different heat exchanger parameters such as Reynolds number, individual heat transfer coefficient, overall heat transfer coefficient, fin effectiveness, surface effectiveness and heat exchanger effectiveness have been analyzed.

From the analysis of heat transfer characteristics of cross flow plate fin type heat exchanger the following main conclusions have been arrived:

- The heat exchanger effectiveness increases with the increase in concentration of non-Newtonian fluid.
- The individual heat transfer coefficient increases with the increase in concentration of non-Newtonian fluid.
- The overall heat transfer coefficient increases with the increase in concentration of non-Newtonian fluid.

REFERENCES

[1] K. Sukanya, M. Laxmi Deepak Bhatlu, Neethu Jayan, K. Saranya and S. Karthikeyan, "Effect of non-Newtonian fluids on the performance of plate type heat exchanger" Journal of critical reviews, Vol 7, issue 7, 2020.

[2] Seyed shahab Mozafarie and Kourosh Javaherdeh, "Numerical design and heat transfer analysis of a non-Newtonian fluid flow for annulus with helical fins," Engineering Science and Tecnology International journal, 22, 2019, 1107-1115.

[3] Karuppannan Muthamizhi and Ponnusamy Kalaichelvi, "Development of Nusselt number correlation using dimensional analysis for plate heat exchanger with a Carboxymethyl cellulose solution," 2015.

[4] Manoj B. Kumbhare and S. D. Dawande, "Performance Evaluation of Plate Heat Exchanger in Laminar and Turbulent flow conditions," International Journal of Chemical Science and Applications vol 4, issue 1, 2013. 77-83.

[5] S. Nadeem, Rashid Mehmood and Noreen Sher Akbar, "Non-orthogonal stagnation point flow of a nano non-Newtonian fluid towards a stretching surface with heat transfer," International Journal Heat and Mass Transfer, Vol 57, (2013), Pages 679-689.

[6] Salam K. Al-Dawery, Ayham M.Alrahawi, Kalid M. Al-Zobai "Dynamic modeling and control of plate heat exchanger," International Journal of heat and mass transfer Vol 55, (2012), 6873-6880.

[7] M. Thirumarimurugan, T. Kannadasan and S. Gopalakrishnan,"Performance analysis of cross flow finheat exchanger for Immiscible system using ANN," International journal of chemical and environmental engineering, 2010, Vol 1, No.1.

[8] M.Thirumarimurugan and T. Kannadasan. "Simulation studies on plate type heat exchanger using ANN," International journal of ChemTech Reserch, Vol 1, No.2, pp349-354, 2009.

[9] A.A. Lambert, S. Cuevas, J.A. del Río and M. López de Haro, "Heat transfer enhancement in oscillatory flows of Newtonian and viscoelastic fluids" 2009, International Journal of Heat and Mass Transfer, Volume 52, (2009) 5472-5478.

[10] Isabel M. Afonso, Paulo Cruz, Joao M. Maia and Luis F. Melo, "Simplified numerical simulation to obtain heat transfer correlations for stirred yoghurt in a plate heat exchanger" Science Direct, 86 (2008) 296-303.

[11] Jorge A.W. Gut and Jose M. Pinto, "Modeling of plate heat exchangers with generalized configurations," International journal of Heat and Mass Transfer, 46 (2003) 2571-2585.

[12] Yimin Xuan and Qiang Li, "Heat transfer enhancement of nanofluids," International journal of Heat and Fluid flow, 21 (2000) 58-64.