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Numerical Investigation And Optimization Of Double Pipe Heat Exchangers Using Complex Proportional Assessment Techniques

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ABSTRACT :

This study presents the results and conclusions derived from an investigation into the performance and optimization of a double pipe heat exchanger. Numerical simulations conducted using ANSYS Fluent successfully predict the outlet temperature of both hot and cold fluids. The COPRAS method is applied for multi-objective optimization technique. The research begins by setting up a double pipe heat exchanger model within ANSYS Fluent, a powerful computational fluid dynamics (CFD) tool known for its precision in simulating fluid flow and heat transfer. This setup involves defining the geometry of the heat exchanger, specifying the materials for the pipes and fluids, and establishing the initial and boundary conditions. The hot fluid, typically water, flows through the inner pipe, while the cold fluid flows through the outer pipe in a counter-current configuration, maximizing the temperature gradient and thus the heat transfer efficiency. The core of the study focuses on multi-objective optimization using the COPRAS (Complex Proportional Assessment) method, a decision-making tool that ranks the efficiency of various experimental setups based on multiple criteria. This method is particularly suited for engineering applications where trade-offs between different objectives, such as maximizing heat transfer while minimizing energy consumption, need to be evaluated. By applying COPRAS, the study identifies the top three optimal experiments from a large set of simulations, highlighting those configurations that achieve the best balance of performance metrics. optimization, leading to the identification of the top three optimal experiments for the heat exchanger. Notably, simulations numbered 9, 3, and 4 exhibit promising outcomes based on specified parameters such as mass flow rates and inlet temperatures of both hot and cold fluids. Optimal values for the hot water outlet temperature (T2) and cold-water outlet temperature (t2) are determined, shedding light on the system's efficiency under varying conditions. These findings contribute valuable insights to the enhancement of double pipe heat exchangers in diverse industrial applications.

Keywords: Finite elements, ANSYS, Optimization, heat exchanger

1. Introduction :

Heat transfer is the transfer of energy from higher temperature medium to lower temperature medium. This process continues until the two mediums will be of same temperature. It is a unit operation. Heat transfer occurs in heating and cooling of liquid/solid/air, refrigeration, evaporation, drying and distillation. Modes of heat transfer are (i) conduction (ii) convection (iii) radiation. The mechanism of heat exchanger is to transfer heat from one medium to another which is at a different temperature. The medium can be either liquid or gas. Heat exchanger can raise or lower the temperature of the medium based on the applications. Heat exchanger is used in many engineering applications such as, water heaters, free cooling, heat recovery, heat pump isolation, thermal storage system, sludge treatment, pre heating and cooling. The types of heat exchangers include: Double tube heat exchanger (DTHE); Shell and tube heat exchanger (STHE); Plate Heat Exchanger (PHE); Spiral Heat Exchanger (SHE); Finned Tube Heat Exchanger (FTHE) etc. Heat exchanger is classified according to the (1) transfer process (2) number of fluids (3) degree of surface compactness (4) construction (5) flow arrangements (6) heat transfer mechanism. Industries designate heat exchangers based on the cost, high/low pressure limits, thermal performance, temperature range, fluid flow capacity, clean ability. Heat exchangers and especially double pipe heat exchangers play an important role in industrial and engineering applications such as: air-conditioning, petrochemical industry, power plants, refrigeration, solar water heaters, process industries and chemical and nuclear reactors. Due to this various applications, convective heat transfer in a heat exchanger has been investigated in several researches during the past decades and different heat transfer improvement techniques have been presented to enhance the overall heat transfer performance of heat exchangers. Using of the double pipe with louvered strip inserts [1], finned double pipe [2-4], metal foam filled double pipe [5, 6] and the helical wires in double pipe heat exchangers [7] are some of these techniques. In addition, nanofluids different especial properties have been a subject of interest in several researches to improve heat transfer and for other applications [8]. The effectiveness of nanofluids on heat transfer performance is presented in various studies [9–13]. Among previously studied investigations on heat transfer performance in heat exchangers, the following researches can be mentioned: Goodarzi et al. [14] have carried out an experimental investigation on heat transfer performance, friction factor, specific heat capacity and viscosity of a counter-flow double pipe heat exchanger. They found that the heat transfer of working fluid may enhance due to increasing the Reynolds number or the nanomaterial percentage. An experimental study on effect of discontinuous helical turbulators on flow and heat transfer characteristics of a double pipe water to air heat exchanger has been done by Sheikholeslami et al. [15]. The results revealed that increasing the open area and pitch ratios decreases the friction factor and Nusselt number. Additionally, thermal performance enhances with open area ratio but reduces as pitch ratio is increased. Hashemian et al. [16] have performed a numerical investigation on multi-criteria design analyses in a novel form (conical) of double pipe heat exchangers. The effects of hydraulic, geometrical and thermodynamic characteristics are analyzed in this paper. At the optimum condition, the results showed 55% enhancement in effectiveness and 40% in heat transfer improvement number. A numerical study on a nonuniform transverse magnetic field effects on hydro-thermal characteristics of a ferrofluid in a counter flow double pipe heat exchanger has been done by Shakiba and Vahedi [17]. They concluded that applying the magnetic field increases the Nusselt number, friction factor and pressure drop. An experimental and numerical investigation on effects of using conical ring on turbulent flow and heat transfer in a double pipe air to water heat exchanger has been carried out by Sheikholeslami et al. [18]. They concluded that enhancement of open area ratio, pitch ratio and Reynolds number reduces the friction factor. Additionally, increasing the open area and pitch ratios reduces the Nusselt number which increases with Reynolds number. Han et al. [19] have investigated a multi-objective shape optimization using a fully developing 3-D heat transfer and flow model, to fulfill the geometric design of double pipe heat exchangers with inner corrugated tube using the RSM method. In this study, the optimum designing parameters of double pipe heat exchangers with inner corrugated tube are presented. Prithiviraj and Andrews [20] have investigated a 3-D simulation on fluid flow and heat transfer in shell-and-tube heat exchangers. They studied the effect of the baffle cut and baffle spacing on the pressure drop. Their computed results were in good compliance with the experiments. A numerical investigation on the effect of non-uniform blowing or suction through the porous wall of a circular pipe has been done by Bubnovich et al. [21]. They found the effects of the angle and the velocity profile of the entering flow on the internal wall temperature, Nusselt number, and the wall shear stresses for non-isothermal laminar flows with Péclet numbers between 10 and 1000. Cheng et al. [22] have performed a 3-D periodically developed flow and heat transfer characteristics in a triangular wavy fin-and-tube heat exchanger. They found that increasing the wavy angle, tube diameter, or wavy density enhances both the friction factor and Colburn factor. The primary objective of this study is to investigate the heat transfer characteristics of a double pipe heat exchanger. The objective of this research work is to study the Double pipe heat exchanger and its performance parameters, Simulated data was collected and made according to DOE guidelines. optimize the performance parameters of the double pipe heat exchanger, the MCDM technique (COPRAS) will be employed.

2. COPRAS Method

Enhancing decision-making in material selection involves considering various criteria and logically organizing the components of complex problems. Multi-Criteria Decision Making (MCDM) serves as a decision-making tool assisting researchers in material selection based on performance criteria for optimal outcomes. Among the available MCDM techniques, the Complex Proportional Assessment (COPRAS) method is a mathematical approach employed to address problems with finite alternatives and competing criteria. COPRAS adopts a sequential ranking and evaluation process for alternatives based on their relevance and utility levels [18].

Table 1 – Factor and Parameters

	Parameter	Level (V)		
		Level-1	Level-2	Level-3
A	MFR of hot fluid m_h (Kg/min)	**1**	**2**	**3**
B	MFR of cold fluid m_c (Kg/Sec)	**1**	**2**	**3**
C	hot water inlet temperature T_1 (°C)	**65**	**65**	**65**
D	cold water inlet temperature t_1 (°C)	**32**	**32**	**32**

3. Numerical Simulations :

The computational analysis for all examples is performed using the commercial software ANSYS Fluent 24. Second-order upwind discretization techniques are applied for momentum and energy. The numerical calculation method employed is the Semi-Implicit Method for Pressure Linked Equations (SIMPLE). A viscous-laminar model is utilized, considering a Reynolds number range of 100 to 1000.

Table 2 – Materials properties of working fluid

Types of fluids	K(W/mK)	Cp(J/kgK)	ρ (kg/m3)
Water	0.613	4179	997.1

3.1. Modeling and meshing

A typical heat exchanger with the geometry specifications available in design of experiment table are modeled using ANSYS 24. The model essentially consists of three regions namely the double pipe heat exchanger with the dimension mention in table 3 as shown in Figure 1.

Table 3 – Dimensions of selected pipe

Outer diameter	20 mm
Inner Diameter	10 mm
Length	40 mm

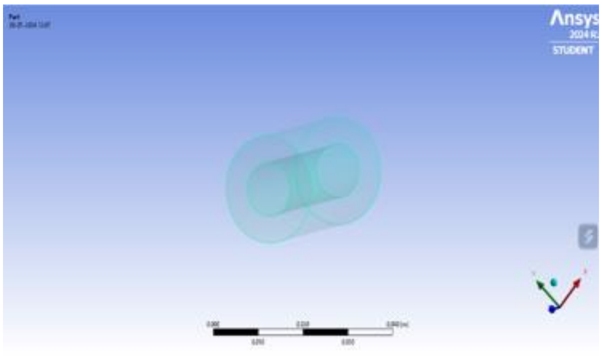

Figure 1 CAD Model of Heat Exchanger

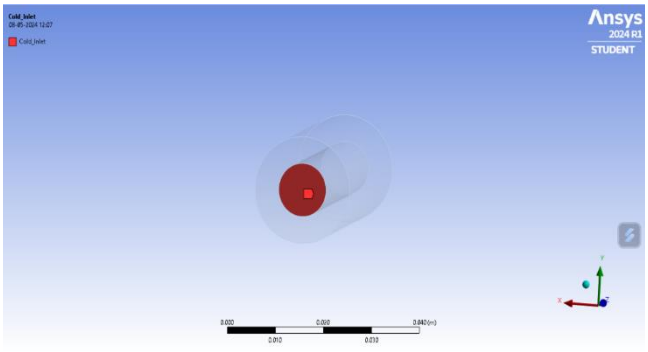

Figure 2 Cold inlet CAD Model

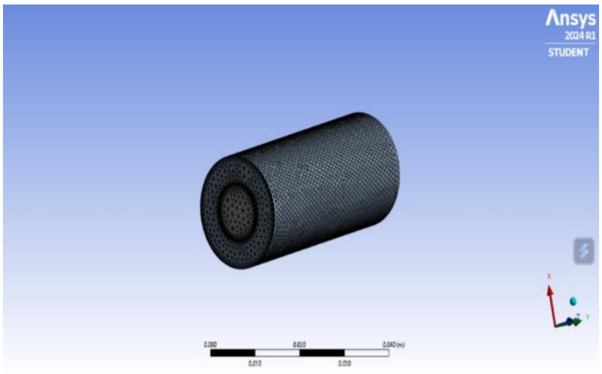

Figure 3. Mesh Model of Double pipe heat exchanger

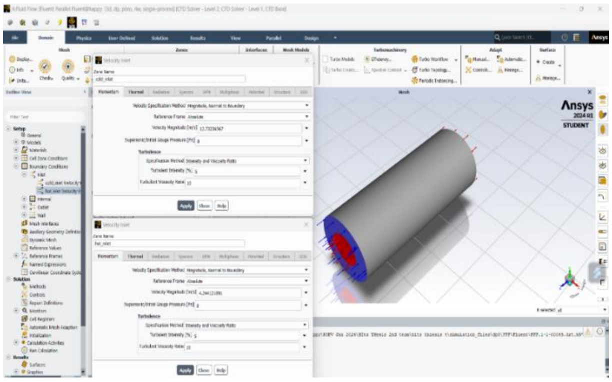

Figure 4. Mesh Model of Double pipe heat exchanger

Simulation Result

The results predicted by the CFD simulation for the different models of double pipe heat exchanger are shown in figure shown below. These simulation results which are mentions in Figure 5 We have used colored contours for these sections of the double pipe heat exchanger. These cantors are provided the detailed result of hot outlet temperature (T_3) and cold outlet temperature (t_2).

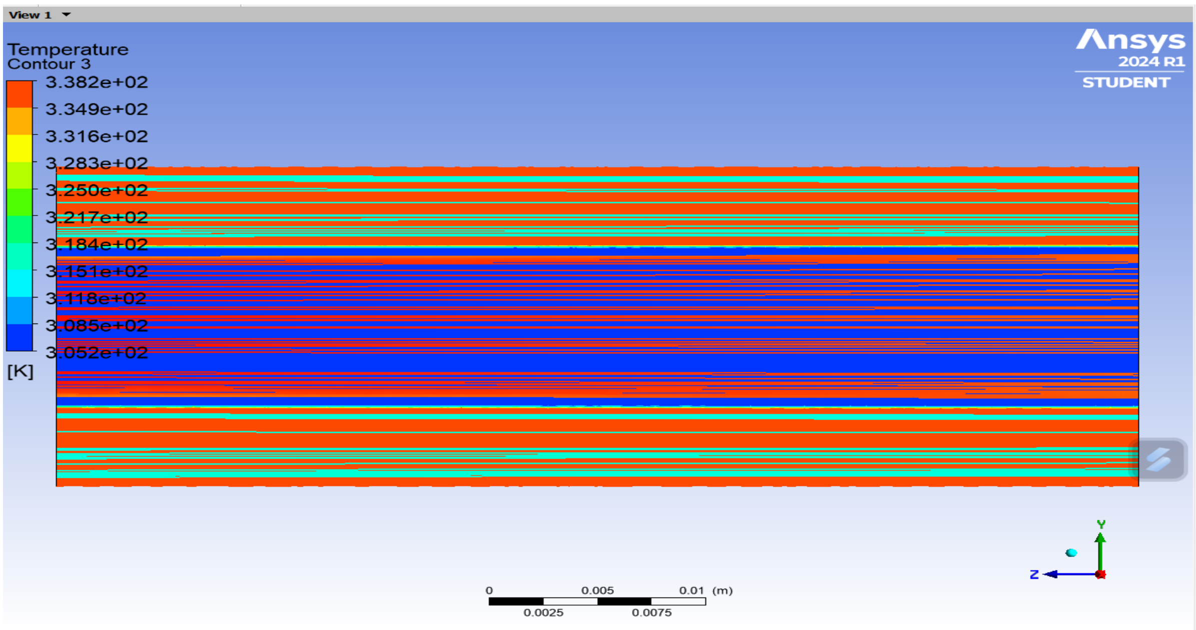

Figure 5. Outlet temperature hot water sample 1

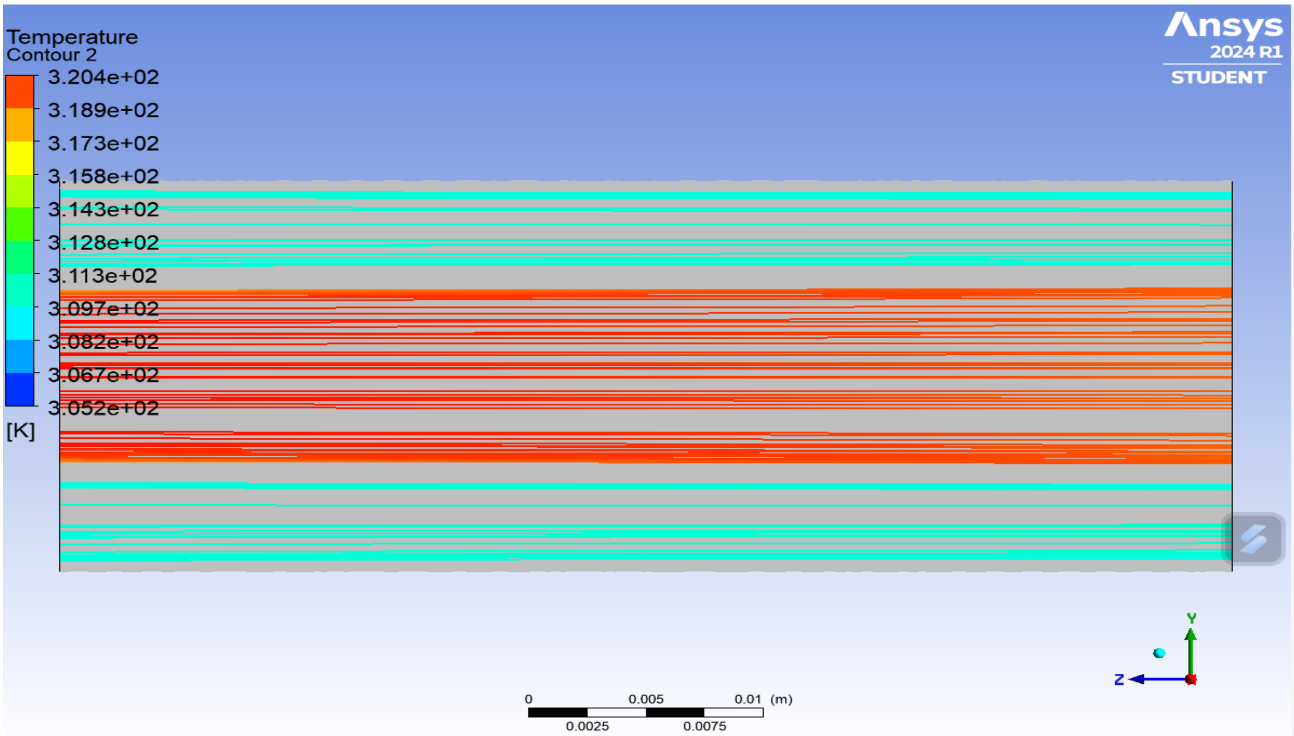

Figure 6 Outlet temperature cold outlet sample 1

Table 4. Simulated result according to DOS

Simulation No.	**Input Parameters**				**Responses**	
	MFR of hot fluid m_h	MFR of cold fluid m_c	hot water inlet temperature	cold water inlet temperature	Hot water outlet temperature	Cold water outlet

			(T_1)	(t_1)	(T_2)	temperature (t_1)
1	1	1	65	32	60	47
2	1	2	70	34	50	37.9
3	1	3	75	36	53.6	38.9
4	2	1	70	36	53.8	39.3
5	2	2	75	32	53.5	43.5
6	2	3	65	34	53.6	43.6
7	3	1	75	34	48.7	36.9
8	3	2	65	36	48.9	36.8
9	3	3	70	32	55.1	36.9

4. Results and Discussion :

4.1. Analysis of Variance for performance score Hot water outlet temperature (T_2)

ANOVA, a statistically based objective decision-making tool, is employed to detect differences in the average performance among groups of tested items. It aids in formally assessing the significance of all main factors and their interactions by comparing the mean square against an estimate of experimental errors at specific confidence levels, as illustrated in Table 4. From Table 4, it can be observed that the cold-water inlet temperature (t_1) has the maximum effect on the hot water outlet temperature, accounting for 48.44%. This is followed by the mass flow rate (MFR) of the cold fluid at 22.38%, the MFR of the hot fluid at 21.62%, and the hot water inlet temperature at 7.55%.

Table 5. Analysis of Variance performance score Hot water outlet temperature (T_2)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
MFR of hot fluid mh	2	21.482	10.741	*	*
MFR of cold fluid mc	2	22.229	11.114	*	*
hot water inlet temperature	2	7.496	3.748	*	*
cold water inlet temperature	2	48.109	24.054	*	*
Error	0	*	*		
Total	8	99.316			

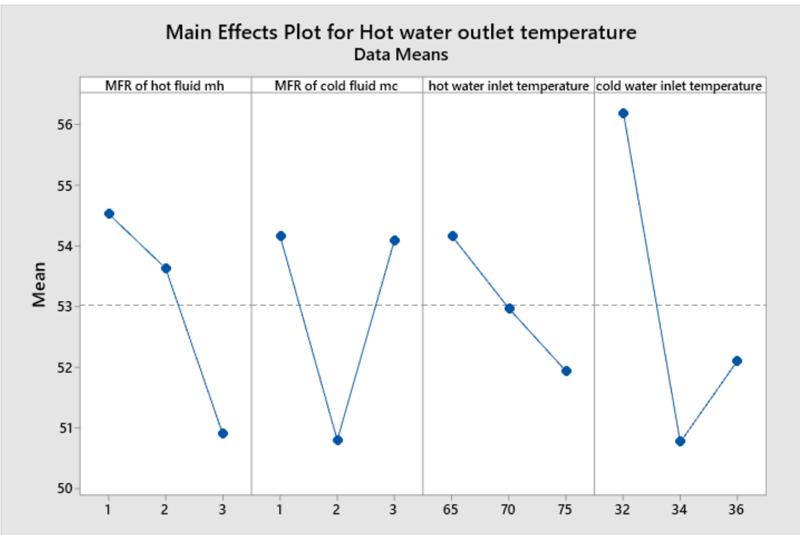

Figure 7. Effect of process parameter on hot water outlet temperature

Observations from Figure 7 reveal that the optimal values for the hot water outlet temperature (T_2) are achieved with a mass flow rate of the hot fluid (m_h) at 3 Kg/min, a mass flow rate of the cold fluid (m_c) at 2 Kg/min, a hot water inlet temperature (T_1) of 75°C, and a cold-water inlet temperature (t_1) of 34°C.

4.2. Analysis of Variance for performance score cold water outlet temperature (t_2)

ANOVA serves as a statistically grounded, objective decision-making tool employed to detect any disparities in the average performance across groups of tested items. It aids in formally evaluating the significance of all primary factors and their interactions by comparing the mean square against an estimation of experimental errors at predetermined confidence levels, as presented in Table 6 . From Table 6, it can be observed that the mass flow rate (MFR) of the hot fluid has the greatest impact on the cold-water outlet temperature, accounting for 43.61%. This is followed by the hot water inlet temperature at 27.29%, the cold-water inlet temperature at 24.94%, and the MFR of the cold fluid at 4.14%.

Table 6. Analysis of Variance performance score cold water outlet temperature

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
MFR of hot fluid mh	2	47.849	23.924	*	*
MFR of cold fluid mc	2	4.542	2.271	*	*
hot water inlet temperature	2	29.949	14.974	*	*
cold water inlet temperature	2	27.369	13.684	*	*
Error	0	*	*		
Total	8	109.709			

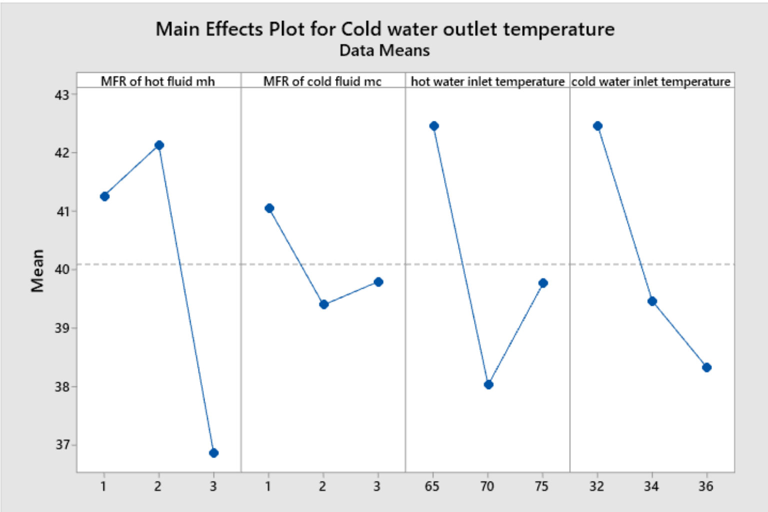

Figure 8 Effect of process parameter on cold water outlet temperature

From figure 8 it is observed that the optimum value for cold water outlet temperature (t_2) are MFR of hot fluid (m_h=2 Kg/min), MFR of fluid (m_c=1 Kg/min), hot water inlet temperature (T_1=65 ºC) and cold-water inlet temperature (t_1=32 ºC).

5. Conclusions :

In present study following are the results and concluding remarks which have been obtained during the above research attempt:

- Numerical simulation were perform by using ANSYS fluent for predicting the outlet temperature of hot and cold fluid successfully.
- COPRAS method is used for multi objective optimization of double pipe heat exchanger.
- The top three optimum experiments for the double pipe heat exchanger are simulation No 09 (MFR of hot fluid = 3 Kg/min, MFR of cold Fluid = 3 Kg/min, hot water inlet temperature 70 ^{O}C, cold water inlet temperature 32 ^{O}C), simulation number 3 (MFR of hot fluid = 1 Kg/min, MFR of cold Fluid = 3 Kg/min, hot water inlet temperature 75 ^{O}C, cold water inlet temperature 36 ^{O}C), and simulation number 4 (MFR of hot fluid = 2 Kg/min, MFR of cold Fluid = 1 Kg/min, hot water inlet temperature 70 ^{O}C, cold water inlet temperature 36 ^{O}C).

- The optimum value for hot water outlet temperature (T_2) are MFR of hot fluid (m_h=3 Kg/min), MFR of fluid (m_c=2 Kg/min), hot water inlet temperature (T_1=75 ºC) and cold water inlet temperature (t_1=34 ºC).
- It is observed that the optimum value for cold water outlet temperature (t_2) are MFR of hot fluid (m_h=2 Kg/min), MFR of fluid (m_c=1 Kg/min), hot water inlet temperature (T_1=65 ºC) and cold water inlet temperature (t_1=32 ºC).

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