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Performance of Working Fluids in a Waste Heat Recovery System Using Heat Pipes

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Abstract*: Waste heat recovery systems are used to recover the waste heat in all possible ways. It saves the energy and reduces the man power and materials. Heat pipes have the ability to improve the effectiveness of waste heat recovery system. The present investigation focuses to recover the heat from heating, ventilation, and air condition system (HVAC) with three different working fluids refrigerant (R410a) and nano refrigerants(R410a+Tio_2, R410a+Al_2o_3). Design of experiment was employed, to fix the number of trials. Fresh air temperature, flow rate of air, filling ratio and mass volume of nano particles are considered as factors. The responses effectiveness, thermal resistance and heat gained at evaporator section are considered. The results were analyzed using Response Surface Methodology.

Key words : Heat pipe, waste heat recovery system, Nano refrigerants, Nano Particles,Tio_2, Al_2o_3, RSM

I. INTRODUCTION

Growth in population and global warming have increased the energy demand for heating ventilation and air conditioning [HVAC] systems. HVAC ensures the indoor air quality which is very essential. The recent investigations are focused on to reduce the energy consumption for HVAC as major portion of being consumed by HVAC. Waste heat recovery is one of method to reduce the energy required for HVAC systems. Air to air heat exchangers are needed for recover the heat from HVAC systems . To improve the efficiency, heat pipes have been found more suitable. Heat pipe is a heat conducting device that would transfer/recover heat without any additional energy and with minimum loss. Heat pipe design is flexible according to its application and it can be designed. Initial investigations are focused on the material of wick, angle of the inclination, filling ratios and shape. Investigations on working fluids are gaining more attention on now days. The working fluids have been selected based on the temperature range of heat pipe. Some of investigations on waste heat recovery system using heat pipes are reviewed. S.Seshan et al., [1] suggested using a heat pipe in waste heat recovery system (WHRs) to improve the effectiveness. Littwin et al [2] used heat pipes for heat recovery system from fire tube boilers. The advantages are compact design, reduction in thermal induced stress, improved efficiency and easy to clean. Peretz [3] reported the heat transfer effectiveness depends on the number of rows and heat capacity of working fluid. Azad et al., [4] simulated the thermal performance of heat exchanger row by row. Copper – water heat pipes were investigated by the many investigators like Chi [5] Dunn and Ray [6] Seshan and Vijayalakshmi [7] for its compatibility within the temperature range 100° to 150°. Akyart et al., [8] simulated to recover waste heat from gas turbine using steel – water heat pipe at minimum temperature range. After their investigation they positively reported for recovery system using heat pipe. S.b.Riffat [9] investigated self finned heat pipe exchanger for natural ventilated building for cooling purpose. The heat pipes were arranged in four rows. M.H.Habeebullah et al., [10] experimentally tested recovery system from exhaust gases using heat pipe. It was able to recover the heat up to .93 %. S.H.Noie et al., [11] designed heat pipe using methanol as working fluid for waste heat recovery system to recover the cooling from surgery room. After experimental investigation they recommended that the effectiveness of the system increased due to finned tube, increase in the number of rows and proper insulation. Feng yang et al., [12] recovered the heat from engine exhaust and proved heat pipes (steel – water thermosyphon) were more effective in recovery system and the heat transfer rate also increased between the air to air. Francisco Javier et al., [13] tried to improve the indoor air quality by means of recovery system by adopting heat pipe technology and considered parameters like temperature, flow rate of air and relative humidity. Best results were obtained in heat pipe assisted recovery system. M.S.Soylemez [14] optimized the heat recovery system for finding effective temperature. Design optimization was done by Yu-ze-tao et al., [15] using NTU methods. Song lin et al [16] implanted and tested the heat pipe heat exchanger for indoor dehumidification process. The study recommended the CFD analysis to predict the thermal performance of heat pipe heat exchanger. The survey indicates a two step process for preparation of nano fluid in heat pipes. It was concluded that addition of surfactant reduces the heat transfer. Fins are attached to outside of heat pipes in the investigation of finned gravitational heat pipes are used. Refrigerant and nano refrigerators have been tested with different filling ratio, temperature, airflow rate and mass concentration of nano particles. The experiment has been conducted based on the design of experiments.

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Experimental Setup

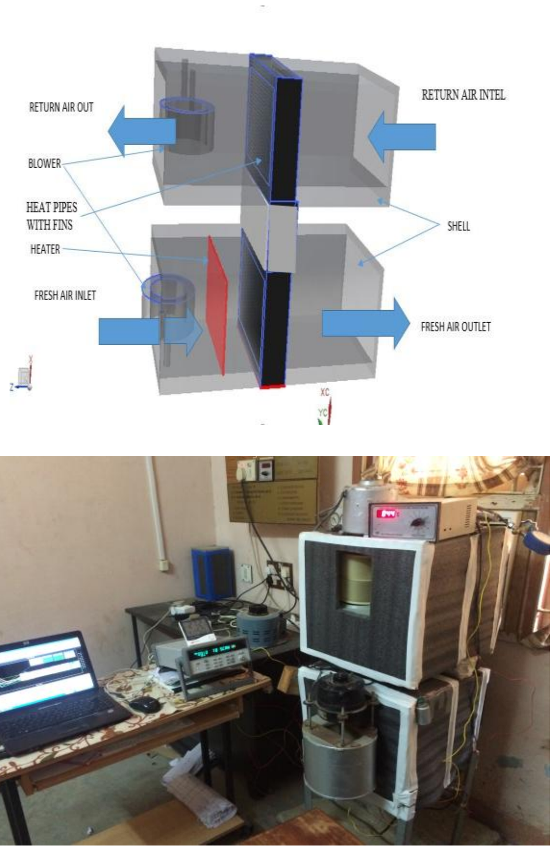


Figure 1: Schematic of Experimental setup and actual setup

The schematic of experimental setup is shown in Fig. 1. It assists two air ducts of 0.4 x 0.4 m^2 cross section area and equipped with finned tube heat pipe heat exchanger. Return air and fresh air have been made to flow in these ducts in cross flow without mixing. The duct has been well insulated to minimize the losses. In the evaporator section, fresh air is heated with the help of electrical coil heater to find optimum temperature. In practical application the heater is not required. Atmospheric temperature has been found to be sufficient for desired level. The heat exchanger consists of 68 copper tubes having a diameter of 10 mm arranged in 4 rows in a zig-zag manner. The heat pipes with a wick of 0.2 mm diameter wire mesh has been used. The heat pipes were provided with fins of thickness of 0.5 mm. The input power has been varied with the help of an autotransformer. Speed adjustable blowers were used in both the ducts to vary the flow rate of air. The temperature distribution at the wall of heat pipes and surface of fins have been measured with the help of T type thermocouple. Three of them are provided at the side of evaporator, three on condenser side and five have been provided at the adiabatic section and air ducts. All the thermocouples were connected to the Agliant Datalogger. The velocity of air for both condenser and evaporator sections were measured using vane type anemometer.

Test procedure

The study was to find out the enhancement of effectiveness in the heat pipe heat exchanger by waste heat recovery system. The flow rate of air was controlled by blowers. The fresh air temperature was varied using electrical heating coil by adjusting the autotransformer while the return air temperature was maintained as a constant.

The heat rejected from the air stream in the evaporator section can be calculated as

$$Q = m\, C_p\, (T_i - T_o) \qquad (1)$$

The effectiveness ($\in$) of heat pipe heat exchanger at evaporator side is represented as,

$$\in = \frac{T_i - T_o}{T_i - T_R} \qquad (2)$$

Where m is the mass flow rate of air in m/s, C_p is the specific heat of air in J/kg/K, T_i is the inlet temperature of fresh air in K, T_o is the exit temperature of the fresh air in K and T_R is the return air temperature in K.

RESULT AND DISCUSSION

The experimental values of the effectiveness have been used in the RSM. A regression analysis is carried out to develop a best fit model to the experimental data. Table 1, indicates the maximum and minimum levels of input parameters. Table 2Shows the analysis of variance (ANOVA) for effectiveness. The model is significant since the probability values less than 0.05. For this analysis A-Inlet air temperature, B-Flow rate of air, C-Filling ratio and D-Volume of nano are considered as variables. The interaction between (AB) has more significant than AC and BC for the all cases prediction R- square value, Adj R-Squared and adequate precision values are listed out in the corresponding tables. Based on ANOVA table the following empirical has been developed to predict the effectiveness of heat pipe heat recovery system using three different working fluids.

Case 1. R410a (Table 1) Case 2. R410a +Tio_2 Case 3. R410a +$A1_2O_3$

Table 1: Process Parameters

Parameters	Level		
	-1	0	-1
A. Inlet air temperature, °C	30	38	46
B. Flow rate of air, m/s	3.0	4.2	5.4
C. Filling ratio %	20	30	40
D. Nano fluid volume added, ml,	50	100	150

The Model F-value of 52.79 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant.

In this case A, B, C, AC, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 402.72 implies the Lack of Fit is significant. There is only a 0.01% chance that a "Lack of Fit F-value" this large could occur due to noise.

The model generated with RSM to estimate effectiveness is given below

ANOVA for Response Surface Quadratic Model for R410a

Table 2: ANOVA for Response Surface Quadratic Model for R410a

Analysis of variance table [Partial sum of squares - Type III]					
	Sum of		Mean	F	p-value
Source	Squares	df	Square	Value	Prob > F
Model	0.032466	9	0.00360729	52.7939696	<0.0001
A-Inlet air temperature	0.001382	1	0.001382453	20.2326979	0.0002
B-Flow rate of air	0.000392	1	0,000392163	5.73945033	0.0270
C-filling ratio	0.023906	1	0.023905613	349.867182	< 0.0001
AB	9E-08	1	9E-08	0.00131718	0.9714
AC	0.002601	1	0.002601	38.0665632	<0.0001
BC	0.000121	1	0.000121	1.77087818	0.1990
A^2	1.94E-05	1	1.93646E-05	0.28340816	0.6006
B^2	4.96E-07	1	4.96327E-07	0.00726392	0.9330
C^2	0.003955	1	0.003954955	57.8821722	<0.0001
Residual	0.001298	19	6.83277E-05		
Lack of Fit	0.001295	9	0.00014385	402.716793	<0.0001
Pure Error	3.57E-06	10	3.572E-07		
Cor Total	0.033764	28			
Std. Dev.	0.008266		R-Squared	0.9615498	
Mean	0.702055		Adj R-Squared	0.94333655	
C.V. %	1.177408		Pred R-Squared	0.81463928	
PRESS	0.006258		Adeq Precision	28.8971581	

Effectiveness =0.20787+0.012985 × Inlet air temperature-6.80790E-00

× Flow rate of air+0.020272× filling ratio-1.56250E-005 × Inlet air temperature × Flow rate of air -3.18750E-004 × Inlet air temperature × filling ratio+4.58333E-004 × Flow rate of air × filling ratio-2.65097E-005 × Inlet air temperature^2 -1.88626E-004 × Flow rate of air^2 -2.42466E-004 × filling ratio^2

Similarly ANOVA MODEL has been was obtained for nano refrigerants and their respective model are given below

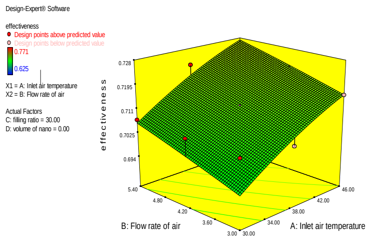
ANOVA for Response Surface Quadratic Model for R410a +Tio_2

Effectiveness =-2.21307 + 0.11187 × Inlet air temperature + 0.052700 × Flow rate of air +0.033041 × filling ratio-2.89258E-004×volume of nano-3.90885E-003 × Inlet air temperature × Flow rate of air - 1.09488E-003 × Inlet air temperature × filling ratio-1.81875E-005 × Inlet air temperature × volume of nano+2.22292E-004× Flow rate of air × filling ratio-1.86250E-004× Flow rate of air × volume of nano+4.00000E-006× filling ratio × volume of nano-6.82676E-004 × Inlet air temperature^2+0.014042 × Flow rate of air^2 +1.24250E-004×filling ratio^2+8.17150E-006 × volume of nano^2

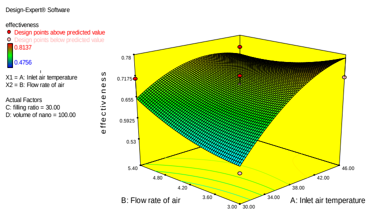
ANOVA for Response Surface Quadratic Model for R410a +Al_2O_3

Effectiveness = -1.82820+0.12470 × Inlet air temperature +0.13624× Flow rate of air-0.023048 × filling ratio -2.09014E-003× volume of nano-5.17969E-003 × Inlet air temperature × Flow rate of air +4.33437E-004×Inlet air temperature × filling ratio+1.01250E-004 × Inlet air temperature × volume of nano+3.08333E-004× Flow rate of air ×filling ratio+1.91792E-004 × Flow rate of air × volume of nano-3.74500E-005×filling ratio ×volume of nano -1.44973E-003 × Inlet air temperature^2+6.14641E-003 ×Flow rate of air ^{2}+1.43921E-004× filling ratio^2-7.42967E -006× volume of nano^2 .

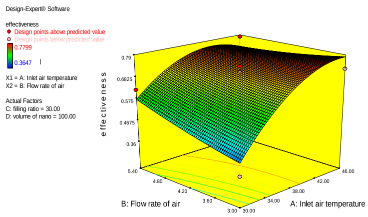
RSM technique has been effectively used to develop the empirical relationship between the experimental variable and the effectiveness.



R410a



R410a+Tio_2

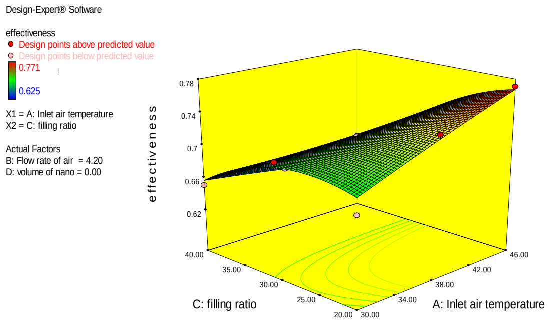


R410a+Al_2o_3

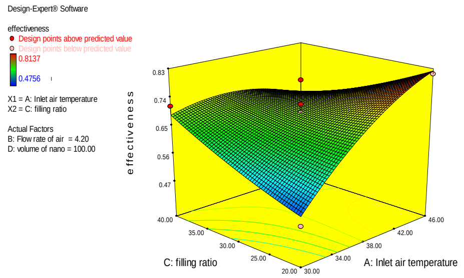
Figure 2. Effectiveness Vs Fresh air inlet temperature and flow rate of Air

It has been observed from Figure -2 R410 the effectiveness of the system increase with inlet air temperature, due to the fact that the temperature gradient between the evaporator and condenser section. Here working fluid plays a vital role in improving the effectiveness of the system. Increasing the inlet air temperature, results in more heat generation and the working medium R410 builds pressure and more vapor flows into condenser section. The exit air carries the heat away from the system. Similarly variation in filling ratio will also shows the effect in effectiveness.

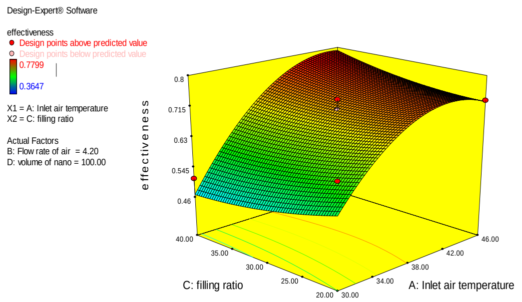
From anova results the effectiveness increases with increase of fresh air inlet temperature comparatively higher than the flow rate of air. Three fluids behave in similar fashion. Effectiveness considerably increased in the cases of nano refrigerants.



R410a



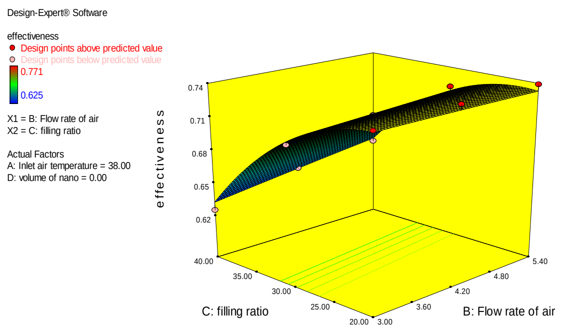
R410a+TiO_2



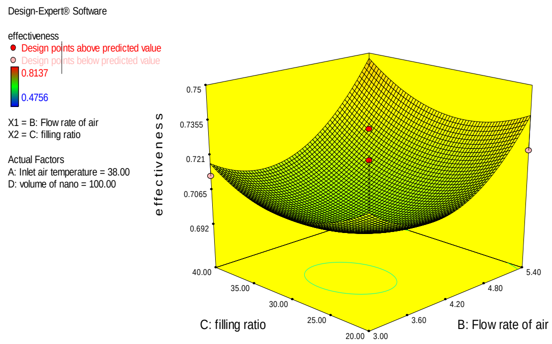
R410a+Al_2O_3

Figure 3. Effectiveness Vs Fresh air inlet temperature and Filling ratio

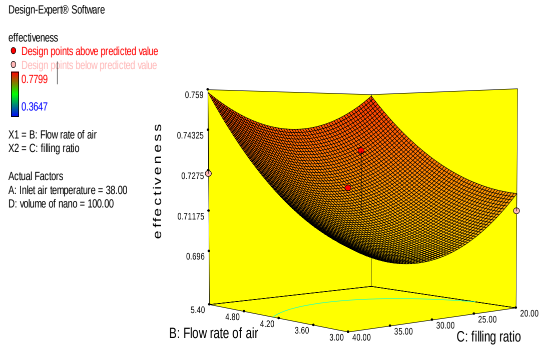
Figure-3. shows the comparison of factors Fresh air inlet temperature and filling ratio for three fluids. Both fluids(nano refrigerants) performs better at low filling ratio and high temperature, while R410a+Al_2O_3 shows better performance in high filling ratio and high temperature. This results indicates that the gas operated heat pipes perform better even at low filling ratios.



R410a



R410a+TiO_2



R410a+Al_2O_3

Figure 4. Effectiveness Vs Flow rate of air and Filling ratio

Figure-4 clearly shows that Flow rate of air is not having much impact compare to filling ratio.R410a having higher impact on effectiveness while comparing with filling ratio and flow rate. Remaining two fluids are performing better at high filling ratio and flow rate of air.

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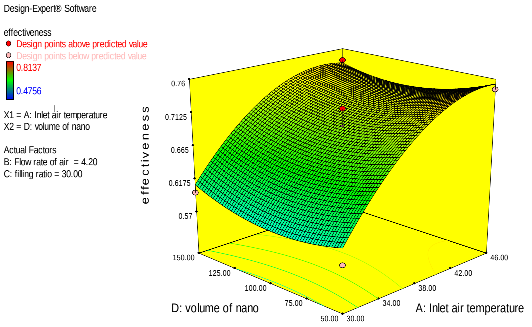
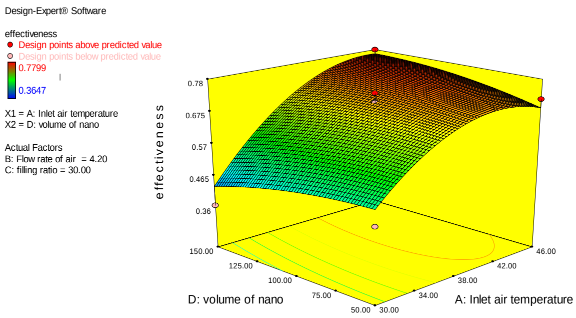


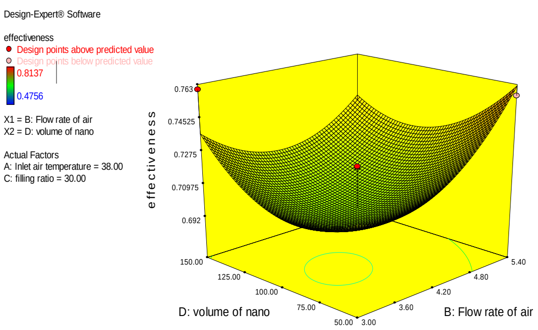
R410a+TiO_2



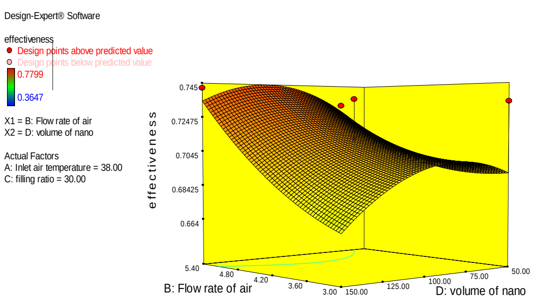
R410a+Al_2O_3

Figure 5. Effectiveness Vs Volume of nano and Fresh air temperature

Figure 5. Indicates the effectiveness increases with increase of volume of nano particle compare with fresh air inlet temperature. It also shows higher performance at high temperature, i.e nano particle absorbs more heat at evaporator section and releases the heat at condenser section.



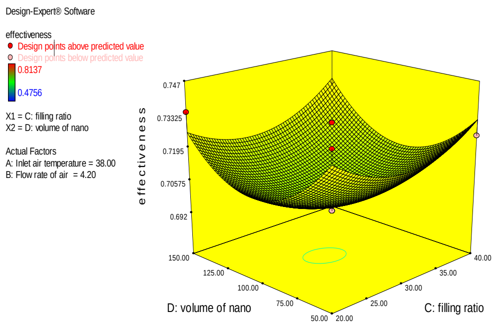
R410a+TiO_2



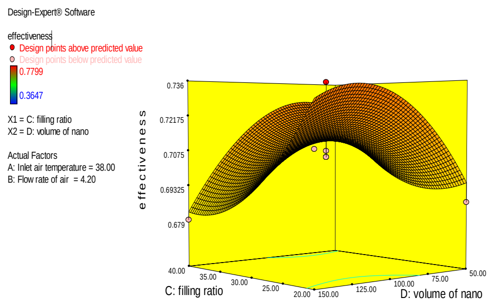
R410a+Al_2O_3

Figure 6. Effectiveness Vs Volume of nano and Flow rate of air

Flow rate of air also having some impact while comparing with volume of nano particle indicated in Figure-6.



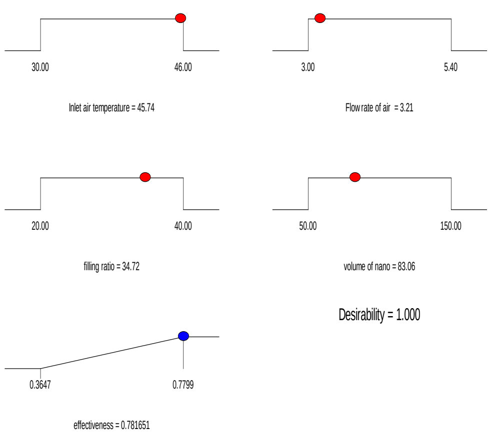
R410a+TiO_2



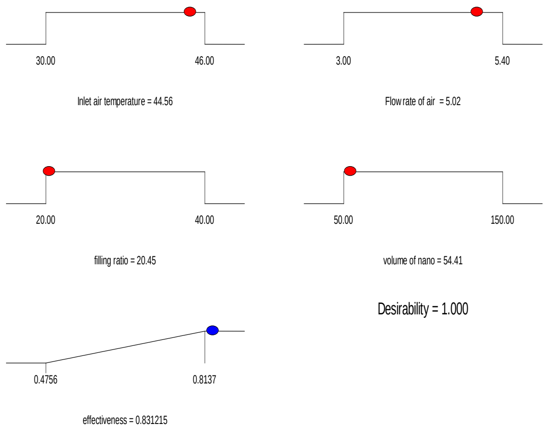
R410a+Al_2O_3

Figure 7. Effectiveness Vs Volume of nano and Filling ratio

In case of filling ratio and volume of nano partcle shows more impact at minimum and maximum level of input .considering all the factors, fresh air inlet temperature and the volume of nano particle having higher impact compare to the other factors. It shows the thermal resistance is high at lower level and reduces when the temperature increases. Heat carrying capacity of working fluid increases with increase of nano particle. The optimized result were shown in Figure-7.



R410a+TiO_2



R410a+Al_2o_3 R410a

Figure 8.Optimized results for R410a+Tio_2 and R410a+Al_2o_3

From Figure-8, its clearly identified, the value of effectiveness is high for R410a+ Al_2o_3 when compare to R410a+Tio_2 and the base fluid R410a

CONCLUSION

In this experiment, effectiveness of the heat pipe heat exchanger for three different working fluid are optimized by RSM. Now a days energy conservation is very important. This system saves energy by 10% and also predict the optimum effectiveness for each working fluid under varies filling ratio and inlet temperature. Addition of nano particle improves the effectiveness and also saves energy. Refrigerant filled heat pipes behave like a gas operated heat pipe. Even in minimum filling ratio it shows better performance. Inlet air velocity increase the effectiveness with the combination of increase in temperature. It gives maximum effectiveness at minimum filling ratio, maximum temperature and maximum air velocity. Less amount of Al_2o_3 (54.41ml) required to maximize the effectiveness. Al_2o_3 having better performance compare to Tio_2 and R410a base fluid.

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