Design and Optimization of a Condenser for HVAC Automobile System.

Parikshit A. Ladke[1], C.S. Choudhari[2]

[1]*M.E, Department of Mechanical Engineering, AISSMS, COE, Pune, India*
[2]*Professor, Department of Mechanical Engineering, AISSMS, COE, Pune, India*

Abstract - *This paper presents design and optimization of condenser for automobile air conditioning system. In automobile air conditioning system condenser plays a vital role. In automobile air conditioning R134a is widely used refrigerant which is not environmental friendly because of its higher GWP value hence there is need of to replace R134a with the environmentally friendly refrigerant . Design of condenser is done with help of various correlations and optimization of condenser is done by varying different geometric parameters. In optimization of condenser the optimum values obtained are 5.2 outer diameter, 2 rows and 12 fin per inch.*

Key Words: Alternative refrigerants, Condenser, Optimization.

1. INTRODUCTION

Refrigeration means the cooling or removal of heat from a system. The heating, ventilation and air conditioning of the automotive system are designed to provide comfort to driver and passengers. One of the important things to be fulfilled is comfort. Human comfort is the state of mind that expresses satisfaction with the surrounding environment according to American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).The main function of an air conditioning control system is to modulate the A/C system capacity to match the design condition and climate change, in order to maintain the indoor environment within desirable limits at optimum energy use levels during the entire drive duration. One of the important part in air conditioning system is condenser. The condenser is a heat exchanger located at front of the vehicle and receives high-pressure, hot refrigerant from the compressor. In air conditioning system refrigerant flows through the condenser and cools off from the wind when driving at highway speeds or air blowing from electric cooling fan. A condenser in which desuperheating of high temperature vapor changes the phase from vapour to liquid and sub cooling of condensate occurs. The condenser is an important device and the main function of condenser is to remove heat of hot vapor refrigerant discharged from the compressor. The hot vapor refrigerant contains the heat absorbed by the evaporator and the heat of compression due to the mechanical energy of the compressor motor. The heat from the hot vapor refrigerant in a condenser is removed by transmitting it to the walls of the condenser tubes and then from the tubes to the cooling medium. The cooling medium is generally air or water.

J.B. Copetti et al. done performance and optimization analyses of this heat exchanger with refrigerant R-134a. A computer program was developed to study the condenser pass to pass. The heat exchanger was divided into elements and, for each one, it was applied the e-NTU method. The simulation also made possible the thermal exchange optimization through the variation of the geometric parameters like refrigerant-side pass arrangement, number of tubes per pass, number of channels, height and width of the tube, density of fins and louver angle [1].

Vivek Sahu et al. experimental analysis of domestic refrigeration system by using wire-on-tube condenser with different spacing of wire, operating parameters like heat transfer rate , condenser pressure and condenser temperature , refrigerating effect is increased by using wire-on-tube condenser comparatively power consumption remain same as with air cooled condenser in a domestic refrigeration system they observed [2].

Patil Deepak P. et al. experimentally analyse performance of refrigeration system on three condensers viz. micro-channel, round tube and coil tube using R134a and R290 refrigerants. These three condensers are kept in parallel with other components of refrigerating unit while construction. The performance of refrigeration system is checked for each condenser at various cooling loads in the range from 175 W to 288 W. The performance of the condenser is measured for whole refrigeration unit in terms of coefficient of performance, efficiency of the system, heat rejection ratio, and heat rejected from condenser and heat transfer coefficient [3].

2. DESIGN

Design of condenser is done by using various correlations to calculate the heat transfer coefficient from air side and refrigerant side. Propane is used as refrigerant because its thermophysical properties are better as compared to recently used refrigerant in automobile condenser. It is eco-friendly natural refrigerant which has very low Global Warming Potential and zero Ozone Depletion Potential and has no direct impact on the greenhouse effect. Heat transfer of finned tube air cooled condenser is given by

$$Q = U_t A_t LMTD \tag{1}$$

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (2)$$

$$U_t = \frac{1}{\frac{1}{h_i}\frac{A_t}{A_i} + \frac{1}{h_f} + \frac{A_t}{A_i}\frac{r_i \ln(d_o/d_i)}{K_w} + \frac{1}{h_o \eta_o}} \quad (3)$$

2.1 Air side heat transfer

Air side heat transfer coefficient calculated using wang and chi correlation (2000).

$$j = \begin{cases} 0.108\mathrm{Re}_{dc}^{-0.29}\left(\frac{X_t}{X_l}\right)^{c_1}\left(\frac{p_f}{d_c}\right)^{-1.084}\left(\frac{p_f}{D_h}\right)^{-0.786}\left(\frac{p_f}{X_t}\right)^{c_2} & for\ N_r = 1 \\ 0.086\mathrm{Re}_{dc}^{c_3}.N_r^{c_4}\left(\frac{p_f}{d_c}\right)^{c_5}\left(\frac{p_f}{D_h}\right)^{c_6}\left(\frac{p_f}{X_t}\right)^{-0.93} & for\ N_r \geq 2 \end{cases} \quad (4)$$

Where

$$c_1 = 1.9 - 0.23\ln RE_{dc}$$

$$c_2 = -0.236 + 0.126\ln \mathrm{Re}_{dc}$$

$$c_3 = -0.361 - \frac{0.042N_r}{\ln \mathrm{Re}_{dc}} + 0.158\ln\left[N_r\left(\frac{p_f}{d_c}\right)^{0.41}\right]$$

$$c_4 = -1.224 - \frac{0.076(X_l/D_h)^{1.42}}{\ln \mathrm{Re}_{dc}}$$

$$c_5 = -0.083 + \frac{0.058N_r}{\ln \mathrm{Re}_{dc}} \quad c_6 = -5.735 + 1.21\ln\frac{\mathrm{Re}_{dc}}{N_r}$$

Outside heat transfer coefficient is given as

$$h = jG_{\max}C_p(P_r)^{-2/3} \quad (5)$$

2.2 Fin efficiency

To determine the overall surface efficiency for a finned tube heat exchanger, it is necessary to determine the efficiency of the fins. Fin efficiency is calculated using Schmidt (1945) correlation the empirical relation for the equivalent radius is given by

$$\frac{R_e}{r} = 1.27\psi(\beta - 0.3)^{1/2} \quad (6)$$

The coefficients ψ and β are defined as

$$\psi = \frac{X_t}{2r} \text{ And } \beta = \frac{1}{X_t}\left(X_l^{\,2} + \frac{X_t^{\,2}}{4}\right)^{1/2}$$

The fin efficiency can be expressed as

$$\eta_f = \frac{\tanh(m.l)}{m.l} \quad (7)$$

Where, $l = R_e - r$

The total surface efficiency of the fin, η_o is therefore expressed as

$$\eta_o = 1 - \frac{A_f}{A_t}(1 - \eta_f) \quad (8)$$

2.3 Refrigerant side heat transfer

The refrigerant heat transfer is calculated using the Dittu-Boelter correlation which is valid for fully developed flow in circular tubes with moderate temperature variations (Incropera& DeWitt, 1996).

$$Nu_D = 0.023\mathrm{Re}_D^{0.8}\mathrm{Pr}^{0.3} \quad (9)$$

The two-phase flow heat transfer model developed by Shah is a simple correlation which is given as

$$\bar{h}_{TP} = \bar{h}_L\left[(1-x)^{0.8} + \frac{3.8x^{0.76}(1-x)^{0.04}}{p_r^{\,0.38}}\right] \quad (10)$$

For complete condensation, the mean two-phase heat transfer coefficient reduces to the following expression,

$$\bar{h}_{TPM} = \bar{h}_L\left(0.55 + \frac{2.09}{p_r^{\,0.38}}\right) \quad (11)$$

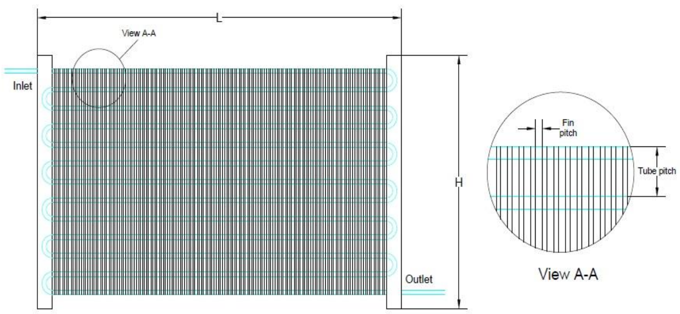

Fig -1: Condenser

3. OPTIMIZATION

When designing and optimizing the condenser to yield the COP of the air conditioning system there are a large number of parameters that can be varied. For this investigation, the optimization done through by varying the geometric design parameters specific to the condenser coil. As part of the optimization process, comparisons are made between the seasonal performances of air-conditioning systems with condensers of various geometric configurations. There are a large number of condenser coil geometric design parameters that can be varied in order to optimize the seasonal performance of an air-conditioning system. These parameters include the tube diameter, the tube spacing, the number of refrigerant parallel flow circuits, the number of tubes per refrigerant parallel flow circuit, and the fin spacing or pitch.

4. RESULTS AND DISCUSSIONS

The geometric parameter varied with fixed condenser frontal area is the tube diameter. The frontal area, the number of rows, the fin pitch, the tube spacing and the number of tubes per circuit are all maintained at the values utilized for the base configuration. Figure 2 shows the effect of varying the tube diameter on the coefficient of performance of automotive condenser. in these case different diameter of tube are optimized while designing it is observed that there is huge impact on varying the condenser tube diameter at the early stage it linearly increases after some interval it goes on decreasing as the diameter increases above 5.2 mm. Diameter 5.2 mm gives the better coefficient of performance as compared to the other diameter. The optimum value obtained while varying the tube diameter is 5.2 mm and it give the optimum result of coefficient of performance.

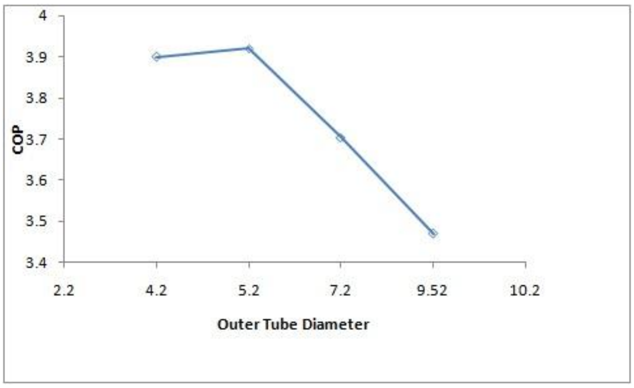

Chart -1: Effect of outer diameter on COP

The next geometric design parameter varied while fixing the condenser frontal area is the fin pitch. The frontal area, tube diameter, number of rows, number of tubes per circuit and the tube spacing are all fixed to the values of the base configuration. Figure 3 shows the effect on the coefficient of performance by varying the fin pitch of the condenser. while optimizing the condenser by varying the fin pitch per inch it is observed that the at the initial stage coefficient of performance is less as the fin pitch increases the coefficient of performance is going on increasing up to 12 fin per inch it goes on increasing after that it will goes on decreasing. At 12 fin per inch gives the optimum result related to the coefficient of performance.

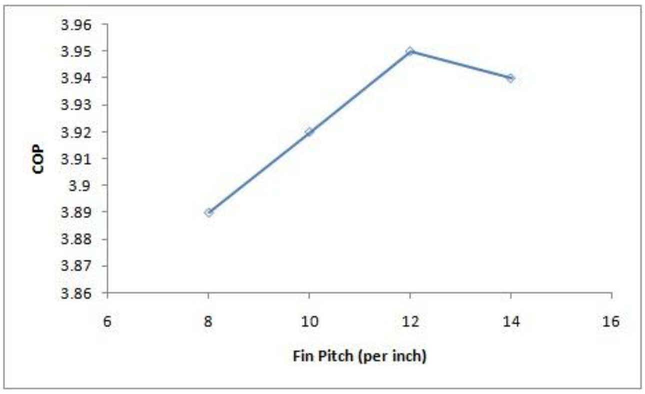

Chart -2: Effect of fin pitch on COP

The number of tubes per circuit, fin spacing, tube diameter, frontal area, and tube spacing are all fixed to the values of the base configuration figure 4 shows the effect of the air velocity on the seasonal COP for varying numbers of rows. For automotive air conditioning system condenser when the number of rows is 2 is gives the optimum result i.e optimum coefficient of performance of the system but as the number of rows increases the coefficient of performance is going on decreasing also less than two number gives poor result as compared to the 2 number of rows.

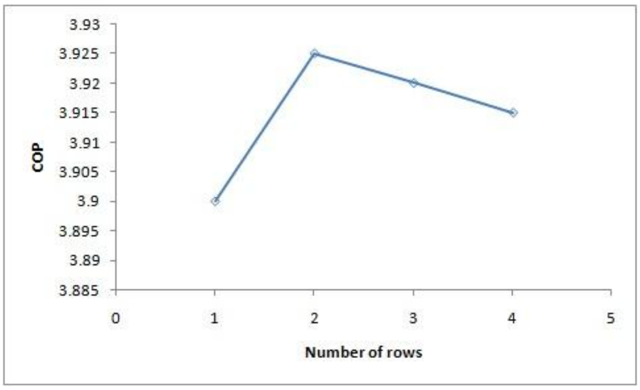

Chart -3: Effect of Number of rows on COP

CONCLUSIONS

In optimization it is concluded that by keeping the frontal area of condenser constant and varying geometrical parameter it is observed that as the outer diameter increases the COP of the system is decreases. Also from varying the number of rows and fin per inch it is concluded that at 12 fins per inch gives better performance and at 2 number of rows gives better performance.

REFERENCES

[1] S. Sharmas Vali and M. L. S Deva Kumar (2011) ,Experimental Analysis of the Effect of Varying the Condenser FINS Spacing on Vapor Compression Refrigeration System Performance,International Journal of Mechanical Engineering Volume 4.

[2] J.B. Copetti and M.H. Macagnan (2009), design and optimization of minichannel parallel flow condensers, Seventh International Conference on Enhanced, Compact and Ultra-Compact Heat Exchangers: From Microscale Phenomena to Industrial Applications.

[3] VivekSahu and PoojaTiwari (2013), Experimental Investigation of the Refrigerator Condenser By Varying the Fins Spacing of the Condenser, ISSN (Print): 2321-5747, Volume-1, Issue-1, 2013.

[4] Patil D.P. Bhangale J.H. and Deshmukh K.S. (2014),Review paper on refrigeration system using microchannelcondenser,International Research Journal of Mechanical Engineering (IRJME) Volume 1

[5] Mehendale Sunil, Aute Vikrant; and RadermacherReinhard (2014) ,Principles of Refrigerant Circuit Optimization in Single Row Microchannel Condensers, International Refrigeration and Air Conditioning Conference.

[6] Jignesh K. Vaghela (2015), Theoretical And Experimental Evaluation Of Automobile Air-Conditioning System UsingR134a,International Journal of Science, Technology & ManagementVolume No 04.

[7] Yoo, SeongYeon and Lee, DaeWoong (2004), An Experimental Study on Performance of Automotive Condenser and Evaporator,International Refrigeration and Air Conditioning Conference.

[8] Mao-Gang He, Xin-Zhou Song, Huan Liu, Ying Zhang (2014),Application of natural refrigerant propane and propane/isobutene in large capacity chest freezer, Applied Thermal Engineering 70 732e736.

[9] M. M. Rahman , H. Y. Rahman, (2012) , Hydrocarbon as refrigerant for domestic air conditioner: a comparative study between R22 and R290, Elixir Thermal Engg. 53 11976-11979.