HEFAT2007
5th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
Sun City, South Africa
Paper number:PP1

PERFORMANCE ANALYSIS OF AIR-COOLED CONDENSER USING MICRO-FIN TUBES

P.A.Patil
Assistant Professor and ASHRAE Associate Member
Department of Mechanical Engineering, AISSMS College of Engineering, Pune –01, India
Email ID: - papatil73@yahoo.co.in

Dr. S.N. Sapali
Assistant Professor
Department of Mechanical Engineering, College of Engineering, Pune –01, India
Email ID: - k_sapali@yahoo.co.in

ABSTRACT

In-tube condensation is quite common in refrigeration and air-conditioning applications. It is the binding choice for air-cooled and evaporative condensers. In-tube condensation is often thought of as a process of film-wise condensation of a vapor inside a tube. Since augmentation can result in smaller and more efficient devices, potential savings are quite substantial. An experimental program designed to investigate potential augmentation techniques has been carried out worldwide as part of a large study of in-tube condensation.

Copper circular smooth or enhanced tubes with plate aluminum fins on the air side (fin-and-tube heat Exchangers) are the usual geometry in air-cooled condensers. Enhanced tubes such as micro fin tubes are typically made of copper and have an outside diameter from 4 to 15 mm, a single set of 50-70 fins with helix angle from 6 to 30°, fin height from 0.1 to 0.25 mm, triangular or trapezoidal fin shapes with an apex angle from 25 to 90°.

Air-cooled condensers operate at a greater condensing temperature than water-cooled condensers; hence the compressor (and the refrigeration system) delivers 15 to 20% lower capacity. Therefore one has to use a larger compressor. At the same time, the compressor consumes greater power. Hence the air-cooled system has a lower overall energy efficiency. This paper manly emphasis on increase in overall performance of the air-cooled condenser.

The objective of this study is to analyze the theoretical performance of air-cooled condensers using micro-fin tubes. The enhancement factor (ratio of heat transfer coefficient of micro-fin tube to heat transfer coefficient of plane tube) considered to be 1.5. The overall performance of condenser for different refrigerants has also been studied. The refrigerants used for study are R-134a, R-404a and R-22.The performance of condenser is analyzed for 55^0 C condensing temperature because most of the air cooled condensers in India are working on this condensing temperature. The % saving in fan power is estimated upto 90%with the use of micro-fin tubes, 29% reduction in compressor power; and 17% increase in cooling capacity, on the other hand the % reduction in size of condenser is up to 32%. It is also found that the performance of condenser also varies with the refrigerant used.

Keywords: - Air-cooled, condenser, in tube condensation, enhancement, microfintubes, energy consumption, overall performance.

INTRODUCTION

Heat transfer in air-cooled condenser is a function of the tube inside (hi) and outside (ho) film coefficients, the inside (Ai) and outside (Ao) areas of the tube. The $\mathbf{h_O}$ (airside) is very much lower compared to the hi (refrigerant side). The overall heat transfer coefficient (Ut) increases with increase in value of hi, ho, Ai. The total outside heat transfer area including fin area (A_t) increases rate of heat transfer (q) but decreases Ut. (e.g.100% increase in At will cause 40% reduction in Ut and 20% increase in q). The noise level put the limit on face velocity, which increases ho, consequently rate of heat transfer. The use of enhanced tubes such as micro fin tubes increase both hi and Ai. The rate of heat transfer, q from an air-cooled condenser is given by the standard expression:

$$q = U_t A_t \Delta T_m$$

Heat transfer takes place sequentially from the refrigerant to the inside wall of the tube, through the tube wall, to the outside wall of the tube to the fins and to the ambient air flowing over the coil. Hence, the overall heat transfer coefficient, **Ut** is a function of the tube inside and outside film coefficients, the thermal conductivity of the tube material, **k** and the inside and outside areas of the tube.

LITERATURE REVIEW

The literature review of micro fin tubes has been taken from International journals for getting optimum value of enhancement factor. The contribution of various researchers is as follows;

Schlager et al. (1987) has reported an extensive literature search on micro-fin tubes and other forms of in-tube enhancement. For condensation, a survey of three publications showed typical values of heat transfer enhancement factors varying from 1.6 to 2.0[1]. Schlager, Pate, Bergles (1990) studied evaporation and condensation heat transfer and pressure drop in horizontal, 12.7 mm micro fin tubes with R-22. The enhancement factors range from 2.3 to 1.6 for evaporation and 2.0 to 1.5 for condensation[2]. Eckels Pate (1991) reported evaporation and condensation of HFC-134a and CFC-12 in a smooth tube and a micro-fin tube. During condensation the HFC-134a HTC were about 25% higher [3].
Eckels, Doerr, Pate (1994) reported In-tube heat transfer and pressure drop of R-134a and ester lubricant mixtures in a smooth tube and a micro-fin tube. The addition of the ester lubricant decreased the heat transfer coefficient during condensation in all cases. The pure R-134a HTC in the micro-fin tube was 100% to 200% higher than those in the smooth tube at the same mass flux[6]
Eckels, Tesene (1999) studied a comparison of R-22, R-134a, R-410a and R-407c condensation performance in smooth and enhanced tubes, A comparison of the performance of the different refrigerants reveals that R-134a has the highest HTC followed by R-22 and R-410a [4]. Smit, Meyer (2002) studied R-22 and zeotropic R-22/R-142b mixture condensation in micro fin, high-fin, and twisted tape insert tubes. It was found that micro-fins were more suitable as an enhancement method than the twisted tubes or high fins. Also, that the HTC and pressure drop decrease as the mass fraction of R-142b increases [5].

A number of studies have reported for various refrigerants for micro-fin tubes, but very less number of papers has been published on eco-friendly refrigerants and for operating conditions encountered in practice, such as effect of superheating, sub cooling, condenser pressure, temperature difference between refrigerant and cooling medium etc.

NOMENCLATURE

ΔT_m	^0C	Logarithmic temperature difference between refrigerant and air
Ut	[W/m ^{2}K]	Overall heat transfer coefficient based on total surface area (outer area + fin area)
Ai	m^2	Inside surface area
Ao	m^2	Outside surface area
At	m^2	Total surface area (Ao + A_{fin})
k	[W/m K]	Thermal conductivity
hi	[W/m ^{2}K]	Inside film coefficient
ho	[W/m ^{2}K]	Outside film coefficient
μ_f	Ns/m^2	Viscosity of liquid refrigerant
FV	m/s	Face velocity
η_f	%	Fin efficiency
T	K	Saturation temperature
cp_f	kJ/kg K	Specific heat of liquid refrigerant
C_1 C_2		Constants of proportionality obtained from performance data
T_H	K	Condensing temperature
T_L	K	Evaporating temperature
FP	W	Fan power
CP	W	Compressor power

OPERATING CONDITIONS

Evaporating temperature= 10 ^{O}C
Condensing temperature = 55 ^{O}C
Degree of superheat =18^{O}C
Degree of sub cooling = 3^{O}C

ANALYSIS

The performance analysis of air-cooled condenser using micro fin tubes has been carried out with the help of performance data of R-134a condensing unit provided by Indigenous Industry. It is based on certain assumptions as follows;

- The pressure drop in condenser is not considered in the analysis.
- Fan velocity assumed to be constant for obtaining performance curves except performance curve of fan power.
- The condensing temperatures assumed to be constant for obtaining performance curve of fan power.
- The wall resistance is neglected on account of high thermal conductivity of copper and low wall thickness.

The design calculations of plane tube air-cooled condenser are firstly validate with the help of available performance data. The simple mathematical analysis is done in excel using iteration technique.

The condenser used for analysis is having following specifications

Cooling Capacity = 3 TR (Tons of refrigeration) (for 10^{o}C evaporating temperature)
Size= 55.88cm X 45.72cm X 4R
Tube diameter= 9.52 mm (Plane tube)
No of fins = 12 to 13 fin/inch.

EQUATIONS USED

- $\frac{1}{Ut} = (\frac{At}{Ao} x \frac{Ao}{Ai})\frac{1}{hi} + \frac{1}{ho} x \frac{1}{\eta f}$ [7]
- $cp_f = 1.1978 + 0.00415T - 1x10^{-6}T^2 + 1x10^{-7}T^3 + 2.5 \times 10^{-9} T^4$[8]
- $(\ln\mu_f) = -3.3528 + 714.25/T - 0.19969 \times 10^{-2}T$[8]
- $Nu = 0.026 (Pr)^{1/3} (Re)^{0.8}$(for refrigerant side heat transfer coefficient)[9]
- $ho = 38 (FV)^{0.5}$[8]
- $FP = C_1 \times FV^3$[8]
- $CP = C_2 \times (T_H/T_L - 1)$[8]

Effect on cooling capacity

The capacity of air- cooled condensers various with the operating conditions such as ambient temperature, condensing temperature, overall heat transfer coefficient. With the surface area and the value of U being fixed capacity of any one condenser depends only on the mean temperature difference between the air and the condensing refrigerant. Since most air-cooled condensers come equipped with fans or blowers, the quantity of air circulated over the condenser is also fixed.[10] Thus the condenser capacity directly various with ambient temperature. The cooling capacity of system decreases with ambient temperature,as shown in Fig 1.

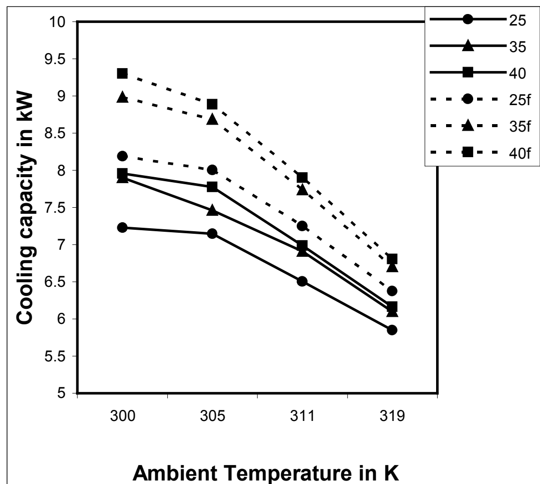

Fig 1:- Effect of microfining,fin-tube ratio and ambient temperature on cooling capacity

The use of micro fin tubes in the condenser improves the performance. The % rise in cooling capacity decreases with ambient temperature (as shown in Fig.1). During high ambient conditions when the cooling demand is more the micro fin tube condenser gives the 7 % more cooling than that of plane tube condenser. The cooling capacity also increases with fin-tube ratio. The micro fin tube condenser with 40 fin-tube ratio gives the 17% more cooling than that of plane tube condenser with 25 fin-tube ratio.

Effect on condensing temperature

The condensing temperature increases with ambient temperature. The use of micro fin tubes with high fin tube ratio maintains the low condensing temperature. It is found that for plane tubing with fin-tube ratio 25, the condensing temperatures are 54^0C and 71^0C for 27^0C and 46^0C ambient temperatures respectively. The micro fin tubing with fin-tube ratio 40 reduces the condensing temperatures to 49^0C and 62^0 C.

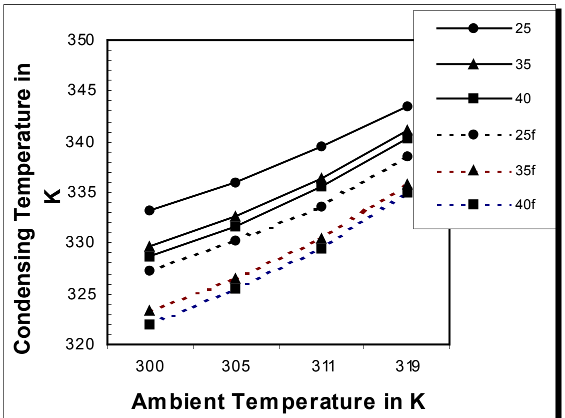

Fig2:-Effect of microfining,fin-tube ratio and ambient temperature on condensing temperature

Effect on compressor power

The compressor power increases with ambient temperature due to increase in condensing temperature. The use of micro fin tubing reduces the compressor power substantially. It is found that the compressor power reduces upto 29% using micro fin tubes.

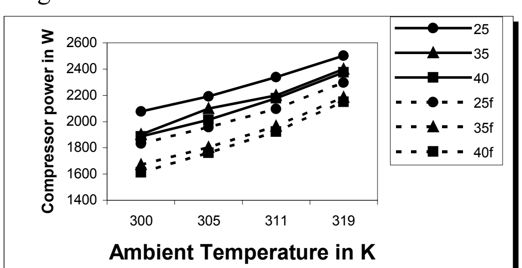

Fig3:-Effect of microfining,fin-tube ratio and ambeint temperature on compressor power

Effect on fan power

Fan, which is used for forced cooling can also be used to control compressor pressure. Because fan power increases in proportion to the cube of fan speed, energy consumption can be reduced substantially by slowing the fan. It is found that the fan power is reduced upto 90% using microfin tubes.

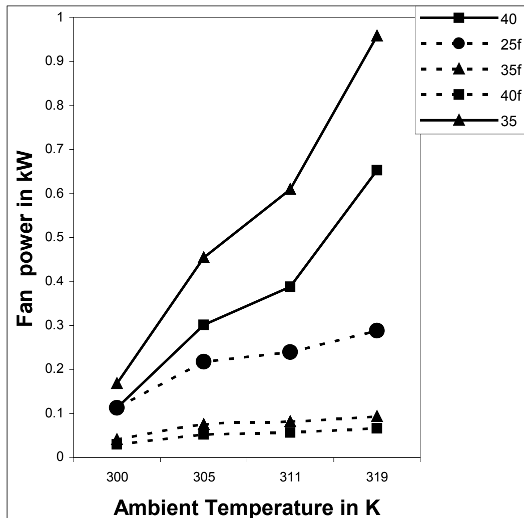

Fig 4:-Effect of microfining, fin-tube ratio and ambient temperatureon fan power

Effect on overall heat transfer coefficient

In air-cooled condensers external fining is provided in order to increase the airside film coefficient, consequently the overall heat transfer coefficient tends to decrease. The total outside heat transfer area including fin area (A_t) increases rate of heat transfer (q) but decreases Ut. (e.g.100% increase in At will cause 40% reduction in Ut and 20% increase in q). However the micro-fin tubes allow the higher fin-tube ratio because it enhances both q and Ut (due to increase in hi and Ai). It is also found that the ambient temperature has negligible effect on overall heat transfer coefficient (Ut), it slightly decreases with ambient temperature. The Ut increases up to 51.35% for micro fin tubing with fin-tube ratio 40 as compared to the plane tubing with same fin-tube ratio.

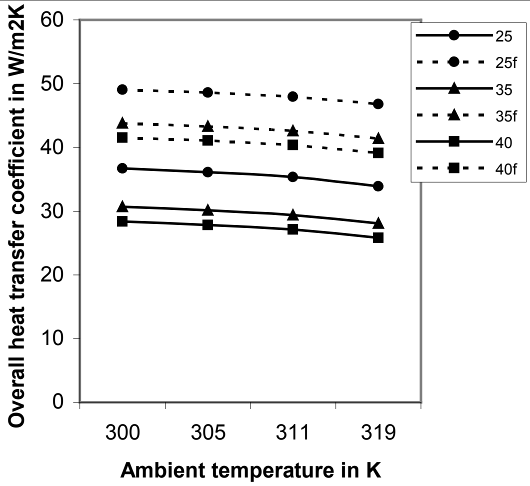

Fig5:- Effect of microfining,fin-tuberatio and ambient temperature on overall HTC

Effect on outer surface area

The outer heat transfer surface area mainly depends on overall heat transfer coefficient, rate of heat rejection and temperature difference between refrigerant and ambient air. The increase in ambient temperature demands more area due to decrease in temperature difference. The use of micro fin tubing reduces the surface area due to increase in Ut. It is found that micro fin tubing reduces the area by 32% for fin-tube ratio 40 as compared to the plane tubing with same fin-tube ratio. The % reduction in area decreases with decreasing fin tube ratio.

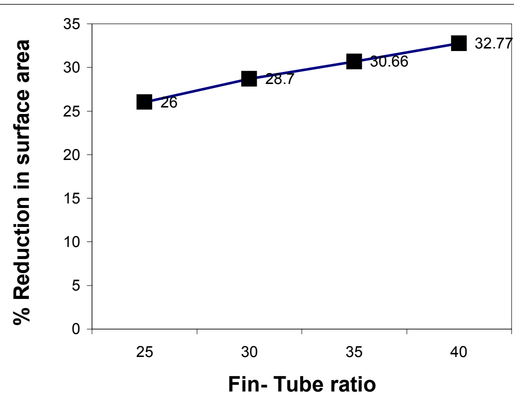

Fig 6:-Effect of microfining and fin-tube ratio on surface area

Effect on Coefficient of performance (COP)

The COP of the system decreases with ambient temperature. It increases with fin-tube ratio. But the COP of the system provided with micro fin tube condenser (fin-tube ratio 25) is always greater than that of plane tube condenser of any fin tube ratio. It is found that COP increases up to 28% for the micro fin tubing with 40 fin-tube ratio.

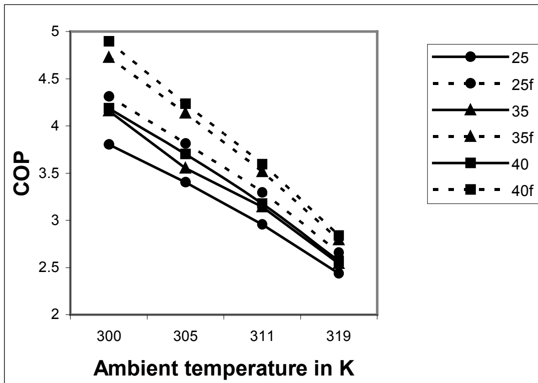

Fig7:- Effect of microfinning, fin-tube ratio and ambient temperature on COP

Effect on cooling capacity for different refrigerants

The micro fin tubing in condenser for commonly used refrigerants i.e. R-22,R-134a,R404A and R-507C has also been analyzed. It is found that R-134a system gives the better overall performance amongst the others. The performance of R-404a system is best for high ambient temperature. The performance of R-22 is average.

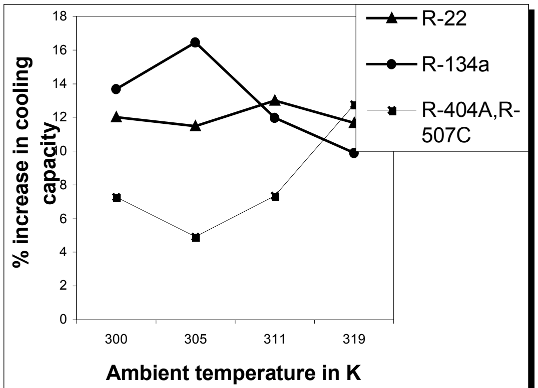

Fig No.8:- Effect of microfining,and refrigerant used on cooling capacity

CONCLUSION

Large number of in-tube condensers is manufactured each year. The augmentation can result in smaller more efficient devices, and substantial potential savings is quite possible.

The predicted performance of air-cooled condenser using micro fin tubes under similar operating conditions (with enhancement factor 1.5) shows great potential. The cooling capacity increases up to 17%, compressor power reduces upto 29%, fan power reduces upto 90%, and overall coefficient of performance upto 28%. The micro fin tube condenser performance is best for highest fin-tube ratio (40). It also allows to use high ambient temperature and gives 7% more cooling than that of same configuration of plane tube condenser. Increasing fin tube ratio can further increase the cooling capacity. Micro fining shows great promise for window air-conditioner because size of condenser reduces to 32% using micrfin tubes.

The condenser performance also varies considerably with refrigerant used. 134a system gives the better overall performance amongst the others. The performance of R-404a system is best for high ambient temperature. The performance of R-22 is average. Thus it is necessary to develop the performance co-relations considering all effects for optimum designing of equipment.

REFERENCES

[1] Schlager, L. M., Bergles, A.E. and Pate M.B. 1987. "A survey of refrigerant heat transfer and pressure drop emphasizing oil effects and in-tube augmentation." ASHRAE Transactions, Vol. 93, Part 1, pp. 392-416.

[2] Schlager,L.M.,Pate M.B.,,Bergles A.E. Nov. 1990. "Evaporation and condensation heat transfer and pressure drop in horizontal, 12.7-mm micro-fin tubes with refrigerant 22." ASME Journal of Heat Transfer.

[3]Eckels S. J.,Pate M.B. 1991-II. "Evaporation and condensation of HFC-134a and CFC-12 in a smooth tube and a micro-fin tube." ASHRAE Transactions.

[4] Steve J. Eckels, Brian A. Tesene. 1999-II. "A comparison of R-22, R-134a, R-410a, and R-407c condensation performance in smooth and enhanced tubes: Part I, Heat transfer." ASHRAE Transactions: Research.

[5] Smit F.J.,Meyer J.P. Oct. 2002. "R-22 and zeotropic R-22/R-142b mixture condensation in micro-fin, high-fin, and twisted tape insert tubes." ASME Journal of Heat Transfer.

[6].Steven J. Eckels, Doerr T.M.,Pate M.B. 1994-II. "In-tube heat transfer and pressure drop of R-134a and ester lubricant mixtures in a smooth tube and a micro-fin tube: Part II-Condensation." ASHRAE Transactions: Research.

[7].ASHRAE Hand book 2004, HVAC Systems and Equipment.

[8]Arora C.P."Refrigeration and Air conditioning", Tata Mc Graw- Hill Publishing Company Ltd., Second edition,2004

[9] Cengle Y.A." Heat Transfer", Tata Mc Graw-Hill Publishing Company Ltd., Second edition, 2003

[10] Roy J. Dossat" Principle of refrigeration" ,Prentice-Hall International, Inc.,Fourth Edition,1999