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Design of Roll Bond Evaporator for Room Air Conditioner using Eco-friendly Refrigerant, R-32 (DiFluoroMethane)

P.S.Ravi [1], Dr Arkanti Krishnaiah [2], Dr Boda Hadya [3], Dr Md. Azizuddin [4]

Research Scholar, Dept. of Mechanical Engineering, Osmania University, Hyderabad, India[1]

Professor & Head, Dept. of Mechanical Engineering, UCE, Osmania University, Hyderabad, India[2]

Assistant Professor, Dept. of Mechanical Engineering, UCE, Osmania University, Hyderabad, India[3]

Professor, Dept. of Mechanical Engineering, Deccan College of Engineering and Technology, Hyderabad, India [4]

ABSTRACT: Every refrigeration and air conditioning appliance uses an evaporator as a heat exchanger device which gives the desired cooling effect. Tube and fin type evaporators are more commonly used in air conditioners. Only domestic refrigerators use Roll bond evaporators as cooling plates. Roll bond evaporator gives more uniform cooling as compared to Tube and fin evaporator. A design of a roll bond evaporator for a room air conditioner, using eco friendly refrigerant R-32 is presented in this paper. Phase out of the refrigerant R-22 is approaching fast. An alternative to R-22 is presented and the design parameters are compared for the two refrigerants.

KEYWORDS: Eco friendly refrigerant, R-32, Roll bond evaporator.

I. INTRODUCTION

While the global warming phenomenon is on the rise, indiscriminate use of refrigeration and air conditioning appliances are also increasing. This has become a cyclic phenomenon. World is looking forward for ways to curb global warming, without compromising on quality of life. Air conditioning systems have to be designed so that their contribution to global warming is as minimum as possible. In Indian scenario, use of refrigeration and air conditioning devices is on rise. Last two decades has seen unprecedented rise in usage of these products. India has seen that the consumption of HCFCs has tripled, compared to that of consumption five years back. This behaviour is expected to continue. A well defined roadmap for HCFC phase-out, with fixed goals, actions and timelines to control and reduce production and consumption of HCFCs has been formulated by The Government of India, in line with the accelerated control schedule for HCFCs under the Montreal Protocol.

With an aim of finding alternative solutions to this problem a roll bond evaporator is proposed to be used in room air conditioner. Further, the usage of eco friendly R-32 refrigerant in place of R-22 will contribute to reduction of global warming phenomenon. It is note-worthy to mention that the manufacturing process of roll bond evaporator is simple and cost of manufacturing is less.

II. RELATED WORK

Many researchers in their work have prominently pointed out the usage of roll bond evaporator as a heat exchanger device. P.S. Ravi, Dr Arkanti Krishnaiah et al. [1] have given a procedure for finding inside heat transfer coefficient has been for a roll bond evaporator using two phase correlations. Fieramonte, Luigi [2], have found out that the performance of roll bond evaporator is more. Thy experimented with different materials of different thickness for manufacture of roll bond evaporator. Chandrakant Patel [3] used a roll bond evaporator for cooling apparatus of computer sub system. Christian J.L Hermes et al. [4] experimentally validated that a numerical simulation model for

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plate type roll bond evaporators. Anderson SW et al. [5] have studied the flow of refrigerant R-22 through a horizontal tube and gave a correlation to find the heat transfer coefficient. Bio Pierre [6] in their publication studied the impact of Flow resistances of refrigerants which are in boiling conditions. Chawla J M [7] gave correlations of convective heat transfer coefficient for two- phase liquid-vapour flow. The flow through evaporator is predominantly two-phase; this correlation gives an insight of heat transfer coefficient taking viscosity of refrigerant into consideration. Lavin JG and EH Young [8] studied heat transfer characteristics of evaporating refrigerants in two-phase flow. Dembi NJ et al. [9] in their paper presented the effect of use of wire screens in D-X evaporators. Dhar P L [10], in his PhD Thesis, gave the procedure to Optimise a Refrigerating system. The procedure to design different types of heat exchangers of different geometry and for different conditions has been elaborated by Kern D Q [11]. Piert E L and H S Isbin [12] have given correlations for two phase flow in natural circulation evaporators. Heat transfer data books, Manuals from Heat transfer Research Institute, The Tubular Exchanger Manufacturers Association, Inc. (TEMA) etc have given practical approach to design a heat exchanger depending upon consumer needs. P.S. Ravi et.al [13] has given the procedure to design a roll bond evaporator using R-22 as refrigerant. P.S. Ravi et.al [14] in their research work have used eco friendly refrigerant R-410A for roll bond evaporator.

III. PROPERTIES OF R-32 (DI FLUORO METHANE)

The refrigerant to be used in the roll bond evaporator is Di fluoro methane (R-32). It is an eco friendly refrigerant. The properties of R-32 are listed below.

Molar mass	g/mol	52.02
Melting point	°C	-136.81
Boiling point (at 1.013 bar)	°C	-51.65
Temperature glide at 1.013 bar	K	0
Saturated liquid density at 25°C	kg/m^3	961
Saturated vapour density at boiling point	kg/m^3	2.987
Vapour pressure at: 25°C 50°C	 bar bar	 16.9 31.4
Critical temperature Critical pressure Critical density	°C bar kg/m^3	78.11 57.82 424
Latent heat of Vaporisation at 1.013 bar	kJ/kg	381
Thermal conductivity of liquid at 25°C Thermal conductivity vapour at 1.013 bar	W/(m.K) W/(m.K)	0.135 0.0124
Surface tension at 25°C	10^{-3} N/m	6.79
Solubility in water at 25°C Solubility in solvents		Insoluble Soluble in alcohols
Viscosity of liquid at 25°C Viscosity of vapour at 1.013 bar	10^{-3} Pa-s 10^{-3} Pa-s	0.114 0.113
Specific heat of liquid at 25°C Specific Heat of Vapour at 1.013 bar	kJ/(kg.K) kJ/(kg.K)	1.94 0.848
Cp/Cv ratio at 25°C at 1.013 bar		1.252
Flammability in air - Lower flammability limit - Upper flammability limit	 % volume % volume	 12.7 33.4
Flash point	°C	<-50
NF-EN 378 classification		L2
Ozone Depletion Potential	(R-11 = 1)	0
GWP	(CO_2 = 1)	675

IV. R-32 AS REFRIGERANT IN ROLL BOND EVAPORATOR

Tube and fin evaporators using R-22 as refrigerant are used in room air conditioners. The present paper deals with design of roll bond evaporator using R 32 as refrigerant. The area of roll bond evaporator is found in the design.

Design parameters: A window air conditioner with a capacity of 1 ½ TR (heat load of 18000 BTUH) is considered for the design. The refrigerant which is considered for the design is eco friendly refrigerant R 32. The roll bond evaporator the plate is made of BWG 14. Outside diameter of evaporator tube is 12.7 mm. A temperature of 50° C is taken as condensing temperature and evaporator temperature as 5° C for the refrigerant.

Evaluation of refrigerant side heat transfer coefficient.

The following assumptions are made for the analysis: 1. Refrigerant is dry and saturated before entering compressor. 2. There is no sub cooling of refrigerant.

- From basic p-h diagram for Refrigerant R-32, enthalpies at state 1 and state 4 are 518 kJ/kg and 297.2 kJ/kg respectively.
- The mass flow rate is calculated from the relation m (h1-h4) = heat load. The heat load for this device is 1.5 TR. The estimated mass flow rate of refrigerant is m = 0.02377 kg s^{-1}. Finding quality of steam at state 4, dryness fraction is obtained as 0.28566.
- LMTD Calculation, with R 32 as refrigerant, surface temperature of evaporator is 6°C for an air conditioner. From LMTD calculations, LMTD = 17.527 ° C.
- From P.S Ravi, Dr Arkanti Krishnaiah et.al journal papers [13] [14], assumed value of Overall heat transfer coefficient is 20 $W/m^2 K$, for refrigerant – air, as heat transfer fluids.
- Heat load , Q = 1.5 TR = 5250 W
- From the relation Q = U A (LMTD), the area of evaporator is A = 14.976 m^2. This is assumed value of Area of roll bond evaporator.
- From the relation of Area, with the given outside diameter of the evaporator tube, the Length of evaporator tube is 375 m.
- The inside diameter is calculated to be d_i= 8.484 mm**.**

Single phase correlations

- **Butterworth correlation** Stanton number, $St = E\, Re^{-0.205}\, Pr^{-0.505}$,

Where $E = 0.0225 \exp\{-0.0225 (\ln Pr)^2\}$ Stanton number = $h/(\rho\, u\, Cp)$, Reynolds number $Re = (4m)/(\pi\, d_i\, \mu)$, Prandtl number, $Pr = (\mu C_p)/k$, ρ is density of refrigerant, u is velocity of refrigerant, Cp is specific heat at constant pressure, k is thermal conductivity of refrigerant, μ is dynamic viscosity of refrigerant.

The heat transfer coefficient so calculated for R-32 is 1703.9 W/m^2K

- **Dittus Boelter equation** Nusselt's number $Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$,

Nusselt's number is given by Nu = (h d)/k

The heat transfer coefficient so calculated for R-32 is 1760.94 W/m^2K

- **Gnielinski equation** $Nu_d = \{(f/8) \times (Re - 1000) Pr\}/\{1 + 12.7 (f/8)^{0.5} (Pr^{2/3} - 1)\}$
  Friction factor, $f = (0.79 \ln Re - 1.164)^{-2}$

The heat transfer coefficient so calculated for R-32 is 1605 W/m^2K

In all the above calculations, the length of evaporator is not considered and also the refrigerant is assumed to be in single phase. But, in roll bond evaporator, the refrigerant is in two phase. So two phase correlations are considered for further calculations.

The following calculations show the estimation of inside heat transfer coefficient of refrigerant in two-phase.

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Two phase correlations

- **Spitter, Parker, Quinston Correlation.** $(h D /k) = C_1\{ [GD/\mu_L]^2 [J \Delta x\, h_{fg}\, g_c /(L g)] \}^{0.4}$

where D is inside diameter of the tube, $C_1 = 8.2 \times 10^{-3}$, G = m/A , Δx = difference in quality of refrigerant, h_{fg} is enthalpy of evaporation, L is length of evaporator, g_c for SI system is 1 and g is acceleration due to gravity

The heat transfer coefficient so calculated for R-32, in two- phase flow is 2649.84 W/m^2K

- **Bio-Pierre correlation for complete evaporation**

This correlation considers complete evaporation of refrigerant with 5 to 7K of super heat.

$Nu_m = 0.0082 (Re_f^{\,2} k_f)^{0.4}$, where k_f is load factor = $(\Delta x\, h_{fg})/L$

The heat transfer coefficient so calculated for R-32 , in two- phase flow is 6605.12 W/m^2K

- **Two phase Chato- Wattelet correlation**

$h_{tp} = h_1[4.3 + 0.4 (Bo.\, 10^4)^{1.3}]$

h_1 is from single phase correlation, Dittus Boelter correlation is considered. ,where $Bo= q^{//}/(G\, h_{fg})$, $q^{//} = q/A$

The heat transfer coefficient so calculated for R- 32 in two- phase flow is 7582.9 W/m^2K

- **Chaddock correlation**

$h_{tp} = 1.85\, h [Bo \times 10^4 + (1/ H_{tt})^{0.67}]^{0.6}$,

Where, $H_{tt} = [(1-x)/x]^{0.9} \times (\rho_g/\rho_f)^{0.5} (\mu_f/\mu_g)^{0.1}$ here the subscripts g and f refers to gaseous phase and liquid phase respectively. The heat transfer coefficient so calculated for R-32 , in two- phase flow is 4821.73 W/m^2K

- **Chato/Dobson correlation**

$h_{tp} = f(\chi_{tt}) \{ [\rho_L (\rho_L- \rho_v)g\, h_{fg}\, k_l^3]/[d\, \Delta T\, \mu_L] \}^{0.25}$

where $f(\chi_{tt}) = 3.75 /(\chi_{tt})^{0.23}$ and $\chi_{tt} = [(1-x)/x]^{0.9} \times (\rho_g/\rho_f)^{0.5} (\mu_f/\mu_g)^{0.1}$

The heat transfer coefficient so calculated for R-32 , in two- phase flow is 5309.12 W/m^2K

- **Chaddock Brunemann's correlation**

$htp = 1.91\, h [Bo\, 10^4 + 1.5 (1/ \chi_{tt})^{0.67}]^{0.6}$

The heat transfer coefficient so calculated for R-32, in two- phase flow is 6322.47 W/m^2K

To consider the effects of all the parameters in two- phase flow the average value of all the above heat transfer coefficients is taken for further calculations. The average inside heat transfer coefficient for the refrigerant R-32 is found to be 5548.43 $W/m^2 K$.

P.S.Ravi et.al [13] in their research paper has found that the outside heat transfer coefficient (air side) for this design conditions is 20.29 W/m^2K.

The overall heat transfer coefficient is found out by taking into consideration thickness of ice formed on the roll bond evaporator. The expression is

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$$\frac{1}{U_0 A_0} = \frac{1}{A_i h_i} + \frac{1}{A_i h_{fi}} + \frac{\Delta x}{K A_{HT}} + \{\frac{\Delta x}{K A_{Frost}}\}_{\text{frost}} + \frac{1}{A_0 h_0}$$

The overall heat transfer coefficient as found from the above expression is 17.41 W/m^2K. The percentage error in the assumed value and calculated value is 13 %. The above design is repeated once again. In the second iteration, it has been found that the overall heat transfer coefficient is 17.42 W/m^2K.

Using this relation the area of roll bond evaporator is found out to be 17.19 m^2 and length of the roll bond evaporator tube to be 147 m.

V. DESIGN RESULTS -COMPARISION OF R-32 WITH R-22

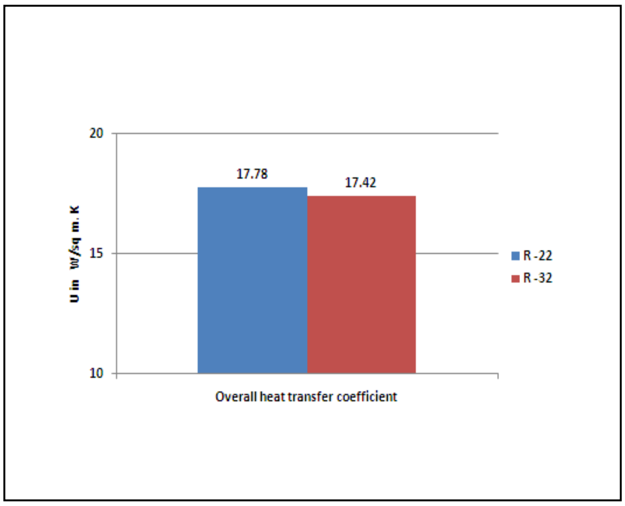
The following table gives comparison of design parameters between R-22 and R-32 which are used as refrigerants in roll bond evaporators.

	R-22	R-32
Evaporator pressure	583 kPa	850 kPa
Condenser pressure	1942.3 kPa	3040 kPa
Overall heat transfer coefficient	17.78 W/m^2K	17.42 W/m^2K
Area of roll bond evaporator	17.3 m^2	17.19 m^2
Length of roll bond evaporator	148 m	147 m

VI. GRAPHS AND CONCLUSIONS

The above results are plotted on the graphs shown below.

- Overall heat transfer coefficient



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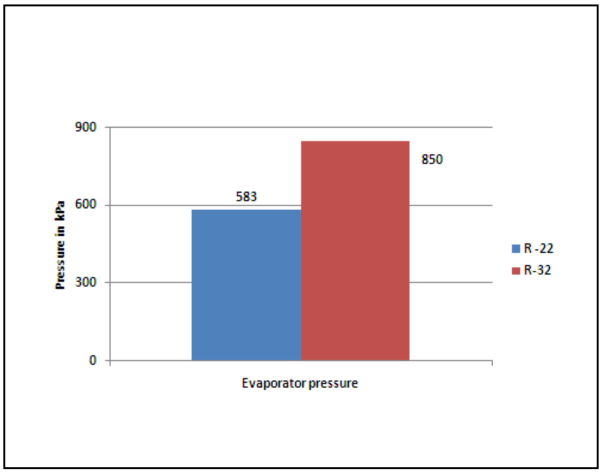
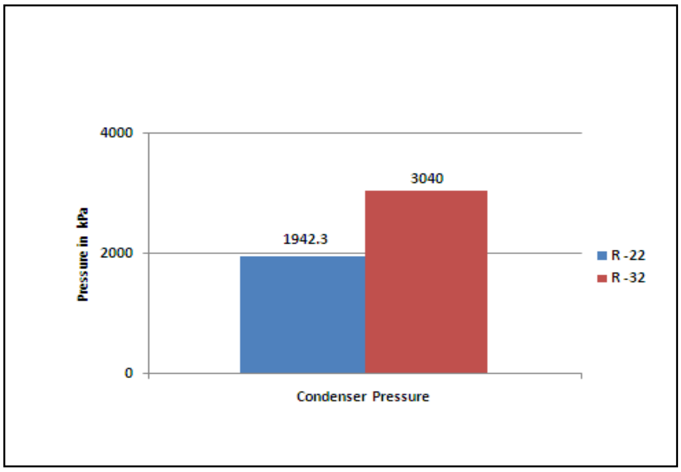
It can be concluded that the heat transfer characteristics of R-32 are on par with that of R-22. Hence R-32 can be used as a substitute to R-22 in Room air conditioner.

- Evaporator and Condenser pressures





The operating pressures of R-32 are 45.78 % higher at evaporator and at condenser it is 56.5 % higher than that of R -22. As R-32 is an eco friendly refrigerant, it can be used in RAC systems, by altering the manufacturing process, so as to get sufficient strength to withstand high operating pressures.

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BIOGRAPHY

Mr P.S. Ravi is a Research Scholar(PhD Scholar) ,doing research in Mechanical Engineering Dept, College of Engineering, Osmania University, Hyderabad & is Working as Lecturer in Mechanical Engineering, SS Government Polytechnic, Zaheerabad, India. His areas of interest are Refrigeration and Air Conditioning, Heat Transfer

Dr. Arkanti Krishnaiah is working as Professor & Head, Mechanical Engineering Dept, College of Engineering, Osmania University, Hyderabad . He is a Post doctorate and his specialization /areas of interest include Materials Forming, Severe Plastic Deformation and Nano materials. He has more than 30 publications to his credit, and is presently guiding five (05) research works (PhD) and has completed two research projects sponsored by AICTE.

Dr. Boda Hadya is working as Assistant Professor, Mechanical Engineering Dept, College of Engineering, Osmania University, Hyderabad. His specialization /areas of interest include Thermal Engineering, Heat Transfer and Refrigeration and Air conditioning and has completed one research project.

Dr. Md. Azizuddin is working as Professor in Mechanical Engineering Department, Deccan College of Engineering and Technology, Hyderabad, India. His Specialization / interest Area include Refrigeration and Air conditioning, Thermal Engineering. He has more than seventeen years of teaching experience and published seventeen papers in various national and international journals and conferences. He is presently guiding one research scholar for PhD.