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Evaluation of Refrigerant Side Heat Transfer Coefficient for R-410A to be used in Roll Bond Evaporator for a Window Air Conditioner

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ABSTRACT: *This paper presents the design calculations for evaluating refrigerant side heat transfer coefficient for an evaporator which is manufactured by roll bonding process. The design for the roll bond evaporator is done using eco friendly refrigerant R-410A. Apart from being an eco friendly refrigerant, R 410 A contributes to significant increase in Coefficient of Performance (COP) of the unit when compared to R-22. The paper discusses replacement of tube and fin evaporator with a roll bond evaporator. The use of roll bond evaporator decreases the cost of total window air conditioner.*

Keywords: *Roll bond Evaporator, R-410 A, Room, Air conditioner,Two-phase Correlations* **.**

I. INTRODUCTION

With the world looking for ways to save the planet from global warming, the scientific world is looking for the ways to reduce the global warming phenomenon. The depletion of Ozone layer is another area of concern. One of the main culprits responsible for depletion of Ozone layer is release of chlorine into atmosphere from CFC and HCFC refrigerants used in all refrigeration and air conditioning applications. The world has stood united to successfully phase out CFC completely. The refrigerant presently being used in air conditioners is R-22, $CHClF_2$. The economic liberalization policies in developing country like India resulted in sustained growth in the purchasing power of people. This in turn has increased demand for consumer, commercial and industrial products. The consumption of HCFCs (through use of air conditioning equipment) has grown steadily at an average annual rate of over 11% in the past 15 years. Much of this growth has occurred in the past few years. The consumption of HCFCs in India has tripled, compared to that of consumption five years back. This trend is expected to continue. The Government of India has formulated a well defined roadmap for HCFC phase-out, which spells out fixed goals, actions and timelines to control and reduce production and consumption of HCFCs in line with the accelerated control schedule for HCFCs under the Montreal Protocol. Actions have been formulated, to ensure compliance with the 2013/2015 targets as well as the broader phase-out targets by 2030. One such possible alternative to HCFC refrigerants is R-410A. R 410A is a mixture of equal proportion of HFC refrigerants R 32 (CH_2F_2, difluromethane) and R 125 (CHF_2-CF_3, pentafluroethane). The properties of R410A are very close to that of R22.

Another way of reducing global warming is to develop products which are highly efficient, which consume less power, while delivering the desired refrigerating effect in a refrigerating and air conditioning system. In the pursuit of optimizing the system for its energy requirement in a window air conditioner, it was found that , compared to that of a traditional tube and find evaporator, an evaporator made from roll bond process gives more uniform distribution of cooling effect. Further, the process of manufacturing of roll bond evaporator is very simple and manufacturing cost is also low.

II. LITERATURE SURVEY

The following literature gives a conclusion that the refrigerant R410A can be used as substitute for R-22 in a window air conditioner with some design modifications. S.S. Jadhav, K.V.Mali [1] in their journal paper compared the performance of R410A with R 22. They concluded that R410A has a higher volumetric efficiency, better thermal exchange properties, overall COP than R-22. CY.Park, P.Hrnjak [2], made an experimental and numerical study on residential air conditioning systems using R410A as refrigerant. P.A. Domanski, D.Yashar, M.Kim [3], have studied the performance of finned tube evaporator using different refrigerants inclusive of R410A. Further the following works throw light on suitability of using roll bond evaporator as a good heat exchanger. P.S.Ravi, Dr Arkanti Krishnaiah , Dr Suresh Akella , Dr Md. Azizuddin[4] [5], in their journal papers have designed a roll bond evaporator for a window air conditioner using R-22 as refrigerant.. The design of roll bond evaporator [6] [7] is done on the same lines as that of a tube and fin evaporator with suitable modifications. Anders Johannson, Per Lundqvist [8] in their thesis said that the properties of R410A may not suit for the existing systems which are run with R-22 and hence they are not suitable for them. But for new systems, R410A is a favored refrigerant.

III. ECO FRIENDLY REFIGERANT, R410A

R-410A, is a mixture of difluoromethane (CH_2F_2, called R 32) and pentafluoroethane (CHF_2CF_3, called R-125), which is used as a refrigerant in air conditioning applications. R-410A cylinders are colored pink. The Physical properties of the refrigerant are listed in Table 1

Table 1: Physical Properties of R410A

Property	Value
Formula	CH2F2 – 50 %
	CHF2CF3 – 50 %
Molecular Weight	72.6
Melting point (°C)	−155
Boiling point (°C)	−48.5
Liquid density (30°C), kg/m3	1040
Vapor density (30°C), air=1.0	3
Vapor pressure at 21.1°C (MPa)	1.383
Critical temperature (°C)	72.8
Critical pressure, MPa	4.86
Gas heat capacity (kJ/(kg·°C))	0.84
Liquid heat capacity @ 1 atm, 30°C, (kJ/(kg·°C))	1.8

When using azeotropic refrigerants, like R 410 A the leak-tightness of systems should be maintained at a tighter level than the previous generation of refrigerant i.e. R-22. Instead of the mineral oils commonly used with R-22 systems, synthetic polyolester (POE) oils meet this requirement and will be utilized more universally, with virtually all R-410A systems. POE oils are a family of synthetic lubricants. Unlike natural mineral oils, POE oils are completely wax-free and are the best choice of lubricants for use with the new generation of chlorine-free HFC refrigerants, such as R-410A. This is because they provide superior lubrication, offer better thermal stability, and are more miscible in HFC refrigerants than mineral oils. POE oils are also highly biodegradable.

IV. ROLL BOND EVAPORATOR

A roll bond evaporator provides flexibility in design of any refrigeration system. Two sheets of aluminum are rolled together by applying heat and pressure during the rolling process such that the two sheets are effectively welded together into a single sheet. Before the rolling/welding operation, a special coating called “weld stop” is applied between the two sheets to prevent them from welding together in the areas where the coating is applied. It is possible to create a serpentine shaped un-welded region within this welded part, by applying the coating in a serpentine pattern. By applying hydraulic pressure to this un-welded region, it is possible to inflate the un-welded serpentine region to form a serpentine passage throughout the plate. Thus a plate with an integral serpentine passage can be created in a very cost effective manner. Except for the passage the evaporator plate is primarily flat. One end of the evaporator plate is connected to the exit of expansion valve and the other end to the compressor inlet.. Fig 1 gives a basic idea of roll bond evaporator. Fig 2 gives cross sectional view of the roll bonded evaporator gives which gives a good idea of the passage of refrigerant. The refrigerant passes are inflated during the manufacturing process such that the walls of the passes protrude out equally on either side of the evaporator plate.

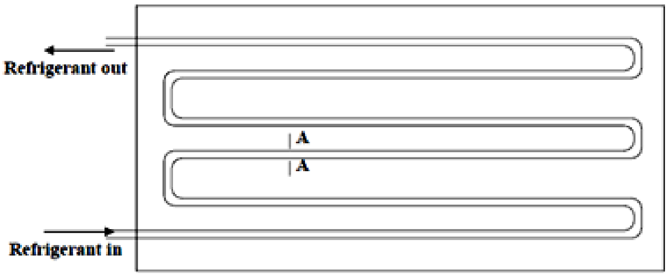

Fig 1: Roll bond evaporator

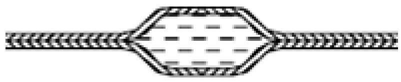

Fig 2: Cross section at A-A

IV. ROLL BOND EVAPORATOR IN WINDOW AIR CONDITIONER

Presently all window air conditioners use Tube and fin evaporators using R-22 as refrigerant. This paper evaluates the refrigerant side heat transfer coefficient using R 410A as refrigerant, in a roll bond evaporator. To find the area of roll bond evaporator, calculation of refrigerant side heat transfer coefficient is important.

4.1. 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 410A. 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.

4.2 Evaluation of refrigerant side heat transfer coefficient.

4.2.1 Basic calculations:

Fig 3 shows a basic P-h diagram for the window air conditioner. 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.

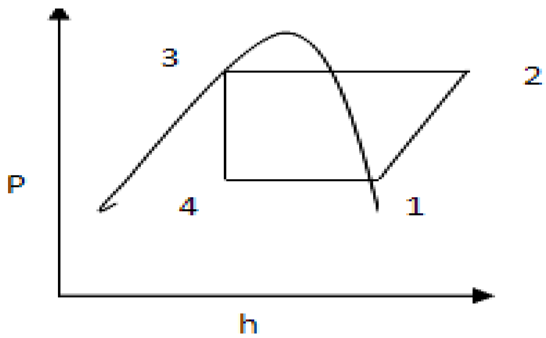

Fig 3. Basic pressure-enthalpy diagram

- From Refrigerant R-410A properties, enthalpies at state 1 and state 4 are 422.4 kJ/kg and 285.1 kJ/kg respectively.
- The mass flow rate is calculated from the relation m (h_1-h_4) = heat load. (1)
  The heat load for this device is 1.5 TR. The estimated mass flow rate of refrigerant is m = 0.0382 kg s^{-1}. Finding quality of steam at state 4, dryness fraction is obtained as 0.36.
- LMTD Calculation With R 410A as refrigerant, surface temperature of evaporator is 6°C for a air conditioner.
  From LMTD calculations, LMTD = 17.53 ° C.
- From P.S Ravi, Dr Arkanti Krishnaiah et.al journal papers [4] [5], assumed value of Overall heat transfer coefficient is 17 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 = 17.62 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 75 m.
- The inside diameter is calculated to be d_i= 8.484 mm.

4.2.2. Single phase correlations

4.2.2.1 Butterworth correlation

Stanton number, $St= E\, Re^{-0.205}\, Pr^{-0.505}$, Where $E = 0.0225 \exp\{ -0.0225 (\ln Pr)^2\}$

Stanton number $= h/(\rho\, u\, C_p)$, 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, C_p 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-410 A is 1789.86 W/m^2K

4.2.2.2 Dittus Boelter equation

Nusselt's number $Nu = 0.023\, Re^{0.8}\, Pr^{0.4}$, Nuseelt's number is given by $Nu = (h\, d)/k$

The heat transfer coefficient so calculated for R-410A is 1814.7 W/m^2K

4.2.2.3 Correlation from heat transfer data book

Nusselt's number $Nu = 0.026\, Re^{0.8}\, Pr^{(1/3)}$

The heat transfer coefficient so calculated for R-410A is 1948.74 W/m^2K

4.2.2.4 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-410A is 1715.51 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.

4.2.3. Two phase correlations

4.2.3.1 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-410A , in two- phase flow is 2913.77 W/m^2K

4.2.3.2 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-410A , in two- phase flow is 7262.85 W/m^2K

4.2.3.3 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- 410A in two- phase flow is 7843.83 W/m^2K

4.2.3.4 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-410A , in two- phase flow is 5072.78 W/m^2K

4.2.3.5 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-410A , in two- phase flow is 5048.33 W/m^{2}K

4.2.3.6 Chaddock Brunemann's correlation

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

The heat transfer coefficient so calculated for R-410A, in two- phase flow is 5791.97 W/m^{2}K

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-410A is found to be 5791.97 W /m^2 K

V. COMPARISION OF PARAMETERS - R-22 & R-410A

The performance parameters as obtained by the above calculations are compared with the design results obtained by P.S. Ravi, Dr.Arkanti Krishnaiah et.al [5]. Table 2 and Fig4 and Fig 5 give the comparison of R-22 & R410A

Table 2: Comparison between R22 and R 410A

Refrigerant	**Inside heat transfer coefficient in SI Units**		**P_{evap} at 5°C in kPa**	**P_{cond} at 50°C in kPa**
	For single phase	For Two phase		
R 22	1162.8	4041.2	583.78	1942.3
R 410A	1715.4	5791.97	933.9	3061

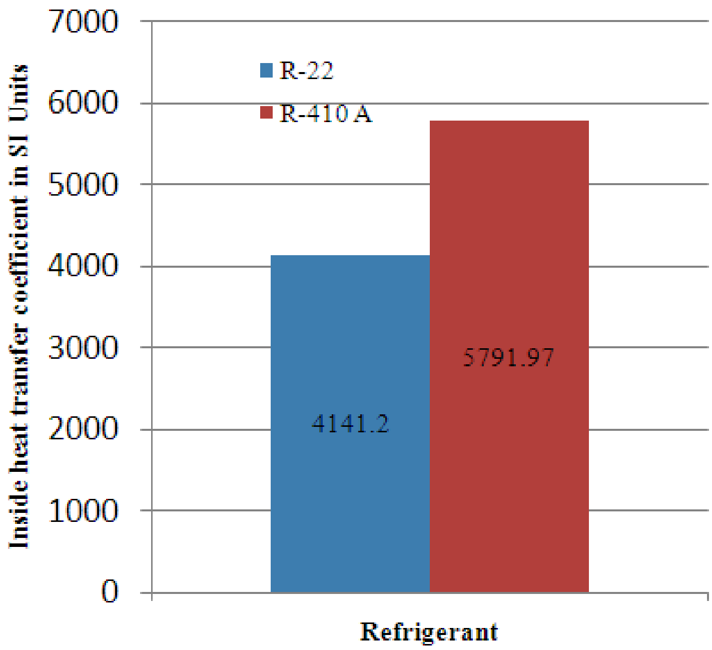

Fig 4. Comparison of inside heat transfer coefficient

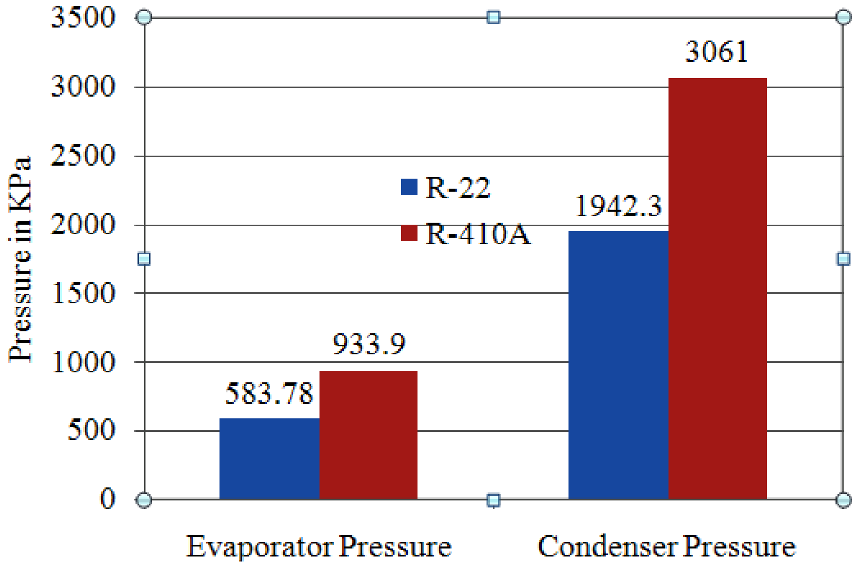

Fig 5. Comparison of pressures

VI. CONCLUSIONS

The above results conclude that R 410A possess very good heat transfer characteristics when compared to R-22. It is evident from the fact that the inside heat transfer coefficient for two phase correlation as obtained above for R 410A is 43% higher than that of R 22. But the major concern for operation is high evaporator and condenser pressure. If design and manufacturing modifications can be done so as to withstand high operative pressures, R 410A can be conveniently used instead of R 22. It can be concluded that the refrigerant R 410A is eco friendly and possess good heat transfer characteristics compared to R 22.

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