International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Experimentation and Performance Analysis of Natural Draft Wire on Tube Condenser

Shivam Raosaheb Badwar, Mahesh Joshi, Shrikant Mandale, Anil Kujur

***Abstract:** This project is sponsored by the company Whirlpool of India Limited, situated at Ranjangaon MIDC, Pune. A simple design methodology of Wire on Tube heat exchanger used in domestic refrigeration systems focuses on both energy saving and cost reduction in this study. A wire on tube condenser is two-phase natural convection heat exchanger which rejects heat absorbed by the refrigerant in the evaporator and heat addition by compressor to atmospheric temperature changing its phase. The main objective of this research paper is to study impact of condenser tube length and number of wires, its pitches on performance of domestic refrigerator and desire to find optimum design of wire on tube heat exchanger compatible with on/off compressor in 185 liter 3 star single door model. Mathematical model are used to analyze performance of entire refrigeration system. Experiments were conducted under controlled climatic chamber and varying ambient temperature as per BEE standard and procedures. It was found that experimental results have 5% to 8% deviation range with results obtained from mathematical model. Optimum design of wire on tube heat exchanger selected has main focus on both energy saving and cost reduction.*

***Keywords:** Heat Exchanger, Optimum design, Energy saving, Evaporator, Refrigerant*

I. INTRODUCTION

The largest Portion of electrical power is consumed by private households in the OECD countries is because of refrigeration system (IEA, 2003) [1]. Today energy saving, quality and cost reduction are crucial parameters as per Indian domestic refrigerator market is concern to beat the competition and succeed in this competitive world. Nowadays, Energy consumption of domestic refrigerators is reduced considerably by the refrigerator manufactures, due to the bold labeling of BEE and Energy rating changes expected from 2020. As energy rating will get stringent, it's important to search new ways to reduce energy consumption with minimal cost addition to meet energy target set by BEE. Each component in refrigeration systems (Evaporator, condenser, Compressor, and capillary tube) shown in fig. 1(a) are in cycle and therefore has impact on overall performance of system and its cost. The major Energy losses in the system are caused by irreversible heat transfer processes and pressure losses in the system. A wire on tube condenser is a simple device having single tube of steel bent in serpentine parallel passes carrying the refrigerant is electro-welded with low carbon steel solid wires on both sides of tube which acts as extended surfaces (fins) for increasing heat transfer area between refrigerator and surrounding environment as shown in fig. 1(b). The refrigerant entering expansion device should be sub cooled liquid that can be achieved by increasing additional surface area for heat transfer which reduces throttling losses and therefore potentially increases efficiency of refrigeration system. As condenser effective sub cooling increases, COP of refrigeration system reaches maximum as its ratio of refrigerating effect achieved in evaporator to specific compressor work. The latent heat of vaporization and specific heat of liquid are main dominating factor to determine maximum COP with sub cooling of refrigerant achieved at condenser outlet [2]. Experimental investigation has also shown impact of sub cooling and its benefit on performance of refrigeration system. It has proved that COP and cooling capacity can be increased by 10% to 12% for different refrigerant (R12, R134a, R152a) keeping condensing temperature constant [3].Some publications also examined the effect of the refrigerant gas charge on the COP which indirectly gave the relationship between sub cooling and COP [4]. Maximum COP was achieved by varying charge of R290 refrigerant in a heat pump having thermostatic expansion valve. They cleared that the system has responded to increase of gas charge by increasing the condenser sub cooling since system has no receiver installed [5].Optimization of condenser capacity to weight ratio by varying pitches of tube and wires was carried out experimentally and using approach of finite element variable conductance with combination of different thermodynamic correlation[6]. FEM analysis for determining of refrigerant phase change and sub cooling achieved in wire and tube condenser using R134a refrigerant and also to find feasibility of using condenser with different refrigerant in retrofitted refrigerator [7]. A comparison between performance of wire-and-tube and hot-wall condensers was carried out to find condenser capacity and pressure loss in system with AS/NZS 4474-1997 standards with experimentation in same operating condition for both types of condenser and also evaluated heat transfer coefficient, profile of temperature distribution by simulation.

Manuscript published on 30 September 2019
* Correspondence Author
Shivam Badwar*, is pursuing M.Tech. in School of Mechanical & Civil Engineering, MIT-AOE, Pune, Maharashtra (India)
Prof. Mahesh P. Joshi is Assistant Professor with School of Mechanical & Civil Engineering, MIT-AOE, Pune, Maharashtra (India)
Mr. Shrikant Mandale is with PDC department as Engineering Manager at Whirlpool of India Ltd., Pune, Maharashtra (India)
Mr. Anil Kujur is with PDC department as Engineering Deputy Manager at Whirlpool of India Ltd., Pune, Maharashtra (India)

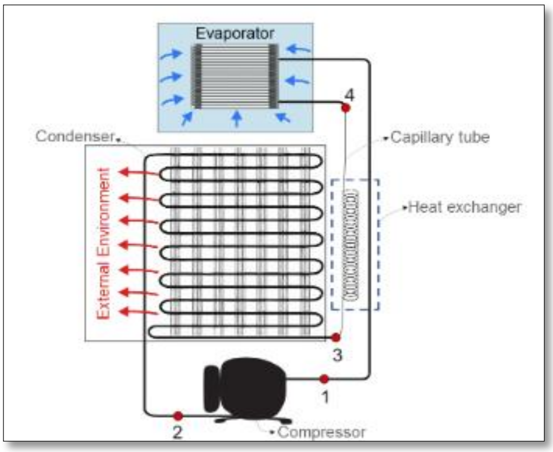
© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

This work was supported by the PDC Department of Whirlpool of India LTD., Ranjangaon, Pune, Maharashtra (India)

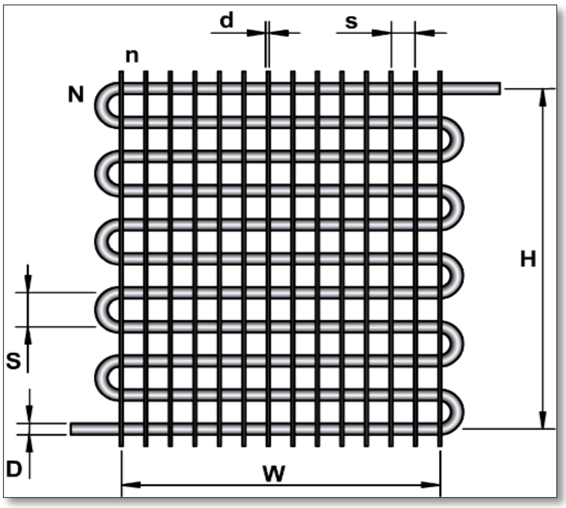
It mainly focused that skin condenser are 10% to 16% more capacity because of larger area for heat transfer than that of commonly used Wire on tube condenser [9].

In the condenser, as sub cooled region increases it also contributes to the decrease in pressure drop [8].

The thought process behind the present study is to investigate and analyze impact of tube length and number of wires that leads to increase heat transfer area and ultimately increases effective sub cooling region which directly affects on overall performance in term of energy rating of Refrigeration system. The study involved use of mathematical model to determine performance of overall refrigeration system also experimentation work was carried out according to BEE standard procedure in NABL accredited lab. The Experimental results were validated with results obtained from mathematical model and optimum design of wire and tube condenser was finalized that can meet BEE Energy target for 3 star rating.



(a)



(b)

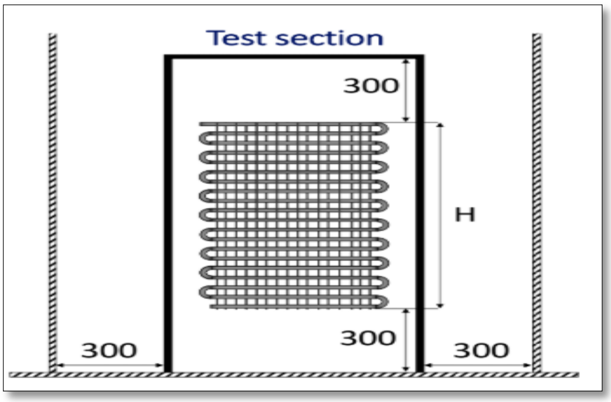
Fig.1. Refrigeration systems with WoT condenser

II. EXPERIMENTATION

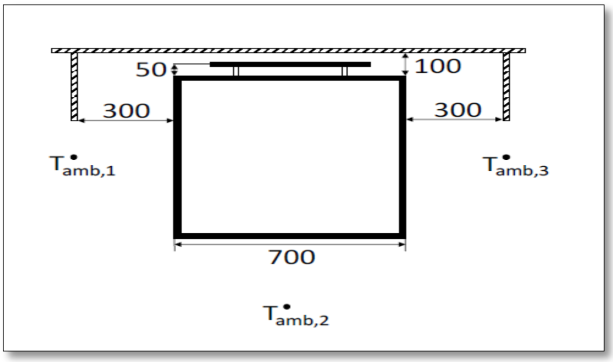
A. Test Setup

The test setup used for performing the experiments was in NABL accredited lab according to BIS 15750:2006 standards. The experimental setup comprises (a) the test stall, (b) the Refrigeration Test Software as Data Acquisition system and (c) the controlled climate chamber in which the experiments were conducted.

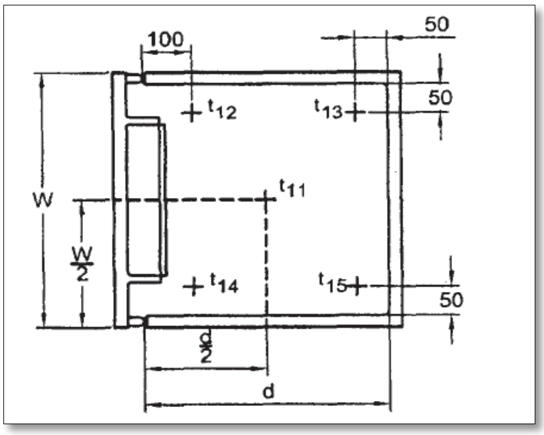
Test stalls were made up from wood with black coated paint on it as shown in fig 2. RTS system was used for recording of temperature, humidity, power consumption, wattage, voltage, Power factor and Experiments have been carried out in a chamber where the environmental parameters can be controlled. Variation in Temperature and humidity of chamber was within considerable range. Fig 2(a) shows front view of test setup where refrigerator is placed in center of stall and stall height is 300mm from floor. Distance from back wall should be 100mm from back panel of refrigerator and 50mm from condenser as shown in fig 2(b). Two Thermocouples are placed to record ambient temperature at 300mm distance from side walls and one in front of refrigerator door.



(a)



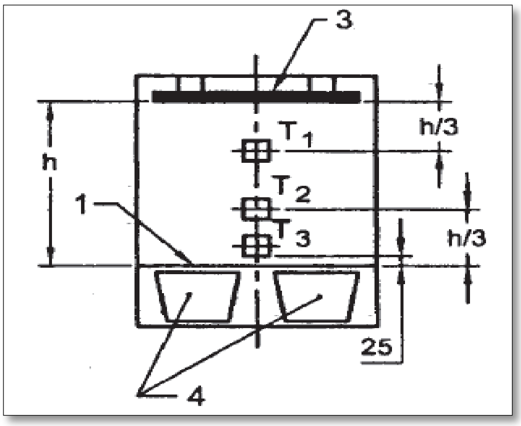
(b)



(c)

Retrieval Number: C5174098319/2019©BEIESP
DOI:10.35940/ijrte.C5174.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication



(d)

Fig. 2.Experimental Setup as per BIS standards [10]

B. Performance testing

Performance testing is done to check cooling capacity and energy consumption of product that is delivered to consumer. The objective of following test is to define star rating of product manufactured as per BEE standards. The test standard and procedure used in experiment are according to guidelines provided inBEESchedule-5 and BIS 15750:2006 standards.

The Test carried out on the refrigeration system should meet the requirements as set in IS 1476 (Part-I): 2000.

I] No Load Pull Down Test

A] Purpose:

The test was carried out to find whether system is balanced in all aspects of cooling capacity according to BEE schedule.

B] Test Condition:

a) Room ambient temperature= 43 ± 0.5 ° C.

b)Thermocouple Location according to IS15750:2006 clause

C] Procedure:

a) Keep product in Soaking for 16 hours in 43 ± 0.5 ° C.

b) Run product in bypass condition for 6 hrs

D] Acceptance

a) The target temperature for FC should reach below -13 ° C

b) The target temperature for RC should reach below 0± 2.5 ° C.

II] Energy Consumption Test:

A] Purpose:

The test was carried out to find whether Energy consumed by product meets criteria set by BEE to achieve 3 Star rating

B] Test Condition:

a) Room ambient temperature= 32 ± 0.5 ° C.

b) Relative humidity = 60 ±15% for testing

c) Air velocity of chamber = 0.25 m/s

d) Target temperature of energy calculation:

FC= -6°C, RC= 3°C

e) Thermocouple Location according to IS15750: 2006

C] Procedure:

a) Run product till target temperature is achieved

6 hours stable data for Energy calculation

D] Acceptance

a) Energy consumed by product should be less that target value of energy consumption according to BEE standards.

III. MODEL DESCRIPTION

Wire on Tube is a condenser type of heat exchanger that uses tubes and wires as a natural convection mechanism to improve the heat transfer from the refrigerant to the surroundings. It is a Steel tube coil with electro welded wires on both sides, produced according to product's design, and it is grouped into Static Condensers Group. The condenser affects the performance of the system, a lower condensing temperature drives a lower energy consumption. Also, the compressor manufacturers have guidelines for condensing temperatures to guarantee compressor lifetime reliability. Inlet to condenser is approximately at 7.5 bar pressure with temperature of 65°C which is outlet of compressor. Condensing temperature of Refrigerant is 45 ° C for ambient temperature of 32 ° C during energy test.

A. Thermodynamic and Thermo physical properties

Ref Calc and Ref Prop software are used to determine thermodynamic and thermo physical properties required to form set of equation. Refrigerant properties for R600a are obtained from Ref Prop software for each temperature and pressure.

Table 1: Condenser model data

Sr no.	Parameter	Values
1.	Condenser tube diameter	4.76 mm
2.	Condenser wire diameter	1.3-1.6mm
3.	Thickness of tube	0.55mm
4.	Material of tube and wire	Low carbon steel
5.	Density of tube	7850 kg/m^3
6.	Thermal conductivity	50W/m5 ° C
7.	Compressor (BTU/EER)	368/5
8.	Evaporator	Roll and bond type
9.	Expansion device	Capillary
10.	Refrigerant used	R600a
11.	Refrigerant charge	36 gm

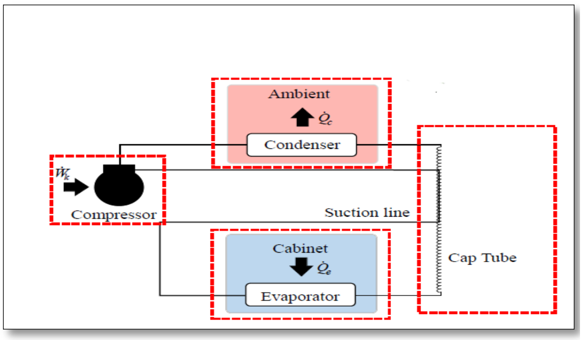
Table 2: Test sample details

Condenser	Length	No. of tubes	No. of wires	Wire pitch	Tube pitch
Sample 1	7.7	13	66	12.5	60
Sample 2	7.7	13	106	7.5	60
Sample 3	7.7	13	136	5.9	60
Sample 4	7.823	15	136	5.9	52
Sample 5	8.345	17	136	5.9	52

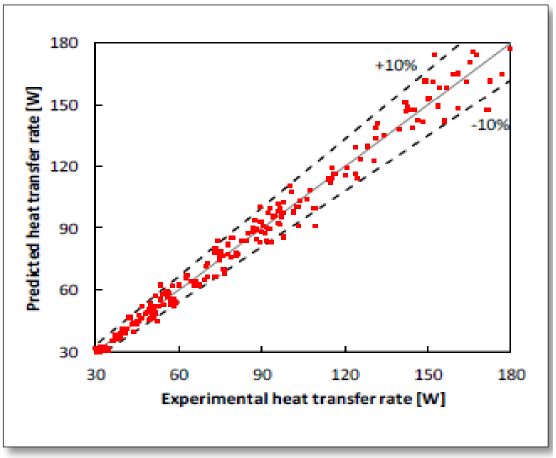
IV. MATHEMATICAL MODELING AND CORRELATION

Mathematical models are one which consists of empirical correlation and formulas for determination of overall performance of refrigeration system that can be evaluated using Set of equation for predicting energy consumption of system by changing some parameter that affects most system. It consists of formulas and empirical correlation fed in software which are developed by each subject matter experts based on their practical knowledge to analyze impact of every small changes that affects performance of system. The software gives us similar information that is obtained from experimental work with marginal differences in results as shown in fig 3(b). It is much difficult to obtain overall performance of system by simulation model as accurate as by this mathematical model because as it's developed on practical knowledge as that of assumption in simulation models. Results obtained for heat transfer rate as shown by experimentation work and mathematical model is within

$\pm$10% range



(a)



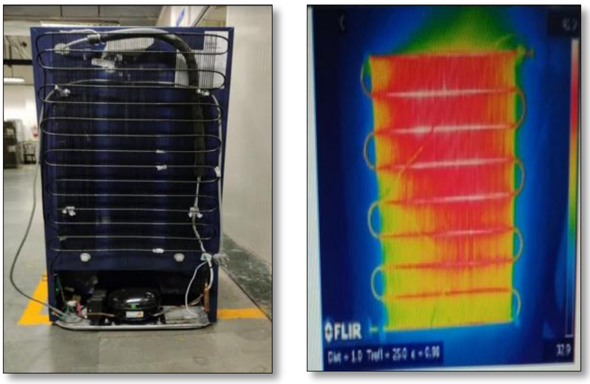
(b)

Fig.3. Mathematical model and its results

V. RESULTS AND DISCUSSION

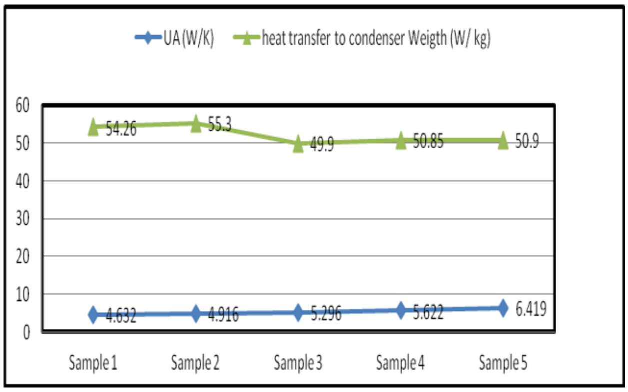
Design of Experiments (DOE) was carried out to find optimum Condenser design for 185L 3S model which provides both cost and Energy benefits. One parameter was changed each time (wire pitch, Tube pitches, refrigerant charge, Length) and its effects were analyzed**.** During the experiments temperature, Power consumptions, wattage are recorded at interval of 15 sec each. The condenser performance is measured on how much heat the component can exchange before the fluid gets into the capillary tube, in other words, the better the condenser the closer to the ambient temperature the fluid will get into the capillary tube. It means more sub cooling temperature achieved will give better Performance in term of efficiency. Sample 5 shows highest heat transfer rate among all condenser design samples tested. Heat transfer rate is calculated by using WoT correlation developed using practical knowledge

Results obtained from experimental work and predicted energy from mathematical model shows maximum variation of 5% as shown in fig 5 (c).From results calculated it's good to say that sample 3 is optimum design of WoT condenser and is feasible design for practical application. Average 4-5% positive margin is good sign considering testing error, process variation, manufacturing losses. It also shows good ratio of heat transfer rate to condenser weight which directly helps in reduction of product weight. Heat transfer coefficient due to convection and radiation was determined using WoT correlation. Combined heat transfer coefficient (UA) was calculated for all samples. Fig 5(a) shows heat transfer to condenser weight ratio and UA which is linear graph gradually increasing from 5.6W/K to 6.5 W/K. Overall surface and single fin efficiency graph is shown in fig 5(b) Thermal cameras are beneficial for finding of Heat transfer areas. Image captured using the infrared camera Flir SC600 shows region where maximum heat transfer occurs during phase change (latent heat) and sensible heat rejection as shown in fig 4.



(a) (b)

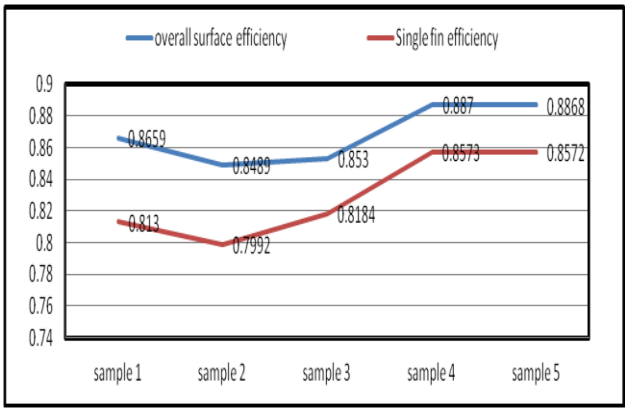
Fig. 4.Actual and thermal camera image



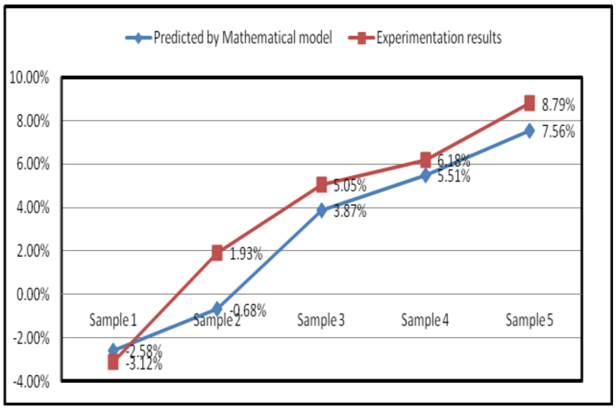
(a)

Retrieval Number: C5174098319/2019©BEIESP
DOI:10.35940/ijrte.C5174.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication



(b)



(c)

Fig 5.Experimental and mathematical modeling results

VI. CONCLUSION

In this research following conclusion have been withdrawn

1. Design of experiment (DOE) helped to determine effect of every single parameter changed at a time on overall performance of refrigerator. It was found that optimum condenser design for 185L 3S model was 13 x 136 condensers that gave both benefits in terms of energy and cost saving.
2. Mathematical model used to determine overall performance of refrigeration system found as important tool for prediction of heat transfer rate, energy margin and can give actual results with marginal difference as results obtained from experimentation.
3. WoT correlation developed using practical knowledge obtained from Subject Matter Experts (SME). The correlation was found highly beneficial correlation for design of Wire on Tube condenser.
4. After analysis of mathematical model results further Experimentation were carried out as per BIS standards and BEE regulation for Energy, Star rating calculation.

VII. FUTURE SCOPE

- Testing in accordance with IEC standards
- New software development with consideration of customer usage(Door opening, manual /auto defrost condition, load in system)
- Study energy effects due to change in diameter and thickness of wire on tube.

ACKNOWLEDGEMENT

I would like to take this opportunity to explain my gratitude to all supporting staff that has generously helped me to give proper guidance for my thesis work. I am thankful to my guide **Prof. M. P. Joshi** for his valuable guidance & constant support. Also, I want to extent my sincere gratitude towards **Mr. Shrikant Mandale** & **Mr. Anil Kujur** from PDC Department, Whirlpool of India LTD., for providing a live project, allowing for experimentation project during my Internship period and necessary support.

REFERENCES

1. International Energy Agency , 2003.
2. Domanski, P.A., Didion, D.A., Evaluation of suction-line/liquid-line heat exchanger in the refrigeration cycle, International Journal of Refrigeration 17, 1994 487-493.
3. Pottker, Gustavo and Hrnjak, Predrag S., "Effect of Condenser Subcooling of the Performance of Vapor Compression Systems: Experimental and Numerical Investigation" (2012). International Refrigeration and Air Conditioning Conference. Paper 1328.
4. Linton, J.W., Snelson, W.K., Hearty, P. F, Effect of condenser liquid subcooling on system performance for refrigerants CFC-12, HFC-134a and HFC-152a. ASHRAE Transactions 98, 1992,160-146.
5. Yamanaka Y, Matsuo H, Tuzuki K, Tsuboko T, Development of Sub-cool system, SAE Technical Paper Series, paper 970110, 1997
6. Corberan, J.M., Martinez, I.O., Gonzalves, J, Charge optmisation study of a reversible water-to-water propane heat pump, International Journal of Refrigeration 31, 2008. 716-726
7. P.K. Bansal, T.C. Chin, Modelling and optimization of wire-and- tube condenser, Int J Refrigeration 26 (2003) 601–613
8. Ahmadul Ameen, S.A. Mollik, Khizir Mahmud, G.A. Quadir, K.N. Seetharamuet, Numerical analysis and experimental investigation into the performance of a wire-on-tube condenser of a retrofitted refrigerator, International Journal of Refrigeration 29 (2006) 495–504
9. P. K. Bansal & T. Chin (2003) Heat Transfer Characteristics of Wire-and-Tube and Hot-Wall Condensers, HVAC&R Research, 9:3, 277-290.
10. Refrigeration and Air Conditioning Sectional committee, ME 03.

NOMENCLATURE

Symbol	Meaning
H	Height (mm)
S	Pitch of tube (mm)
S	Pitch of wires, (mm)
D	Tube diameter, (mm)
d	Wire diameter (mm)
n	Number of wires
N	Number of tubes
W	Width (mm)
h_c	Heat transfer coefficient (W / m^2K)

Subscripts

f	Refers to fluid
r	radiation
c	convection

Abbreviations

WoT	Wire on Tube
BEE	Bureau of Energy Efficiency
FC	Freezer compartment
RC	Refrigerator compartment
EC	Energy consumption
DC	Direct Cool

BTU	British Thermal Unit
RTS	Refrigeration Test Software
DAQ	Data Acquisition
BIS	Bureau of Indian Standards

AUTHORS PROFILE

Mr. Shivam Raosaheb Badwar is a student of Masters of Technology in Heat Power from School of Mechanical and Civil Engineering, MIT AOE, Pune, 412105. He has received the Bachelor of Engineering degree in the department of Mechanical Engineering from Savitribai Phule Pune University, Maharashtra. His research interest includes Refrigeration and Air conditioning, Heat Transfer, Thermal Engineering. **shivambadwar@gmail.com**

Prof. Mahesh Prakash Joshi is an Assistant Professor in the Mechanical department, MIT AOE, Pune. He is a total of 15 years of teaching experience at UG & PG level. He is pursuing his Ph. D from Symbiosis International University. His areas of interests are alternative fuel technology, engine testing, and thermal analysis.**mpjoshi@mech.mitaoe.ac.in**

Mr. Shrikant Mandale currently works as Engineering Manager at PDC Department of Whirlpool of India Limited, Pune. He had also worked at Tech Mahindra as Design Engineer. He received the Bachelor's degree in Mechanical Engineering from Pune University. He has overall 13 years industrial expeience in design and refrigeration system. **shrikant_mandale@whirlpool.com**

Mr Anil Kujur is currently employed with Whirlpool of India Limited, Pune. Ex-employee of LG electronics. He received the Masters degree in Mechanical Engineering from IIT Madras. He has Overall 8 years' experience in Refrigeration and Air conditioning.
anil_kujur@whirlpool.com