International Journal of Research
Available at https://edupediapublications.org/journals

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 12
April 2018

# Analytical and Experimental Investigations of Evaporator with R30-R160 Mixture

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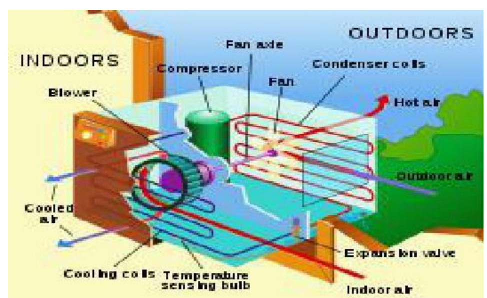
**ABSTRACT:** *Now a day's refrigeration has become a basic need for the people all around the world. It's been used for storing food to cryo-cooling the liquid H2 and liquid O2 used as rocket fuels. Domestic or industrial refrigeration of foods or public places are probably the most widely used application of refrigeration. So, Here a domestic and basic Vapor Compression Refrigeration Cycle is analyzed and experimented with mixture of refrigerants R30 & R160 hoping to get higher heat transfer rates without the expense of COP of the unit as individual refrigerants are not showing good results. The azeotropic mixture of R30 & R160 is made with R160 concentrations of 0%, 20%, 40%, 60%, 80% and 100% in R30 and it is used in a Refrigeration unit with different flow rates by fixing the other input parameters constant. Both the analytical heat transfer rates and experimental heat transfer rates at different flow rates are found out and noted. The values are compared to get a clear picture of the heat transfer rates at different flow rates. In this thesis the analysis and experiment it is known that higher flow rates of the refrigerant mixture increases the heat transfer rates but in the expense of higher work consumption which will affect the coefficient of performance of the refrigerant unit which is not advisable to use since the work utilization of the good refrigeration unit should be lesser for unit of refrigeration. CFD analysis to determine the heat transfer coefficient, mass flow rate, heat transfer rate, pressure drop and velocity at different mass flow rates (1, 1.5 &2kg/min) and they are compared with the experimental results for proposing an appropriate mixture of refrigerant blend at best flow rate.*

**INTRODUCTION TO AIR CONDITIONER**

An **Air Conditioner** also referred as **AC** is a domestic home appliance, system, or mechanism designed to dehumidify and extract heat from a confined or closed space. The cooling is carried out on the basis of simple refrigeration cycle. In general, a complete system or unit of heating, ventilation and air conditioning is known as "HVAC". Its purpose, in a building or an automobile, is to provide comfort during either hot or cold weather.




A typical home air conditioning unit.

**INTRODUCTION TO EVAPORATOR**

It is in the evaporators in which the cooling effect actually takes place in the refrigeration or the air conditioning systems. For many people the evaporator is the main part of the refrigeration system and they consider other parts as less useful.

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The evaporators are heat exchanging surfaces that transfer the cooling effect from the refrigerant to the substance or space be cooled, thus removing the heat from the space or substance. The evaporators are used in wide variety of diverse applications like refrigeration and air conditioning processes and hence they are available in wide variety of designs, sizes, and shapes.

They are also differentiated depending on the application, direction of air circulation around the evaporator, construction of the evaporator, method of feeding the refrigerant and also the refrigerant control.

TYPES OF EVAPORATORS OR CLASSIFICATION OF THE EVAPORATORS: In the large refrigeration and air conditioning plants the evaporator is used for chilling the water. In such cases shell and tube type of heat exchangers are used as the evaporators. In such plants the evaporators or the chillers are classified as:

1) Dry expansion type of evaporators

2) Flooded type of the evaporators

## LITERATURE SURVEY

In the paper by Kiran B. Parikh, an Evaporator is the Main component of Air-conditioning system. This paper presents the study of the fin tube type Evaporator; An Experimental data were collected from the IC ICE MAKE Company. After collecting data of fin tube evaporator model is prepared using solid works. At the end, FEA analysis is carried out on it using ANSYS CFX, The result of analysis is compared with Experimental result. In the paper by Carless OLIET, summarizes the research work carried out by the authors on domestic refrigerator no-frost evaporators. It has explanation of experimental unit that is currently being constructed to test isobutane fin-and-tube evaporators, together with a short description of the numerical tools developed. The first preliminary experimental results using single-phase coolants are then given together with their numerical counterparts. The numerical results are presented in detail in order to both complementing the experimental information obtained, and to show its potential as an analysis and design tool. In the paper by Shun P. Sar Sanju Tez, behavior of cryogenic nitrogen in a room-temperature evaporator is analyzed. The foundation of the formation of an ice layer surrounding the evaporator is presented.

## INTRODUCTION TO CAD

Computer-aided design (CAD) is that the use of pc systems (or workstations) to help within the creation, modification, analysis, or improvement of a style. CAD package is employed to extend the productivity of the designer, improve the standard of style, improve communications through documentation, and to form an info for producing. CAD output is usually within the type of electronic files for print, machining, or alternative producing operations. The term CADD (for pc assisted style and Drafting) is additionally used.

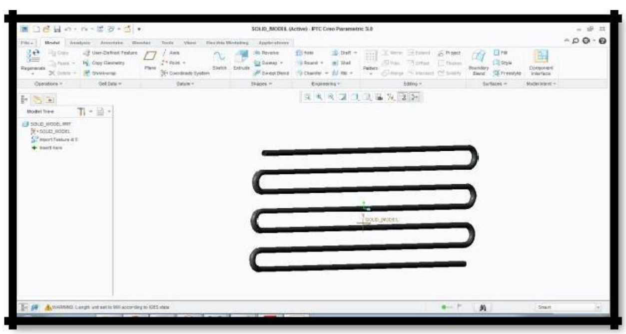
## INTRODUCTION TO CREO

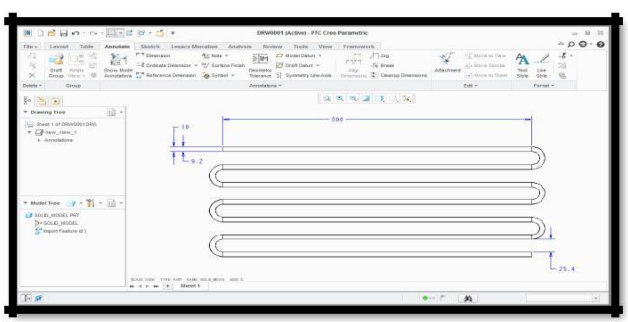
PTC CREO, earliest called Pro/ENGINEER, is 3D modeling package utilized in engineering science, design, producing, and in CAD drafting service companies. It had been one among the primary 3D CAD modeling applications that used a rule-based constant quantity system. Parameters, dimensions and options to capture the behavior of the merchandise, it will optimize the event product in addition because the style itself.

## EVAPORATOR DIMENSIONS

**Tube length = 500mm, Tube inside = 9.2 mm**

**Tube outside = 10.0mm, Tube spacing = 25.4 mm**





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p-ISSN: 2348-795X
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## INTRODUCTION TO FEA

Finite Element Analysis may be a technique of finding, sometimes roughly, sure issues in engineering and science. It's used primarily for issues that no precise resolution is required. Mainly used in some mathematical modeling of a structure or member in design or thermal analysis. Strategies of this kind area unit required as a result of analytical strategies, sophisticated issue that are used in engineering. For instance, in engineering strength of materials or the mathematical theory of snap are often want to calculate analytically the stresses and strains during a bent beam.

## ANSYS Mechanical

ANSYS Mechanical may be a finite part analysis tool for structural analysis, as well as linear, nonlinear and dynamic studies. This framework product provides finite parts to model behavior, and supports material models and equation solvers for a good vary of mechanical style issues. ANSYS Mechanical conjointly includes thermal analysis and coupled-physics capabilities involving acoustics, electricity, thermal–structural and thermo-electric analysis.

## Fluid Dynamics

ANSYS Fluent, CFD, CFX, FENSAP-ICE and connected package area unit procedure Fluid Dynamics package tools employed by engineers for style and analysis. These tools will simulate fluid flows during a virtual setting — for instance, the fluid dynamics of ship hulls; turbine engines (including the compressors, combustion chamber, turbines and afterburners); craft aerodynamics; pumps, fans, HVAC systems, combining vessels, hydro cyclones, vacuum cleaners, etc.

### Refrigerant Blend Calculations

## FLUID PROPERTIES

| Fluids | Density (kg/m3) | Thermal conductivity (w/m-k) | Specific heat (j/kg-k) | Viscosity (kg/m-s) |
|---|---|---|---|---|
| **R-30** | **1326.6 kg/m$^3$** | **0.0042 w/m-k** | **1043.0 j/kg/k** | **0.000279 kg/m-s** |
| **R-160** | **921.0 kg/m$^3$** | **0.0337 w/m-k** | **1023.0 j/kg/k** | **0.00043 kg/m-s** |
| **Water** | 998.2 kg/m$^3$ | 0.6 W/m-k | 4182 J/kg-k | 0.001003kg/m-s |

## NOMENCLATURE

$\rho_{R30}$ = Density of R30 kg/m$^3$

$\rho_{R160}$ = Density of R160 kg/m$^3$

$\rho_w$ = Density of water kg/m$^3$

$\rho mix$ = Density of R30-R160 mixture kg/m$^3$

$\phi$ = Volume fraction

$C_{pR30}$ = Specific heat of R30 j/kg-k

$C_{pR160}$ = Specific heat of R160 j/kg-k

$C_{pmix}$ = Specific heat of R30-R160 mixture j/kg-k

$\mu_{R30}$ = Viscosity of R30 kg/m-s

$\mu_{R160}$ = Viscosity of R160 kg/m-s

$\mu_{mix}$ = Viscosity of mixture kg/m-s

$K_{R30}$ = Thermal conductivity of R30 W/m-k

$K_{R160}$ = Thermal conductivity of R160 W/m-k

$K_{mix}$ = Thermal conductivity of R30-R160 W/m-k

## FORMULAS

| PROPERTIES | FORMULA |
|---|---|
| **DENSITY** | $\rho_{mix} = \phi \times \rho_{R160} + [(1-\phi) \times \rho_{R30}]$ |
| **SPECIFIC HEAT** | $C_{pmix} = \frac{\phi \times \rho\ 160 \times C_{pR160} + (1-\phi)(\rho\ 30 \times C_p\ 30)}{\phi \times \rho\ 160 + (1-\phi) \times \rho\ 30}$ |
| **THERMAL CONDUCTIVITY** | $K_{mix} = \frac{K1+2K2+2(K1-K2)(1+\beta)^3 \times \phi}{1+2\ 2-(\ 1-\ 2)(1+\ )^3 \times} \times k_2$ |
| **VISCOSITY** | $\mu_{mix} = \mu_{R160}(1+2.5\phi)$ |

Aezotropic properties

| Volume fraction ($\phi$) | Density (kg/m$^3$) | Specific heat (j/kg-k) | Thermal conductivity (w/m-k) | Viscosity (kg/m-s) |
|---|---|---|---|---|
| 0.2 | 1245.48 | 1040.042 | 0.0076 | 0.0004185 |
| 0.4 | 1164.36 | 1036.67206 | 0.0111808 | 0.000558 |
| 0.6 | 1083.24 | 1.32.7972 | 0.019106 | 0.0006975 |
| 0.8 | 1002.12 | 1028.2951 | 0.038677 | 0.000837 |

e-ISSN: 2348-6848
p-ISSN: 2348-795X
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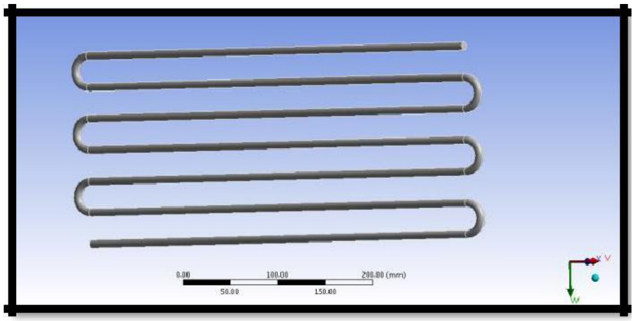
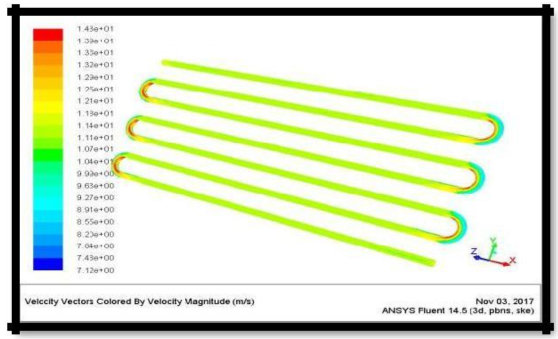
**Model for Mass flow inlet 1 kg/min**

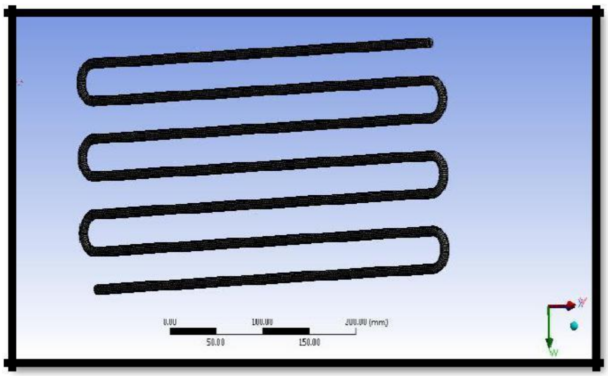
**IMPORTED MODEL**



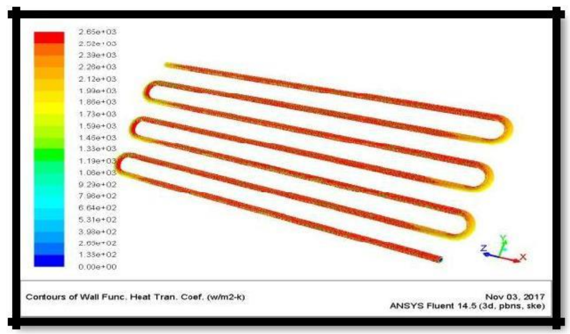
Velocity




**MESHED MODEL**



Heat Transfer Coefficient

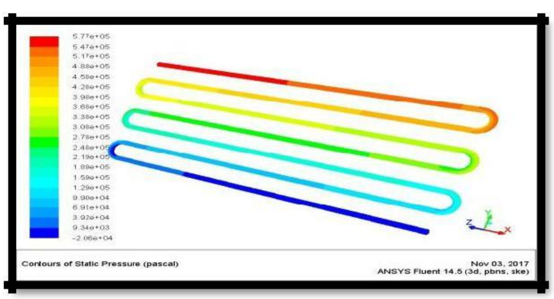



**No 'of nodes and elements**

| Statistics | |
|---|---|
| Nodes | 147120 |
| Elements | 120099 |

**Fluid -R30**

Pressure




Mass Flow Rate & Heat Transfer Rate

```
              Mass Flow Rate                 (kg/s)
-------------------------------- --------------------
                       inlet              1.0000001
            interior-___msbr              2452.7971
                      outlet            -0.99904591
                 wall-___msbr                      0
-------------------------------- --------------------
                         Net          0.00095421076

         Total Heat Transfer Rate                (w)
-------------------------------- --------------------
                       inlet             -40833.457
                      outlet              40794.746
                 wall-___msbr                      0
-------------------------------- --------------------
                         Net             -38.710938
```

**RESULT TABLE: Analytical**

**Investigation Mass flow rate 1 kg/min**

| Fluid | Pressure (Pa) | Velocity (m/s) | Heat transfer coefficient (w/m²-k) | Mass flow rate (kg/s) | Heat transfer rate(W) |
|---|---|---|---|---|---|
| R-30 | 5.77e+05 | 1.43e+01 | 2.65e+03 | 0.00095421 | 38.710938 |
| (Φ=0.2) | 6.61e+05 | 1.52e+01 | 3.12e+03 | 0.0018023252 | 73.214844 |
| (Φ=0.4) | 7.16e+05 | 1.63e+01 | 3.43e+03 | 0.004491 | 182.23047 |
| (Φ=0.6) | 8.89e+05 | 1.75e+01 | 4.31e+03 | 0.001823 | 73.769531 |
| (Φ=0.8) | 9.66e+05 | 1.88e+01 | 6.24e+03 | 0.002842 | 114.39844 |
| R-160 | 1.12e+06 | 2.06e+01 | 8.19e+03 | 0.004652 | 185.85547 |

**Mass flow rate 1.5 kg/min**

| Fluid | Pressure (Pa) | Velocity (m/s) | Heat transfer coefficient (w/m²-k) | Mass flow rate (kg/s) | Heat transfer rate(W) |
|---|---|---|---|---|---|
| R-30 | 1.34e+06 | 2.15e+01 | 3.83e+03 | 0.0047117 | 192.57813 |
| (Φ=0.2) | 1.52e+06 | 2.28e+01 | 4.49e+03 | 0.00090575218 | 36.8984 |
| (Φ=0.4) | 1.81e+06 | 2.344e+01 | 4.92e+03 | 0.0032984 | 133.6132 |
| (Φ=0.6) | 2.00e+06 | 2.63e+01 | 6.19e+03 | 0.003185482 | 134.1289 |
| (Φ=0.8) | 2.74e+06 | 2.84e+01 | 8.93e+03 | 0.006955 | 279.98043 |
| R-160 | 1.86e+06 | 3.09e+01 | 1.17e+04 | 0.00254344 | 101.82031 |

**Mass flow rate 2 kg/min**

| Fluid | Pressure (Pa) | Velocity (m/s) | Heat transfer coefficient (w/m²-k) | Mass flow rate (kg/s) | Heat transfer rate(W) |
|---|---|---|---|---|---|
| R-30 | 2.25e+06 | 2.86e+01 | 4.97e+03 | 0.0035150051 | 144.34375 |
| (Φ=0.2) | 3.39e+06 | 3.05e+01 | 5.83e+03 | 0.012027264 | 489.45313 |
| (Φ=0.4) | 2.63e+06 | 3.26e+01 | 6.38e+03 | 0.00502657 | 204.19531 |
| (Φ=0.6) | 4.10e+06 | 3.50e+01 | 7.99e+03 | 0.0093023 | 376.00781 |
| (Φ=0.8) | 3.10e+06 | 3.78e+01 | 1.15e+04 | 0.007047 | 283.2812 |
| R-160 | 3.33e+06 | 4.12e+01 | 1.51e+04 | 0.0077912 | 311.95313 |

**EXPERIMENTAL INVESTIGATIONS**

**AIM:**

The main motto of this experiment is to conduct the performance test on a refrigeration test rig with R30 and R160 at different proportions and at different flow rates to find out a suitable azeotropic composition for the taken test unit at different test conditions

**EQUIPMENT/APPARATUS:**

1. Refrigeration test rig
2. Measuring jar
3. Stop watch
4. Safety glasses

**SPECIFICATIONS:**

Compressor : 1/3 Ton of refrigeration

Condenser : Air cooled

Exp Device : Capillary tube or Expansion value

Evaporator coil : Immersed in S.S. water tank

Refrigerant : R30 & R160 mixture

**DESCRIPTION:**

The test rig consists of hermetically sealed compressor. The Compressed refrigerant from the compressor is sent to an air cooled condenser and the condensate in liquid form is sent to the expansion valve/capillary tube for throttling. Due to throttling temperature of the refrigerant falls and the cold refrigerant absorbs heat from the water in the evaporator tank. The refrigerant is then returned to the compressor.

A suitable filter and a transparent rotameter are fixed to visually observe the liquid. Refrigerant is fitted in the refrigerant line from condenser to evaporator. A thermocouple is provided to measure the temperature of the water in the evaporator tank. An energy meter is provided to measure the energy input to the compressor. Suitable pressure gauges are provided at the compressor inlet (evaporator outlet), Condenser inlet (Compressor outlet), condenser outlet (before throttling) and evaporator inlet (after throttling) to study the refrigeration cycle operating between the two pressures.

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e-ISSN: 2348-6848
p-ISSN: 2348-795X
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A thermostat is provided for the cutting off the power to the compressor when the water temperature reaches asset value. A voltmeter and an ammeter are provided to monitor the inlet power supply. A voltage stabilizer is provided for the protection of compressor. Provisions are provided in the refrigerant pipe line for charging the test ring with additional refrigerant if necessary. Additional 4 No's of thermocouples are fitted at the condenser and evaporator inlet and outlet for studying the temperature at the 4 points in the refrigeration cycle.

**THEORY:**

A refrigerator consists of a compressor connected by suitable pipelines to a condenser, a capillary tube and an evaporator. Refrigerant of R30&R160 mixture at different proportions in vapor state from the evaporator is compressed in the compressor and sent to the condenser. Here it condenses in to liquid and it is then throttled. Due to throttling temperature of refrigerant drops and the cold refrigerant passes through the evaporator absorbing heat from the object to be cooled. The refrigerant is then returned to the compressor and the cycle is completed.

**PROCEDURE:**

1. Fill up the evaporator tank with a known quantity of water (8, 10 & 12 liters).
2. Switch on the compressor.
3. After about 5 minutes after steady state had set in immerse the evaporator coil in the water tank
4. Note the initial energy meter reading and water temperature in the water tank.
5. After a known period of time (60, 40 & 20 minutes) note down the energy meter reading and water temperature.
6. Calculate the actual COP.
7. Note the refrigerant pressures at compressor inlet (evaporator outlet), Condenser inlet (Compressor outlet), condenser outlet (before throttling) and evaporator inlet (after throttling) using the pressure gauges.
8. Note the temperatures at compressor inlet (evaporator outlet), Condenser inlet (Compressor outlet), condenser outlet (before throttling) and evaporator inlet (after throttling) using the thermocouples provided.
9. Find out the temperature differences at evaporator coil by iterating the experiment at different flow rates of the refrigerant and tabulate them
10. Calculate the heat transfer rates at evaporator coil at different proportions of refrigerant mixture and different flow rates
11. Choose the optimum flow rate and proportion of the refrigerant mixture suitable for the taken refrigeration unit and compare it with analytical values

**PRECAUTIONS:**

1. Before noting the water temperature, physically stir the water to ensure the temperature is uniform in the water tank.
2. Since COP depends on the evaporator temperature and condenser temperature, the calculated COP (which is an average value) will be different for varying evaporator, condenser and water temperatures.
3. When the compressor turns off (by the thermostat) or is switched off manually, do not turn on the power immediately. Allow a few minutes for the pressure in the compressor inlet and outlet to equalize. The time delay provided in the voltage stabilizer is for the purpose only. Immediate starting will cause load on the compressor and may lead to burn out.

**SAMPLE CALCULATIONS:**

Quantity of water in the evaporator tank, m = ………. kg

Time taken for experiment, τ = …………….Sec

Initial temperature of water, T1= ………..C

Final temperature of water, T2= ………..C

Initial energy meter reading, E1= ………….kWh

Final energy meter reading, E2= ………….kWh

Refrigerating effect per hour = m(T1-T2)/ τ

kW Energy input = (E2-E1)/ τ ………..kW

$$= \frac{mCdT}{\tau}$$

- Heat transfer rate in W

m – Mass of water in cooling tank in kg (8, 10, 12)

C - Specific heat of water in J/kgK (4180)

dT – Temperature difference in water in C

T1 – Initial temperature of water in C (30)

T2 – Final temperature of water in C

τ - Time in sec (3600, 2400, 1200)

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 12
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**RESULT TABLE: Experimental Investigation**

**Mass flow rate 1 kg/min**

| Ref % | T2 (C) | | | | T1-T2 | Q (W) |
|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Avg T2 | (C) | |
| R30 | 25.94 | 26.56 | 26.02 | 26.14 | 3.86 | 35.85511 |
| 0.2 | 22.21 | 21.44 | 22.35 | 22 | 8.00 | 74.31111 |
| 0.4 | 9.97 | 9.98 | 10.20 | 10.05 | 19.95 | 185.31333 |
| 0.6 | 21.66 | 21.98 | 23.74 | 22.46 | 7.54 | 70.03822 |
| 0.8 | 17.92 | 17.11 | 17.59 | 17.54 | 12.46 | 115.73955 |
| R160 | 9.98 | 11.12 | 10.10 | 10.40 | 19.60 | 182.06222 |

**Mass flow rate 1 kg/min**

| Ref % | T2 (C) | | | | T1-T2 | Q (W) |
|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Avg T2 | (C) | |
| R30 | 18.89 | 18.68 | 19.61 | 19.06 | 10.94 | 190.53833 |
| 0.2 | 28.22 | 27.91 | 27.69 | 27.94 | 2.06 | 35.87833 |
| 0.4 | 23.92 | 23.62 | 23.20 | 23.58 | 6.42 | 111.81500 |
| 0.6 | 22.40 | 2242 | 2256 | 22.46 | 7.54 | 131.32166 |
| 0.8 | 14.01 | 14.89 | 13.55 | 14.15 | 15.85 | 276.05416 |
| R160 | 22.98 | 23.92 | 25.16 | 24.02 | 5.92 | 104.15166 |

**Mass flow rate 1 kg/min**

| Ref % | T2 (C) | | | | T1-T2 | Q (W) |
|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Avg T2 | (C) | |
| R30 | 18.89 | 18.68 | 19.61 | 19.06 | 10.94 | 190.53833 |
| 0.2 | 28.22 | 27.91 | 27.69 | 27.94 | 2.06 | 35.87833 |
| 0.4 | 23.92 | 23.62 | 23.20 | 23.58 | 6.42 | 111.81500 |
| 0.6 | 22.40 | 2242 | 2256 | 22.46 | 7.54 | 131.32166 |
| 0.8 | 14.01 | 14.89 | 13.55 | 14.15 | 15.85 | 276.05416 |
| R160 | 22.98 | 23.92 | 25.16 | 24.02 | 5.92 | 104.15166 |

**Energy Meter**

**Expansion Devices**

**Flow meter**

**Pressure Gauge**


**Evaporator Tank**

International Journal of Research
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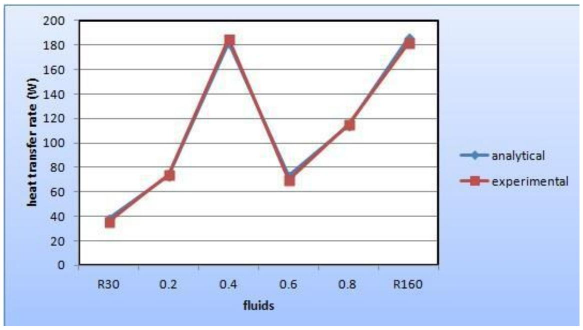
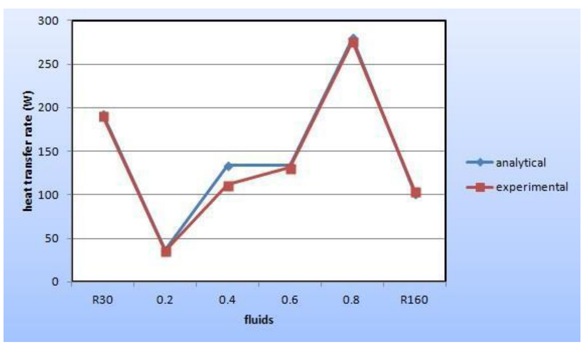
**COMPARISON GRAPHS**

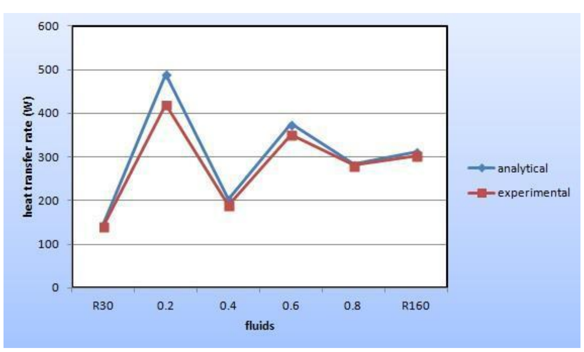
Heat Transfer Rate of analytical and experimental investigation at 1 kg/min



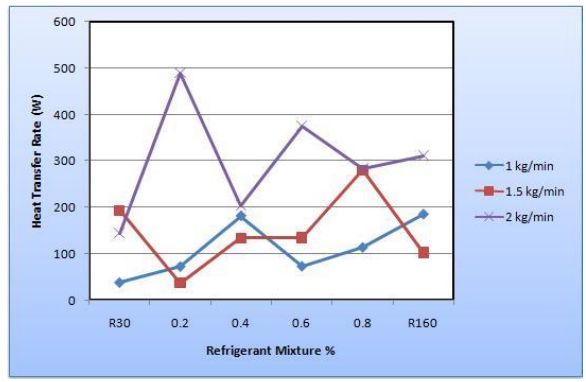

Heat Transfer Rate of analytical and experimental investigation at 1.5 kg/min



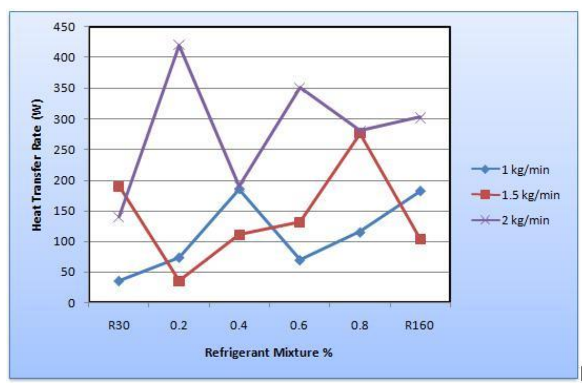

Heat Transfer Rate of analytical and experimental investigation at 2 kg/min




Analytical Heat Transfer Rates at different proportions




Experimental Heat Transfer Rates at different proportions



## CONCLUSION

The azeotropic mixture of R30 & R160 is made with R160 concentrations of 0%, 20%, 40%, 60%, 80% and 100% in R30 and it is used in a Refrigeration unit with different flow rates by fixing the other input parameters constant.

Both the analytical heat transfer rates and experimental heat transfer rates at different flow rates are showing same results with little deviation. The values are compared to get a clear picture of the heat transfer rates at different flow rates.

From the data obtained from the analysis and experiment it is known that higher flow rates of the refrigerant mixture increases the heat transfer rates but in the expense of higher work consumption which will affect the coefficient of performance of the refrigerant unit which is not advisable to use since the work utilization of the good refrigeration unit should be lesser for unit of refrigeration.

So, moderate flow rate i.e. 1.5 kg/min is suitable and recommended for the refrigeration unit with the use of our refrigerant blend.

Though the concentration of R160 in the R30 doesn't follow a particular fashion in the heat transfer rates at different flow rates, it has been observed that higher R30 concentration mixtures consume more work for pumping and flow as R30 is denser than R160 which is again not advisable as it lowers the COP of the refrigeration unit. Also higher concentrations of R30 shows corrosion in the tubing used in the evaporator and condenser units.

So, it is suggested that higher concentrations of R160 is yielding fruitful results compared to higher concentrations of R30. Then 20% R30 & 80% R160 is used since it is giving higher heat transfer rates with lower work consumption.

From the results it's been confirmed that 20% R30 – 80% R160 mixture at 1.5 kg/min flow rate is best suited for the refrigeration unit without compromising the COP of the unit

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