Effect of different capillary tube diameters on the performance of VCR system

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Abstract: A refrigerant is a vital fluid that is used in cooling mechanism which acts as a heat carrier by undergoing phase changes from gas to liquid and back to gas in the refrigeration cycle. Earlier, Chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) dominated the industrial and domestic refrigeration sector. CFCs and HCFCs are referred as ozone depleting substances (ODS) since the presence of chlorine make them non- bio degradable by natural agents and last very long in the atmosphere after their release and once these gases reach the stratosphere, results in thinning of ozone layer. The mandate of Montreal Protocol approved by the United Nation's Environmental Protection Agency (UNEP) enforces the phase out of all ozone depleting substances in developing countries by 2030 and Kyoto Protocol emphasizes the reduction in emission of green house gases including refrigerants like CFCs and HCFCs. The wide spread of environmental concerns like ozone depletion potential (ODP) and global warming issues are posing a challenge to the refrigeration and associated industries A detailed experimentation was carried out in a vapour compression test rig to compare the performance and effectiveness of the system based on the following parameters: i) Evaporator Load (Qe), ii) Condenser Load (Qc), iii) Work done by Compressor (Wc), Refrigeration Effect (R.E), iv) Coefficient of Performance (COP) and v) Effectiveness (□) of the system. The experimental results showed that R600a (Isobutane) a hydrocarbon performed better than R12 (CFC), and R152a (Difluoroethane) in terms of COP and energy consumption. The comparison between the four refrigerants selected for the study revealed that hydrocarbon refrigerant R600a (Isobutane) recorded the lowest temperature of -3.7^{0}C in the chiller for the capillary diameter of 0.044‖ (1.18 mm). Moreover, the energy consumption by hydrocarbon R600a was 8% and 30% less for capillary diameters 0.044‖ and 0.050‖. Than R12. Based on their environmental benefits hydrocarbon refrigerant R600a is selected as a suitable eco friendly alternate refrigerant which is cost effective, energy efficient and safe to the environment.

***Keywords* - ClF_2CCF_2Cl, HC mixture, Coefficient of Performance, $C_2H_4F_2$, GWP**

1.INTRODUCTION

The methods of production of cold by mechanical processes are quite recent. Long back in 1748, William Coolen of Glasgow University produced refrigeration by creating partial vacuum *over ethyl ether*. But, he could not implement his experience in practice. The first development took place in 1834 when Perkins proposed a hand-operated compressor machine working on ether. Then in 1851 came Gorrie's air refrigeration machine, and in 1856 Linde developed a machine working on ammonia. The pace of development was slow in the beginning when steam engines were the only prime movers known to run the compressors. With the advent of electric motors and consequent higher speeds of the compressors, the scope of applications of refrigeration widened. The pace of development was considerably quickened in the 1920 decade when du Pont put in the market a family of new working substances, the fluoro-chloro derivatives of methane, ethane, etc.—popularly known as chioro fluorocarbons or CFCs—under the name of Freons. Recent developments involve finding alternatives or substitutes for Freons, since it has been found that chlorine atoms in Freons are responsible for the depletion of ozone layer in the upper atmosphere. Another noteworthy development was that of the ammonia-water vapour absorption machine by Carre. These developments account for the major commercial and industrial applications in the field of a refrigeration.

2. METHODS OF REFRIGERATION

2.1 DISSOLUTION OF CERTAIN SALTS IN WATER

When certain salts such as sodium chloride, calcium chloride. Salt-petre. etc., are dissolved in water, they absorb heat. This property has been used to produce refrigeration. By this method the temperature of water can he lowered much below 0°C, the freezing temperature of water. Calcium chloride lowers the water temperature upto around —50°C while sodium chloride upto —20°C. The salt used for refrigeration has to be regained by evaporating the solution. On one hand the refrigeration produced is quite small and on the other hand, the regaining process of salt is so cumbersome that this is not feasible for commercial exploitation.

2.2 CHANGE OF PHASE

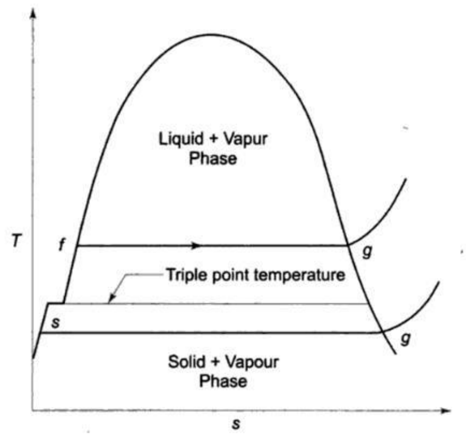


Figure 1.1 Refrigeration due to phase change

2.3 THROTTLING PROCESS

If a fluid at high pressure is expanded through a valve or constriction, either of the three effects are expected depending upon initial and final conditions: (1) Te>Ti (ii) Te=Ti and (iii) Te<Ti, as shown in Fig. (1.2), where Ti is the inlet temperature and T_B. T_A and Tc are the corresponding values of the exit temperature Te for the above respective cases. The rise or fall in the temperature at the end of throttling is dependent upon the state after throttling on the constant enthalpy curve.

3. REFRIGERANTS IN THE AFTERMATH OF OZONE LAYER DEPLETION

The most important requirement for refrigerants in the aftermath of ozone layer depletion is that it should be a non-Ozone Depleting Substance (non-ODS). Out of this requirement two alternatives have emerged. The first one is to look for zero ODP synthetic refrigerants and the second one is to look for ―natural‖ substances. Introduction of hydro fluorocarbons (HFCs) and their mixtures belong to the first route, while the reintroduction of carbon dioxide (in a supercritical cycle), water and various hydrocarbons and their mixtures belong to the second route. The increased use of ammonia and use of other refrigeration cycles such as air cycle refrigeration systems and absorption systems also come under the second route. Both these routes have found their proponents and opponents. HFC134a (synthetic substance) and hydrocarbons (natural substances) have emerged as alternatives to Freon-12. No clear pure fluid alternative has been found as yet for the other popular refrigerant HCFC-22.

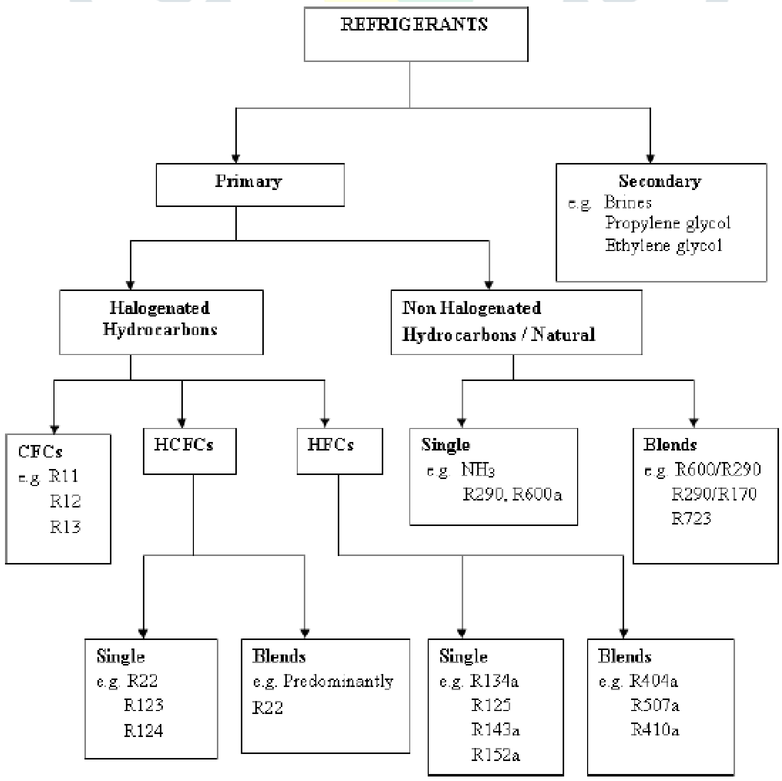


Figure 3.1 Classification of refrigerants

4. LITERATURE REVIEW

R. Cabello, E. Torrella and J. Navarro-Esbri [1], have analyzed the performance of a vapour compression refrigeration system using three different working fluids (R134a, R407c and R22). The operating variables are the evaporating pressure, condensing pressure and degree of superheating at the compressor inlet. They analyzed that the power consumption decreases when compression ratio increases with R22 than using the other working fluids.

B.O. Bolaji et al[2] investigated experimentally the performances of three ozone friendly hydro fluorocarbon (HFC) refrigerants R12, R152a and R134a. R152a refrigerant found as a drop in replacement for R134a in vapour compression system.

B.O. Bolaji[3] discussed the process of selecting environmental-friendly refrigerants that have zero ozone depletion potential and low global warming potential. R23 and R32 from methane derivatives and R152a, R143a, R134a and R125 from ethane derivatives are the emerging refrigerants that are non toxic, have low flammability and environmental-friendly. These refrigerants need theoretical and experimental analysis to investigate their performance in the system.

James M. Calm [4], has studied the emission and environmental impacts of R11, R123, R134a due to leakage from centrifugal chiller system. He also investigated the total impact in form of TEWI and change in system efficiency or performance due to charge loss. He also summarized the methods to reduce the refrigerant losses by the system like design modifications, improvement in preventive maintenance techniques, use of purge system for refrigerant vapour recovery, servicing and lubricant changing in system.

Samira Benhadid-Dib and Ahmed Benzaoui [5], have showed that the uses of halogenated refrigerants are harmful for environment and the use of "natural" refrigerants become a possible solution. Here natural refrigerants are used as an alternative solution to replace halogenated refrigerants. The solution to the environmental impacts of refrigerant gases by a gas which contains no chlorine no fluorine and does not reject any CO2 emissions in the atmosphere. The researchers showed that emissions have bad effects on our environment. They also concerned by a contribution to the reduction of greenhouse gases and by the replacement of the polluting cooling fluids (HCFC).

Eric Granryd [6], has enlisted the different hydrocarbons as working medium in refrigeration system. He studied the different safety standards related to these refrigerants. He showed the properties of hydrocarbons (i.e. no ODP and negligible GWP) that make them interesting refrigerating alternatives for energy efficient and environmentally friendly. But safety precautions due to flammability must be seriously taken into account.

Y. S. Lee and C. C. Su [7], have studied the performance of VCRS with isobutene and compare the results with R12 and R22. They used R600a about 150 g and set the refrigeration temperature about 4 °C and -10 °C to maintain the situation of cold storage and freezing applications. They used 0.7 mm internal diameter and 4 to 4.5 m length of capillary tube for cold storage applications and 0.6 mm internal diameter and 4.5 to 5 m length of capillary tube for freezing applications.

5. EXPERIMENTAL SETUP

5.1 WORKING OF A REFRIGERATION SYSTEM

A vapour compression cycle is used in most household refrigerators, freezers and air conditioners. In this cycle, a circulating liquid called refrigerant enters the compressor as low-pressure vapour or slightly above the temperature of the refrigerator interior. The vapour is compressed and exits as high-pressure superheated vapour. The superheated vapour travels under pressure through coils or tubes comprising "the condenser", which are passively cooled by exposure to air in the room. The condenser cools the vapour, which liquefies. This liquid refrigerant is forced through a metering or throttling device, also known as an expansion valve (essentially a pin-hole sized constriction in the tubing) to an area of much lower pressure. The sudden decrease in pressure results in explosive-like flash evaporation of a portion of the liquid. The latent heat absorbed by this flash evaporation is drawn mostly from adjacent still liquid refrigerant, a phenomenon known as "auto-refrigeration". This cold and partially vaporized refrigerant continues through the coils or tubes of the evaporator unit. Refrigerant leaves the evaporator, now fully vaporized and slightly heated, and returns to the compressor inlet to continue the cycle.

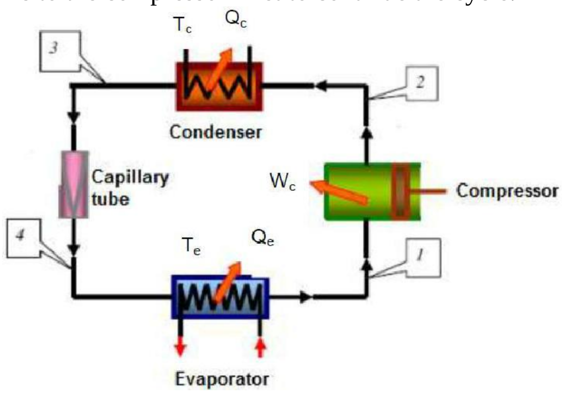
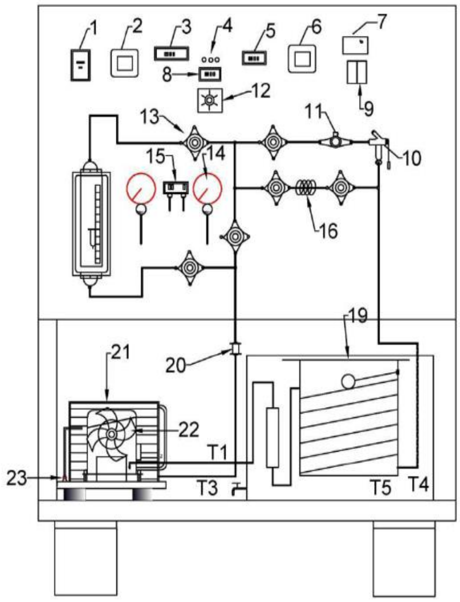


Fig. 5.1 Schematic diagram of single stage vapour compression Refrigeration system

The experimental set up consist of a reciprocating compressor, an air cooled condenser, an expansion device usually a capillary device and coiled evaporator surrounding the vessel for cooling of liquids. The actual view and the line diagram of the vapour compression refrigeration system are shown in Fig. 4.4(i) and 4.5. The actual view of the chiller unit filled with water with a sensor to measure the temperature of water at noted intervals is shown in Fig. 4.4(ii).



S.NO	DESCRIPTION
1	MAINS
2	E/METER FOR FAN
3	DIGITAL VOLTMETER
4	INDICATORS
5	DIGITAL AMMETER
6	E/METER FOR COMPRESSOR
7	THERMOSTAT
8	DIGITAL TEMP.INDICATOR
9	5A SWITCHES
10	THERMOSTATIC EXPANSION VALVE
11	SOLENOID VALVE
12	TEMP.SELECTOR SWITCH
13	HAND SHUTOFF VALVE
14	PRESSURE GAUGES
15	HP-LP CUTOUT
16	CAPILLARY
17	ROTAMETER
18	25mm M.S SQUARE TUBE FRAME
19	CHILLER
20	FILTER DRIER
21	CONDENSER
22	COMPRESSOR
23	CHARGING VALVE

Fig.5.2 (i) Actual view of the experimental set up of vapour compression refrigeration system

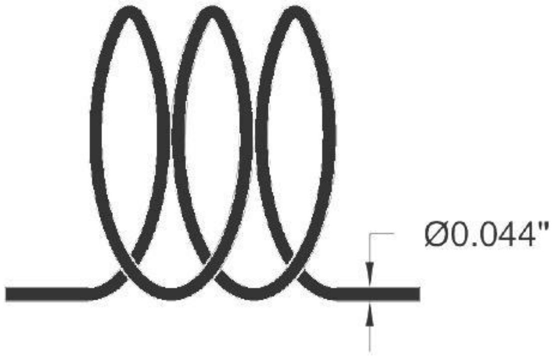


Fig. 5.3 Schematic diagram showing capillary diameter ϕ= 0.044" inch"

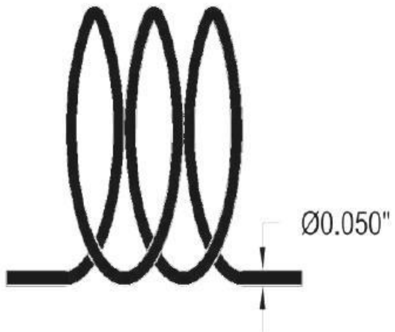


Fig. 5.4 Schematic diagram showing capillary diameter ϕ= 0.050" inch

Table 5.1 Properties of refrigerants

Properties	Name of the Refrigerant			
	R-12	**R-134a**	**R-404a**	**R-600a**
Environmental Classification	CFC	HFC	HFC	HC
Molecular Weight	120.9	102.3	97	58.12
Boiling Point (1 atm. F)	-21.6	-14.9	-51.8	34
Critical Pressure (psia)	600	588.3	548.2	37.96
Critical Temperature (F)	233.5	213.8	162.5	151.98
Critical Density (lb./ft^3)	35.3	32.0	35.84	228
Heat of Vaporization (BTU/lb.)	71.2	93.3	66.37	601.26
Ozone Depletion Potential (CFC 11 = 1.0)	1.0	0	0	0
Global Warming Potential (CO_2 = 1.0)	107205	1320	3859	20
ASHRAE Standard 34 Safety Rating	A1	A1	A1	A

6. RESULTS AND DISCUSSION

The parameters time and temperature are dependent on each other. The temperature of water gradually decreases with respect to time. The graphs plotted from Fig. 5.1 to 5.3 refer to time versus water temperature for the four refrigerants and various capillaries used in the study. Fig. 5.1 shows the comparison of time for different capillary diameters. The graph clearly indicates that the capillary diameter 036‖ has recorded a minimum temperature of 2.5^{0}C and the diameters 0.044‖ showed very less difference in temperature with the initial temperature of water.

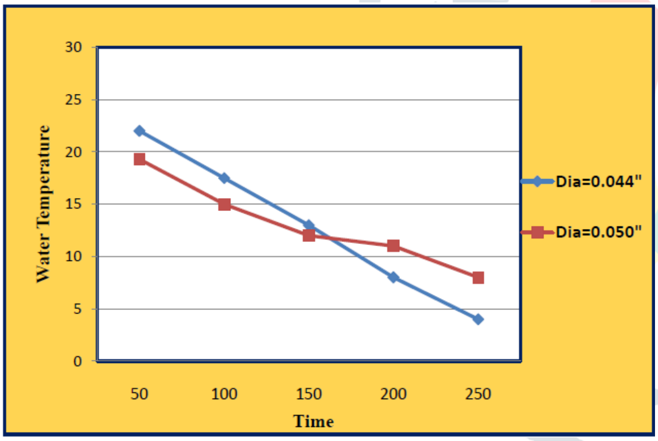


Fig. 6.1 Time versus water temperature for refrigerant R134a

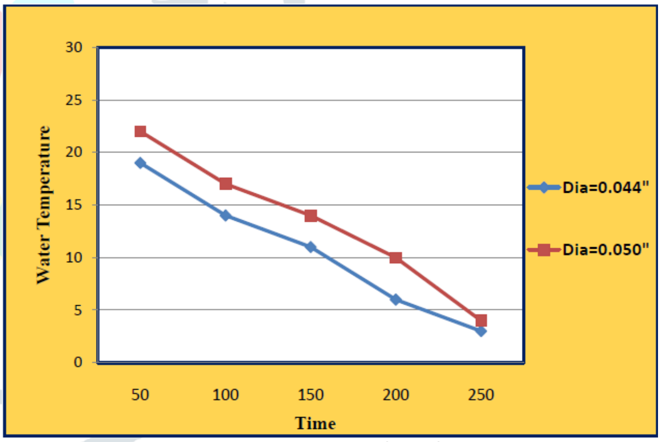


Fig. 6.2 Time versus water temperature for refrigerant R152a

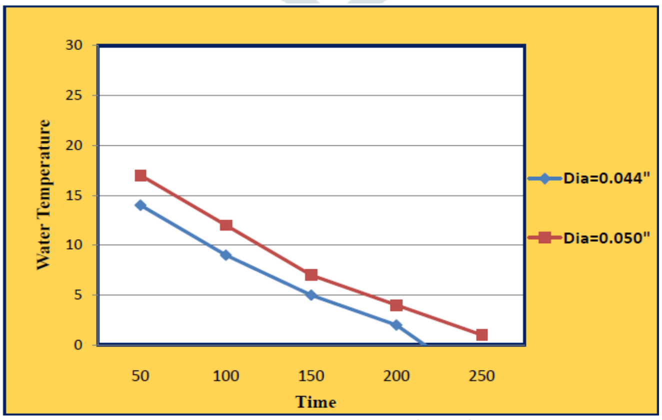


Fig. 6.3 Time versus water temperature for refrigerant R600a

The work of compression is dependent on the discharge pressure and temperature. Fig 5.4 to 5.6 shows the graphs plotted with the experimental data for time versus work of compression for the refrigerants selected for the study. The results displayed in the Fig. 5.4 to 5.6 shows progressive increase in the work of compression as time increases, which will be an influencing factor for the increase or decrease in the evaporator temperature. It is clear from the above graphs, that the increase of capillary diameter increases the load on the compressor which in turn decreases the evaporator temperature. The results showed that the diameter 0.36‖ required more of compression work than for diameters 0.030‖, irrespective of the refrigerants used for the analysis.

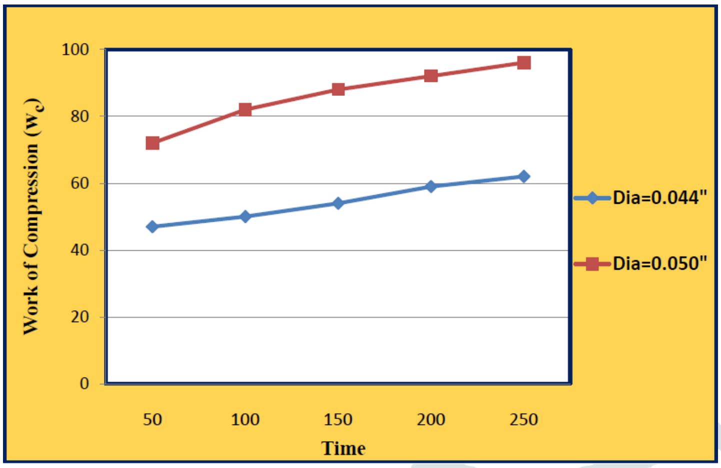


Fig. 6.4 Time versus work of compression for refrigerant R134a

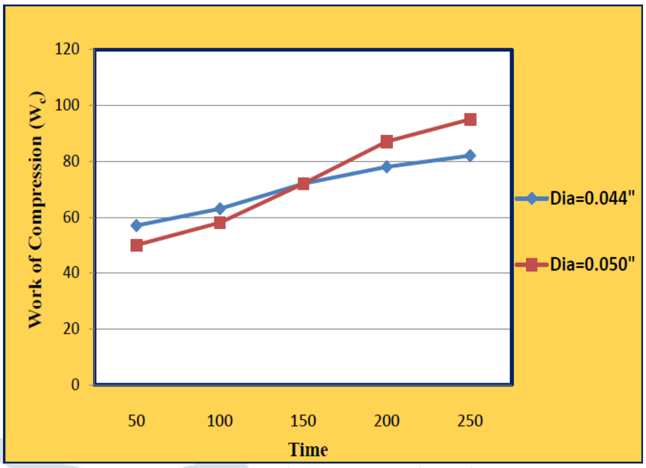


Fig. 6.5 Time versus work of compression for refrigerant R152a

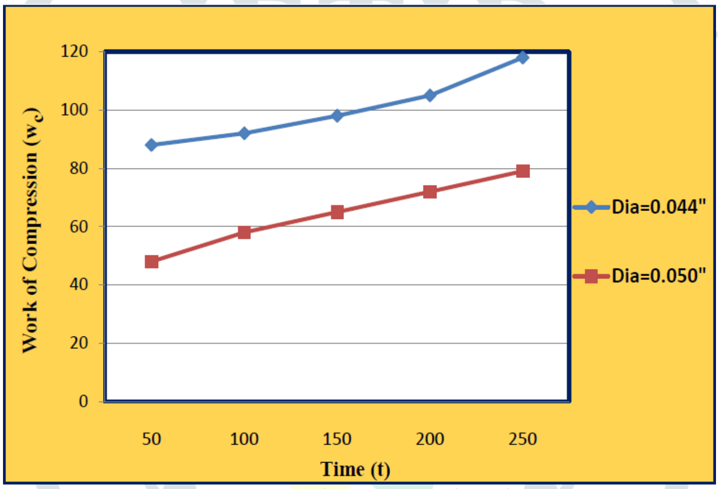


Fig. 6.6 Time versus work of compression for refrigerant R600a

7. CONCLUSION

Selection of alternate refrigerants to replace CFC based working systems that pose threat to environmental degradation is the objective of the study. The need for significant improvement in the system efficiency has prompted the researchers to find suitable alternate refrigerant for CFC. The research work was carried out to analyze and compare the various thermo physical properties of drop in refrigerants R152a (HFC blend) and R600a (HC) with R134a (CFC) refrigerants with different capillaries diameters of 0.44 inch, 0.50 inch for a length of 10 m.

Fig 5.1 In this diagram shows the variation between water temperatures versus time, here two different capillary diameter tubes used for experiment, in this figure 0.044‖ capillary tube gives minimum water temperature than 0.050‖ capillary tube for R134a refrigerant.

Fig 5.2 In this diagram shows the variation between water temperatures versus time, here two different capillary diameter tubes used for experiment, in this figure 0.044‖ capillary tube gives minimum water temperature than 0.050‖ capillary tube for R152a refrigerant.

Fig 5.3 In this diagram shows the variation between water temperatures versus time, here two different capillary diameter tubes used for experiment, in this figure 0.044‖ capillary tube gives minimum water temperature than 0.050‖ capillary tube for R600a refrigerant

Fig 5.4 In this diagram shows the variation between works of compression versus time, here two different capillary diameter tubes used for experiment, here 0.050‖ diameter tube have more compression work than 0.044‖ capillary tube for R134a refrigerant.

Fig 5.5 In this diagram shows the variation between works of compression versus time, here two different capillary diameter tubes used for experiment, here 0.050‖ diameter tube have more compression work than 0.044‖ capillary tube for R152a refrigerant.

Fig 5.6 In this diagram shows the variation between works of compression versus time, here two different capillary diameter tubes used for experiment, here 0.044‖ diameter tube have more compression work than 0.050‖ capillary tube for R600a refrigerant.

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