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DEPARTMENT OF MECHANICAL AND CHEMICAL ENGINEERING (MCE)

COMPARISON OF PERFORMANCE OF A 500 WATT REFRIGERATION SYSTEM WITH ONE COMPRESSOR AND THREE REFRIGERANTS

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Abstract

Currently in Bangladesh, most low capacity refrigerant systems (below 1 ton refrigerating effect) use R-12 compressors with R-12 refrigerant fluid. But with the global policy changes of phasing out R-12, these systems need to be replaced. However, changing compressors to fit the replacing fluid is a costly process. This paper finds out whether R-22 and R-134a are suitable for use with R-12 compressors and by comparative analysis determine which one is the best replacement for the systems.

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Preface

In general, refrigeration is defined as any process of heat removal. More specifically, refrigeration is defined as the branch of science that deals with the process of reducing and maintaining the temperature of a space or material below the temperature of the surroundings.

To accomplish this, heat must be removed from the body being refrigerated and transferred to another body whose temperature is below that of the refrigerated body. Since the heat removed from the refrigerated body is transferred to another body, it is evident that refrigerating and heating are actually opposite ends of the same process. Often only the desired result distinguishes one from the other.

The largest application of refrigeration, which is the process of cooling, is for air conditioning. In addition, refrigeration embraces industrial refrigeration, including the processing and preservation of food; removing heat from substances in chemical, petroleum and petrochemical plants; and numerous special applications such as those in the manufacturing and construction industries.

The vapour compression refrigeration cycle is the most widely used refrigeration cycle in practice. For this reason and appropriateness of favorable conditions in this endeavor, the vapour compression cycle is used for analysis of the system involved. The system consists of mainly four components, namely compressor, condenser, capillary tube and evaporator. By the subsequent compression, condensation, expansion and evaporation of a refrigerant the cooling is achieved.

The basic operation of the refrigeration system is studied all over the world and previously experiments have been carried out by a number of people. The design and construction techniques are sufficiently well understood.

Refrigeration has become a part of modern day to day life in Bangladesh. It is used widely in households and industries, especially in the city areas. Given the hot climate of our country the refrigeration system manufacturing industries have recently experienced a boom in the market for their products.

In our country, for systems of capacity below 1 ton, only R-12 refrigerant is used. This is mainly because compressors for R-22 are not available below the capacity of 1 ton, and even the compressors which are available are generally very expensive. This is why as R-12 compressors are available for all capacities and reasonably cheap and affordable; R-12 refrigerant is widely used in all systems.

It is a well known fact that R-22 and R-134a, as compared to R-12, have much suitable properties to be used in Bangladeshi climate conditions, and offers advantages such as higher cooling effect. In our work we attempted to investigate if there was a way to enable the use of different refrigerants in refrigeration systems below 1 ton capacity in Bangladesh, learning about efficiencies and outputs of these refrigerants, comparing them and contrasting them.

Introduction

Refrigeration is a process by which a system pumps out heat from within the system by employing a cycle by doing work. Conventional refrigeration systems consists of a working fluid whose unique characteristic properties enable this transfer of heat. In Bangladesh and worldwide, refrigeration systems of capacities below 1 ton use only R-12 refrigerants. The main reason is due to relatively high condensing pressures, although R-22 has desirable properties such as greater refrigerating effect and higher Coefficient of Performance and also the property of being eco-friendly is a great advantage.

This project is a continuation of a previous project named "Design and Construction of a 500 Watt Refrigeration System" by Md. Mustafizur Rahman and Saiham Siraj of Islamic University of Technology in 2011. Rahman and Siraj's project sought to develop a refrigeration system that employed R-22 fluid as refrigerant to produce a cooling effect of 0.5 kW cooling capacity using a R-12 compressor. After building the system, they analyzed it and obtained desired satisfactory results within expectation.

Our project comprises of furthering their findings where 3 kinds of refrigerants, namely – R-22, R-134a, and R-12, will be employed in the system. The procedure will consist of formulating result calculations, running the system with specified refrigerants individually, calculating observations and calculating cooling capacity, efficiencies and coefficient of performance for each refrigerant and checking practical data with available ones for error-finding and improvisation.

The central objective is to determine how the pre-built system functions with each refrigerant and which one brings about the optimum performance, i.e. highest cooling capacity, efficiencies and Coefficient of Performance (COP) within required and safe operating conditions.

Background

The first known artificial refrigeration was demonstrated by William Cullen at the University of Glasgow in 1748. Cullen let ethyl ether boil into a partial vacuum; he did not, however, use the result to any practical purpose.

In 1805, an American inventor, Oliver Evans, designed the first refrigeration machine that used vapor instead of liquid. Evans never constructed his machine, but one similar to it was built by an American physician, John Gorrie.

In 1842, the American physician John Gorrie, to cool sickrooms in a Florida hospital, designed and built an air-cooling apparatus for treating yellow-fever patients. His basic principle--that of compressing a gas, cooling it by sending it through radiating coils, and then expanding it to lower the temperature further--is the one most often used in refrigerators today. Giving up his medical practice to engage in time-consuming experimentation with ice making, he was granted the first U.S. patent for mechanical refrigeration in 1851.

Commercial refrigeration is believed to have been initiated by an American businessperson, Alexander C. Twinning, in 1856. Shortly afterward, an Australian, James Harrison, examined the refrigerators used by Gorrie and Twinning and introduced vapor-compression refrigeration to the brewing and meatpacking industries.

Ferdinand Carré of France developed a somewhat more complex system in 1859. Unlike earlier compression-compression machines, which used air as a coolant, Carré's equipment contained rapidly expanding ammonia. (Ammonia liquefies at a much lower temperature than water and is thus able to absorb more heat.) Carré's refrigerators were widely used, and vapor compression refrigeration became, and still is, the most widely used method of cooling.

Carl (Paul Gottfried) von Linde in 1895 set up a large-scale plant for the production of liquid air. Six years later he developed a method for separating pure liquid oxygen from liquid air that resulted in widespread industrial conversion to processes utilizing oxygen (*e.g.,* in steel manufacture).

Refrigerators from the late 1800s until 1929 used the toxic gases ammonia (NH3), methyl chloride (CH3Cl), and sulfur dioxide (SO2) as refrigerants. Several fatal accidents occurred in the 1920s when methyl chloride leaked out of refrigerators. Three American corporations launched collaborative research to develop a less dangerous method of refrigeration; their efforts lead to the discovery of Freon. In just a few years, compressor refrigerators using Freon would become the standard for almost all home kitchens. Only decades later, would people realize that these chlorofluorocarbons endangered the ozone layer of the entire planet.

This led to the research for more environmental-friendly, efficient refrigerants with high cooling capacities.

Qualitative Comparison of Refrigerants Used

R12

Refrigerant-12 (CCl_2F_2) probably has been the most widely used of all of the refrigerants. It is a safe refrigerant in that it is non-toxic, non-flammable, and non-explosive. Furthermore, it is a highly stable compound that is difficult to break down even under extreme operating conditions. However, if brought into contact with an open flame or with an electrical heating element, R-12 will decompose into highly toxic products.

Along with its safe properties the fact that R-12 condenses at moderate pressures under normal atmospheric conditions and has a boiling temperature of -21.6°F (-29.8°C) at atmospheric pressure makes it a suitable refrigerant for use in high-, medium-, and low-temperatures applications and with all three types of compressors.

The fact that R-12 is oil-miscible under all operating conditions not only simplifies the problem of oil return, but also tends to increase the efficiency and capacity of the system in that the solvent action of the refrigerant maintains the evaporator and condenser tubes relatively free of oil films, which otherwise would tend to reduce the heat transfer capacity of these two units.

The refrigerating effect per pound for R-12 is relatively small compared with those of some other popular refrigerants.

Some of the more common applications for R-12 include automotive air-conditioning, home freezers and refrigerators, liquid chillers, dehumidifiers, ice-makers, water fountains and transport refrigeration. Unfortunately, R-12 has unusually high ozone depletion potential and is being replaced by other refrigerants.

R-22

Refrigerant-22 ($CHClF_2$) has a boiling point at atmospheric pressure of -41.4°F (-40.8°C). Developed originally as a low temperature refrigerant, it has been used in the past in domestic and farm freezers and in commercial and industrial low-temperature systems down to evaporator temperatures as low as -125°F (-87°C). Its primary use today is in packaged air-conditioners, where, because of space limitations, the relatively small compressor displacement required is a decided advantage.

Both the operating pressure and adiabatic discharge temperature are higher for R-22 than for R-12. Power requirements are approximately the same. The principal advantage of R-22 over R-12 is the smaller compressor displacement requires, being approximately 60% of that required for R-12. Hence, for a given compressor displacement, the refrigerating capacity is approximately 65% greater with R-22 than with R-12.

Refrigerant-22 is an HCFC and, like HCFCs, is a transitional refrigerant and will be phased out in the early part of the twenty-first century.

R-134a

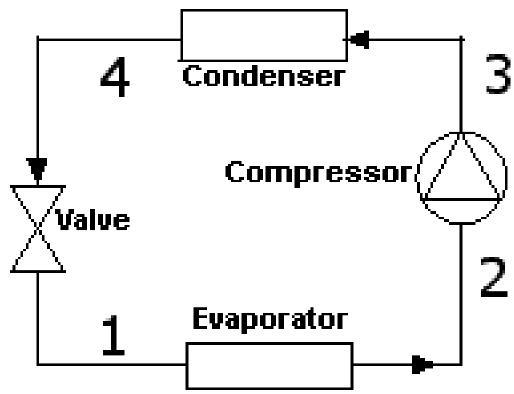
Refrigerant-134a is one of the leading candidates to replace R-12 in many applications employing this refrigerant. Refrigerant-134a is an HFC and has zero ozone depletion potential and a low green-house effect. It is non-flammable and non-explosive and preliminary data indicates a favorable toxicology as well as chemical stability within the refrigerating system, although it dies have a relatively high affinity for moisture.

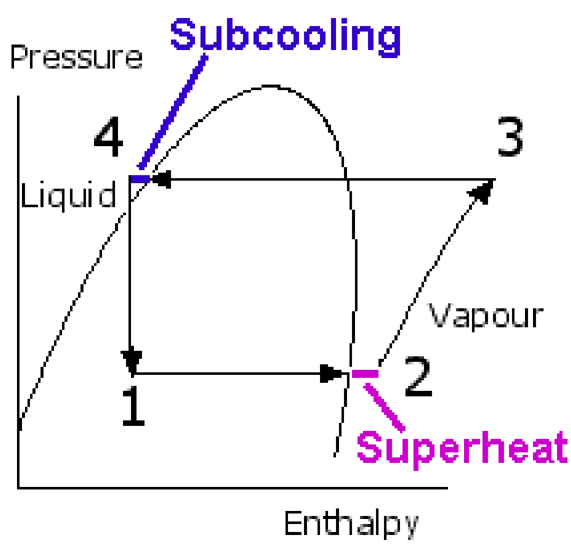
The physical and thermodynamic properties of R-134a approach those of R-12 closely enough to provide similar levels of performance in systems with evaporator temperatures of 20°F (-7°C) and above. For example, both the isentropic discharge temperature and horsepower required per ton of refrigeration are nearly the same for both refrigerants. Heat transfer coefficients are significantly higher for R-134a than for R-12.

Refrigerant-134a has a miscibility problem with the mineral oils normally used with halocarbon refrigerants. However a replacement of mineral oils with ester-based synthetic lubricants solves the problem.

Working Principle

The vapour compression system is the most important refrigeration system. A schematic diagram of the vapour compression refrigeration system and the corresponding pressure-enthalpy diagram are shown below:





The system consists of four components and the cycle consists of four different processes. As illustrated above.

The system components are:

- Compressor
- Condenser
- Expansion Device
- Evaporator

The cycle processes consist of:

- Process 1-2: Heat Absorption at Constant Pressure
- Process 2-3: Isentropic Compression
- Process 3-4: Heat Rejection at Constant Pressure
- Process 4-1: Isenthalpic Expansion

The refrigerant gas coming from the evaporator is compressed by the compressor to a high pressure. By being compressed the gas gets superheated and then the gas is cooled and condensed in a condenser with the help of cooling water or atmospheric air. The magnitude of high pressure required in the condenser depends on the properties of particular refrigerant and thus it is different for different refrigerants. After being condensed at high pressure, the condensate becomes a saturated liquid at that pressure which is then expanded in a throttle valve at low pressure. In this process the liquid gets practically evaporated and becomes a wet vapour at low pressure. The low pressure wet vapour then enters an evaporator where it further evaporates by absorbing heat from the surroundings. Absorption of heat from the surroundings takes place at low temperature which corresponds to saturation temperature at the evaporation pressure. The amount of heat absorbed at the evaporator is the refrigeration effect of the plant. After evaporation the dry saturated vapour is again sucked by the compressor. Thus the cycle goes on.

The compressor has to be driven either by electric motor or an engine, requiring work input to the system. The condenser rejects heat from the system to the surroundings through the cooling medium. Heat is received by the system, to the surroundings in the evaporator.

Components of the Pre-Built System

Capillary Tube

Cooling Effect

Condenser

Capillary Tube

Compressor

Filter Drier and Pressure Gauge

Cooling fan for forced convection

The Complete System

Operation and Data Collection

Using a pump we produced vacuum inside the system to suck out any unwanted substances and air, and to make it ready to be charged with refrigerant. First R-12 refrigerant was charged. The system was started and the test run was commenced. After some time the condensing and evaporating pressure became stable and they were found to be within the safe range, also cooling was obtained. Thus we concluded that the system was stable, safe and ready to operate.

Next we began with the system operating with the **R-12** refrigerant, and some time was allowed till the system reached steady state. Then the following observations of data were made using thermometers, thermocouples, pressure gauge and anemometers from the relevant points and recorded as:

R-12

Condenser fan speed – Maximum

Evaporator fan speed – Maximum

	Observation	Symbol	Value	Unit
1	Mean air velocity	v	2.25	m/s^2
2	Entering air temperature	$t_{\alpha 1}$	33.87	°C
3	Leaving air temperature	$t_{\alpha 2}$	34.8	°C
4	Condenser area	A	(12x11.5)= 138	$inch^2$
5	Temperature at evaporator outlet	t_2	32.4	°C
6	Temperature at compressor exit	t_3	91.5	°C
7	Temperature at condenser outlet	t_4	43.0	°C
8	Evaporator Pressure	P_1	9	psi
9	Condenser Pressure	P_2	162.5	psi

The system was then switched off and allowed to cool for half an hour, before discharging the system. By discharging the R-12 refrigerant was evacuated from the system, and again after producing vacuum inside the system refrigerant R-134a was charged into it. We carried out the test run again and similar observations as before confirmed that the system was stable, safe and fully operational.

It was then safe to go on to the full operation of the **R-134a** system, and as before after attaining stable conditions of the working system we observed the following data using thermometers, thermocouples, pressure gauge and anemometers from the relevant points and recorded them as:

R-134a

Condenser fan speed – Maximum

Evaporator fan speed – Maximum

	Observation	Symbol	Value	Unit
1	Mean air velocity	v	2.93	m/s
2	Entering air temperature	$t_{\alpha 1}$	30.72	°C
3	Leaving air temperature	$t_{\alpha 2}$	31.58	°C
4	Condenser area	A	138	$inch^2$
5	Temperature at evaporator outlet	t_2	27.8	°C
6	Temperature at compressor exit	t_3	73.2	°C
7	Temperature at condenser outlet	t_4	38.7	°C
8	Evaporator Pressure	P_1	12	psi
9	Condenser Pressure	P_2	170	psi

Once again, the system was then switched off and allowed to cool for half an hour, before discharging the system. By discharging the R-134a refrigerant was evacuated from the system, and again after producing vacuum inside the system refrigerant R-22 was charged into it. We carried out the test run again and similar observations as before confirmed that the system was stable, safe and fully operational.

It was then safe to go on to the full operation of the **R-22** system, and as before after attaining stable conditions of the working system we observed the following data using thermometers, thermocouples, pressure gauge and anemometers from the relevant points and recorded them as:

R-22

Condenser fan speed – Maximum

Evaporator fan speed – Maximum

	Observation	Symbol	Value	Unit
1	Mean air velocity	v	2.27	m/s
2	Entering air temperature	$t_{\alpha1}$	30.78	°C
3	Leaving air temperature	$t_{\alpha2}$	31.9	°C
4	Condenser area	A	138	$inch^2$
5	Temperature at evaporator outlet	t_2	28	°C
6	Temperature at compressor exit	t_3	97.2	°C
7	Temperature at condenser outlet	t_4	41.6	°C
8	Evaporator Pressure	P_1	16	psi
9	Condenser Pressure	P_2	230	psi

Calculations

From the observational data obtained during the operations of both the R-12 and R-134a systems we can calculate separately:

R-12

Mean Air Velocity over the condenser, v=2.25 m/s

Entering Air Temperature, $t_{\alpha1}$ = 33.87°C

Leaving Air Temperature, $t_{\alpha2}$ = 34.8°C

Fan Diameter, d=0.3048m

Fan Area, A = 138 $inch^2$ = 0.089 m^2

Air Mass Flow Rate, $m_a = \rho A v$ = 0.244 kg/s

Temperature at suction to compressor, t_2 = 32.4°C

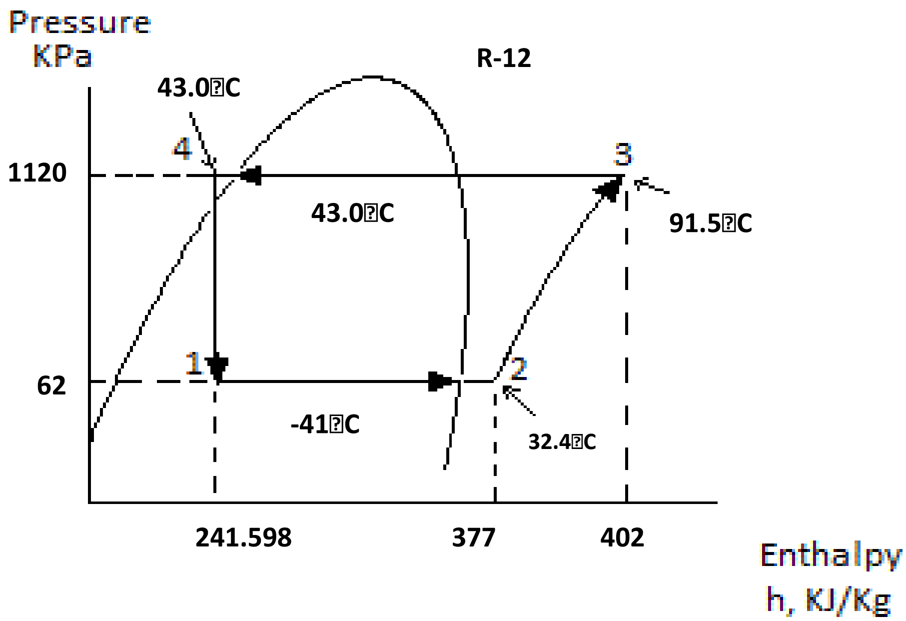
Temperature at compressor exit, t_3 = 91.5°C

Temperature at condenser outlet, t_4 = 43.0°C

Evaporator Pressure, P_1 = 9 psi= 62 kPa

Condenser Pressure, P_2 = 162.5 psi= 1120 kPa

From the observed data we can draw the following P-h diagram:



From the p-h diagram and table for R-12 the following values of enthalpy are noted down:

$h_1 = h4 = 241.598$ kJ/kg

$h_2 = 377$ kJ/kg

$h_3 = 402$ kJ/kg

As heat rejected in the condenser must be equal to the heat absorbed by the air passing over it,

$$m_a \, \Delta t_a C_{p_a} = m_r \, (h_3 - h_4)$$

Refrigerant Mass Flow Rate,

$m_r = \overline{} = 1.42 \text{x} 10^{-3}$ kg/s

Cooling Effect,

$Q_e = m_r (h_2-h_1) = 1.42x10^{-3} (377-241.598) = 0.193$ kW

Heat Rejected in the Condenser,

$Q_c = m_r (h_2-h_1) = 1.42x10^{-3} (402-241.598) = 0.228$ kW

Compressor Work,

$W_c = m_r (h_3-h_2) = 1.42x10^{-3} (402-377) = 0.0355$ kW

Coefficient of performance,

COP = (Heat absorbed/Compression work) = Q_e/W_c = (0.193/0.0355) = 5.44

Heat Rejection Ratio,

HRR = (Heat rejected/Heat absorbed) = Q_c/Q_e = (0.228/0.193) = 1.18

R-134a

Mean Air Velocity over the condenser, v=2.93 m/s

Entering Air Temperature, $t_{\alpha 1}$ = 30.72°C

Leaving Air Temperature, $t_{\alpha 2}$ = 31.58°C

Fan Diameter, d=0.3048m

Fan Area, A = 138 $inch^2$ = 0.089 m^2

Air Mass Flow Rate, $m_a = \rho A v$ = 0.305 kg/s

Temperature at suction to compressor, t_2 = 27.8°C

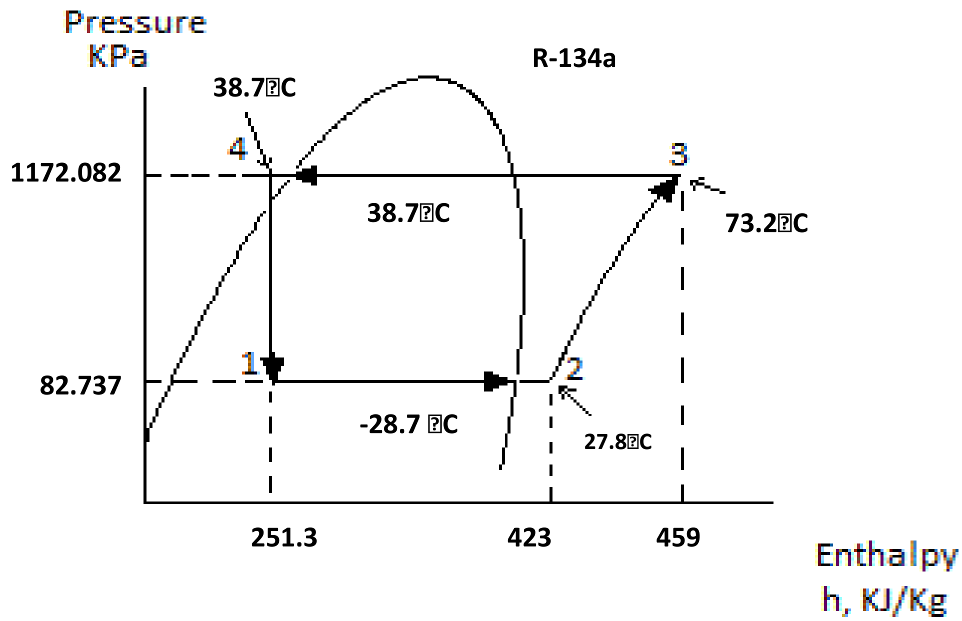
Temperature at compressor exit, t_3 = 73.2°C

Temperature at condenser outlet, t_4 = 38.7°C

Evaporator Pressure, P_1 = 12 psi= 82.737 kPa

Condenser Pressure, P_2 = 170 psi= 1172.082 kPa

From the observed data we can draw the following P-h diagram:



From the p-h diagram and table for R-134a the following values of enthalpy are noted down:

$h_1 = h4 = 251.3$ kJ/kg

$h_2 = 423$ kJ/kg

$h_3 = 459$ kJ/kg

As heat rejected in the condenser must be equal to the heat absorbed by the air passing over it,

$$m_a \, \Delta t_a C_{p_a} \;=\; m_r \, (h_3 - h_4)$$

Refrigerant Mass Flow Rate,

m_r = ―――――――― = 1.27×10^{-3} kg/s

Cooling Effect,

$Q_e = m_r (h_2 - h_1) = 1.27\text{x}10^{-3} (423-251.3) = 0.218$ kW

Heat Rejected in the Condenser,

$Q_c = m_r (h_2 - h_1) = 1.27\text{x}10^{-3} (459-251.3) = 0.264$ kW

Compressor Work,

$W_c = m_r (h_3 - h_2) = 1.27\text{x}10^{-3} (459-423) = 0.046$ kW

Coefficient of performance,

COP = (Heat absorbed/Compression work) = Q_e/W_c = (0.218/0.046) = 4.74

Heat Rejection Ratio,

HRR = (Heat rejected/Heat absorbed) = Q_c/Q_e = (0.264/0.218) = 1.21

R-22

Mean Air Velocity over the condenser, v=2.27 m/s

Entering Air Temperature, $t_{\alpha 1}$ = 30.78°C

Leaving Air Temperature, $t_{\alpha 2}$ = 31.9°C

Fan Diameter, d=0.3048m

Fan Area, A = 138 $inch^2$ = 0.089 m^2

Air Mass Flow Rate, $m_a = \rho A v$ = 0.246 kg/s

Temperature at suction to compressor, t_2 = 32.3°C

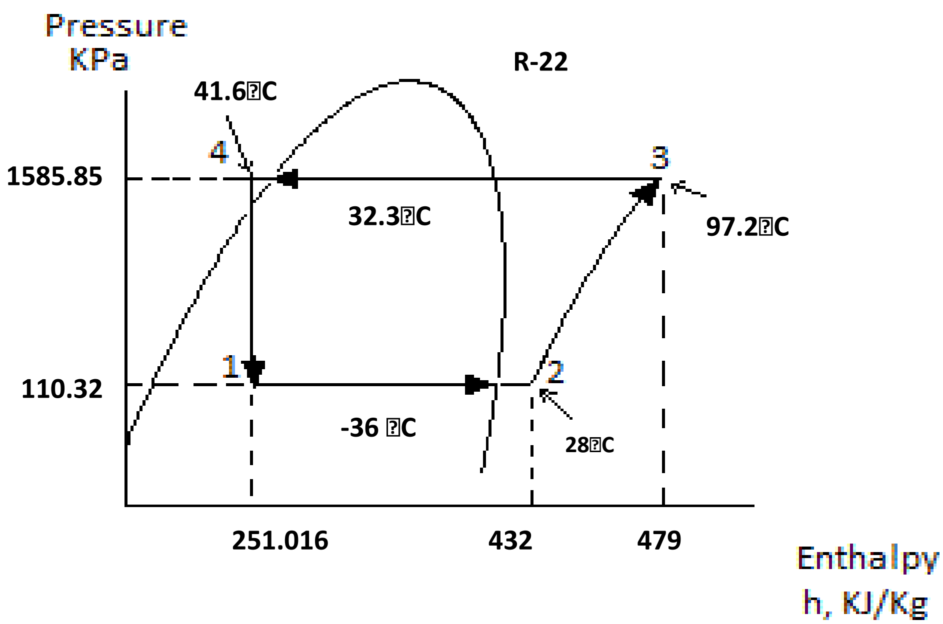
Temperature at compressor exit, t_3 = 97.2°C

Temperature at condenser outlet, t_4 = 41.6°C

Evaporator Pressure, P_1 = 16 psi= 110.32 kPa

Condenser Pressure, P_2 = 230 psi= 1585.85 kPa

From the observed data we can draw the following P-h diagram:



From the p-h diagram and table for R-22 the following values of enthalpy are noted down:

$h_1 = h4 = 251.016$ kJ/kg

$h_2 = 432$ kJ/kg

$h_3 = 479$ kJ/kg

As heat rejected in the condenser must be equal to the heat absorbed by the air passing over it,

$$m_a \, \Delta t_a C_{p_a} \; = \; m_r \, (h_3 - h_4)$$

Refrigerant Mass Flow Rate,

m_r = ―――――――― = $1.215x10^{-3}$ kg/s

Cooling Effect,

$Q_e = m_r (h_2-h_1) = 1.215x10^{-3} (432-251.016) = 0.220$ kW

Heat Rejected in the Condenser,

$Q_c = m_r (h_2-h_1) = 1.215x10^{-3} (479-251.016) = 0.277$ kW

Compressor Work,

$W_c = m_r (h_3-h_2) = 1.215x10^{-3} (479-432) = 0.0571$ kW

Coefficient of performance,

COP = (Heat absorbed/Compression work) = Q_e/W_c = (0.220/0.0571) = 3.853

Heat Rejection Ratio,

HRR = (Heat rejected/Heat absorbed) = Q_c/Q_e = (0.277/0.220) = 1.26

Quantitative Comparison

From the calculated results we tabulate the following parameters which illustrate the comparison of the performance of the same system working with different refrigerants under the same ambient conditions:

	Condenser pressure, p_c	**Temperature at condenser, T_c**	**Evaporator Pressure, p_e**	**Temperature at evaporator, T_e**	**Work done by compressor, E_c**	**Heat rejected by Condenser, Q_c**	**Refrigerating Effect, Q_e**	**Coefficient of Performance, COP**	**Specific Volume at condenser, ν_c**	**Specific volume at evaporator, ν_e**
	kPa	°C	kPa	°C	kW	kW	kW		m^3/kg	m^3/kg
R-12	1120	43.0	62	-41	0.0355	0.228	0.193	5.44	$0.806x10^{-3}$	0.350
R-134a	1172.08	38.7	82.737	-28.7	0.046	0.264	0.218	4.74	$0.807x10^{-3}$	0.0445
R-22	1585.85	32.3	110.32	-36	0.0571	0.277	0.220	3.853	$0.728x10^{-3}$	0.380

Results

By using energy balance in the condenser mass flow rate of refrigerant was found. There may be little error but it is acceptable within experimental variations. Work of compression is less for refrigerant R-12. Refrigerant capacities are 0.193 kW for R-12, 0.218 kW for R-134a 0.220 kW for R-22. C.O.P values are 5.44, 4.74, and 3.853 for R-12, R-134a and R-22 respectively.

Performance Analysis

While the objective of the study was to compare which refrigerant gave the best performance in the said system with and R-12 compressors, several factors have to be taken into account, such as conditions of refrigerant use, advantages and disadvantages of different refrigerators. According to our observation, all of the refrigerants, R-12, R-134a, and R-22 showed satisfactory performance, affirming the notion that all of them can be used in the compressor. Since R-12 was the control subject, evidence showed that R-134a and R-22 are suitable substitutes with reasonable limits.

By default, since a R-12 is manufactured to perform with R-12 refrigerant, it produces the highest COP. However, when R-134a and R-22 were tested in the system, they both showed similar COPs and HRRs compared to that of R-12. The refrigerating effect is highest for R-22 and that of R-134a is approximately equal. And then again, COP is much higher for R-134a that for R-22, assuming it a worthy replacement as well. Thus both are suitable with individual benefits – R-134a is cheaper and economical and R-22 gives greater cooling.

One disadvantage for R-22 is that its operating pressure is very high and has a risk of damaging the compressor by overheating. Further work can be done by researching on how to extend the construction of the system and reduce the overheating. Two plans seem viable – attach a fan to release the heat to the surrounding air, or branch out a tube from the evaporator beginning and coil it around the compressor to absorb the heat.

Conclusion

The project can be laid out as below:

Premise

- Bangladesh does not use R-22 or R-134a compressors due to high initial costs and R-12 systems already being in use in most facilities with less that 1 Ton cooling capacities. R-12 has been phased out. Thus there is a need for an alternative refrigerant to be used with an R-12 compressor for economic convenience. Small capacity compressors (under 1 Ton) are not available in the market.

Action Plan

- The project tests which refrigerant among R-12, R-134a and R-22 performs well in a 500W R-12 compressor refrigerant system, initially constructed prior to the experiments.

Interpretation of Results

- Results show that both R-22 and R-134a are good substitutes for R-12 and can be used in systems with an R-12 compressor.
- R-22 is cheaper, R-134a is environmentally-friendly
- R-12 compressor can still be used and purchased for use with experimented alternative refrigerants – an economical choice for consumers.

Limitations

- R-22 renders the compressor to overheat and may damage it if used without caution

Ultimate Findings

- While R-22 giver better performance, R-134a gives a higher COP and is suitable for use and manufacture of sustainable systems. Both can be used as substitutes but R-134a is a better choice.

Further Work

- This research can be extended to find methods of mitigating R-22 overheating the compressor
- It can also take into account various other refrigerants' performances and make a comparative analysis to see if even better alternative refrigerants can be used for the refrigerating system under 1 Ton capacity.

References

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