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PERFORMANCE OF DOMESTIC REFRIGERATOR WHEN THE HOT GAS REFRIGERANT INJECTED TO SUCTION LINE

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Abstract: In this research work, it is proposed to reduce the compressor work by decreasing the pressure ratio. To achieve this, one of the possibilities is to bleed a fraction of high-pressure refrigerant gas from the outlet of the compressor to inject into the inlet of the compressor (i.e., suction line). In general, the refrigerant gas in the suction line of the compressor is at low pressure. When the high-pressure refrigerant gas from the delivery line is bled and mixed with the low-pressure refrigerant gas in the suction line, the resultant suction pressure will be higher than the normal and hence the pressure ratio can be reduced, saving compressor work. To study the effect on the "Coefficient of Performance"(COP) of the system, experiments conducted for different mass fractions of refrigerant bypassed from the delivery line to the suction line.

Keywords: Rotameter, Bypass valve, check valve, R-134a refrigerant.

Introduction:

Most of the domestic sector refrigerators work on vapour compression refrigeration systems.R-134a belongs to Hydrofluorocarbon (HFC) family its eco-friendly nature. For a refrigeration system, the coefficient of performance can be improved either by reduction of compressor input work or by increasing refrigeration effect. The technique of hot gas injection in this research work is used to increase the cooling capacity and lower the discharge temperature of the refrigerant. when the refrigeration system starts running both pressure valves differ significantly. Therefore, the technique of hot gas injection to the suction line is needed to reduce the pressure difference on both sides.

The purpose of this research work is to determine the increase in performance of a refrigerator utilizing hot gas refrigerant from the compressor's discharge which was injected into the suction line. This method is adopted from the heat pump cycle, which is useful to maintain the balance of the capacity of the evaporator and compressor when the pressure and temperature of the refrigerant at the suction channel are low.

Therefore, the application of this engineering method to domestic refrigerators is expected to reduce the load of the compressor when doing compressor work, this has an impact on the increased value of Coefficient of Performance (COP) and the decrease of energy/power required as the driving force.

Vapour Compression Refrigeration System:

The basic components of a vapour compression refrigeration system are shown in the below figure which consists of an evaporator, compressor, condenser and an expansion valve. First the low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve where it is compressed to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through the delivery or discharge. Then the high pressure and temperature vapour refrigerant enters into the condenser which consists of coils of pipe then cooled and condensed.

A refrigeration system can also be used as a heat pump, in which the useful output is the high temperature heat rejected at the condenser. Alternatively, a refrigeration system can be used for providing cooling in summer and heating in winter. Such systems have been built and are available now.

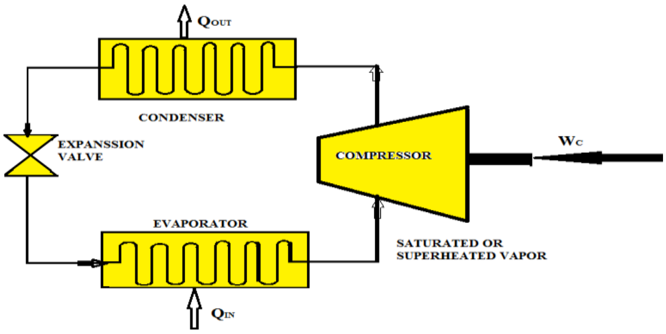

Figure 1: Vapour compression refrigeration cycle.

The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water. The condensed liquid refrigerantfrom the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve. Expansion Valve is also calledthrottle valve or refrigerant control valve. The function of the expansion valve is to allow the liquidrefrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporized in the evaporator at the low pressure and temperature. An evaporator consists of coils of pipe in which the liquid- vapour. Refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium (air, water or brine) which is to be cooled.

Literature review:

In order to reduce energy consumption and improve the efficiency of the refrigerator, some researchers use suction-liquid heat exchangers. In 2016, E T Berman, S Hasan and Mutaufiq of Indonesia, worked on the hot gas injection to the suction line to reduce compressor work and saving electric power needed by refrigerator. They kept brine solution as the cooling load inside the refrigerator and the thermometer is placed inside the brine container to determine changes in temperature for every 1°c.They compared the results for both normal and hot gas injection and for hot gas injection the COP is slightly increases**[1].**

Ji Young Jang et al designed a new high temperature and low-pressure hot gas bypass method for continuous heating called Dual Spray Hot Gas method (DSHG). They found that the most effective flow rate was 50% in this case. They kept surrounding conditions around 20C DBT and 10C WBT. They used temperature sensors for initialization and termination of defrosting cycle. This cycle starts when temperature difference between outdoor and evaporator coil is became 80C and terminated when this difference becomes 50C. defrostation cycle time is around 10min. during this cycle indoor temperature drops from 430C to 330C. They suggested that during this stage reduction in speed of indoor fan is necessary. Found that when compared with reverse cycle defrosting method, the total heating capacity was increased by 17%. During 4 hour of operating duration there were around 4 DSHG and 2 RCD cycles in DSHG cycle the overall input power was increased by 7-8%. The overall energy efficiency was increases by 8% in DSHG compared to RCD. They also found that when outdoor temperature falls below 20C, the indoor heating supply in the defrosting range may drops below 50% **[13]**

Ju-Suk Byun et al studied hot gas bypass method for frost growth retardation. For this work they had used 1.5 hp capacity heat pump with R22 as a refrigerant. Ambient conditions set for testing was 20C DBT and 10C WBT. They conducted four cases of testing depends on bypassed gas amount. For this they used 0kg/min, 0.2kg/min, 0.3kg/min and 0.4kg/min bypassed gas amount. They carried test for 4 hours for each case. Hot refrigerant gas was directly injected at the inlet of the outdoor coil for 5 minutes at every 20 min interval. They found that when bypassed gas amount was 20% of total gas that is 0.2kg/min, highest value of heating capacity and COP has been achieved by system. In this case COP of system was 20% higher than that of no gas bypassed case. During entire cycle of four hours, the average COP and integrated heating capacity of system was improved by 8.5% and 5.7% respectively **[14]**

Schematic Diagram:

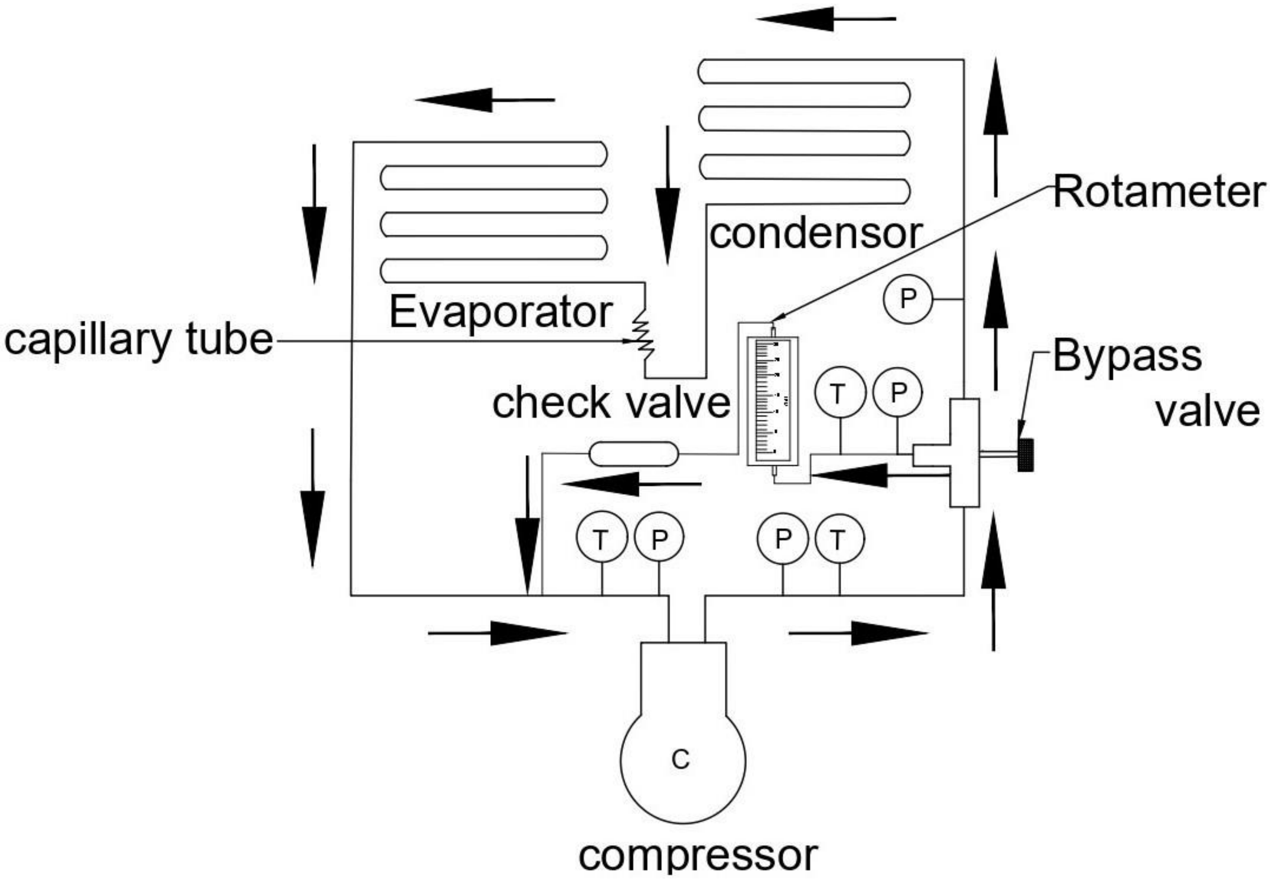

Figure 2: schematic diagram

Experimental Setup:

In the present research work, the refrigerant selected is R-134a is widely used in a domestic refrigerator, because of better environmental and energy performances. A new refrigerator test system was built up according to the requirement of this study. R-134a is used as a refrigerant in a 160L capacity refrigerator. A bypass system is included in the existing system. It consists of a rotameter bypass valve and check valve.

R134a refrigerant:

The refrigerant gas R-134a is a HFC replacing R-12 in new installations. As all HFC refrigerants not damage the ozone layer. It has a great chemical and thermal stability, low toxicity and is non-flammable, besides having an excellent compatibility with most materials.

R-134a is an alternative refrigerant to R-12 for the facility retrofitting or for new installations. It is widely used in automobile air conditioners and household refrigerators. It is also widely used in the industrial and commercial chillers in addition to transport in positive temperatures.

R-134a is a substance with very low toxicity. The index LCL0 inhalation in rats during 4 hours is less than 500,000 ppm and NOEL in relation to heart problems is about 75,000 ppm. In exposure for 104 weeks at a concentration of 10,000 ppm was observed no effect.

R-134a is not toxic, non flammable.

Chemical Name: 1,1,1,2- Tetrafluoroethane (R-134a)

Compressor:

In this experiment Reciprocating (piston type) compressor is used to compress the refrigerant. This compressor is hermitacally sealed type. Hermetic sealed compressor is one in which the two halves are sealed by welding or brazing. Electric motor and reciprocating mechanism are placed inside this housing.

Piston type reciprocating compressors are widely used in domestic refrigerators due to their compact size, low cost, and high efficiency.

Figure 3: Compressor

The below fig shows the experimental setup and the bypasssing system consists of Byass valve, Rotameter and check valve.

The check valve used to allow the refrigerant only in the forward direction and the pressure guages and thermocouples are attached to take the temperature and pressure readings.

Figure 4: Experimental Setup

Rotameter:

The rotameter is an industrial flow meter used to measure the flowrate of liquids and gases.
In this experiment Glass tube purge rotameter is used. The tube is precision formed of borosilicate glass, and the float is precisely machined from metal, glass or plastic. The metal float is usually made of stainless steel to provide corrosion resistance. The float has a sharp metering edge where the reading is observed by means of a scale mounted alongside the tube. End fittings and connections of various materials and styles are available. The important elements are the tube and float, often called the tube-and-float combination, because it is this portion of the rotameter which provides the measurement. In fact, similar glass tube and stainless steel float combinations are generally available, regardless of the type of case or end fittings the application can demand, so as best to meet customer requirements. The scale of the rotameter can be calibrated for direct reading of air or water, or it may have a scale to read a percent of range or an arbitrary scale to be used with conversion equations or charts. Safety-shielded glass tube rotameters are in general use throughout industry for measuring both liquids and gases. They provide flow capacities to about 60 GPM, and are manufactured with end fittings of metal or plastic to meet the chemical characteristics of the fluid being metered.

Small, 6 mm (1 ⁄ 4”) tubes are suitable for working pressures up to 500 psig, but the operating pressure for a large 51 mm (2”) tube may be as low as 100 psig.

Selection of Rotameter:

Rotameter selection is based on the following factors:

- Type : Purge rotameter

- Flow range : 0.5 LPM to 7 LPM
  (i.e. 0.01 kg/s to 0.12 kg/s)
- Operating pressure : 22 bar
- Operating temperature: 0-100 degree centigrade
- Viscosity: 15.103 mpa.s
- Specific gravity: 1.21

Based on the above operating conditions the rotameter is selected and the readings are noted down at different mass flow rates.

As per SI units: 0.5 LPM = 0.01 kg/s.

Mass flow rates are taken in kg/s according to the above conversion relation.

Finned copper condenser:

In this experiment air cooled finned copper condensor is used.The finned copper condenser is used to get the better cooling effect. The fins are formed using aluminium alloy and these fins are attached to copper coil by gas welding. It gives better cooling effect than aluminium condenser.

Figure 5: Finned copper condenser

Specifications of refrigerator:

Company name	:	Kelvinator
Capacity	:	185 liters
Compressor type	:	1/7th type HP
Condensor coil	:	1/4th inch copper coil

Experimental procedure:

The nitrogen gas is filled in the compressor and the leak detection test (soap bubble test) is conducted and confirmed that there are no leakages in the system. Then vacuum is created and then the system with R-134a weighing 120g refrigerant is charged into the compressor. Temperature and pressure readings are noted by using thermocouples and pressure gauges respectively at required places for the normal cycle. After noting the readings R-134a refrigerant is discharged from the compressor and vacuum is created by using a vacuum pump. The R-134a refrigerant weighing 120g is charged into the compressor and using the bypass valve from the compressor outlet hot gas refrigerant injected to the suction line in different mass fractions. This hot gas refrigerant is bypassed by using bypass valve. To get different mass fractions rotameter is used. It consists of flow rate indication from 0.5 LPM to 7 LPM (0.01 kg/s to 0.12 kg/s). Initially float of rotameter is at the bottom. The mass flow rate readings are taken by means of rotameter needle valve. This needle valve is used to fix the float to desired flow rate. For the first flow rate the rotameter neddle valve is set the float to 0.5 LPM (0.01kg/s) which gives approximately 10% of hot gas refrigerant is bypassed to the suction line and the remaining 90% goes to the condenser. As the float rises pressure increases. For the different flow rates pressure is increases gradually which allows hot gas refrigerant to inject into the suction line through non return (check) valve.

From the calculations, approximately 10% of hot gas is bypassed and the remaining 90% goes to the condenser. After that the temperature and pressure readings are noted by using thermocouples and pressure gauges respectively. Similarly, the process is carried out for 0.02, 0.03,0.04 and 0.05 kg/s mass flow rates. The mass of hot gas refrigerant bypassed for the above mass flow rates of rotameter, which is approximately 20%, 30%, 40% and 50% respectively. The experiment is carried out for 5 different mass fractions bypassed to the suction line.

SAMPLE CALCULATION:

Performance of domestic refrigerator when 40% of hot gas refrigerant is bypassed to the suction line using R134a as refrigerant:

S. No	Pressure (bar)		Temperature (^{0}C)				Time (Min)
	Suction pressure (P_s)	Discharge pressure (P_d)	Inlet temp. of compressor (T_1)	Outlet temp. of compressor (T_2)	Outlet temp. of condenser (T_3)	Evaporator temperature (T_4)	
1	1.1	1.1	31.2	32.2	38.1	23.9	0
2	1.3	16.9	32.4	56.6	42.8	1.0	10
3	1.9	18.7	32.6	67.8	43.9	-7.2	20
4	2.5	19.9	33.4	67.9	44.7	-10.2	30
5	2.5	20.1	33.5	68.5	44.8	-12.6	40
6	2.7	20.1	33.9	68.8	44.9	-17.8	50
Avg	**2.0**	**16.1**	**32.8**	**60.3**	**43.2**	**-3.8**	

Table 1: Observation table for 40% of hot gas is bypassed

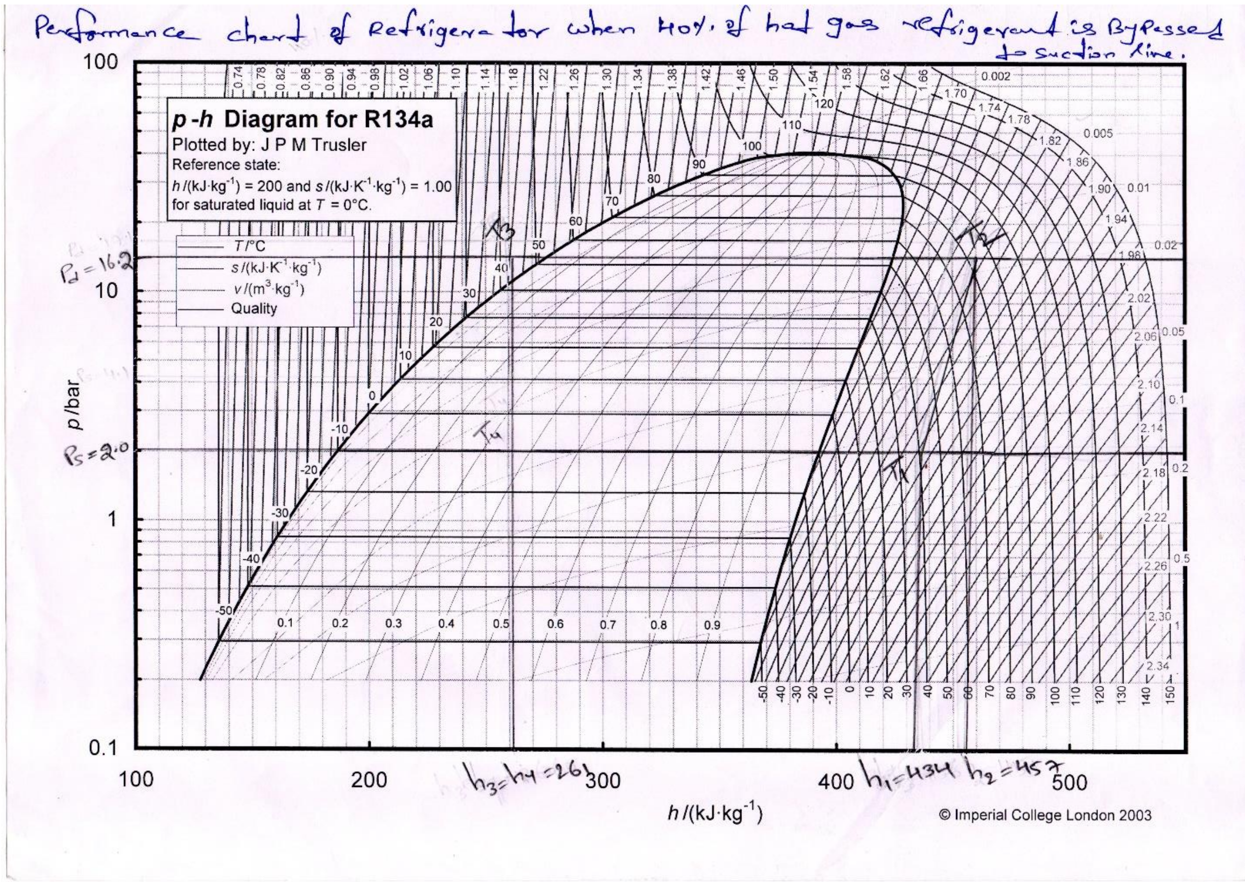

Figure 6: P-h chart when 40% of hot gas refrigerant is bypassed using R-134a as a refrigerant

CALCULATIONS OF PERFORMANCE PARAMETERS:

Net Refrigeration Effect (NRE) = h_1-h_4

Work done by the Compressor (WD) = h_2-h_1

Mass Flow Rate to obtain 1TR (MFR) = 210/NRE

Compressor Power = MFR (h_2-h_1)

Refrigeration capacity = MFR (h_1-h_4)

Heat rejected by the condenser = h_2-h_3

Co-efficient of Performance (COP) = NRE/WD

Pressure Ratio = p_d/p_s

RESULTS AND DISCUSSIONS:

Comparison of Refrigeration Effect:

The figure 7 shows that the comparison of refrigeration effect of both the existing and the bypassed system. The refrigeration effect is maximum at 40% bypass.

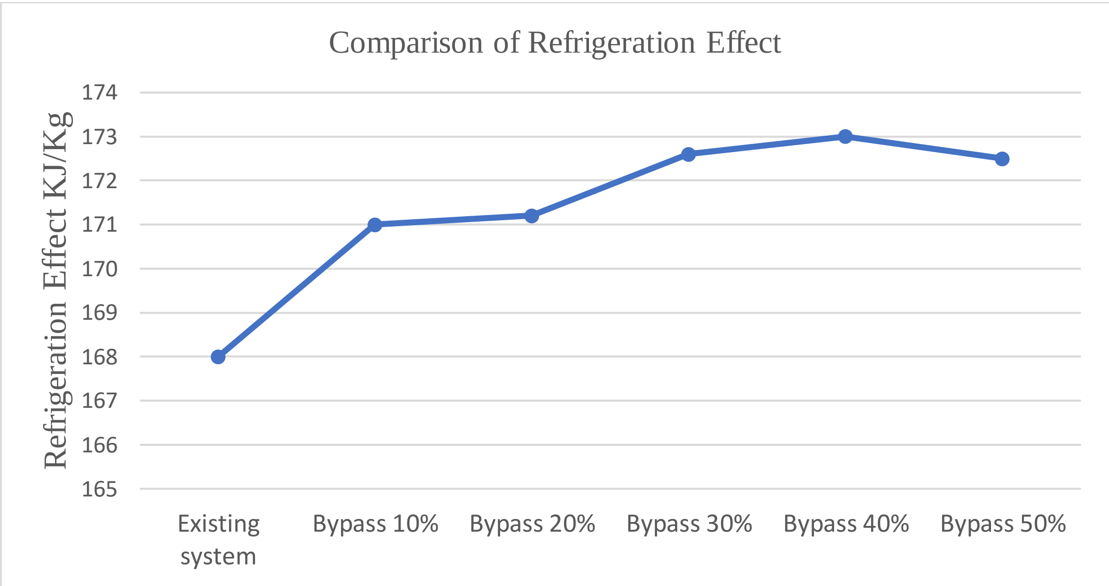

Figure 7: Comparison of Refrigeration Effect

Comparison of Compressor Work:

The figure 8 shows the comparison of compressor work of both existing and bypassed systems. The compressor work is minimum at 40% bypass.

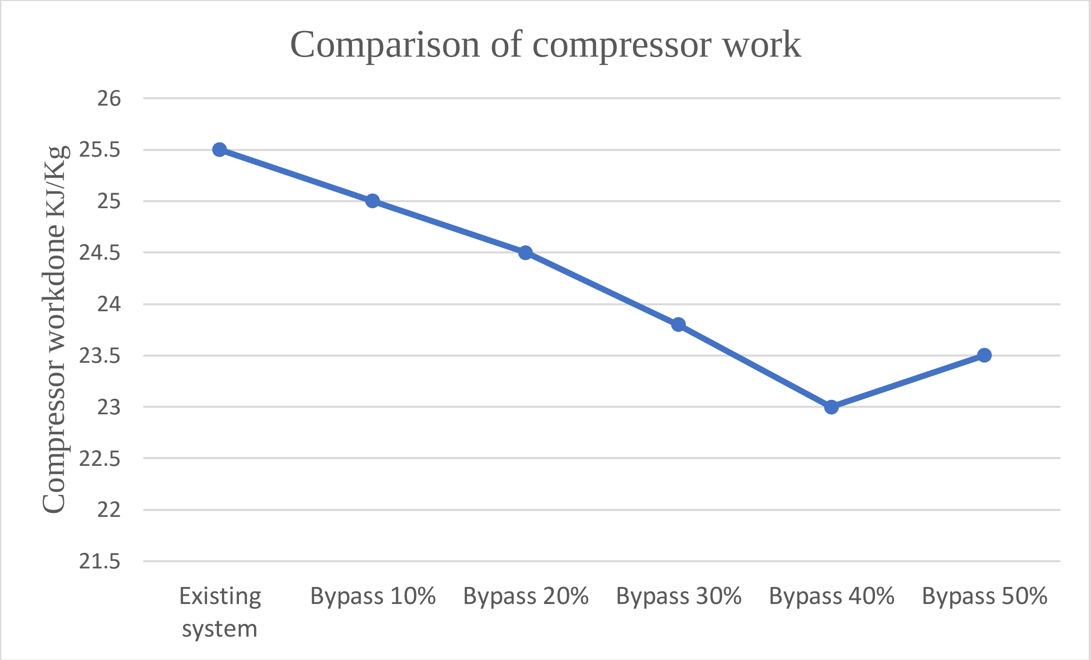

Figure 8: Comparison of Work done by Compressor

Comparison of COP:

The figure 9 shows the comparison of Coefficient of Performance of the existing and bypassed system. The COP is maximum at 40% bypass.

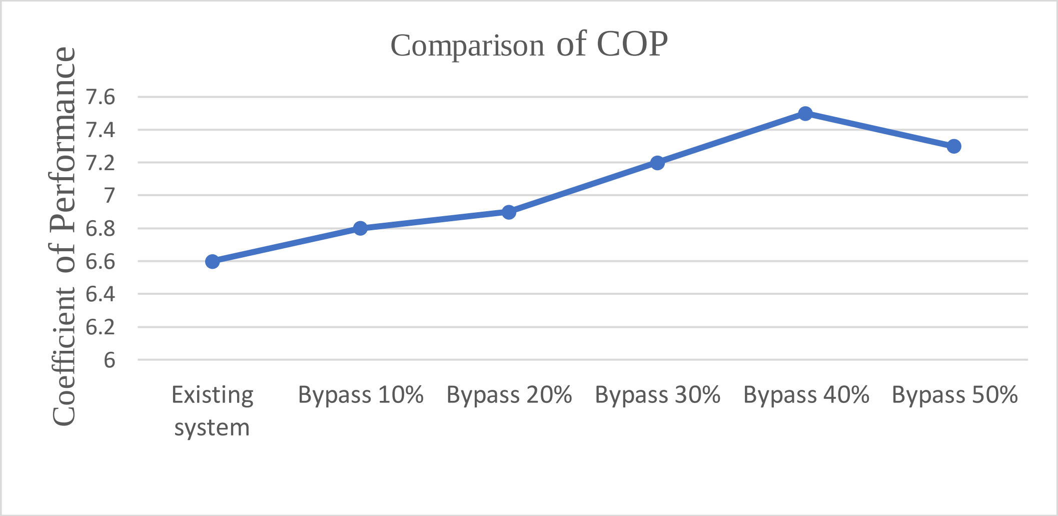

Figure 9: Comparison of COP

Comparison of pressure ratio:

The figure 10 shows the comparison of pressure ratio of the existing and bypassed system. The pressure ratio is minimum at 40% bypass.

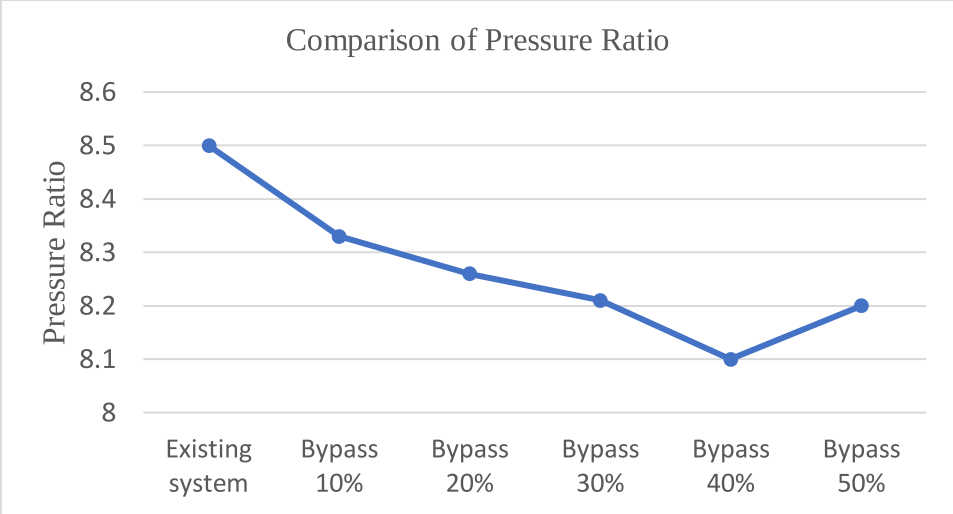

Figure 10: Comparison of Pressure ratio

CONCLUSION:

This paper aims to provide an experimental analysis of the performance of domestic refrigerators using R-134a as refrigerant when it is bypassed.

By comparing both the existing and bypassed system it is observed that COP is increased gradually and it is maximum at 40% bypassed i.e.,increases 13% of COP than existing system and it is also observed that the compressor work decreases gradually and it is minimum at 40% bypassed i.e., decreases of 9% in compressor work than the existing system.

By comparing both the existing and bypassed system it is observed that pressure ratio decreased gradually and it is minimum at 40% bypassed i.e., reduces 5% of pressure ratio than existing system.

Hence it is concluded that by using the bypassed system gives increases in refrigeration effect and reduces the pressure ratio and compressor work of a domestic refrigerator with R-134a as a refrigerant.

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