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PERFORMANCE TEST ON VAPOUR COMPRESSION REFRIGERATION SYSTEM USING R290 & R134a MIXTURE

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Abstract- This paper deals with the evaluation of the performance of a refrigeration system by using different refrigerant mixtures. This refrigeration system works under vapour compression cycle with the basic principle " The liquid when evaporates absorbs heat". The refrigerant continues changing from liquid to vapour state when absorbing heat and from vapour to liquid when giving out heat. The refrigerants used in the system are R134a (Tetrafluoroethane), R290 (Isobutane) and Blend of Tetrafluoroethane and Propane (R134a and R290).
This project deals with a comparison study of the performance of different refrigerant mixtures mentioned below with R134a kept as a comparison parameter. The above refrigerants are mixed based on weight proportions in different ratios, and their following mixtures used are:
Analysis-1: R134a
Mixture-1: R134a 80% and R290 20%
Analysis-2: R134a (with L.S. heat exchanger)
Mixture-2: R134a 80% and R290 20% (with L.S. heat exchanger)

The usage of R134a must be phased out according to Kyoto Protocol due its high global warming potential (GWP) of 1300.In the present work, an experimental investigation has been conducted with hydrocarbon refrigerant mixtures as an alternate to R134a

Index Terms- R134a 80% and R290 20%, R134a 80% and R290 20%, COP, refrigeration input.

1. INTRODUCTION

In India, about 80% of the domestic refrigerators use R134a as refrigerant due to its excellent thermodynamic and thermo physical properties. But R134a has high GWP of 1300. The higher GWP due to R134a emissions from domestic refrigerators leads to identifying a long term alternative to meet the requirements of system performance, refrigerant-lubricant interaction, energy efficiency, environmental impacts, safety and service. The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) calls for reductions in emissions of six categories of greenhouse gases, including hydro fluorocarbons (HFCs) used as refrigerants. Refrigerators are identified as major energy consuming domestic appliance in household environment. Many researchers have reported that hydrocarbon mixed refrigerants is found to be an energy efficient and environment friendly alternative option in domestic refrigerators.

2) COMPONENTS AND FABRICATION:

Compressor: The reciprocating compressor sucks the low pressure and low temperature refrigerant during its suction stroke and delivers it as high pressure and high temperature. The reciprocating compressors are built in sizes ranging from a fraction horse power to several hundred horse power. These are used of refrigerant plant ranging in sizes from 0.25 ton to 1000 tons capacity per unit.
Reciprocating Compressor has piston, cylinder, inlet valve, exit valve, connecting rod, crank, piston pin, crank pin and crank shaft. Inlet valve and exit valves may be of spring loaded type which get opened and closed due to pressure differential across them. Let us consider piston to be at top dead centre (TDC) and move towards bottom dead centre (BDC). Due to this piston movement from TDC to BDC suction pressure is created causing opening of inlet valve. With this opening of inlet valve and suction pressure the atmospheric air enters then cylinder.Air gets into cylinder during this stroke and is subsequently compressed in next stroke with both inlet valve and exit valve closed. Both inlet valve and exit valves are of plate type and spring loaded so as to operate automatically as and when sufficient pressure difference is available to cause deflection in spring of valve plates to open them.
After piston reaching BDC it reverses its motion and compresses the air inducted in previous stroke. Compression is continued till the pressure of air inside becomes sufficient to cause deflection in exit valve. At the moment when exit valve plate gets lifted the exhaust of compressed air takes place. This piston again reaches TDC from where downward piston movement is again accompanied by suction. This is how reciprocating compressor.
Evaporator: The process of heat removal from the substance to be cooled or refrigerated is done in the evaporator. The liquid refrigerant is vaporized inside the evaporator (coil or shell) in order to remove heat from a fluid such as air, water etc.
Evaporators are manufactured in different shapes, types and designs to suit a diverse nature of cooling requirements. Thus, we have a variety of types of evaporators, such as prime surface types, finned tube or extended surface type, shell and tube liquid chillier, etc. In the dry-expansion evaporator, the liquid refrigerant is generally fed by an expansion valve. The expansion

valve controls the rate of flow of refrigerant to the evaporator in such a way that all the liquid is vaporized and the vapour is also superheated to a limited extent by the time it reaches the outlet end. At the inlet of the evaporator, the refrigerant is predominantly in the liquid form with a small amount of vapour formed as a result of flashing at the expansion valve.

As the refrigerant passes through the evaporator, more and more liquid is vaporized by the load. The refrigerant, by the time it reaches the end of the evaporator, is purely in the vapour state and that too superheated. Thus the evaporator in its length is filled with a varying proportion of liquid and vapour. The amount of liquid in the evaporator will vary with the load on the evaporator. The inside of the evaporator is far from dry but wetted with liquid. All the same, this type is called the dry-expansion system to distinguish it from the flooded system and also probably because by the time the refrigerant reaches the evaporator outlet it is no more wet (no liquid) but dry (superheated) vapour.

The evaporator becomes cold and remains cold due to the following reasons:

1 The temperature of the evaporator coil is low due to low temperature of the refrigerant inside the coil.

2 The low temperature of the refrigerant remains unchanged because any heat it absorbs is converted to latent heat as boiling proceeds.

The three heat-transfer resistances in evaporators are:

(a) Refrigerant side for the transfer of heat from solid surface to the liquid refrigerant.

(b) Metal wall.

(c) Cooled-medium side which could be due to air, water, brine or any other fluid or a wetted surface on a cooling and dehumidifying coil.

The heat transfer from solid surface to the evaporating refrigerant is of primary interest here. However, the mechanism of boiling i so complex because of the influence of such factors as surface tension, saturation temperature, latent heat and nature of the solid surface, in addition to the usual transport properties, that it is very difficult to predict the heat-transfer coefficient analytically. Nevertheless, no attempt is made here to present correlations applicable to evaporating refrigerants which are available in the large amount of published information available on the subject.

Expansion tube: An expansion device is another basic component of a refrigeration system.

The basic functions of an expansion device used in refrigeration systems are to:

1. Reduce pressure from condenser pressure to evaporator pressure, and

2. Regulate the refrigerant flow from the high-pressure liquid line into the evaporator at a rate equal to the evaporation rate in the evaporator

Under ideal conditions, the mass flow rate of refrigerant in the system should be proportional to the cooling load. Sometimes, the product to be cooled is such that a constant evaporator temperature has to be maintained. In other cases, it is desirable that liquid refrigerant should not enter the compressor. In such a case, the mass flow rate has to be controlled in such a manner that only superheated vapour leaves the evaporator. Again, an ideal refrigeration system should have the facility to control it in such a way that the energy requirement is minimum and the required criterion of temperature and cooling load are satisfied. Some additional controls to control the capacity of compressor and the space temperature may be required in addition, so as to minimize the energy consumption. The expansion devices used in refrigeration systems can be divided into fixed opening type or variable opening type. As the name implies, in fixed opening type the flow area remains fixed, while in variable opening type the flow area changes with changing mass flow rates. There are basically seven types of refrigerant expansion devices. These are:

1. Hand (manual) expansion valves
2. Capillary Tubes
3. Constant pressure or Automatic Expansion Valve (AEV)
4. Thermostatic Expansion Valve (TEV)
5. Float type Expansion Valve
6. Electronic Expansion Valve

Capillary tubes: This is the type of expansion device used in this system. Instead of an orifice, a length of a small diameter tube can offer the same restrictive effect. A small diameter tubing is called capillary tube, meaning hair-like. The inside diameter of the capillary used in refrigeration is generally about 0.5 to 2.28 mm (0.020 to 0.090). The longer the capillary tube and/or the smaller the inside diameter of the tube, greater is the pressure drop it can create in the refrigerant flow; or in other words, greater will be the pressure difference needed between the high side and low side to establish a given flow rate of the refrigerant. The length of the capillary tube of a particular diameter required for an application is first roughly determined by empirical calculations. It is then further correctly established by experiments. The capillary tube is not self-adjusting. If the conditions change, such as an increase in the discharge/condenser pressure due to a rise in the ambient temperature, reduction in evaporator pressure, etc. the refrigerant flow-rate will also change. Therefore a capillary tube, selected for a particular set of conditions and load will operate somewhat less efficiently at other condition. As soon as the plant stops, the high and low sides equalize through the capillary tube. For this reason, the refrigerant charge in a capillary tube system is critical and hence no receiver is used. If the refrigerant charge is more than the minimum needed for the system, the discharge pressure will go up while in operation. This can even lead to the overloading of the compressor motor. Further during the off-cycle of the unit, the excess amount will enter the cooling coil and this can cause liquid flood back to the compressor at the time of starting. Therefore, the refrigerant charge of the capillary tube system is critical. For this reason, a refrigerant liquid receiver cannot be used. The charge should be exactly the quantity as indicated by the manufacturer of the refrigeration unit. Since the capillary tube equalizes the high side with the low side during the off-cycle, the idle pressures at the discharge and suction of the compressor will be equal. Therefore at the time of starting, the compressor motor need not overcome the stress of the difference of pressure in the suction and the discharge sides. In other words the compressor is said to start unloaded.

The capillary tube is quite a simple device and is also not costly. Its pressure equalization property allows the use of a low starting torque motor. The liquid receiver is also eliminated in a capillary tube system because of the need to limit the refrigerant charge.

All these factors help to reduce the cost of manufacture of the systems employing a capillary tube as the throttling device.
The capillary tube is used in small hermetic units, such as domestic refrigerators, freezers and room air conditioners.
The following are the various types of capillary tube devices,
1. Capillary tube
2. Hand-operated capillary tube valve
3. Automatic or constant pressure capillary tube valve
4. Thermostatic capillary tube valve
5. Low side float valve
6. High side float valve

The automatic capillary tube valve is used in the work.
The pressure reduction in a capillary tube occurs due to the following two factors:
1. The refrigerant has to overcome the frictional resistance offered by tube walls. This leads to some pressure drop, and
2. The liquid refrigerant flashes (evaporates) into mixture of liquid and vapour as its pressure reduces. The density of vapour is less than that of the liquid. Hence, the average density of refrigerant decreases as it flows in the tube. The mass flow rate and tube diameter (hence area) being constant, the velocity of refrigerant increases since = ρVA. The increase in velocity or acceleration of the refrigerant also requires pressure drop.

Several combinations of length and bore are available for the same mass flow rate and pressure drop. However, once a capillary tube of some diameter and length has been installed in a refrigeration system, the mass flow rate through it will vary in such a manner that the total pressure drop through it matches with the pressure difference between condenser and the evaporator. Its mass flow rate is totally dependent upon the pressure difference across it; it cannot adjust itself to variation of load effectively.

The flow through a helical capillary is divided into two distinct regions: a liquid single-phase and a two-phase region. In figure, point 1 denotes condenser exit and point 2 denotes the capillary inlet. There is a small pressure drop from point 1 to 2 due to sudden contraction to capillary diameter. The refrigerant is sub-cooled between points 2 and 3, saturated liquid at point 3 and is a two-phase mixture between points 3 and 4. Point 4 denotes capillary exit.

Balance point of compressor and capillary: The compressor and the capillary tube, under steady state must arrive at some suction and discharge pressures, which allows the same mass flow rate through the compressor and the capillary tube. This state is called the balance point. Condenser and evaporator pressures are saturation pressures at corresponding condenser and evaporator temperatures. The mass flow rate through the compressor decreases if the pressure ratio increases since the volumetric efficiency of the compressor decreases with the increase of pressure ratio. The pressure ratio increases when either the evaporator pressure decreases or the condenser pressure increases. Hence, the mass flow rate through the compressor decreases with increase in condenser pressure and/or with decrease in evaporator pressure.

Condenser: Refrigerator condenser is one of the main operating components that make up the cooling system on a standard refrigerator. It consists of a series of copper tubes that overlap in a grid or coiling pattern. On most models, the condenser is located at the back of the unit, though some may be installed on the bottom or along one side of the unit. While its size can vary, it often covers at least half of the area of the refrigerator wall, and some even cover the entire wall of the unit.

Combined with the evaporator unit within the fridge, the condenser removes heat from inside the refrigerator and transfers it to the outside of the unit. A series of copper tubes or pipes connect the two devices, and liquid refrigerant passes through these tubes to travel from one to the other. As the refrigerant passes through the evaporator, it collects heat energy from within the refrigerator or freezer, leaving the inside of the unit cold enough for food storage. The extra heat energy warms the refrigerant, causing it to transform into a gaseous material. This gaseous refrigerant then travels down to the condenser. As the refrigerant passes into the condenser, a fan blows air onto the copper tubes. This cools the refrigerant inside, and the excess heat energy is exhausted into the room. Once the heat leaves the refrigerant, it transforms back into a liquid, then travels back into the evaporator to repeat this cooling cycle.To maximize the operating life of a refrigerator, owners must perform routine maintenance tasks, which include cleaning the refrigerator condenser coils. By keeping these coils free of dirt and debris, owners will often find that the unit is less likely to break down. A clean unit is also able to operate more efficiently, which may result in lower utility costs.Before attempting to clean the coils, users should unplug the unit or switch off the electrical breaker to reduce the risk of injury. The refrigerator should then be pulled away from the wall to allow access to the unit. Some coils are covered by a plate or panel, which typically slides or snaps off by hand. Once the condenser is exposed, users can clean the coils with a vacuum hose attachment or a stiff brush. It's important to work carefully during this task to avoid bending or damaging the tubes.

There are three types of condensers, viz.
(a) Air- cooled,
(b) Water-cooled and
(c) Evaporative.

As their names imply, air-cooled condensers use air as the cooling medium, water-cooled condensers use water as the medium and the evaporative condenser is a combination of the above, i.e. uses both water and air. In this system we are using an air cooled condenser.

Refrigerant: Any substance capable of absorbing heat from another required substance can be used as refrigerant. Example:- ice, water, air, etc. A mechanical refrigerant which will absorb the heat form the source (which is at low temperature) and dissipate the same to the sink (which is at higher temperature than source). Either in the form of sensible heat (as the case of air refrigerant) or in the form of latent heat (as the case of vapour refrigerant).

Refrigrant-R134a

Tetrafluoroethane is an inert gas used primarily as a "high-temperature" refrigerant for domestic refrigeration and automobile air conditioners. These devices began using 1,1,1,2-tetrafluoroethane in the early 1990s as a replacement for the more environmentally harmful R-12 and retrofit kits are available to convert units that were originally R-12-equipped.

Other uses include plastic foam blowing, as a cleaning solvent, a propellant for the delivery of pharmaceuticals (e.g. bronchodilators), wine cork removers, gas dusters and in air driers for removing the moisture from compressed air. 1,1,1,2-Tetrafluoroethane has also been used to cool computers in some over clocking attempts. It is also commonly used as a propellant for air soft air guns. Tetrafluoroethane, when compressed as inside gas duster cans, is a clear liquid which boils when exposed to atmospheric pressure at room temperature (as seen here) and can be extracted from common "canned air" canisters by simply inverting them during use.

R134a is the most widely used refrigerant in domestic refrigerators. It must be phased out soon according to Kyoto protocol due to its high global warming potential (GWP) of 1300. Hence we come up with several hydrocarbon mixtures as an alternative to R134a refrigerant.

1. Compressor Specifications
- Number of cylinders - One
- Working position Vertical
- Method of compression Single acting
- Number of times of compression of gas Single stage
- Cooling system Air-cooled
- Compressor 1/6 hp, 2440 rpm,1.1amp(max)
- Motor use (Single phase)

2. Condenser
3. Evaporator
4. Pressure Gauges
5. Energy Meter
6. Control Valves
7. Capillary Tubes
8. Channel Temperature Indicator

All the components are fitted and connections are given accordingly and all the gauges are fixed.

3) OBSERVATION:
4)

Pressure and Temperature observations analysis-1: R134a

Time taken (min)	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)
15	23	210	220	30	29.2	43.4	38.7	22.2
30	26	220	225	32	21.9	55.4	43.8	20.8
45	30	225	230	34	18.3	76.6	50.5	19.2
60	34	228	234	36	14.4	84.6	78.2	15.7

Pressure and Temperature observations mixture-1-R-134a 80% and R290 20%

Time taken (mins)	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)
15	26	190	195	30	26.7	45.4	39.7	21.8
30	28	185	190	32	24.3	48.6	45.4	19.4
45	30	180	185	33	19.8	49.9	38.7	16.7
60	32	180	180	33.5	11.7	52.4	37.4	14.3

Pressure and Temperature observations with analysis 2-R134a (with l.S.HEAT EXCHANGER)

Time taken (mins)	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)
15	68	276	278	80	34.5	49.3	42.8	23.7
30	72	280	280	82	34.2	52.2	43.2	23.9
45	72	280	280	82	34.3	53.8	43.1	24.1
60	72	275	280	82	33.4	54.2	43.3	23.6

Pressure and Temperature observations with Mixture 2 – R134a 80% &
R290 20 %(with L.S.HEAT EXCHANGER)

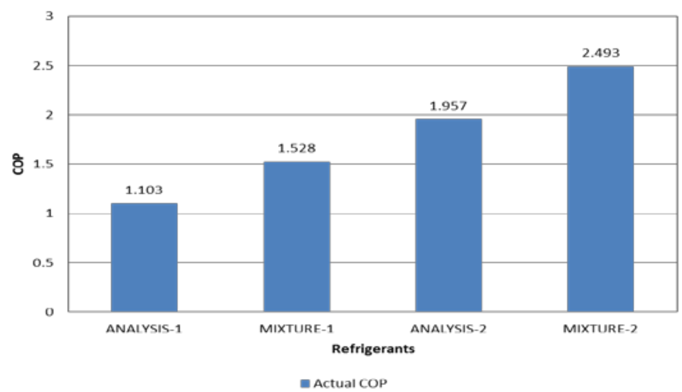
Time taken (mins)	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)
15	68	276	278	80	34.5	49.3	42.8	23.7
30	72	280	280	82	34.2	52.2	43.2	23.9
45	72	280	280	82	34.3	53.8	43.1	24.1
60	72	275	280	82	33.4	54.2	43.3	23.6

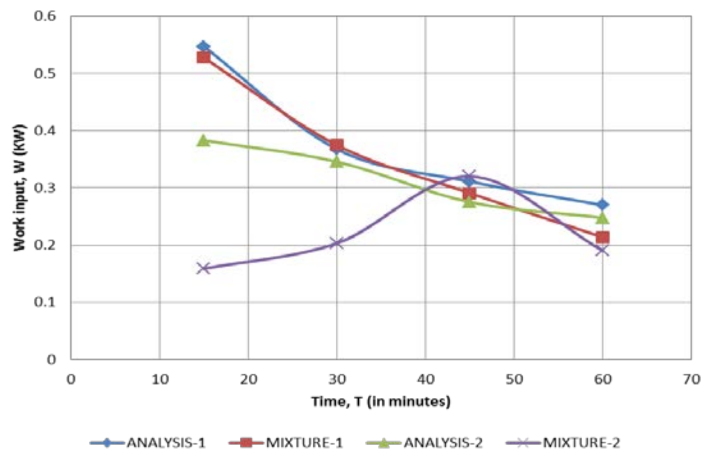
Temperature and time taken for cooling

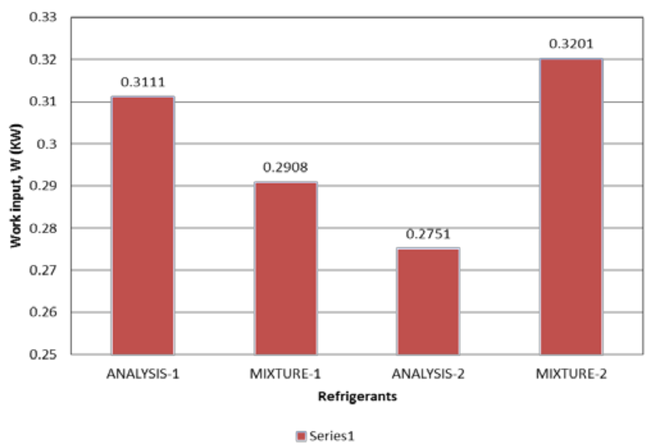
REFRIGERANT	Initial Temperature of Water (°C)	Final Temperature of Water (°C)	Time (min)
ANALYSIS-1	30.2	4.6	60
MIXTURE -1	29.5	1.4	60
ANALYSIS- 2	30.3	2.8	60
MIXTURE- 2	35.8	9.6	60

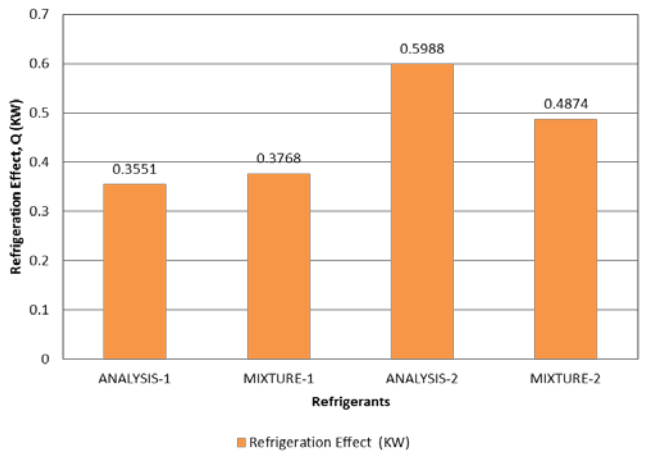
COP FOR ANALYSIS-1 :
Q = (15* 4.187 * (30.2– 4.6)) / 60*60
Q= 0.2977 kW
W = ((1/3200) * (5 / 20.84) * 3600
W=0.2699 kW
COP= 0.2977/0.2699
COP= 1.103
COP OF MIXTURE 1:
Q = (15* 4.187 * (29.5– 1.4)) / 60*60
Q = 0.3268 kW
W = ((1/3200) * (5 / 26.3) * 3600
W = 0.2138 kW
COP = 0.3268/ 0.2138
COP = 1.528
5.3.1.3 COP OF ANALYSIS 2:
Q = (15 * 4.187 * (30.3– 2.3)) / 60*60
Q = 0.4849 kW
W = ((1/3200) * (5 / 20.7) * 3600
W = 0.2477 kW
COP = 0.4849 / 0.2477 = 1.957
COP OF MIXTURE 2:
Q = (15 * 4.187 * (35.8 – 9.6)) / 60*60
Q = 0.4874 KW
W = ((1/3200) * (5 / 29.51) * 3600
W = 0.1907 KW
COP = 0.4874 / 0.1907
COP = 2.49

5) GRAPHS:









This study investigated the performance of different mixtures of refrigerants as the working fluid in a vapor compression refrigeration system. One refrigerant blend is used for this project using different components and proportions. Here R134a refrigerant is used as comparing parameter for the other refrigerant mixtures. By conducting the experimental analysis, we have found out that Mixture-2 R134a 80% and R290 20% (with L.S. Heat Exchanger) have given a maximum coefficient of performance and the Analysis-1 R134a have given a lowest coefficient of performance when compared to other mixtures.

The Mixture-2 R134a 80% and R290 20%(with L.S. Heat Exchanger) have shown a slight increase C.O.P by 24.5% when compared to the C.O.P of R134a in the same system. On analyzing the refrigeration effect, for a given time period mixture-2 shows better cooling effect than other mixtures. But while comparing the work input data, the system when charged with Mixture-2 has operated with low energy consumption than R134a refrigerant.

While considering the energy consumption parameter, it is understood that Mixture-2 R290 80% and R290 20%(with L.S. Heat Exchanger) can be used as an alternate refrigerant to R134a on a long term run. The results show that hydrocarbon mixtures have lower energy consumption. The overall performance of the hydrocarbon mixtures showed that this could be the long term alternative to phase out R134a.

Appendix

COP	Coefficient of performance
Qc	Desired output
Q	Refrigeration Effect (KW)
Ec	Energy meter constant
W	Work input (KW)
P1	Pressure at Evaporator outlet
P2	Pressure at Compressor outlet
P3	Pressure at Condenser outlet
P4	Pressure at Expansion valve outlet
T1	Temperature at Evaporator outlet
T2	Temperature at Compressor outlet
T3	Temperature at Condenser outlet
T4	Temperature at Expansion valve outlet

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