

Thermodynamic Study of Tetrafluoroethane (R134a) Based Vapour Compression Refrigeration System

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Abstract - Energy-Energy analysis of present vapour compression refrigeration system is done using isentropic fluid as refrigerants R134a. This thermodynamic analysis is carried out by 2nd law of thermodynamic approach in terms of COP_{II}. The performance of the system both theoretical and actual experimental have been computed in summer condition. The results of proposed title explains the high grade energy consumption by compressor with 1 TR of cooling effect. COP_{II} indicates the actual energy output from the system in summer climate. Due to higher GWP and ODP of R22, R134a can be used for domestic / commercial and industrial applications.

Keywords: Energy-Energy analysis, VCRS, Hydro fluorocarbon refrigerants, COP_I, COP_{II}

I. INTRODUCTION

The 40-45% of world total energy generated is utilized by the industrial process, and further cooling load of industrial is major energy consumption part [1]. The large amount of heat is transferred between all thermal utilities and its greatly affect the performance. The First Law of Thermodynamic (FLT) is quantitative assessment of energy, it treat the work and heat interaction with equivalent forms of energy between system and surrounding. The FLT does not provide the information about internal losses [2]. The real performance of thermal system and quality of energy transfer process estimated by the approach of Second Law of Thermodynamic (SLT) called concept of exergy. The Exergy is maximum possible work obtained from a system at a given state when interacting with an environment.

It clearly indicates the inefficiencies of a process by locating the degradation of energy. In short exergy efficiency is true or real efficiency and energy efficiency is approximation of real efficiency.[2,3]. The proposed title of work explains the 1st law and 2nd law thermodynamic analysis of conventional vapour compression refrigeration system (VCRS) using isentropic fluid as R134a under summer climatic condition of north India. Several research have been conducted in past, this paper have reviewed some major research on the basis of energy and exergy evaluation of VCRS and another cooling systems for different purpose. Vidal and Zheng [4, 5] analyzed a combined power and refrigeration cycle by the exergy method. This combined cycle utilizes ammonia-water mixture as the working fluid and the simulations has been carried out using ASPEN tool. Another novel absorption power/cooling combined-cycle (APC) carried

out. Kontamaris, Liu and Padilla [6-8] noticed that the absorber temperature decreases in analysis of power and cooling cogeneration using ammonia-water system for the cooling generation from GT plant. Wang *et al* [9, 10] proposed a combined power and refrigeration cycle, which combines the Rankine cycle and the absorption refrigeration cycle with binary ammonia– water mixture as the working fluid. And also studied different working fluids with a thermodynamic systems. Khaliq and Rajesh [11, 12] explained combined 1st and 2nd law of thermodynamic analysis on absorption cooling system for gas turbine heat recovery purpose and trigeneration effect .the results of work conducted shows the effect of pressure ratio, process steam pressure, turbine inlet temperature, refrigeration temperature, etc. Another research explained by the authors is the performance of cycle described by 1st law efficiency, electrical to thermal ratio, 2nd law efficiency, and exergy destruction of each component. Omendra Singh, *et al* [13] computed the thermodynamics of Trigenation (Brayton-Rankine-Kalina combined power cycle) power (TRIGEN) system explained in this paper.

Anyanwu EE reported [14]. The technology of solar adsorption refrigeration is satisfy the Montreal protocol and Kyoto protocol on ozone layer depletion and global warming concern, and other market survey reviewed by Turboden the solar power based refrigeration system is simple and is adaptable for small, medium or large type low grade energy recovery systems because adsorption unit of solar adsorption refrigeration does not possess any problems of emission of greenhouse gases. Kaushalendra and Mishra [15] found maximum exergy destruction in boiler part of thermal power plant analysis.

Compressor of conventional refrigeration consumes larger amount of electrical energy with high destruction rate in VCRS, and author also summarize different thermodynamic systems for low to high grade energy recovery from industrial & power plant sector for combined heating-cooling and power generation by using new trends of working fluid in advanced thermal cycles like organic rankine cycle, kalina cycles supercritical organic rankine cycle etc. In addition, exergy-based economic analysis methodologies exist (e.g., exergoeconomics, thermo economics) [16].



Fig.1 Vapour Compression Test Rig



Fig.2 Compressor of the VCRS.

II. THERMODYNAMIC ANALYSIS

The thermodynamic analysis of the VCRS system is done in consideration of the climatic conditions of the North India. The study follows the principles of vapor compression system.

TABLE I THE EXPERIMENTAL RECORD OF THE OBSERVATIONS OBTAINED IN THIS STUDY ARE LISTED BELOW

Sl. No.	VCRS component	Temperature (°C)	Pressure (bar)	Enthalpy (Joule)
1	Evaporator	21	Suction pressure	426
2	Compressor	55	--	402
3	Condenser	43	--	432
4	Expansion valve	-5	Discharge pressure	--

The efficiency of the system on which the study is carried out will be equal to its compressor work and i.e. 85%. The observations that are recorded are obtained during the

summer season in North India where there is an emergent need of cooling due to high outside temperature of the environment. The exergy loss of the system can be calculated by the exergy loss of each component.

Exergy loss in compressor is given as:
 $\Delta e_w = (h_1 - h_2) + T_0(s_2 - s_1) + W \dots \dots \dots (1)$

Exergy loss in condenser is given as:
 $\Delta e_c = (h_2 - h_3) + T_0(s_3 - s_2) \dots \dots \dots (2)$

Exergy loss in expansion valve is given as:
 $\Delta e_v = (h_3 - h_4) + T_0(s_4 - s_3) \dots \dots \dots (3)$

Exergy loss in evaporator is given as:
 $\Delta e_w = (h_4 - h_1) \left(\frac{T_0}{T_r} \right) + T_0(s_1 - s_4) \dots \dots \dots (4)$

And the net exergy loss of the system can be expressed as:
 $\Delta E = \dot{m}(\Delta e_w + \Delta e_c + \Delta e_v + \Delta e_w) \dots \dots \dots (5)$

Exergetic efficiency can be expressed as:

$$\eta_x = \frac{RE \left(1 - \frac{T_0}{T_r} \right)}{W} \dots \dots \dots (6)$$

Specifications of components used in VCR test rig

1. Compressor: - Hermetically sealed compressor 1/3 TR to work on 220V AC 50Hz and operate on Refrigerant R134a with standard electrical accessories.
2. Condenser: - Fins and Tube type air-cooled condenser.
3. Fan motor: - 1/10 H.P. condenser fan motor with fan.
4. Expansion valve: - Capillary expansion valve.

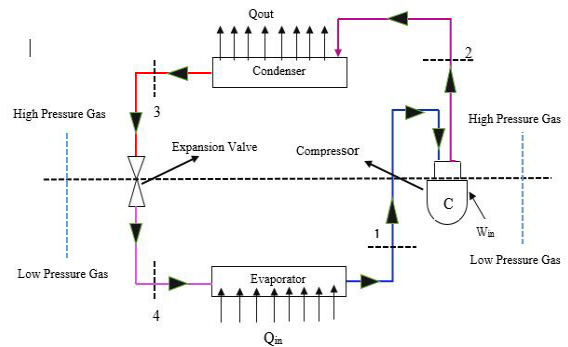


Fig.3 Schematic Diagram of Vapour Compression Refrigeration System.

III. ENERGY –EXERGY ANALYSIS

The performance of a Vapor Compressor Refrigeration System is determined by coefficient of performance abbreviated as COP, which is referred from 1st law of thermodynamic as output by cooling effect with the input of compressor work, the expression for COP_{theo} is-

$$COP_{theo} = COP_I = \frac{RE}{W_C} = \frac{(\Delta H_{evap})}{(\Delta H_{comp})} \dots\dots\dots (7)$$

The practical performance of VCRS is estimated from experimental setup during the laboratory work in summer climate conditions.

$$COP_{exp} = \frac{RE_{act}}{W_{C_{act}}} \dots\dots\dots (8)$$

Where,

$$RE_{act} = \frac{m_w c_{pw} \Delta T}{Time} \dots\dots\dots (9)$$

$$W_{act} = \frac{N_p \times 3600}{T_p \times 3200} \dots\dots\dots (10)$$

Where,

m_w is the mass of water

c_{pw} is the specific heat of water at constant pressure

ΔT is the change in temperature

N_p is the number of pulses

T_p is the time for the pulses recorded.

TABLE II THE EXPERIENTIAL VALUES OF VCRS SYSTEM ARE GIVEN IN THE TABLE BELOW

SL. No.	Parameters	Values
1	m_w	15 kg
2	C_{pw}	4.14 kJ/kg K
3	ΔT	13 degree Celsius
4	Time of cooling	15 minutes

IV. RESULT AND DISCUSSION

The major highlights of experimental work examined by using basic thermodynamics concept of 1st and 2nd law. The results are given in table no-3. The performance of the system is studied in summer conditions of North India for both the cases viz. theoretical and actual experiments. The Carnot COP of the system shows a value of 1.83 and the experimental COP was found to be 1.12 which establishes a decent relation in comparison to Carnot COP. The cooling effect was found having a high value of 807 kJ for which the compressor work is to be high and can be observed having a value of around 720 kJ. The results obtained from

this study describes the high grade consumption of energy with a cooling effect of 1TR (ton of refrigeration).

TABLE III EXPERIMENTAL RESULT

Result Parameters	Values
Cooling Effect	807 KJ
Compressor work	721KJ
COP_{th}	3.4
$COP_{experimental}$	1.12
COP_{carnot}	1.83
COP_{ex} or COP_{II}	0.63

$$COP_{carnot} = \frac{T_0}{T_1 - T_0} \dots\dots\dots (11)$$

$$COP_{II} = \frac{COP_I}{COP_{carnot}} \dots\dots\dots (12)$$

Where,

COP_{II} Is the exergetic coefficient of performance

COP_I Is the theoretical coefficient of performance

COP_{carnot} Is the coefficient of performance of Carnot VCRS cycle.

V. CONCLUSION

The present VCRS system gives 50-60% of actual cooling effect of consumption of electrical energy as input through the compressor work. It is observed that there is a difference in the theoretical and actual COP of the system. The reason for this difference is found out to be the losses that are encountered by the system in the form of thermal loss during the operation of the VCRS system. The 1st law of thermodynamic analysis is unable to explain the quality of energy gain or actual gain, it is estimated by the 2nd law of thermodynamic approach of energy analysis.

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