Numerical Simulation of Vapour Compression Refrigeration System

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Abstract— Simulation analysis of vapour compression cycle is carried out. Numerical simulation model of the system is developed, coupling simulation models of compressor, in MATLAB. Result presented shows the influence of different parameters (condenser temperature, evaporator temperature and refrigerant type) on the performance of the system. Refrigerants, R22 and R134a are considered for the analysis. The objective is to analyse the system under various parameters in order to enhance it.

Keywords-Numerical Simulation, Performance Analysis, Evaporator Temperature, Condenser Temperature, Refrigerant.

I. INTRODUCTION

A vapour compression refrigeration system comprises of four components: compressor, evaporator, condenser and expansion device. The Vapour Compression Refrigeration System is an improved type of air refrigeration system using a liquid refrigerant as medium. Fig. 1 shows the schematic diagram of vapour compression refrigeration system.

The refrigerant entering the compressor as saturated vapour is compressed to higher pressure and temperature. The saturated vapour then is passed through a condenser, which condenses it into liquid. Heat is rejected by the circulating refrigerant which is carried away by air. The condensed liquid refrigerant, in saturated state, is next passed through an expansion valve, which results in reduction in pressure and temperature.

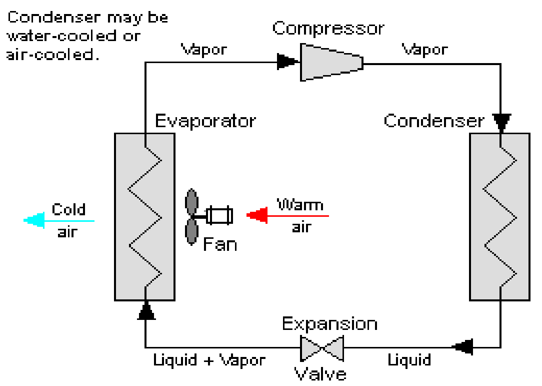

Fig. 1. Schematic diagram of vapour compression refrigeration system[1]

A numerical simulation model of the vapour compression system is developed coupling simulation model for compressor. The model is developed for the study of performance parameters on the system and performance curves are plotted, showing the influence of different aspects.

Refrigerants, R22 and R134a are considered for the analysis. The objective is to analyse the system under various parameters in order to enhance it.

Systematic review of the topic have been carried out, Sharad Choudhary[2] was successful in simulating a VCR model and was able to evaluate the mass flow rate (m), refrigeration effect (RE), compressor work (W_c), volumetric efficiency (η_v) and coefficient of performance (C.O.P) of the whole refrigeration system based on specific input parameters and varying other input parameters. Baskaran et al.[3] performed an analysis on vapour compression refrigeration system with various refrigerant mixtures of R152a, R170, R600a and R290. From their results, the alternative refrigerants except R431a (which is a combination of R152a, R290 at 29% and 71% respectively) have a slightly higher performance than R134a at the condensation temperature at 50˚C and evaporator temperature ranging between -30˚C and 10˚C.Dhumal [4] et al. investigated the influence of various expansion devices on the performance of a refrigerator using R407C as the refrigerant. He found out that capillary tube with diameter of 0.50" shows 90% increase in compressor work with only 50% increase in refrigeration effect. Andrew Alleye[5] has successfully fabricated an experimental setup with a dual evaporator andR134a as refrigerant. Further, he mathematically modeled the system using MATLAB/Simulink Thermosys library.

II. NUMERICAL SIMULATION MODEL

The numerical simulation model of a vapour compression refrigeration system includes many thermodynamic relations. It is simulated on the Matlab platform. The following assumptions are made for analysis of the system".

1. Clearance ratio of the compressor is 5%
2. Evaporator temperature ranges from 40C to 120C
3. Condenser temperature ranges from 420C to 500C
4. Losses are neglected in the system

Following thermodynamics relations[6] are used:

1) Refrigeration Effect

$$RE = h1 - h4 \qquad (1)$$

2) Work done by the compressor,

$$W_c = h_2 - h_1 \qquad (2)$$

3) Coefficient of Performance of the system

$$COP = (h_1 - h_4) / (h_2 - h_1) \qquad (3)$$

4) Volumetric efficiency of the compressor

$$\eta_v = 1 + k - [k * (v_1/v_2)] \qquad (4)$$

Where,
h_1= enthalpy of refrigerant at the outlet of evaporator
h_2= enthalpy of refrigerant at the inlet of condenser
h_3= enthalpy of refrigerant at the outlet of condenser
h_4= enthalpy of refrigerant at the inlet of evaporator
v_1= specific volume of refrigerant at the inlet of compressor
v_2= specific volume of refrigerant at the inlet of condenser
k= clearance ratio of the compressor

The program is coded using MATLAB Software[7]. Based on mathematical calculations, graphs are generated in the graphical user interface. It displays the performance characteristic curves for refrigeration effect, work done by the compressor, volumetric efficiency of the compressor and coefficient of performance against evaporator temperature as shown in Fig. 2.

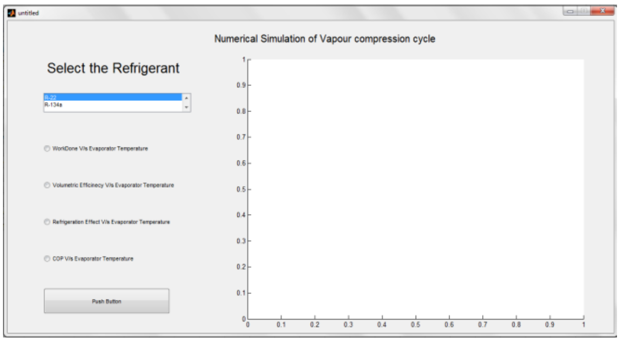

Fig .2. Graphical User Interface in MATLAB

III. SIMULATION ANALYSIS

Based on the numerical simulation model, following graphs are plotted to observe the performance of the system by
the template will do that for you.

1) Varying the evaporator temperature for different fixed Condenser Temperature (42^{0}C, 44^{0}C, 46^{0}C, 48^{0}C and 50^{0}C)
2) Varying the evaporator temperature for different refrigerants (R22 and R134a) at fixed Condenser temperature (46^{0}C)
3) Obtaining appropriate operating temperature range of the evaporator, at fixed condenser temperature (46^{0}C) and refrigerant (R22)

Case1: Variation in the Evaporator temperature for different fixed Condenser temperature[8].

The influence of the evaporator temperature and different fixed condenser temperatures is numerically studied. Fig 3, Fig. 4, Fig. 5 and Fig. 6 show graphs obtained for Refrigeration effect (KJ/kg), compressor work (KJ/kg), volumetric efficiency of compressor and COP of the system against evaporator temperature, respectively.

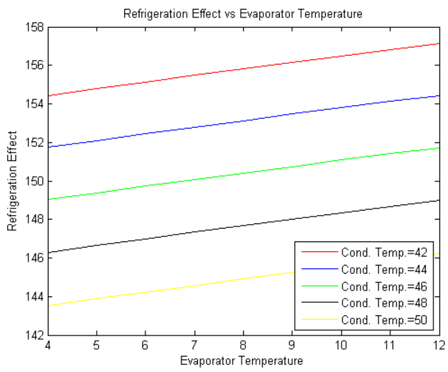

Fig. 3. Graph of refrigeration effect versus evaporator temperature

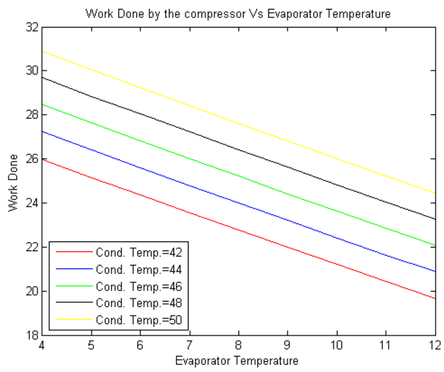

Fig. 4. Graph of work done by compressor versus evaporator temperature

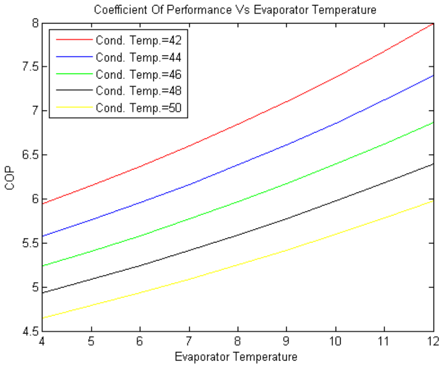

Fig. 5. Graph of coefficient of performance versus evaporator temperature

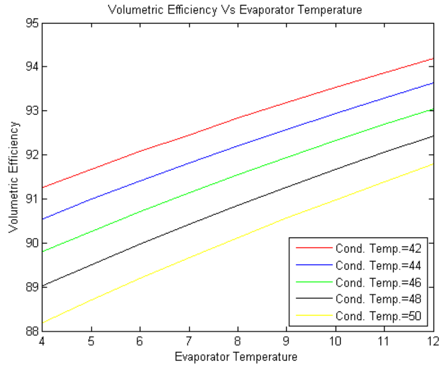

Fig. 6. Graph of volumetric efficiency of compressor versus evaporator temperature

The comparative results shows that for evaporator temperature range of 4^0C to 12^0C

1) Refrigeration effect increases with the increase in evaporator temperature and decreases with condenser temperature.
2) Work done by compressor decreases with the increase in evaporator temperature and increases with condenser temperature.
3) C.O.P increases with the increase in evaporator temperature and decreases with increase in condenser temperature.
4) Volumetric efficiency of compressor increases with the increase in evaporator temperature and decreases with increase in condenser temperature

Change in performance parameters for different fixed condenser temperature and evaporator temperature range of 4^0C to 12^0C is given in Table 1.

TABLE 1

Condenser temperature (˚C)		42	44	46	48	50
Refrigeration effect at evaporator temperature (KJ/Kg)	4 ˚C	154.441	151.751	149.037	146.296	143.529
	12 ˚C	157.133	154.443	151.729	148.988	146.221
Change in refrigeration effect (%)		1.743	1.774	1.806	1.84	1.876
Work Done at evaporator temperature (KJ/Kg)	4 ˚C	25.9785	27.2232	28.4588	29.6764	30.8829
	12 ˚C	19.6617	20.8761	22.0819	23.2703	24.4476
Change in Work Done (%)		24.315	23.332	22.407	21.587	20.838
COP at evaporator temperature	4 ˚C	5.9449	5.5743	5.2369	4.9297	4.6475
	12 ˚C	7.9918	7.3981	6.8712	6.4025	5.981
Change in COP (%)		34.312	32.718	31.207	29.876	28.693
Volumetric Efficiency at evaporator temperature (%)	4 ˚C	91.2595	90.5521	89.8076	89.0231	88.1992
	12 ˚C	94.1945	93.6382	93.0527	92.4358	91.7879
Change in Volumetric Efficiency (%)		3.216	3.408	3.613	3.833	4.069

Case 2: Variation in the Evaporator temperature for different refrigerants at fixed Condenser temperature[9].

The influence of the evaporator temperature for different refrigerants- R22 and R134a is numerically studied. Fig. 7, Fig. 8, Fig. 9 and Fig. 10 shows graphs obtained for Refrigeration effect (KJ/kg), compressor work (KJ/kg), COP of system and volumetric efficiency of compressor(%) against evaporator temperature.

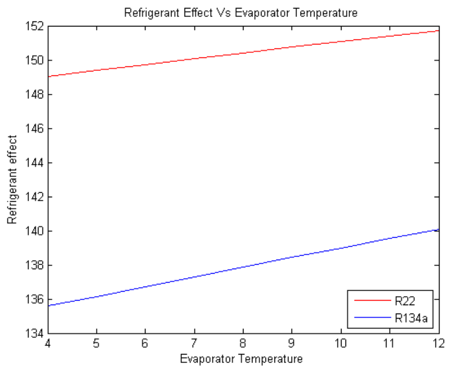

Fig. 7. Graph of refrigeration effect versus evaporator temperature

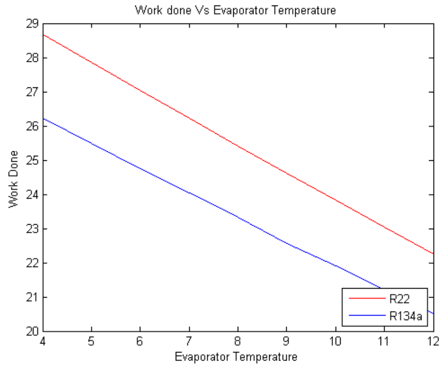

Fig. 8. Graph of work done versus evaporator temperature

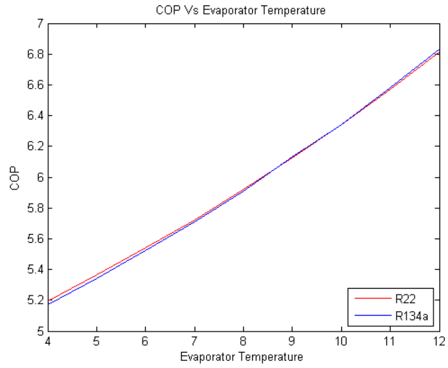

Fig. 9. Graph of coefficient of performance versus evaporator temperature

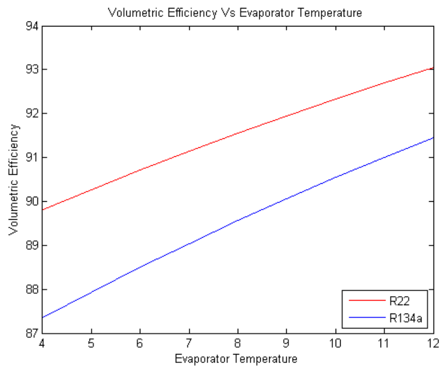

Fig. 10. Graph of volumetric efficiency versus evaporator temperature

The comparative results shows that for evaporator temperature range of 4^0C to 12^0C

1) The work done for compressing R22is higher than R134a.
2) The refrigeration effect produced by R22 is higher than R134a.
3) C.O.P of the system is almost same for both R22 and R134a.
4) Volumetric efficiency of compressor for R22 is higher than R134a.

Change in performance parameters at fixed condenser temperature 46^0C, for different refrigerants and evaporator temperature range of 4^0C to 12^0C is given in Table 2.

TABLE II

Refrigerant used		R-22	R-134a
Refrigeration effect at evaporator temperature (KJ/Kg)	4 ˚C	149.037	135.58
	12 ˚C	151.729	140.09
Change in refrigeration effect (%)		1.806	3.326
Work Done at evaporator temperature (KJ/Kg)	4 ˚C	28.4588	26.2279
	12C	22.0819	20.5085
Change in Work Done (%)		22.407	21.807
COP at evaporator temperature	4 ˚C	5.2369	5.1693
	12 ˚C	6.8712	6.8308
Change in COP (%)		31.207	32.142
Volumetric Efficiency at evaporator temperature (%)	4 ˚C	89.8076	87.3526
	12 ˚C	93.0527	91.4592
Change in Volumetric Efficiency (%)		3.613	4.701

Case 3: Obtaining appropriate operating temperature range of the evaporator, at fixed condenser temperature and refrigerant.

The influence of the evaporator temperature on performance of the system, at a particular condenser temperature is numerically studied. The condenser temperature is 46^0C and the refrigerant used is R22. Fig. 11 shows graph for Refrigeration effect (KJ/kg), compressor work (KJ/kg) and COP of the system against evaporator temperature. Fig. 12 shows graph for the work done and volumetric efficiency of compressor against evaporator temperature. Based on the above two graphs, appropriate operating temperature range of evaporator is obtained.

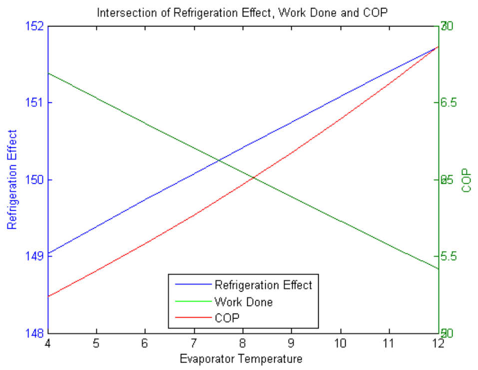

Fig. 11. Graph of intersection of refrigeration effect, work done and coefficient of performance curves

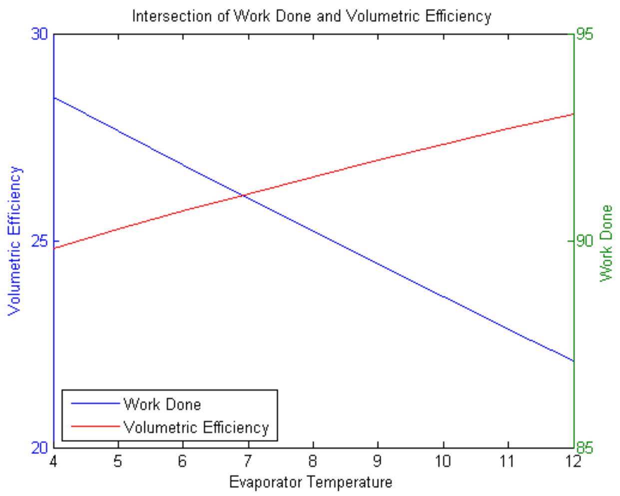

Fig. 12. Graph of intersection of work done and volumetric efficiency curves of compressor

IV. CONCLUSION

The analysis conducted in three different cases is discussed in the respective section. The conclusion from each case is also written. With reference to the analysis in each case it can be concluded that this simulation model can be easily adapted to different refrigerants.

The present study also shows the impact of different parameters which need to be optimized so as to increase the performance. All the observations and the readings in this simulation will be verified with actual data from the proposed experimental set up.

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