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ANALYSIS OF VAPOUR COMPRESSION REFRIGERATION SYSTEMS BY SIMULATION ON MATLAB

Sunil Sanand[1], Mr. Anurag Bagri[2]
[1]M.tech scholar, [2]Assistant Professor, Rabindranath Tagore University, Bhopal

Abstract: Refrigeration systems consume a substantial amount of energy. A large fraction (typically, about 80%) of practical refrigerators are of vapor compression type and operate with mechanical energy input. In most cases the mechanical energy is derived from electric motors. In the present work Pulse wave modulation technique is used to reduce the energy content of the system and to increase the C.O.P of the system. Modeling and analysis work was done on various evaporating temperatures to find out the energy efficiency and C.O.P of the system .The analysis was conducted using MATLAB and verified experimentally. It was seen that the energy savings in the range of 30% were observed and efficiency of the system also improves.

I. INTRODUCTION

1.1 Refrigeration Systems

Refrigeration has had a large impact on industry, lifestyle, agriculture and settlement patterns. The idea of preserving food dates back to at least the ancient Roman and Chinese empires. India is the largest producer of fruits and second largest producer of vegetables in the world. In spite of that per capita availability of fruits and vegetables is quite low because of post harvest losses that account for about 25 to 30% of production. Besides, quality of a sizable quantity of products also deteriorates by the time it reaches the consumer. This is mainly because of perishable nature of the products, which require a cold chain arrangement to maintain the quality and extend the shelf life if consumption is not meant immediately after harvest. In the absence of a cold storage and related cold chain facilities, the farmers are being forced to sell their products immediately after harvest, which results in glut situations and low price realization. Cooling of the harvested product controls the rate of quality loss by slowing down the rate of respiration. The cooler the temperature, the slower is the deterioration and longer is the storage life. Some products like beverages taste good when they are cooled. Use of refrigeration is not limited to food items

By the 1870s, breweries had become the largest users of harvested ice. Though the ice-harvesting industry had grown immensely by the turn of the 20th century, pollution and sewage had begun to creep into natural ice, making it a problem in the metropolitan suburbs. Eventually, breweries began to complain of tainted ice. Public concern for the purity of water, from which ice was formed, began to increase in the early 1900s with the rise of germ theory. Numerous media outlets published articles connecting diseases such as typhoid fever with natural ice consumption. This caused ice harvesting to become illegal in certain areas of the country. All of these scenarios increased the demands for modern refrigeration and manufactured ice. Ice producing machines like that of Carre's and Muhl's were looked to as means of producing ice to meet the needs of grocers, farmers, and food shippers.

1.2 Refrigeration Process:- A refrigeration process indicates the change of thermodynamic properties of the refrigerant and the energy transfer between the refrigerant and the surroundings. The following refrigeration processes occur during the operation of a vapor compression refrigerating system:

1.3 Refrigeration Cycles

Most refrigerants undergo a series of evaporation, compression, condensation, throttling, and expansion processes, absorbing heat from a lower-temperature reservoir and releasing it to a higher temperature reservoir in such a way that the final state is equal in all respects to the initial state. It is said to have undergone a closed refrigeration cycle. When air or gas undergoes a series of compression, heat release, throttling, expansion, and heat absorption processes, and its final state is not equal to its initial state, it is said to have undergone an open refrigeration cycle. Both vapour compression and air or gas expansion refrigeration cycles are discussed.

1.4 Unit of Refrigeration

In inch-pound (I-P) units, refrigeration is expressed in British thermal units per hour, or simply Btu/h. A British thermal unit is defined as the amount of heat energy required to raise the temperature of one pound of water one degree Fahrenheit from 59°F to 60°F; and 1 Btu/h 0.293 watt (W). Another unit of refrigeration widely used in the HVAC&R industry is ton of refrigeration, or simply ton. As mentioned before, 1 ton 12,000 Btu/h of heat removed. This equals the heat absorbed by 1 ton (2000 lb) of ice melting at a temperature of 32°F over 24 h. Because the heat of fusion of ice at 32°F is 144 Btu/lb.

1.5 Types of Refrigeration System

Vapour Compression Refrigeration

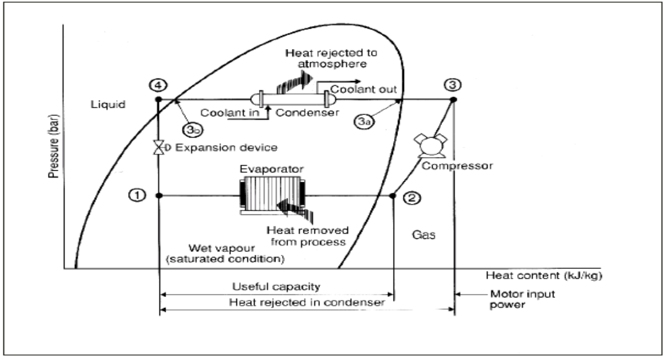


Figure1.1: Schematic of a Basic Vapour Compression Refrigeration System

Absorption Refrigeration

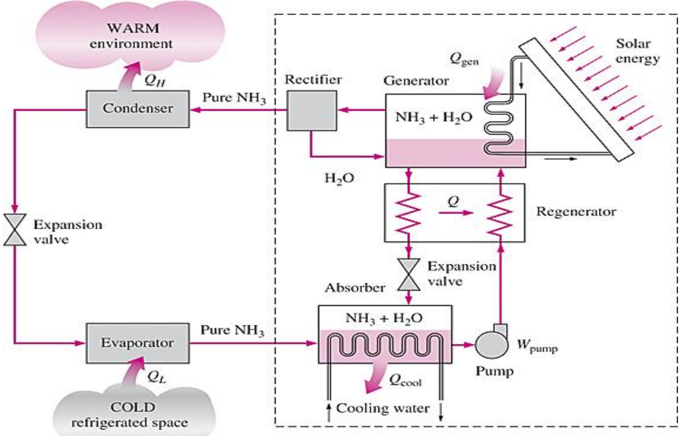


Figure1.2: Schematic of a Vapour Absorption Refrigeration Basic Refrigeration System

1.6 REFRIGERATION SYSTEM COMPONENTS

There are five basic components of a refrigeration system, these are:

- Evaporator
- Compressor
- Condenser
- Expansion Valve
- Refrigerant; to conduct the heat from the product

II. LITERATURE REVIEW

E.Maestrelli et al in 2016 [1]This paper presents the design of a scaled-down prototype of a proposed for a cooling system on environments for replacement of air conditioners by compressor. The operation of the proposed system differs from current systems by compressor to be a system based on the Peltier effect (thermoelectric modules) controlled by PWM ensuring maximum efficiency and precise control of the desired temperature. The prototype foresee the removal of air from the external environment (environment), making him circular of forced mode by a channel which will have its temperature reduced by heat exchange that occurring by indirect contact with the cold surface of the thermoelectric modules, thus arriving to at the environment to be cooled with temperature reduced at relative temperature taken by outside.

Gomes et al in 2016[2] received a patent on multiple evaporator control using PWM compressor. In this they uses two evaporators and they are operating at different fluid pressures. This system is controlled using PWM refrigerant flow switch.

Arianna Latinia et al in 2016[3]TESLA (Transferring Energy Save Laid on Agro industry) is a EU project pointing to the reduction of energy consumption and the improvement of energy efficiency in key agro-food sectors' cooperatives, as those processing fruit and vegetables.

Vaibhav Jaina,et al 2015[4] This paper presents the optimum size and cost estimation of vapor compression-absorption integrated system (VCAIS) using coefficient of structural bonds (CSB) method of thermo economic optimization. The optimum area of heat exchanger is estimated provided overall heat transfer coefficient, operational and cost parameters are known along with CSB values

FatemehTahersima et al 2012 [9] has performed a Economic COP Optimization of a Heat Pump with Hierarchical Model Predictive Control a low-temperature heating system is studied in this Thesis. It consists of hydronic under-floor heating pipes and an air/ground source heat pump.

Stoustrup et al. 2010 [10] has performed the thermal analysis of an HVAC system with TRV controlled hydraulic radiator Automation a control oriented model for an HVAC system is derived in this paper. The HVAC system consists of a room and a hydraulic radiator with a temperature regulating valve (TRV) which has a step motor to adjust the valve opening. The heating system and the room are simulated as a unit entity for thermal analysis and controller design.

Tobias GybelHovgaard et al. 2003 [11] has performed refrigeration system consumes a Substantial amount of energy. Taking for instance supermarket refrigeration system as an example they can account for up to 50 – 80% of the total energy consumption in the supermarket due to the thermal capacity made up by the refrigerated goods in the system there is a possibility for optimizing the power consumption by utilizing load shifting strategies.

The objective of the research is to increase the performance of refrigeration system by using pulse wave modulation technique.

III. METHODOLOGY

There are following methods used in vapour compression refrigeration system with and without pwm techniques:-

Experimental Setup is a experimental refrigeration trainer unit Assembling of Vapour Compression Refrigeration System working unit utilizing a rotary vertical compressor (a key, a spring, and an eccentric sleeve for capacity modulation),a condenser, a expansion device, L.C. Coils, thermostat, switch, evaporator, voltmeter, ammeter and energy meter.

The measurement of power consumption in Vapour Compression Refrigeration System without pulse width modulation technique at control temperature 0ºC, -5ºC,-23ºC.

The measurement of power consumption in Vapour Compression Refrigeration System. with pulse width modulation technique at control temperature 0ºC, -5ºC, -23ºC.

The measurement of Coefficient of Performance in Vapour Compression Refrigeration System without pulse width modulation technique at control temperature 0ºC,-5ºC,-23ºC.

The measurement of Coefficient of Performance in Vapour Compression Refrigeration System. with pulse width modulation technique at control temperature 0ºC, -5ºC, -23ºC.

The comparative analysis of power consumption of Vapour Compression Refrigeration System with and without pulse width modulation.

The comparative analysis of coefficient of performance of Vapour Compression Refrigeration System. with and without pulse width modulation.

Experimental Setup

Figure3.1 (a): Experimental Setup

Brand name : Godrej
Application part : Refrigeration
Type : Refrigeration
Compressor Displacement : 3.0 ml
Refrigerant : R-134 (a)
Rotation (r.p.m.) : 2000/2500/3000
Capacity (W) : 60-110
Current (Amp) : 5Amp. /1.5 Amp.
Input power : 60 W
Power supply : 180V –250V
Measurement : 22 cm x 14.5 cm x 15cm.
Evaporating Temperature : -23.3 ºC
Condensing Temperature : 54.4 ºC
Suction Temperature : 32.2 ºC
Cabinet Temperature : 32.2 ºC

The demand of energy saving products is on the rise because of the environmental controls and people's increased awareness of the global-warming issue. The energy consumption of a refrigerator depends on not only the efficiency of compressor itself, but also the capacity modulation.

REFRIGERENT R-134 (a)

The refrigerant chemical name is Tetra fluoro-ethane.This properties are similar to R-12but with less ozone depletion potential.

Formula : CH_2FCF_3
Molar mass : 102.03 g / mol
Normal Boiling point : -26.3^0 C
Density : $4.25 kg / m^3$
Melting point : 103.3^0C
Soluble : Water

Utilization of MATLAB

MATLAB is an interactive programming language that can be used in many ways, including data analysis and visualization, simulation and engineering problem solving. It may be used as an interactive tool or as a high level programming language. It provides an effective environment for both the beginner and for the professional engineer and scientist. SIMULINK is an extension to MATLAB that provides an iconographic programming environment for the solution of differential equations and other dynamic systems.

SIMULINK MODEL 1

This model Voltage Control PWM based SIMULINK model control convective fan heat, rotational motion sensor, heat generating device, PWM H Bridge control and Mechanical Rotational

Experimental Procedure

In this work we are using pulse with modulation technique for reducing power consumption. So here ultimately we are comparing pulse with modulation technique with simple refrigeration technique (without pwm technique). The working of setup with and without pwm technique as follows:

(a) Without PWM Refrigeration

The refrigeration system uses a moving liquid refrigerant as the medium which takes and exits heat from the space which is going to be cooled and subsequently rejects such heat elsewhere. Systems have four main components without Pulse width modulation technique and with Pulse width modulation technique, we are using five components. Moving refrigerant enters in to the compressor.

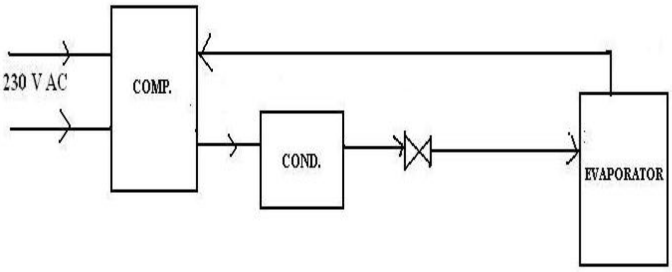


Figure 3.10: Line Diagram for without pwm Refrigeration system

(b) With PWM Refrigeration

Basic function of pulse with modulation converter is to modulate the pulse. In refrigeration process pwm converter has robust role. Best utilization of this setup proved an efficient system .In refrigeration industry; it provides help in the increment of cooling capacity. And also increase the performance of the system .

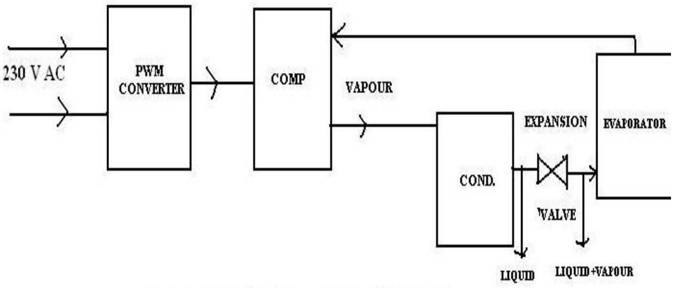


Figure 3.12: Line Diagram for with pwm Refrigeration

IV. RESULT AND DISCUSSION

Simulation results are presented here for the performance of the cooling system. The cooling capacity increases as the inlet generator temperature increases. The COP of the system increases slightly when the heat source temperature increases. The full name of MATLAB is Matrix Laboratory. Matrix Laboratory was written to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects. Matrix Laboratory is a high performance language laboratory .It introduced computation, visualization, and programming environment. Furthermore, Matrix Laboratory provides modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming language. Such factors make Matrix Laboratory an efficient tool for teaching and research. Matrix Laboratory has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving complicated technical problems, is a Matrix Laboratory interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a most standard tool at most universities and industries throughout the world. It has powerful built-in routines that enable a very wide variety of computations and most accurate. It also has easy to use graphics commands that make the visualization of results. Specific applications are collected in packages referred to as toolbox. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering.

4.1 Formula Used

(1) Work done/min = m_g x (n/n-1) × (p_2v_2- p_1v_1) in KJ/min

where,

m_g = Mass flow rate of refrigerant in Kg/min
n = index of expansion
p_1 = suction pressure in N/m^2
p_2 = Discharge pressure in N/m^2
v_1 = suction volume in m^3/kg
v_2 = Discharge volume in m^3/kg

(2)Power = <u>Work done(KJ/min)</u>in KW
60

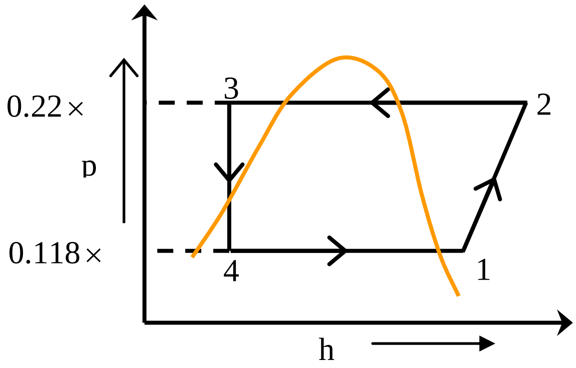
(3)Coefficient of Performance(COP) = <u>Total Refrigeration effect</u>
Work done

(4) Mass Flow Rate of Refrigerant =<u>Cooling capacity (KJ/min)</u>
Refrigeration effect(KJ/Kg)

4.2 Sample Calculation

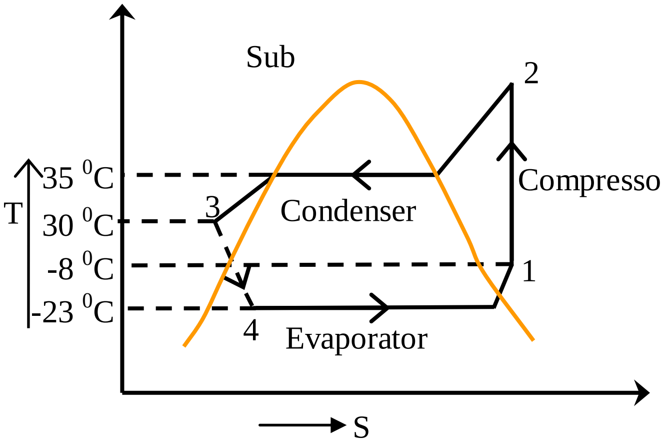
(1) Coefficient of Performance &Power Consumption (Without PWM)

Speed of the compressor = 3000 rpm
Control temperature (Evaporation temperature) = -23^{0}C
Compressor inlet temperature = -8^{0}C
Condensation temperature = 35^{0}C
Cooling capacity = 0.75 Tones
Expansion temperature = 30^{0}C
Suction pressure = 0.118x 10^5 N/m^2
Discharge pressure = 0.22 x 10^5 N/m^2
Refrigerant = R-134 (a)



The following properties given with the help of (R-134(a)) refrigeration chart.

h_2= 445 KJ/Kg, h_{f3}= h_4 = 240 KJ/Kg, v_1= 0.0141m^3/Kg, v_2 =0.0452 m^3/Kg, h_1= 410 KJ/Kg.



Refrigeration effect Re = $h_1 - h_{f3}$ = (410 – 240) = 170KJ/Kg

Mass flow of the refrigerant m_g=(0.75 x 210KJ/min)/170 KJ/Kg
= 0.92 Kg/min

Total Refrigeration effect(T.R.E.) =m_g × Re = 0.92 × 170 KJ/min
= 157.5 KJ/min

Work done = m_g x (n/n–1) × (p_2v_2 – p_1v_1) , where (n=1.01)
= 0.92 x (1.01/1.01– 1) × (0.22x10^5 × 0.0452– 0.118 × 10^5 × 0.0141)
W.D. =76.53 KJ/min

Power = <u>work done in KJ/min</u>= 76.53 /60
60 = 1.27 KW

Coefficient of performance = (T.R.E / work done)
Coefficient of performance = 157.5/76.53
= 2.0

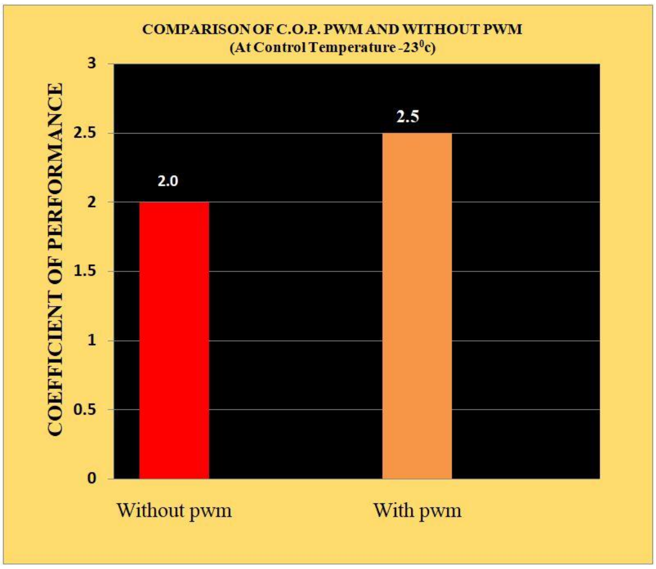
Now Results are found by simulation, using MATLAB at evaporating temperature of -23°C and compressor speed of 3000 rpm (With and without pwm)

4.2.1 Power Consumption

SR NO	TIME (MIN)	VOLTAGE (V)	CURRENT (Amp)		TEMPERATURE (°C)		POWER CONSUMPTION (Kwh/hr)	
			WITHOUT PWM	WITH PWM	WITHOUT PWM	WITH PWM	WITHOUT PWM	WITH PWM
1	0	250	5	1.7	23	23	0.0304	0.0247
2	5	250	2.5	1.4	22	20		
3	10	250	2.3	1.3	15	11		
4	15	250	2.2	1.2	11	0		
5	20	250	2.1	0	0	-15		
6	25	250	2.1	0	-5	-23		
7	30	250	2	0	-14			
8	35	250	2	0	-18			
9	40	250	1.9	0	-22			
10	45	250	1.9	0	-23			

Table 4.1: Power Consumption at evaporating temperature of -23°C and compressor speed of 3000 rpm (With and without pwm)

4.2.2 Coefficient of Performance



Graph 4.1: C.O.P at evaporator temperature of -23°C and compressor speed of 3000 rpm (With and without pwm)

It was observed from the table and graph that the COP with pulse width modulation is 2.5 and 2.0 without pulse width modulation and the power consumption and time duration to achieve evaporator temperature of -23ºC is reduced in case of with PWM refrigeration system.

4.3 Comparison of Experimental Results with Simulation Results

It is observed that results obtained by conducting experiment with simulation results are comparable.

At evaporating temperature of -23°C and compressor speed of 3000 rpm (with and without pwm) power consumption and COP with experimental setup and simulation as follows.

Experimental Result:
Power Consumption = 1.27KW (without PWM)
= 0.0304Kwh/hr
Coefficient of Performance= 2.0(without PWM)
Power Consumption = 1.03 KW (with PWM)
= 0.0247 Kwh/hr
Coefficient of Performance = 2.5 (with PWM)

Simulation Results:
Power Consumption (without PWM) = 0.0304Kwh/hr
Coefficient of Performance = 2.0 (without PWM)
Power Consumption (with PWM) = 0.0247 Kwh/hr
Coefficient of Performance = 2.5 (with PWM)

It was observed from the table and graph that the COP with pulse width modulation is 2.3 and 1.7 without pulse width modulation and the power consumption and time duration to achieve evaporator temperature of -5ºC is reduced in case of with PWM refrigeration system.

V. CONCLUSION

A refrigeration system which is performed on a timed basis consumes excess electrical energy. Defrosting of display cases also disturbs the temperature control of the case resulting in temperatures which exceed the design temperature over a significant time period. The energy consumption during the defrost process can be reduced using more advanced defrost initiation and termination techniques based on demand rather than timed defrost. Although a number of different demands defrost strategies have been proposed in the past, none has found wide acceptance in the food retail refrigeration industry due to poor reliability and high capital cost. Today there are many applications to reduce the absorbed Powers requirements of refrigeration hardware in process cooling industries, commercial air conditioning and data centers facilities. The optimum operation of refrigeration equipment at partial loads is especially significant in condition where the medium annual ambient air temperatures are between +5°C and +20°C, typical for the vast majority of conditions. For even lower ambient temperatures the combination of inverter technology coupled with that of free-cooling, whereby chilled water can be produce using only fans energy, can be effectively used to produce chiller units with even greater efficiencies than previously considered possible. In refrigeration systems pwm techniques play an advantageous role. Refrigeration system consume power at 0°C; 0.0308 Kwh/hr without pwm and consume power 0.0255 kwh/hr with pwm technique. And at -5°C; power consumption is 0.044 kwh/hr without pwm and 0.0251 kwh/hr with pwm technique. Power consumption at -23°C is 0.0304kwh/24hr without pwm and 0.0247 kwh/24hr with pwm. With the help of pwm technique, we can increase the coefficient of performance of the system. The COP of the system at 0°C is 2.2 with pwm and 1.6 without pwm technique. The COP at -5°C is 2.3 with pwm technique and 1.7 without pwm technique. The COP at -23°C is 2.5 with pwm technique and 2.0 without pwm technique.

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