IJEASM
International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 3 Issue 07, July 2022

Vapour Compression Improves Fast Cooling and Energy Efficiency in Industrial Refrigeration Systems

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Abstract: *Modeling and analysis work was done on vapor compressor refrigeration systems for improve energy efficiency. The systems which were modeled in detail compressors have energy usage 6 to 9% lower than the units with horizontal scroll compressors and Air-cooled condensers have energy consumption 11% and secondary loop systems have energy consumption 15%. In response to the environmental concern of global warming, efforts have been made in supermarket [5] refrigeration industry to design or develop refrigeration systems that operate with less refrigerant charge and energy consumption. The "advanced" systems that have been used or developed and have much less refrigerant charge than the parallel and low-cost installation, flexibility in time to order and remodeling. However, the self-contained system has some inherent disadvantages including high equipment cost and low efficiency due to heat transfer.*

Keywords: *Energy Efficiency, Heat Transfer Rate, Energy Consumption and Compressors.*

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1. Introduction

Refrigeration is a process in which work is done to move heat from one location to another. [1] The work of heat transport is traditionally driven by mechanical work, but can also be driven by heat, magnetism, electricity, laser, or other means. Refrigeration has many applications including but not limited to household refrigerators, industrial freezers, cryogenics, [10] and air conditioning. Heat pumps may use the heat output of the refrigeration process, and also may be designed to be reversible, but are otherwise similar to refrigeration units. Energy efficiency under a specific operation condition. [9] The Cool Pack is especially suitable for supermarket refrigeration analysis for which we have well-defined component performance and need to catch the main system characteristics while neglecting some details. The energy efficiency under different operating conditions direct the refrigerant through a condenser and an evaporator of the refrigeration system. [2]

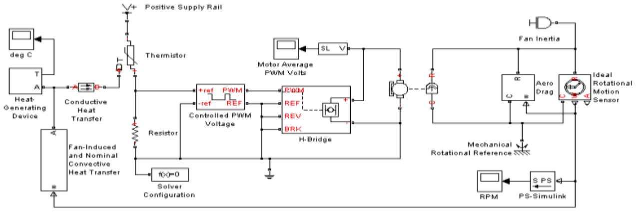


Fig.1. Block diagram energy saving refrigeration system

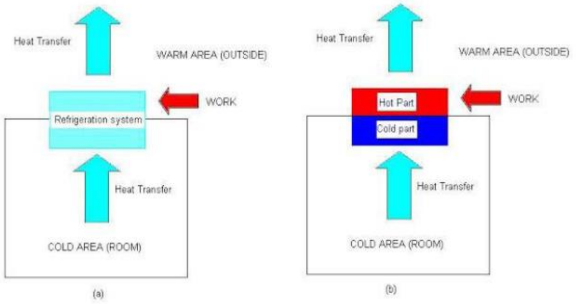


Fig.2. (a) Refrigeration system (b)Refrigeration system produces cold and hot part

Refrigeration has a large impact on industry, lifestyle, agriculture and settlement patterns. The idea of preserving food dates back to the ancient Roman and Chinese empires. However, refrigeration technology has rapidly evolved in the last century, from ice harvesting to temperature-controlled rail cars. [4] The introduction of refrigerated rail cars contributed to the westward expansion of the United States, allowing settlement in areas that were not on main transport channels such as rivers, harbors, or valley trails. Settlements were also popping up in infertile parts of the country, filled with new natural resources. These new settlement patterns sparked the building of large cities which are able to thrive in areas that were otherwise thought to be unsustainable, such as Houston, Texas and Las Vegas, Nevada. In most developed countries, cities are heavily dependent upon refrigeration in supermarkets, [6] in order to obtain their food for daily consumption. The increase in food sources has led to a larger concentration of agricultural sales coming from a smaller percentage of existing farms. Farms today have a much larger output per person in comparison to the late 1800s. This has resulted in new food sources available to entire populations, which has had a large impact on the nutrition of society.

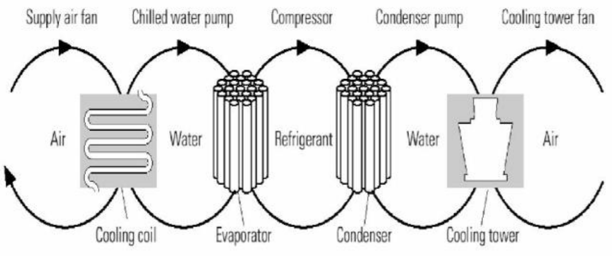


Fig.3. Heat Transfer Loop in Refrigeration System

There are several heat transfer loops in a refrigeration system as shown in Figure 2. Thermal energy moves from left to right as it is extracted from the space and expelled into the outdoors through five loops of heat transfer.

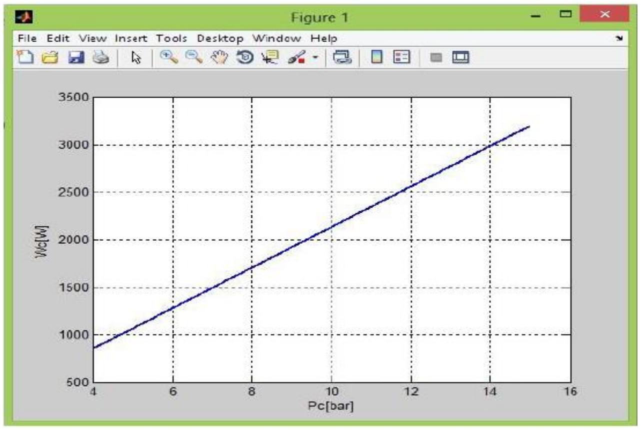


Fig.4. Compressor Power & Condenser Pressure

The optimization of condenser set points to minimise energy use requires a tradeoff between high compressor energy use at high head pressures and high condenser fan and [8] pump energy use to achieve low head pressures. Multi-speed fans and variable speed drive (VSD) fan controls only give significant energy use reductions compared with on/off control if[13] compressors operate highly unloaded and/or the condenser is grossly oversized. Oil separators, discharge and high pressure liquid lines, and expansion and other refrigerant control valves should be designed to operate satisfactorily across the full range of discharge pressures likely to be encountered if discharge pressure is floated. Most industrial refrigeration systems employ compressor discharge (head) pressure controls. Generally these controls modulate the condenser fans (for air-cooled or evaporative condensers) or water flow rates and cooling tower fans (for water-cooled condensers) to keep the head pressure within a specified range. Reducing fan speed or cooling water flow reduces the effective capacity of the condensers so that it equals the required heat rejection by maintaining a larger temperature difference between the refrigerant saturated condensation temperatures

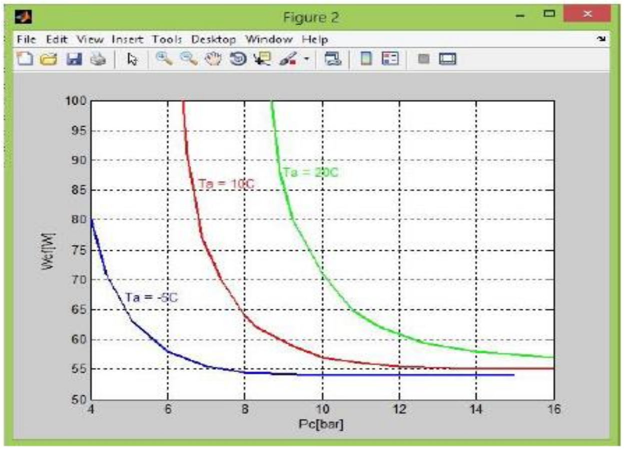


Fig.5. Condenser Fan power & Condenser Pressure

2. Related Work

Oluseyi O. Ajayi et al. (2019) investigated the effect of Al_2O_3 nanoparticles on the working fluids of a vapour compression refrigeration system (VCRS) when used with refrigerant R134a. The nanorefrigerant was used in the vapour compression system without system retrofit. The system's performance analyses were carried out via the freeze capacity tests and energy consumption analysis. The outcome showed that the performance of the Al2O3-dispersed nano-working fluid outperformed that of the conventional working fluid mixture. Specifically, the outcome demonstrated that the system with the nanorefrigerant achieved faster cooling, better performance and improved energy consumption. Thus, using Al2O3 nanoparticles in combination with the working fluids of domestic refrigerators was shown to be feasible. Further to this, based on the performance results, it was necessary to find out the very reason behind the improved thermal performance of the nanoparticle dispersed working fluid. This led to the determination of the thermophysical property of the nanolubricant. The results indicate better thermal conductivity and salinity, implying that the nanolubricant has better heat transfer ability than the base oil (Capella D). In addition to this, the results of the viscosity test showed that the presence of the nanoparticles caused a reduction in the lubricant's viscosity thus portraying a reduction in the energy consumption. However, the pH test results indicate that there may be the need for an improved compressor material selection if the nanorefrigerant will be employed for vapour compression refrigeration purposes in the future.

Nihan Karali et al. (2020) model the costs and benefits of recently proposed new room air conditioner minimum energy performance standards (MEPS) in China. Our results suggest that newly proposed MEPS brings accumulative CO_2 emissions reductions of 12.8% between 2019 and 2050, and accumulative bill saving of 2620 billion RMB to China's consumers. The benefits of the proposed MEPS decrease with longer MEPS revision intervals and increase with shorter intervals—indicating that the intervals should be balanced to maximize benefits while accommodating constraints due to air conditioner manufacturer design cycles. We also model potential nationwide benefits from higher MEPS. Across two increasingly aggressive MEPS scenarios, China's room air conditioner electricity consumption and CO_2 emissions in 2050 are both reduced by 15–53% compared to the proposed MEPS. The highest-efficiency scenario (reaching MEPS of annual performance factor 5.4 in 2025) provides the largest long-term national benefits. These results could inform development of a Chinese regulatory regime that effectively updates room air conditioner MEPS. Because China is the world's largest manufacturer of room air conditioners, the economic, energy, and emissions benefits resulting from higher Chinese MEPS could also have a global reach.

P Saji Raveendran et al. (2020) explores and describes the improvement of energy efficiency of the refrigeration system through the application of the phase change material between wall and coil of the evaporator cabin. The experimental results showed significant effects on system performance such as coefficient of performance increased by 7.1%, per energy consumption decreased by 6.7% and temperature variations were also relatively lower inside the freezer cabinet. This proposed concept would be useful in the event of power failures that are very usual in low grid reliability locations.

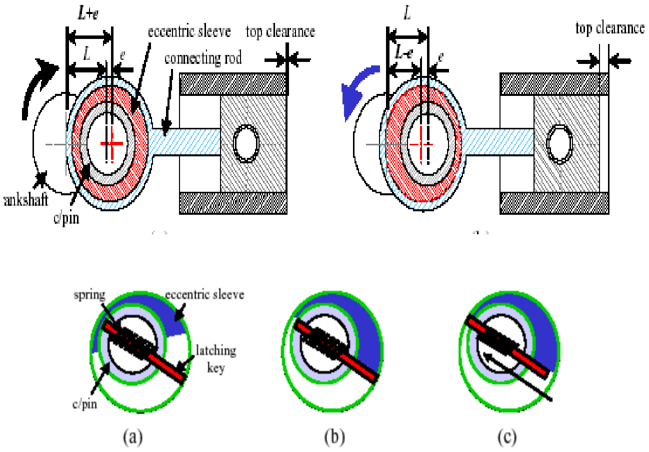
Mark O. McLinden et al. (2020) review the basics of the vapor-compression cycle together with the safety, environmental, and thermodynamic constraints that have led to the current and next generation of refrigerants. The development of new fluids has focused on fluorinated olefins, known as hydrofluoroolefins (HFOs), and blends that contain HFOs. Many of these are slightly flammable, presenting trade-offs between safety and environmental considerations. Engineers also have options with a resurgence of the "natural refrigerants" (ammonia, carbon dioxide, propane, and isobutane). Innovative system designs that reduce the required quantity of refrigerant may allow a wider choice of refrigerants.

Javier Cárcel-Carrasco (2021) A fundamental part of the electric consumption of the main industries of the food sector comes from the refrigeration production, needed in all production phases. Therefore, every measure that aims to optimize the electric consumption and increase the efficiency of centralized industrial refrigeration systems will help the energetic waste of the company, improving reliability and maintenance. Acting on the regulation of capacity of power compressors used can be a good way to save energy. This article shows a case studied by the authors in an industrial company in the meat industry in Spain, where the refrigeration systems have a great importance in the productive process. It displays the methodology used, the description of the taken actions and the results obtained. These combined measures brought about an improvement, with an energetic saving value reaching 400 MWh per year, leading to an equivalent in CO_2 emission reduction of 147.9 tons.

Muhammad Saad Khan et al. (2021) developed a new correlation for the prediction of the coefficient of performance (COP) of single-effect VAR systems under different operating conditions, considering 27 different working fluids and 1,568 literature data points. The developed correlation in-corporates for the first-time fluid parameters such as the boiling points of absorbents and refrigerants, the latent heat of vaporization of refrigerants, and the specific heat of absorbents together with the generator, condenser, absorber and evaporator temperatures. It is further applied for the first time in both small- and large-scale VAR systems, with the former validated based on results from literature and the latter based on ASPEN Plus simulation data, derived from rigorous VAR system models. The small-scale, literature results reveal that the developed COP model is applicable for all data sets with a mean absolute percentage error (MAPE) of 12.25%, for 93.78% of the data that appear within a ± 30% error range. The developed model is also applied to the simulation of large-scale VAR cycles that use ammonia-water (NH3-water) and water-lithium bromide (water-LiBr) for different cooling loads (100 TR, 1000 TR, and 10,000 TR), to evaluate its suitability for high-capacity systems. The maximum MAPE among the model-predicted and ASPEN Plus-generated data is 13.51% for the 100 TR water-LiBr system, with all data found within a ± 30% error band. The developed model can be applied to predict the COP of nu-merous fluids for single effect VAR cycles, paving the way for the investigation of VAR application in large scale, district cooling systems.

3. Experimental Work

The commonly referred to as the heart of the system, the compressor is a belt driven pump that is fastened to the engine. It is responsible for compressing and transferring refrigerant gas. [12] The A/C system is split into two sides, a high pressure side and a low pressure side; defined as discharge and suction. Since the compressor is basically a pump, it must have an intake side and a discharge side. The intake, or suction side, draws in refrigerant gas from the outlet of the evaporator. In some cases it does this via the accumulator. Once the refrigerant is drawn into the suction side, it is compressed and sent to the condenser, where it can then transfer the heat that is absorbed from the inside of the vehicle.



(a) (b) (c)

Fig.6 latching system of capacity modulation of compressor

OBSERVATION TABLE-I (At Control Temperature =0^0C)

SR. NO.	TIME (Min.)	VOLTAGE (V)	CURRENT(Amp.)		TEMPERETURE (℃)		POWER CONSUMPTION(Kwh)	
			WITHOUT PWM	WITH PWM	WITHOUT PWM	WITH PWM	WITHOUT PWM	WITH PWM
1	0	250	5	1.7	25	25	0.0308	0.0255
2	5	250	2.5	1.4	22	20		
3	10	250	2.3	1.3	19	11		
4	15	250	2.2	1.2	17	0		
5	20	250	2.1	0	14			
6	25	250	2.1	0	11			
7	30	250	2	0	8			
8	35	250	2	0	5			
9	40	250	1.9	0	4			
10	45	250	1.9	0	2			
11	50	250	1.8	0	0			

OBSERVATION TABLE-II (At Control Temperature = -5^0C)

SR. NO.	TIME (Min.)	VOLTAGE (V)	CURRENT(Amp.)		TEMPERETURE (℃)		POWER CONSUMPTION(Kwh)	
			WITHOUT PWM	WITH PWM	WITHOUT PWM	WITH PWM	WITHOUT PWM	WITH PWM
1	0	250	5	1.7	25	25		
2	5	250	2.5	1.4	22	20		
3	10	250	2.3	1.3	19	11		
4	15	250	2.2	1.2	17	0		
5	20	250	2.1	0	14	-5		

SR. NO.	TIME (Min.)	VOLTAGE (V)	CURRENT(Amp.)		TEMPERETURE (℃)		POWER CONSUMPTION(Kwh)	
			Without PWM	WITH PWM	WITHOUT PWM	WITH PWM	WITHOUT PWM	WITH PWM
1	0	250	5	1.7	25	25	0.037	0.019
2	5	250	2.5	1.4	22	20		
3	10	250	2.3	1.3	19	11		
4	15	250	2.2	1.2	17	0		
5	20	250	2.1	0	14	-5		
6	25	250	2.1	0	11	-10		
7	30	250	2	0	8	-14		
8	35	250	2	0	5	-18		
9	40	250	1.9	0	4	-20		
10	45	250	1.9	0	2	-23		
11	50	250	1.8	0	0	-25		

CALCULATIONS:-

(1) Comparison of saving in energy , money , time at control temperature at 0^0C

Saving in energy:-

$$\text{Percentage reduction in power consumption} = \frac{0.030 - 0.021}{0.030} = 30\%$$

Saving in money:-

21.6 units costs at the rate of Rs.4 per unit = Rs. 86.4 (Without pwm)

15.12 units costs at the rate of Rs.4 per unit = Rs.60.4(With pwm)

$$\text{Percentage reduction in saving of money} = \frac{86.4 - 60.48}{86.4} = 30\%$$

Saving in time:-

Time consumption to achieve 0^0C= 50 Min. (Without pwm)

Time consumption to achieve 0^0C= 15Min. (With pwm)

(2) Comparison of saving in energy, money, time at control temperature at -5^0C

Saving in energy:-

$$\text{Percentage reduction in power consumption} = \frac{0.044 - 0.0251}{0.044} = 43\%$$

Saving in money:-

31.68 units costs at the rate of Rs.4 per unit = Rs. 126 (Without pwm)

18.07 units costs at the rate of Rs.4 per unit = Rs. 72.28 (With pwm)

$$\text{Percentage reduction in saving of money} = \frac{126.72 - 72.28}{126.72} = 43\%$$

Saving in time:-

Time consumption to achieve -5^0C= 65 Min. (Without pwm)

Time consumption to achieve -5^0C= 20 Min. (With pwm)

(3)Comparison of saving in energy, money, time at control temperature -25^0C

Saving in energy:-

$$\text{Percentage reduction in power consumption} = \frac{0.89 - 0.47}{0.89} = 47\%$$

Saving in money:-

$$\text{Percentage reduction in saving of money} = \frac{106.4 - 56.4}{106.4} = 47\%$$

26.7 units costs at the rate of Rs.4 per unit = Rs. 106.4 (Without pwm)

14.1 units costs at the rate of Rs.4 per unit = Rs. 56.4 (With pwm)

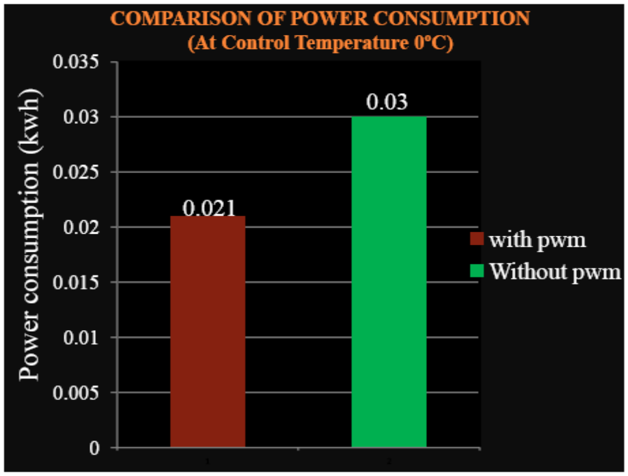
Saving in time:-

Time consumption to achieve -25^0C= 90 Min. (Without pwm)

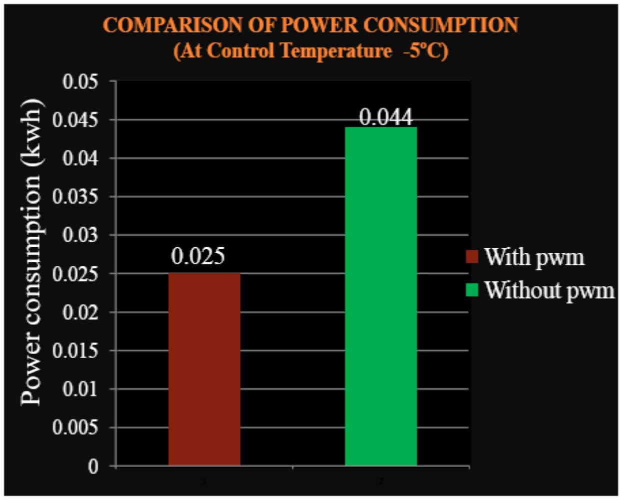
Time consumption to achieve -25^0C= 50 Min. (With pwm)

RESULTS:-

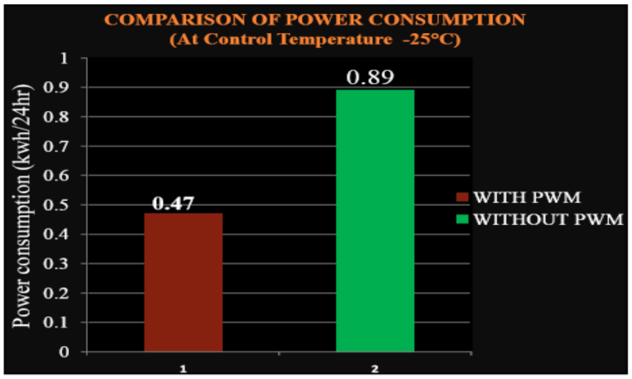
1. Comparison of power consumption with and without pulse width modulation technique at control temperature 0^0C.



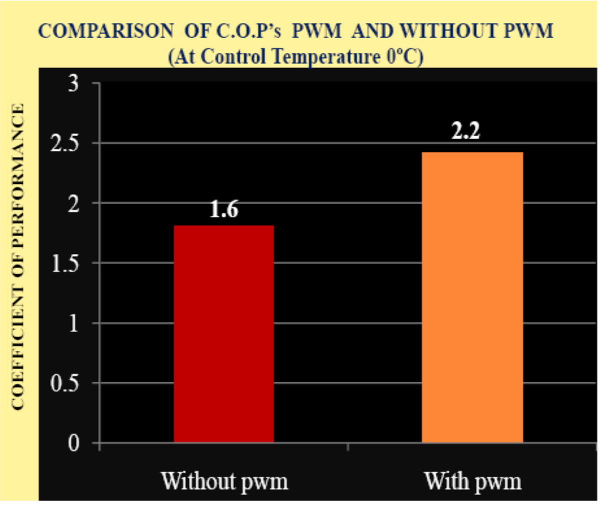
2. Comparison of power consumption with and without pulse width modulation technique at control temperature -5^0C.



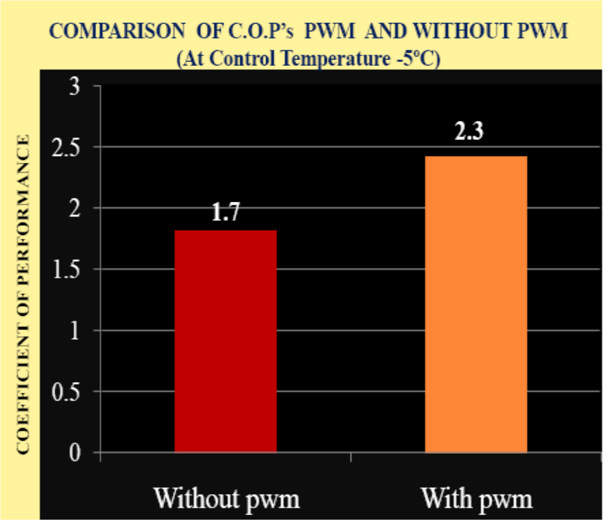
3. Comparison of power consumption with and without pulse width modulation technique at control temperature -25^0C.



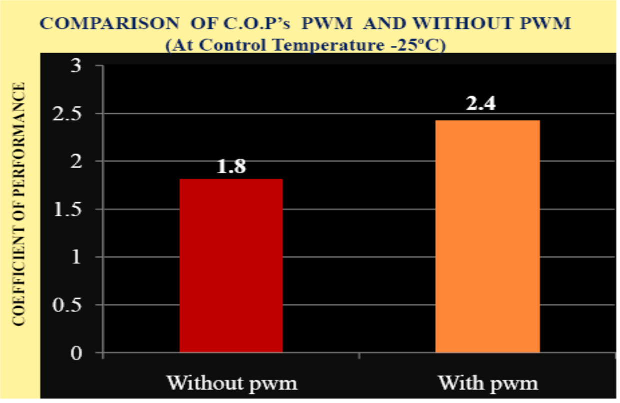
4. Comparison of coefficient of performance with and without pulse width modulation technique at control temperature 0^0C.



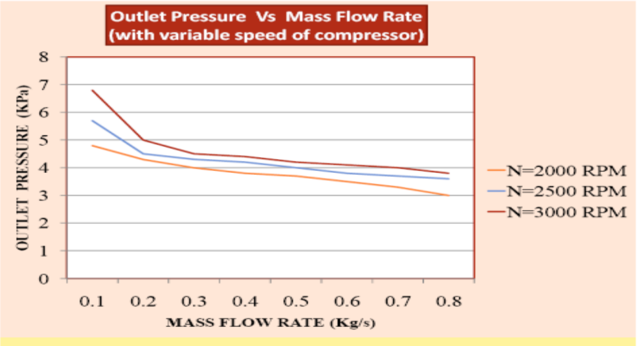
5. Comparison of coefficient of performance with and without pulse width modulation technique at control temperature -5^0C.



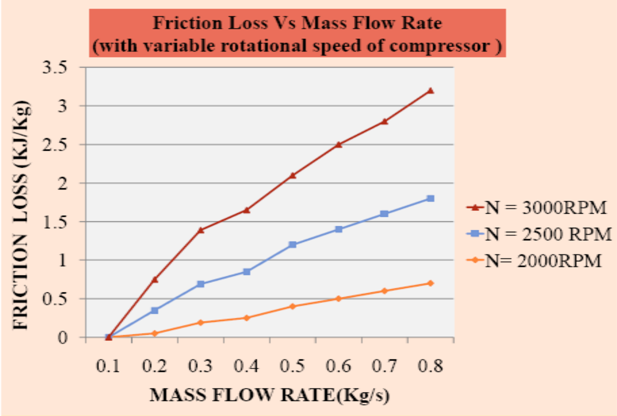
6. Comparison of coefficient of performance with and without pulse width modulation technique at control temperature -25^0C.



7. Outlet pressure versus mass flow rate with variable rotational speed of compressor (2000 RPM, 2500 RPM, 3000 RPM).



8. Friction loss versus mass flow rate with variable rotational speed of compressor (2000 RPM, 2500 RPM, 3000 RPM)



4. Conclusion

I have developed a new experimental working model of V.C.R.S. with PWM technique and applied it for air-conditioning and supermarket refrigeration system. This technique is suitable to be used by power management schemes for minimization of refrigeration loads. This technique gives reduction in power consumption of operating system , saving in money and saving in time because of faster cooling rates. Existing and new supermarket refrigeration systems were modeled and analyzed for their energy efficiency, Based on modeling for representative supermarkets, distributed systems have energy usage 6 to 9% lower than the baseline.

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