Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 3, Issue 5; April-June, 2016 pp. 325-329

http://www.krishisanskriti.org/Publication.html

Experimental Analysis on Capacity Control in Refrigeration System

Akhil Krishnan[1] and Aby S[2]

[1]*Toc H Institute of Science and Technology under Cochin University of Science and Technology, Kerala*
[2]*Department of Mechanical Engineering Toc H Institute of Science and Technology under Cochin University of Science and Technology, Kerala, India*
E-mail: [1]akhilkrishnan008@gmail.com

Abstract—*The main objective of this experimental study is to analyze the power consumed by a refrigeration system with and without capacity control. A freezer room used in industrial refrigeration for storage of ice cream with -25°C storage temperature was selected for experimentation. The analysis reveals that, capacity control by cylinder unloading provides 8 -12% energy savings and capacity control by variable speed control provides 20 - 33% energy savings, compared to refrigeration system without capacity control. The study also reveals that, variable speed control shows significant amount of power saving in lower capacity applications without affecting its performance.*

1. INTRODUCTION

The preservation of perishable commodities, particularly food stuffs is one of the most common uses of mechanical refrigeration. It involves the use of low temperature as a means of eliminating or retarding the activity of spoilage agents. In the early days of mechanical refrigeration, the equipment available was bulky, expensive and not too efficient. This limited the use of mechanical refrigeration to a few large applications such as ice plants, meat packing plants and large storage ware houses. With the development of safe refrigerants and invention of the fractional horse power electric motors, it become possible to produce smaller, more efficient refrigeration systems that is widely used today's applications.

Refrigerated storage may divided in to three general categories; (1) Short term or temporary storage, (2) Long term storage and (3) Frozen storage. For short and long term storages the product is chilled and stored at some temperature above its freezing point, whereas in frozen storage requires freezing of the products and storage at some temperature between 10°F and-10°F, with 0°F and below being most frequently employed [1]. Refrigeration systems are always designed to satisfy maximum load conditions. But, due to wide variation in storage conditions and demand of the product, the load on the system gets varied. So the system operates at part load condition, much of its life. Part load operation is characterized by on/off control of compressor or other capacity control methods [2].

Compressor capacity control techniques can be employed to vary the refrigerant flow rate in the system according to load. Capacity control techniques commonly employed are; on/off control, hot gas bypass, evaporator temperature control, clearance volume control, multiple compressor control, cylinder unloading and variable speed control. Theoretical comparison of these capacity control techniques reveals that, capacity control through variable speed control as being most energy efficient technique [3, 4]. A simulation model for various capacity control shown that, variable speed and variable clearance volume presents best results and hot gas bypass and evaporator temperature control gives worst performance [5]. It was found that 49% better energy efficiency ratio (EER) could be released by two speed compressor than compressor with cylinder unloading. This is due to lower frictional losses at half speed [6].

The performance and reliability factor of frequency controlled reciprocating compressor shown that, while lowering the operating frequency, the mechanical and isentropic efficiencies are improved. Between 20 – 40 % improvement in seasonal energy efficiency ratio was reported with frequency controlled, compared to conventional on/off control [7]. A feasibility study of continuously variable capacity refrigeration system was carried out under the energy efficiency demonstration scheme on behalf of the department of energy [8]. The investigation shown that 56% power saving with high temperature (dairy applications) and 30 % savings with lower temperature (frozen food applications). The energy savings achieved mainly due to variable speed control.

An experimental investigation with variable speed control and cylinder unloading control reveals that with variable speed, volumetric and isentropic efficiencies and COP increases when compressor speed reduces. While in cylinder unloading, it exhibited reduced isentropic efficiency and COP [9]. Also, an evaluation of economic benefits of variable speed compressor reveals that, it leads to reduced energy consumption but intermittent running may not be economical due to high capital cost of the inverter [10].

In a refrigerated room application, the effect of door opening is an important parameter which affects the performance of the system. Due to door opening the atmospheric air enters in to the refrigerated space, which increases the temperature in the room. So the system could operate an additional amount to compensate these temperature increment. An experimental study shown that, due to door opening 10 % of increases in energy consumption compared to system without door opening. The author also proposed that, variable speed control strategy can improve the efficiency of the system [11].

The system efficiency and performance of a refrigeration system also depends on condensing temperature. By controlling condensing temperature, the performance of the system can be improved [12]. The determination of the optimum frequency for each working condition is the key to build control algorithm, which continuously regulated the compressor speed by using an inverter [13]. With an independent control method for the refrigeration system based on PI control law shown that, independent control scheme can guarantee not only precise control but also high COP for the variable speed refrigeration system [14].

The selection of a compressor for a particular application incorporating a variable speed drive is not quite as straight forward. System design has to take into account the anticipated load profile at variable sped operation. Some of the basic requirements of a compressor for variable speed drive applications are [15], [16];

- Proper lubrication at low- and high-speeds must be ensured as inadequate lubrication at low-speeds may increase overheating and friction losses of compressor components.
- The compressor support frame should be designed such that the resonance frequencies are above the operating frequency range. A compressor running at fixed speed imposes vibration on its framework at a set group of frequencies. A variable-speed compressor design will be more complex as each speed will impose different frequencies.
- The VSD should not increase the stresses on the suction and discharge valves. Compressor valves designed to operate at fixed speed may not be suitable for variable-speed operation as imperfect valve action at various speeds may increase valve inefficiencies.
- The capacity of the compressor should vary in direct proportion to speed and the efficiency of the compressor should not decrease within the required speed range.

So, capacity control according to load variation provides considerable amount of energy savings and capacity control by cylinder unloading and variable speed control become more efficient than conventional on/off control for refrigeration compressor.

In this study, experimental analysis on power consumption for reciprocating compressor used in industrial refrigeration, low temperature application with and without capacity control under part load operation was performed. The effect of door opening in power consumed by refrigeration system also taken for analysis.

2. REFRIGERATION TEST FACILITY

The experimentation was carried out on a refrigeration test facility which is based on an industrial freezer room for ice cream storage. The facility is very flexible and allows a wide range of investigations to be carried out. A schematic diagram of the test facility is shown in Fig. 1.

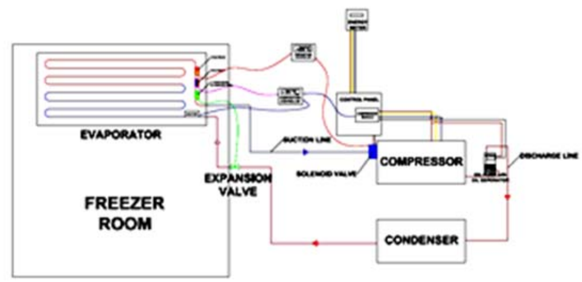

Fig. 1: Refrigeration test facility

The freezer room uses R 404a as refrigerant and has a cooling capacity of 3.52 kW. Thus a reciprocating compressor was selected according to the cooling capacity. The evaporator unit has a capacity of 6 kW, with evaporating temperature of -33°C, with superheating of 5 K, and at a flow rate of 6060 m^3/h. It is equipped with a shell and tube condenser with constant condensing temperature of 40°C of 20.7 kW capacity and Thermostatic expansion valve. The cooling agent used is water, with inlet temperature of 30°C and out-let temperature of 38°C. The design allows the installation of different type of capacity control methods for comparative investigation.

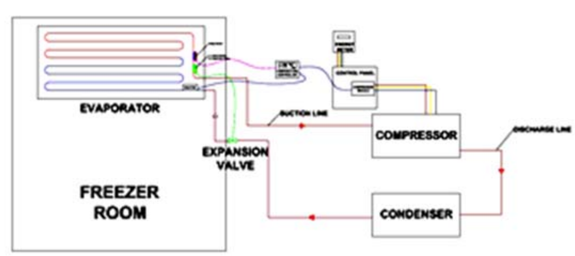

Fig. 2: Existing refrigeration system test facility

The test conditions for the freezer room are achieved through change over the power supply and capacity controlling is achieved. Fig. 2 shown, a schematic diagram of existing refrigerated freezer room. In this system, in addition to compressor, condenser, expansion valve and evaporator, a temperature sensor is used, which sense the room temperature, and when the room temperature is in the required range, a voltage signal is send to compressor module to energize the relay circuit, which cause cutoff the supply to compressor.

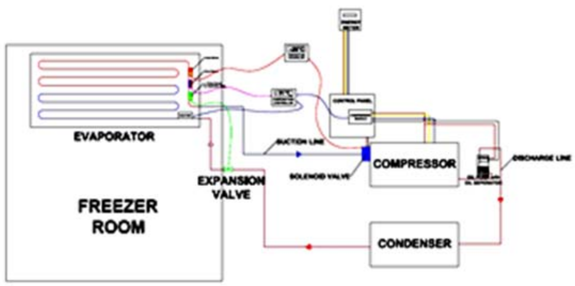

Fig. 3: The schematic diagram of refrigerated freezer room modified with cylinder unloading capacity control test facility.

Cylinder unloading was done by keeping the suction valve open at the time of compression, and thereby load on the motor shaft could be reduced. The opening and closing of the suction valves are controlled by solenoid valves. When the pre-setted temperature was sensed by the sensor, corresponding voltage signal was send to actuator in solenoid valve, thus by energizing it controlling of suction valve by requirement was done.

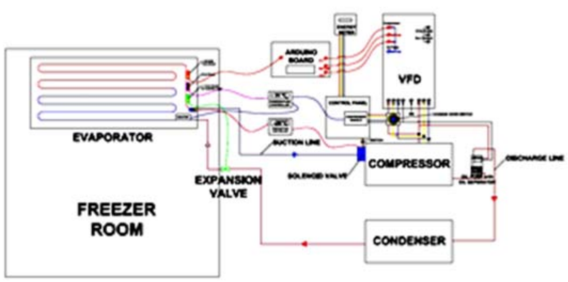

Fig. 4: The schematic of refrigerated freezer room modified with variable speed capacity control test facility.

In addition to an existing system, an analog voltage output temperature sensor and a variable frequency drive (VFD) was used. The VFD operated based on the variable voltage inputs. As the input voltage to VFD varies, the speed of the compressor also varied accordingly. Also an oil separator with oil pump is provided to supply adequate amount of oil in the system if required. In VFD, the permissible limit of frequencies that the compressor can operated was setted. From manufactures data available, the compressor frequency can be varied from 30 Hz to 60 Hz. In this experiment the frequency limit provided is in between 35 – 50 Hz. So at the time of starting, the compressor starts from 35 Hz and it gradually accelerated to 50 Hz, and when any variation in input voltage to VFD occurs, corresponding increase/ decrease in frequency and there by speed of compressor varied.

3. TESTING CONDITIONS

The experiment was conducted in an ice cream manufacturing industry located in Ernakulum district, Kerala, India. The freezer room was fabricated with 110 mm thick PUF insulation with storage temperature of -25°C. The product entered into the room at -5°C and pull down time of 12 hours. The outdoor condition was 35°C DBT and 24°C WBT with 47% RH. The experiment was carried out for 10 days analysis in each methods, and power consumed by each methods were analyzed. The effect of door opening also taken into account.

4. RESULTS AND DISCUSSIONS

The analysis was done based on 10 days observations on power consumed by refrigeration system in various capacity control methods.

Table 1: Power consumption analysis without capacity control

	ENERGY CONSUMPTION [in kWH per Day]	NUMBER OF DOOR OPENINGS
Day 1	79.5	No Door Opening
Day 2	87.2	4
Day 3	99.5	10
Day 4	102.7	12
Day 5	90.6	6
Day 6	85.9	3
Day 7	80.2	2
Day 8	87.6	5
Day 9	90.7	7
Day 10	95.3	8

From the table, it reveals that, as the door opening increases the load on the compressor increases and thereby increased power consumption.

Table 2: Power consumption analysis with cylinder unloading.

	ENERGY CONSUMPTION [in kWH per Day]	NUMBER OF DOOR OPENINGS
Day 1	72.45	No Door Opening
Day 2	81.25	4
Day 3	92.12	10
Day 4	98.67	12
Day 5	85.23	6
Day 6	80.32	3
Day 7	74.21	2
Day 8	82.25	5
Day 9	87.18	7
Day 10	89.88	8

The analysis shown that, there was a small amount of energy saving obtained while capacity controlling was done.

Table 3: Power consumption analysis with variable speed control.

	ENERGY CONSUMPTION [in kWH per Day]	NUMBER OF DOOR OPENINGS
Day 1	63.10	No Door Opening
Day 2	65.12	4
Day 3	66.62	10
Day 4	68.37	12
Day 5	65.33	6
Day 6	65.48	3
Day 7	65.87	2
Day 8	64.21	5
Day 9	65.87	7
Day 10	65.98	8

The analysis reveals that there was a marginal saving in power consumption while speed controlling was done according to load variation.

a. Effect of door opening in power consumption

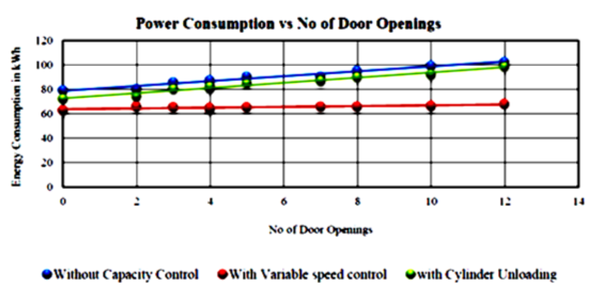

Fig. 5: The comparative analysis on power consumption with and without capacity control, taken the effect of door opening.

The analysis reveals that, door opening has an important role in power consumption of refrigeration system. For systems without capacity control and with cylinder unloading control, the power consumption increases as the number of door opening increases. But in the case of capacity control with variable speed control, only a small amount of variation in power consumption as the effect of door opening in-creases. This is because, in variable speed capacity control method, the compressor control its speed to match with the increase in load regardless of operating at rated speed.

The refrigeration system with variable speed control, the effect of door opening is negligible. Thus, it provide more economical benefit and large amount of power savings, because the door opening cannot be avoidable in the case of a production industry.

b. Power Consumption Analysis

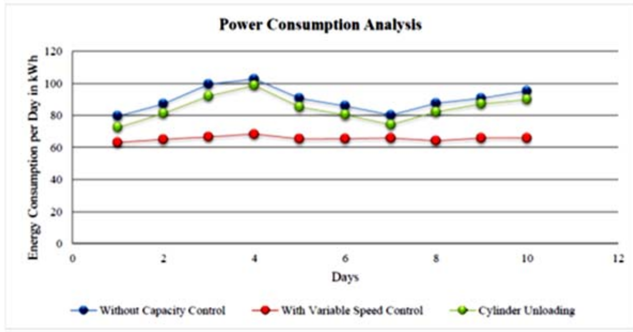

Fig. 6: Power consumed by the refrigeration system with and without capacity control.

From the analysis, it reveals that by controlling capacity of the compressor according to load condition, energy saving can possible.

5. CONCLUSIONS

The experiment was conducted for the analysis of power consumed by refrigeration system under part load operation. The analysis reveals that, capacity controlling according to load variation can minimize considerable amount of power consumption. The power consumed by a refrigeration compressor mainly depends on speed of rotation of compressor, than load on the cylinder. That is, from power consumption analysis it reveals that, by varying speed of rotation of compressor a considerable amount of energy saving was obtained than from cylinder unloading capacity control method.

The main conclusions are;

- By cylinder unloading capacity control, 8 -12% of energy saving was obtained while comparing to system without capacity control.
- The variable speed capacity control produce 20 -33% of energy savings, compared to system without capacity control.
- The effect of door openings induces 10-15% of increase in energy consumption, compared to same system without door openings.
- Use of variable speed capacity control can eliminate the increased power consumption due to door openings.

So, the study concluded that, capacity control through variable speed compressor induce significant savings in power consumed by lower capacity applications.

REFERENCES

[1] Roy. J. Dossatt," Principles of Refrigeration", *Refrigeration Hand Book*.

[2] S.A.Tassou and T.Q.Qureshi, "Comparative performance evaluation of positive displacement compressor in variable speed refrigeration applications ", *Int. J. Refri.* Vol.21.No.1.pp.29-41.1998

[3] H. Janssen and H. Kruse, "Continuous and discontinuous capacity control for high-speed refrigeration compressors", *Proe. Purdue Comp. Tech. Conf, Purdue* University, USA, 1984.

[4] S. M. Zubair and V. Bahel, "Compressor capacity modulation schemes. Heating, Piping, Air-Cond". January, 135-143.1989

[5] E. Pereira Parreira, J. A. R. Parise, "Performance Analysis Of Capacity Control Devices For Heat Reciprocating Compressors", *Heat Recovery Systems & CHP* Vol. 13, No. 5, pp. 451-461, 1993

[6] R. E. Cawley and D. M. Pfarrer, "Part-load Efficiency Advantages of Two-speed Refrigerant Compressors", pp. 42~46.

[7] T. Itami, K. Okoma and K. Misawa, "An experimental study of frequency-controlled compressors*". Proc. Purdue Comp.Tech. Conf., Purdue, USA*, 1982, pp. 297-304.

[8] UK Dept. of Energy, Energy Efficiency Best Practice Programme, General Report 3, "Feasibility and Design Study of Continuously- Variable Capacity Refrigeration Plant". *Dept. of Energy, UK* .1991

[9] A. K. Wong and R. W. James, "Capacity control of a refrigeration system using a variable-speed compressor", *Building Serv. Engng Res. Technol*. 9(2), 63~8 .1988

[10] A. K. Wong and R. C. Legg, "Variable compressor speed control: economic evaluation". *Building Serv. Engng Res.Technol.* 10(1), 21- 27 .1989

[11] Der Yeong Liu, Wen Ruey Chang , Jian-Yuan Lin," Performance comparison with effect of door opening on variable and fixed frequency refrigerators/freezers", *Applied Thermal Engineering* 24 .2004.pp. 2281–2292.

[12] F.W. Yu, K.T. Chan," Experimental determination of the energy efficiency of an air-cooled chiller under part load conditions", *Energy* 30 .2005.pp. 1747–1758.

[13] C. Aprea, R. Mastrullo, C. Renno, "Fuzzy control of the compressor speed in a refrigeration plant", *Int. J. Refri*. 27 (6) .2004.pp. 639–648.

[14] C. Aprea, R. Mastrullo, C. Renno, "Determination of the compressor optimal working conditions", *Applied Thermal Engineering* .2009.pp. 1991-97.

[15] Li Hua, Seok Kwon Jeong, Sam-Sang You," Feed forward control of capacity and superheat for a variable speed refrigeration systems", *Applied Thermal Engineering*. 2009.1067-74

[16] T. Q. Qureshi, S. A. Tassou, "Review Paper – Variable Speed Capacity Control in Refrigeration System." *Applied Thermal Engineering*, Vol. 16, 1996.