INTERNATIONAL JOURNAL OF ELECTRONICS; MECHANICAL and MECHATRONICS ENGINEERING Vol.2 Num.2 pp.(180-189)

ENERGETIC AND EXERGETIC ASSESSMENT OF DISPLAY CASES USED IN THE MARKET APPLICATIONS FOR PREFERENCE REFRIGERANT

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Abstract

This study examines energy and exergy analyses of display cases used to preserve daily products in market applications for different refrigerants. In the study, vapor compression cooling cycle is taken as a model and R22, R134a, R404A and R507C refrigerants used in common application and R407C, R410A and R422D evaluated as alternative refrigerants are studied under constant load in cycle. According to COP and exergy analyses, R134a gas and alternative gas R407C have come forth among the other gases with values 5.33 and 60.86%, and 5.41 and 62.04% respectively. The study finally emphasizes the importance of exergy analysis which is an important method to determine irreversibility of the systems.

Key Words: *Display cases, Cooling, Refrigerant, Exergy Analyses, COP.*

1. INTRODUCTION

Display cases are as used intensively to protect and preserve daily food consumption product like milk products, meat, fish, soft drinking in market applications. Recently, brand share of the daily food consumption products elicit especially the importance of display cases, which protect these products, in sustainable cost of markets. Ongoing climatic deteriorations have provided growth environmental consciousness in Today. It is known that cooling systems and applications is the one of the root cause of emissions. This effect depends on refrigerant and energy consumptions of the systems in cooling applications. Display cases expend approximately %60 of total energy consumptions in the market applications [1]. Therefore, studies of energy saving and reduction of environmental effects in these systems are necessity in activities of the sector. Display cases are used intensively in also many commercial cooling applications as well as market applications. The commercial refrigeration sector is the third largest refrigerant consumer with 17%; mobile air-conditioning with 31%; and unitary air conditioning sector with 28% [2]. The cost of energy consumption is an important item in the large capacity cooling systems, including the commercial sector like market applications. The energy cost for commercial refrigeration, out of which those relating to refrigeration systems represent the vast majority, will typically be in same order of magnitude as the profit generated by a facility.

The design of the refrigeration system is therefore a crucial decision from an economic and environmental viewpoint. For this purpose, equipment changes are made depending on energy save potentials as well as refrigerants. Energy savings potentials for commercial refrigeration equipments are given in Table 1.

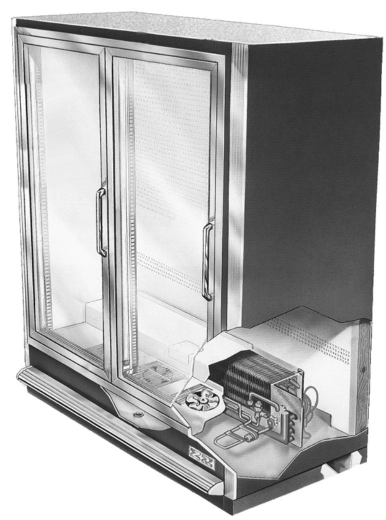
Table 1 Energy savings potential for commercial refrigeration equipment. [3].

Technology	Energy Savings Potential
Grocery store systems	14%
Beverage Merchandisers	45%
Reach-in refrigerators	50%
Reach-in freezers	40%
Refrigerated vending machines	42%
Walk-in coolers and freezers	32%
Ice Machines	20%

In the market application of cooling systems, different cooling temperatures are needed to keep different product fresh. These temperature parameters in the design of cooling systems are for frozen food -29 to -18 ºC, for ice cream -26 to -22 ºC, for fish or shellfish -5 to -1 ºC, for meat or poultry -1 or 3 ºC, for diary product -3 to 8 ºC, for fruit or vegetable 7 or 10 ºC[7].

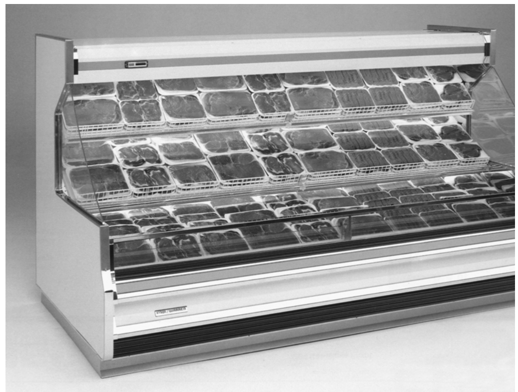
Preserving and production of daily products in sales process is important in the market applications. Therefore, Display cases are used for preserving in cooling medium of these products accessible from weather change. In a typical market, many display cases to have different size and capacity are used. Different type of display cases used in market applications are given in Figure 1.

a. Single-Level Wide Aisle Open Display Case



b. Glass Door Reach-In Display Case

c. Multi-Level Open Dairy Case



d. Multi-Level Open Meat Case

Figure 1 Different display cases [1]

Working system of display case units is vapor compression cooling cycle, which is a thermodynamics model. A typical display case contains an expansion valve and one or more evaporators for case cooling. Evaporator fans circulate case air. The air flow in open cases is blown over the open section of the case, creating an air curtain which separates food from the warmer store air. Multiple fans are required for most cases. Low temperature evaporators and some medium temperature evaporators require periodic defrosting to remove frost which condenses and/or freezes on the evaporator surface. This can be done with electric defrost, or hot gas defrost. The former involves electric resistive heating with a defrost coil which is integrated into the evaporator coil. Hot gas defrosts involves piping and valves which send hot gas from the compressor discharge into the evaporator. Some medium-temperature cases can also use off-cycle defrosts [1]. Cooling cycle of a typical display case is given in Figure 2.

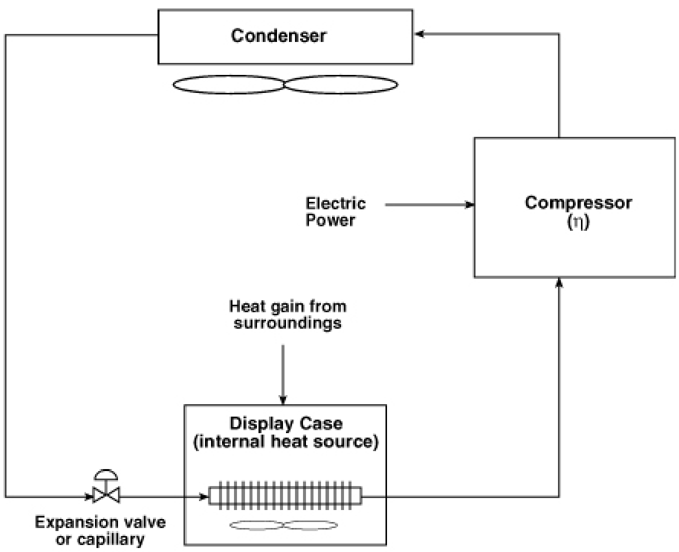


Figure 2 Typical display case refrigerant cycle[1]

Power consumption of the display cases accounts for 60% of the total power consumption of a market and is the most important factor for reducing the power consumption of market applications[8]. The three major factors influencing power consumption of the display case, that is, refrigeration capacity, power for compressor and power for internal fans, and measures were taken to reduce the power consumption of each of these factors. Working conditions of these factors depend on exactly refrigerants. Considering application processes of display cases, R22, R502, R404A, R134a, R507A gasses are used in the units. Refrigerants used in Turkey' applications are R22, R134a and R404A gasses[9]. Cooling capacities of display cases vary between 15 kW and 75 kW, evaporator temperatures vary between temperature -10 ºC and +10 ºC. According to the examinations, it is seen that the evaporator temperature of the units increase as 20 ºC in food and vegetable stands.

3. EXERGY ANALYSES IN COOLING SYSTEMS

As a measure of machine's working activities in cooling systems, thermal efficiency and the coefficient of performance (COP) have been defined. The coefficient of performance (COP) for a cooling machine is;

$$COP = \frac{Q_L}{W_{net}} \qquad (1)$$

where Q_L indicates the temperature moving away from the cooled environment and W_{net} indicates the net work given to the compressor [10]. Cooling machine are systems working based on cycle principle and the energy saving for the cycle may be expressed as follows:

$$W_{net} = Q_H - Q_L \qquad (2)$$

where Q_H is the heat given from machine to outside. In cooling systems, COP is expressed as efficiency according to the first law of thermodynamic. In these systems, working ability of a machine admittedly is explained by the second law of the thermodynamics and this is defined as exergy. In ooling system, exergy efficiency is rate to the possible highest COP_{tr} of the real COP in the same work parameters. In a cooling machine, COP_{tr} It can be expressed as;

$$COP_{tr} = \frac{1}{\frac{T_H}{T_L} - 1} \qquad (3)$$

[11]. Where T_H is the outside temperature and T_L is the environmental temperature moved away. In this case, the exergy efficiency of cooling machine can be expressed as;

$$\eta_{II} = \frac{COP}{COP_{tr}} \qquad (4)$$

4. RESULTS AND DISCUSSION

In the study, energy and exergy analyses of a display case unit having cooling capacity with 25 kW are made under constant load and using different refrigerants. Firstly, parameters taken as reference in vapor compression cooling cycle and mainly evaporator temperature are determined and values of parameters are given in Table 2. Besides, also analyses considering evaluation of power consumption data of compressors together with flows of refrigerant are made for each refrigerant.

Table 2 Cycle Parameters

Evaporator Temperature (ºC)	-10/+20
Evaparator Superheating (ºC)	7
Condenser Temperature (ºC)	40
Condenser Superheating (ºC)	5
Refrigerating capacity (kW)	25

In the study, R22, R502, R404A, R134a,

Thermodynamic features of alternative refrigerants used in systems, along with the

R507A refrigerants used in three separate systems and COP, mass and volumetric flows, compressor forces and exergy outputs of R410A, R407C and R422D refrigerants evaluated alternatively have been analyzed. fluids mentioned above in display cases have been analyzed and results are given in Table 3.

Table 3 Thermodynamics features of refrigerants

Thermodynamics features	Current Refrigerants					Alternative Refrigerant		
	R22	R502	R134a	R404A	R507	R407C	R410A	R422D
Chemical Formula	CHC1F2	R22/115 (48.8/51.2)	CH2FCF3	CHF2CF3/ CH3CF3/ CH2FCF3	CHF2CF3 / CH3CF3	CH2CF3/ CH2F2/ CH2FCF3	CH2F2/ CHF2CF3	CF3CH2F /CF3CHF 2/ CH(CH3) 3
Molecular weight (kg/kmol)	86.5	111.6	102	97.6	98.9	86.2	72.6	109.94
Boiling point at (1.013 bar)	-40.8	-43.3	-26.1	-46.6	-47.1	-43.8	-51.6	-43.2
Enthalpy of evaporation (kJ/kg)	182.5		177.5	140.1	136.2	182.6	186.4	186.4
Critical temp. (ºC)	96.1	82.2	101.1	72.1	70.7	86	70.2	79.55
Critical Pressure (bar)	49.9	40.8	40.6	37.4	70.7	46.3	47.7	39.03
Cp_{likid} (kJ/kgK)	1.26		1.425	1.541	1.54	1.533	1.692	1.4
Cp_{vapor} (kJ/kgK)	0.864		1.011	1.2	1.217	1.107	1.346	0.822
Environmental features								
ODP	0.04	0,221	0	0	0	0	0	0
GWP	1810	5500	1430	3900	4000	1674	2100	2700
Atmospheric life (year)	12	16	14	16		29	29	

Firstly, according to first law of thermodynamic, COP values of display cases for different refrigerants have been examined. Recently, R422D gas, examined as alternative gas in the study, has been proposed as alternative R22 gas due to low GWP and ODP values. COP values of current and alternative refrigerants have been calculated for the -10/40 ºC evaporator/condenser temperatures, and their COP distributions are given in Figure 3.

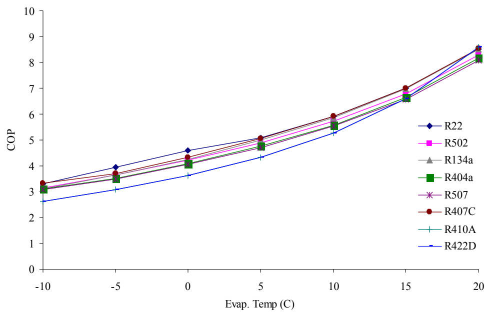


Figure 3 COP of refrigerants

When the results are checked, the COP of refrigerants are found as between 3.29 and 8.51 for R22, between 3.14 and 8.3 for R502, between 3.11 and 8.51 for R134, between 3.12 and 8.15 for R404A, between 3.09 and 8.08 for R507, between 3.32 and 8.55 for R407C, between 3.18 and 8.04 for R410, between 2.61 and 8.59 for R422D respectively. The highest COP value for -5ºC and 5ºC temperature range most widely used in display cases is found between 3.94 and 5.08 for R22 gas, and for the -10 ºC temperature is R407C gas. The volumetric flows of refrigerants have been analyzed and the volumetric flows' changes are given as based on evaporator temperature in Figure 4.

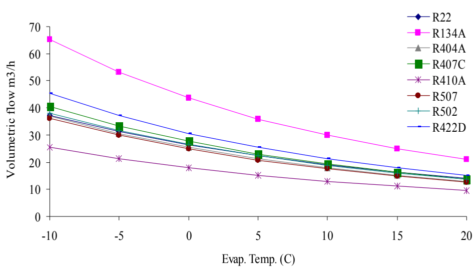


Figure 4 Volumetric flows of refrigerants

When the volumetric flows analyzed, it can be observed that the highest volumetric flow is refrigerant R134 with 65.23 m^3/h in -10 ºC and 21.06 m^3/h in 20 ºC and the lowest volumetric flow is refrigerant R410A with 25.53 m^3/h in -10 ºC and 9.49 m^3/h in 20 ºC. The changes of refrigerants in mass flows have been analyzed based on evaporator temperature and the results are given in Figure 5.

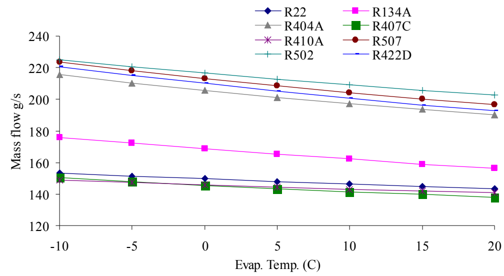


Figure 5 Mass flows of refrigerants

According to the results, it can be observed that R407C gas as based on the evaporator temperature -10 ºC and 20 ºC has the smallest mass flows with 150.3 g/s and 137.97 g/s, R410A with 148.9 g/s and141.04 g/s and the highest mass flow is Refrigerant R502 with 225.12 g/s and 202.59 g/s respectively. Refrigerants' compressor powers, which are needed for 25 kW cooling capacity, have been analyzed based on changes of evaporator temperature and the results of energy consumption distribution of compressor are given in Figure 6.

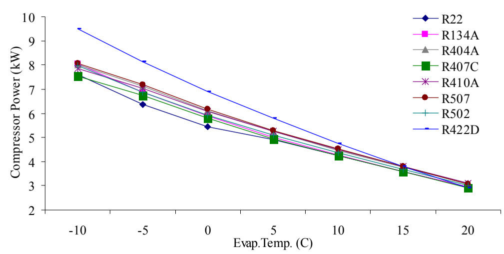


Figure 6 Compressor powers of refrigerants

When their compressor power have been examined according to temperature distributions, if meeting need in the lowest temperatures, is taken into consideration for R22 with 7.59 kW, for R134A with 8.04 kW, for R404A and R407C with 7.54 kW, for R410A with 7.85 kW, for R507 with 8,08 kW and for R502 with 7.97 kW compressor power is needed. According to this data, Refrigerant R407C has less consumption in compressor power compared to other refrigerants. COP and exergy efficiencies of each refrigerant are examined separately for evaporator temperature between -10 ºC and 20 ºC and the results of analyses are given below. Accordingly refrigerant R22's COP and exergy efficiency dependant on evaporator temperatures are given in Figure 7.

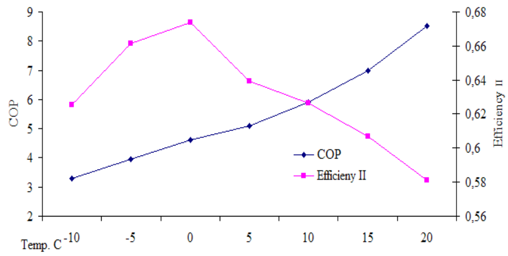


Figure 7 COP and exergy efficiency of R22 gas

For evaporator temperature between -10 and 20 ºC, the exergy efficiency of R22 has been found as average 63.07%. It can be observed that exergy efficiency declines 14% although COP increases 46% between 0 and 20 ºC for R22. For evaporator temperature between-10 ºC and 0 ºC, increase of exergy efficiency has been determined parallel with increase in COP. COP and exergy efficiency of R502, which is the gas used primarily applications, have been calculated based on evaporator temperatures and the results are given in Figure 8.

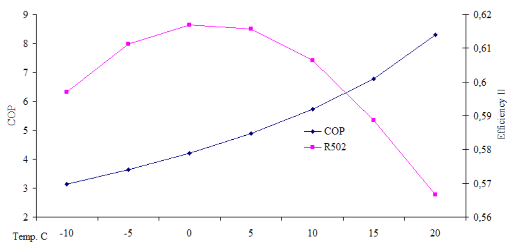


Figure 8 COP and exergy efficiency of R502 gas

The average exergy efficiency of R502 between 10 ºC and 20 ºC has been found 60.03%. This value is 60.94% particularly for between -10 ºC and 10 ºC. R502 gas is harmful gas in terms of environmental and is limited due to high GWP potential. How the COP and exergy efficiency of refrigerant R134A, which is one of the most commonly used, changes according to evaporator temperature is given Figure 9.

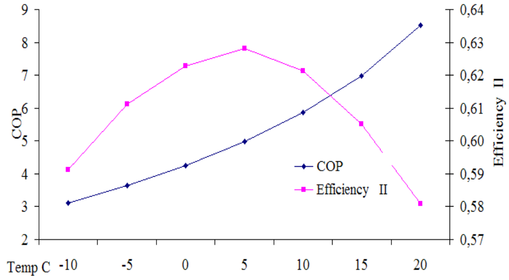


Figure 9 COP and exergy efficiency of R134A gas

Exergy efficiency of R134A for -10 ºC has been found 59.13%, for 20 ºC it is 58.09% with the average being 60.86%. The exergy change dependant on temperatures for R134A has increased by 7% from 10 ºC to 5 ºC and declines after 5 ºC. R134a gas has the highest average COP and exergy efficiency values among gasses used today. COP and exergy efficiency changes of R404A gas, which regularly encounter in commercial applications in Turkey markets, is examined depend on evaporator temperature and the results are given in Figure 10.

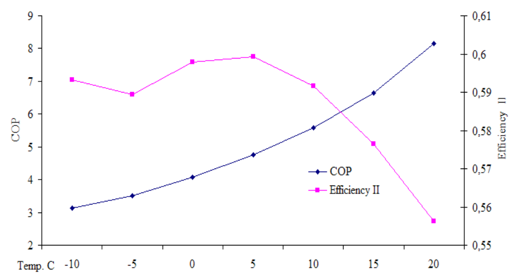


Figure 10 COP and exergy efficiency of R404A gas.

It can be observed that exergy efficiency of R404A has been found 59.4% efficiency between -10 ºC and 10 ºC, and declines significantly between 10 ºC and 20 ºC. It has been determined that the exergy efficiency of R404A has been found average with 58.6%. How COP and exergy efficiency of R507, which is used in the application of commercial refrigeration, change according to temperature, has been analyzed and the results are given in Figure 11.

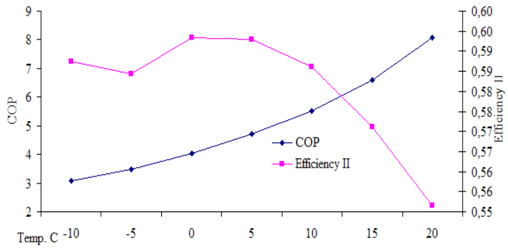


Figure 11 COP and exergy efficiency of R507 gas

It can be observed that the exergy efficiency at 58.95%. There is a sharp decline in exergy efficiency after 5 ºC.For display cases, R407C, R410A and R422D are accepted alternative refrigerant and energy exergy analyses of these gasses are made separately. The temperature based changes of COP and exergy efficiency for R407C, which has recently seen in applications, are given in Figure 12.

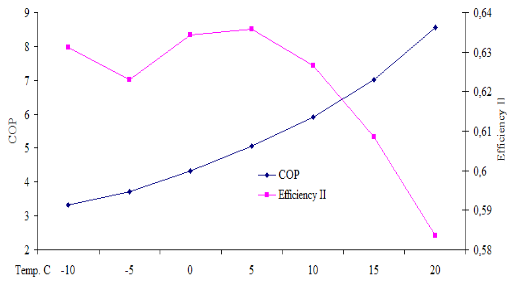


Figure 12 COP and exergy efficiency of R407C gas

The distribution of exergy efficiency for R407C between -10 ºC and 20 ºC is similar to that of R407A. However, average exergy efficiency of R407C according to temperature parameters is 6% more than R404A. Average exergy efficiency of R407C has been found 62.04%. Besides the refrigerants used in the commercial sector, COP and exergy efficiency of R410A have also been analyzed and the changes of COP and exergy efficiency based on temperature are given in Figure 13.

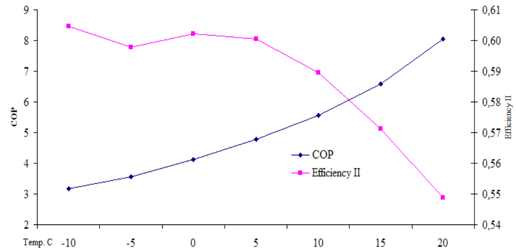


Figure 13 COP and exergy efficiency of R410A gas

COP and exergy efficiency of R410A have also been analyzed and changes of COP and exergy efficiency based on temperature are given in Figure 13. The average exergy efficiency for R410 A between -10 ºC and 20 ºC is 58.8%. It has been observed that changes in the exergy efficiency between -10 ºC and 5 ºC are smaller than the others. COP and exergy efficiency of R422D, which is proposed alternative gas especially including R22 from manufactures, have been calculated based on evaporator temperatures and the results are given in Figure 14.

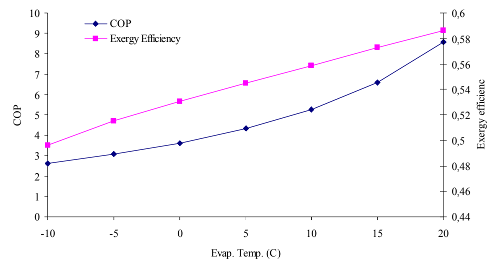


Figure 14 COP and exergy efficiency of R422D gas

COP and exergy efficiency of R410A have also been analyzed and changes of COP and exergy efficiency based on temperature are given in Figure 13. The average exergy efficiency for R410 A between -10 ºC and 20 ºC is 58.8%. It has been observed that changes in the exergy efficiency between -10 ºC and 5 ºC are smaller than the others. The exergy efficiency and compressor power of refrigerants have been analyzed and results are given in Figure 15

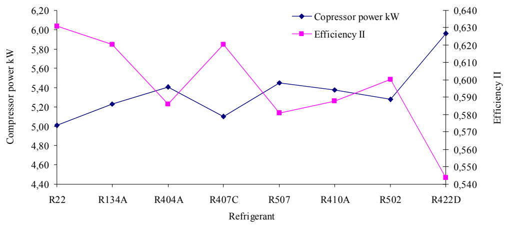


Figure 15 The exergy efficiency and compressor powers of refrigerants

The compressor powers have been evaluated according to refrigerants; R407C consumes energy 5.103 kW in average exergy efficiency 62% and one of the alternative refrigerants R422D 5.961 kW in average exergy efficiency 54.36%.

5. CONCLUSION

In this study, energy and exergy analyses of display cases used in market applications are made under constant load and considering different refrigerants. The results obtained from the study are given below:

a. R134a gas is the best gas that can be preferred among refrigerants with average COP and exergy efficiency 5.33 and 60.86% in the units.
b. Among alternative gasses, R407C gasses will be preferable as the best gas all of the gasses with average COP and exergy efficiency 5.33 and 60.86%.
c. It is seen that average COP and exergy efficiency of R422D gas proposed by manufacturers is the worst of all the gasses. Besides environmental parameters and power requirement of the gas are higher than the others in these applications.

Therefore, in order to evaluate the performance of these systems accurately and to produce correct analyses for energy consumption, considering exergy analyses of these type cooling systems will be useful in preferring refrigerants and in the design and optimization of systems.

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