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ANALYSIS OF R744 REFRIGERATION SYSTEM WITH LIQUID EJECTORS

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ABSTRACT

In recent years, there is a rapid increase in the cooling demand. Hence, not only the consumption of energy, but also the quantity of the refrigerants released into the air is increasing globally leading to planetary heating. Carbon dioxide (CO_2, R744) is a natural refrigerant which is emerging as a potential replacement for HFCs and HCs nowadays because of its attractive properties. However, to avoid liquid entry into the compressor, conventional systems are designed and optimized to keep the exit part of the evaporator dry ensuring no liquid exits the evaporator. This requires superheating of the fluid which also contributes to internal irreversibility leading to lower COP. Hence, the liquid ejectors appeared as the potential option to improve the system COP, by facilitating complete use of the evaporator by avoiding superheating and securing a safe return of liquid refrigerant. This paper presents experimental results of a transcritical R744 system using a liquid ejector. Main aim of the present study is to use a liquid ejector to eliminate superheating of an evaporator and to made a comparison between its ON/OFF switching operation on the overall performance at high ambient temperature conditions (46°C) and its performance. It is observed that the increment in evaporator pressure and decrement in compressor power consumption are 4.5% and 5.5% respectively. Also, from the reduced superheat, it is evident that the proposed design can address the problem of uneven use of heat transfer area in the evaporator due to nonlinear refrigerant distribution and contribute to energy saving.

Keywords: Natural refrigerant; Trans-critical cycle; Liquid ejector; Evaporator; R744

1. INTRODUCTION

In order to improve the overall performance of the existing systems employed for various HVAC applications, it is necessity to optimize the system components to improve the performance of the system. The evaporator is an important component of the cooling system. It performs insufficiently when the available heat transfer area is mostly utilized to superheat the refrigerant. During the continuous normal operating conditions, conventional thermostatic expansion valves installed in the system maintain the quantity of the refrigerant supplied to the evaporator. They are designed and optimized to maintain a constant superheat to ensure that no liquid passes through the evaporator. This reduces the available heat transfer area in the evaporator leading to high terminal temperature difference and energy loss. It is revealed that in order to improve the overall performance of the refrigeration system especially applying R744, the superheat value of the evaporator should be reduced or controlled in effect to reduce the energy loss (Minetto and

Fornasieri, 2011). Processes of reducing the superheat at the exit of the evaporator is also known as hunting problem, defined by ASHRAE (Ashrae, 2009). Two possible reasons reported in the literature for the hunting problem are; designed evaporator characteristics and nature of the mixed-vapor transition related to the thermophysical properties of the refrigerant & heat transfer area of the evaporator (Broersen, 1982).

Methods proposed and reported in the literature for flooding the evaporators, i.e. eliminating the superheat, includes control strategies development to minimize the superheat of the evaporator (typically for R744 systems) (Fallahsohi et al., 2010). Advanced sensor with intelligent technology and innovative design (like thin-film resistance sensors) was also proposed for measuring the liquid mass fraction in superheated refrigerant to reduce the superheating in the evaporator (Shannon et al., 2001). Furthermore, another innovative approach in the field of sensor was also attempted, such as; using optical control sensor. It was installed in R744 supermarket facility to flood the evaporator in order to reduce the superheat of evaporator (Minetto and Fornasieri, 2011). Practicality of the evaporator overfeeding was later experimentally validated and reported by re-using the refrigerant from low pressure liquid receiver in ejector loop (Minetto et al., 2014). R744 based vapor compression systems are popular due to higher or comparable performance to synthetic refrigerants (HCFCs, HFCs and unsaturated HFCs) in colder climatic conditions (Hafner et al., 2014; Singh and Dasgupta, 2017).

Objective of the study is to focus on energy saving by reducing the superheat at evaporator with overfeeding it using liquid ejector in R744 system. System performance is evaluated with flooding the evaporator during switching ON/OFF operation of the liquid ejector. Proposed liquid ejector for flooding the MT evaporator is experimentally studied in order to identify system stability at high ambient temperature for supermarket application and its overall effect on the performance.

2. SYSTEM DESCRIPTION

A distinctly instrumental supermarket facility (Figure 1) of 33 kW cooling capacity working with R744 refrigerant is designed to maintain three different temperatures such as freezing (-29°C), refrigeration (-6°C) and air conditioning (7-10°C). Supermarket test facility is equipped with a heat recovery system to maintain a constant heat load demand. Propylene glycol/water solution is used as a heat transfer medium. Two glycol loop circuits are arranged with different glycol concentrations; 42% for MT, AC load and 56% for LT load.

Evaporator with shell-tube design and gascooler with tube-fin design are installed in the supermarket facility. Three compressors are installed to compromise LT and MT compressors and AUX compressor is arranged to handle high amounts of flash gas which also enables parallel compression operation. Two ejectors are installed, one with low ejection ratio (LERE) and another with high ejection ratio (HERE). One liquid suction accumulator is also installed in order to provide an excess mass of refrigerant to overfeed the evaporators. Temperature sensors, pressure sensors and energy meters are installed at various locations to evaluate the performance of the system and examine the various parametric variations. Test-rig also facilitating seven different modes of operation and it is so designed in order to evaluate various possible configurations for supermarket application at high ambient temperature (up to 46°C).

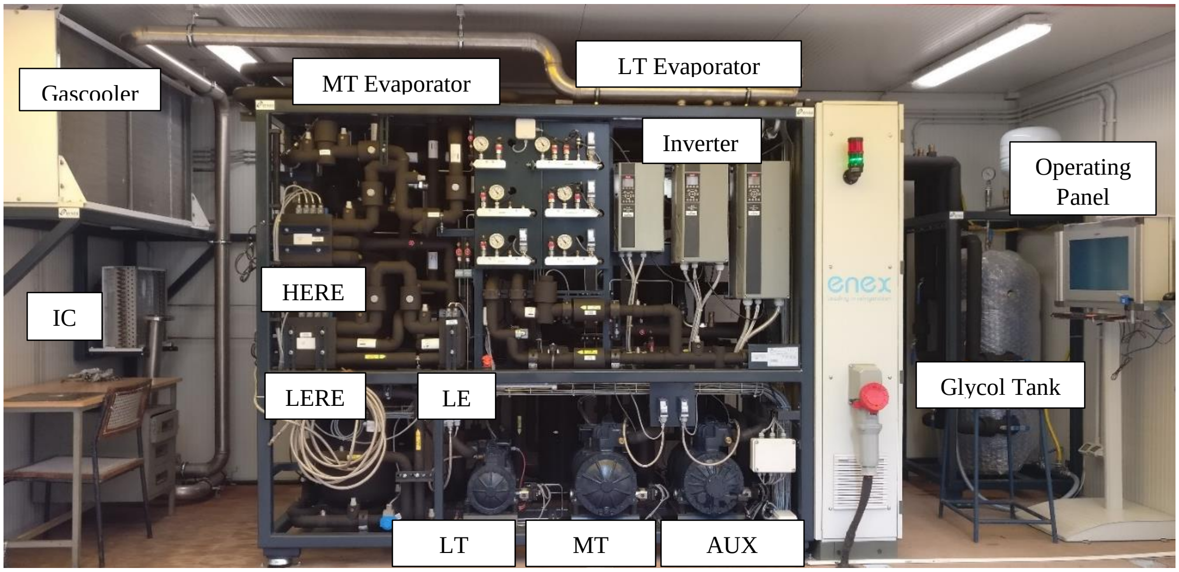

Figure 1. R744 cooling system.

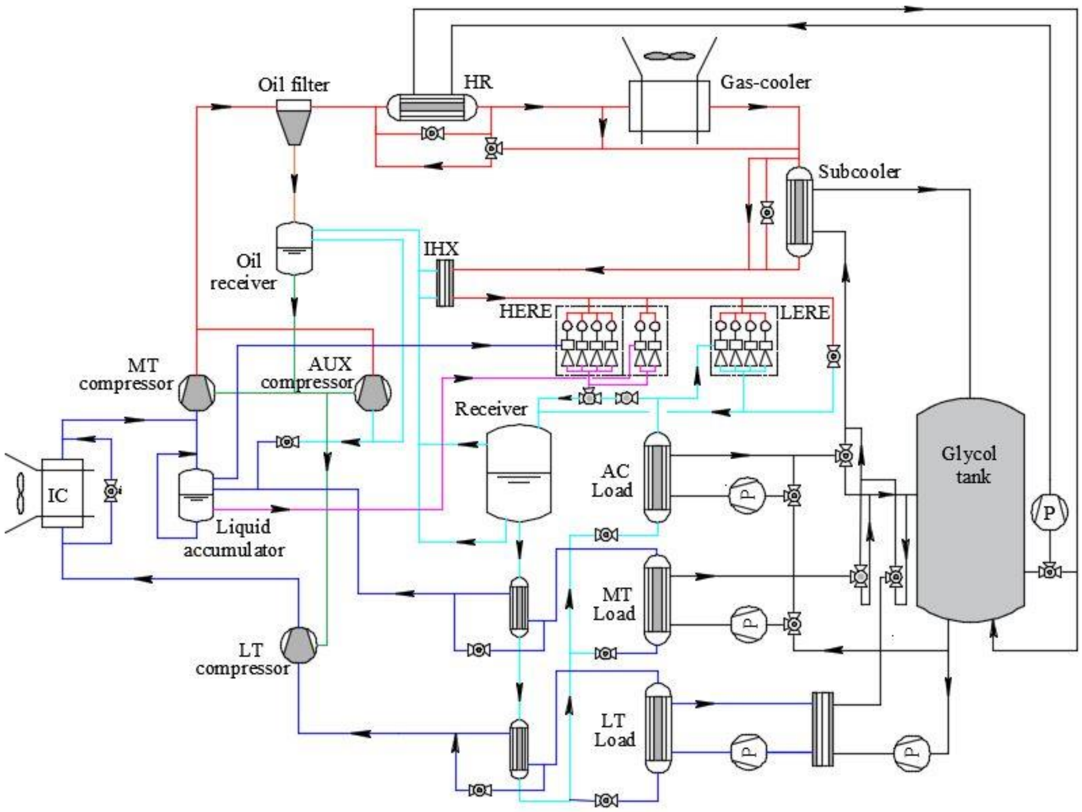

Figure 2. Schematic of the R744 system.

Figure (2) shows the detailed schematic of the R744 supermarket facility projecting various components equipped in the system. For the present study, simple ejector configuration with single MT load and MT compressor is involved in order to evaluate the stability of the system with flooded evaporator using liquid ejector.

Thermostatic expansion valves are so designed and optimized to generate superheated at the exit of the evaporators, which therefore forces the evaporator to use its heat transfer area inefficiently. Liquid ejector operation can be pursued manually during the operation. Flooding the MT evaporator with liquid ejector installed in the system provides the opportunity to use of heat transfer area of evaporator effectively and also results in reduced superheat. Test facility is equipped with a suction accumulator which is used to feed the evaporator with the help of liquid ejector. Low-level and high-level indicator signals for the suction accumulator are arranged to identify the safe level of the refrigerant.

3. FLOODED EVAPORATOR EVALUATION

For the present analysis, the CO_2 supermarket system's stability with flooding evaporator is evaluated for single MT load at high ambient conditions (46°C). The various operating, design and performance related parameters used to compute the performance of the supermarket system in liquid ejector operation are tabulated in Table (1). The data acquisition (DAQ) system equipped with the facility is capable of retrieving the variation of each parameter after every 5 seconds. Averaged values of various parameters are used for computation.

Table 1. Parameters and operation conditions used during performance evaluation.

Operating parameters		**Unit**	**Value**
Gas-cooler outlet temperature		^oC	46
MT evaporator temperature		^oC	-6
Receiver pressure		bar	46
MT Evaporator details			
Design			Shell and Tube
Tube material			Copper
Shell material			Steel
	(L/A/F/B)	mm	3120/2820/2000/150
Quotes	($D/D_p/P$)	mm	60.3/76.6/11
	(H/C/E/G)	mm	65/60/40/60
Heat transfer medium details			
Propylene glycol		%	42
Density		kg dm^{-3}	1.039
Viscosity		$mm^2\ s^{-1}$	7.03
Specific heat		kJ $kg^{-1}K^{-1}$	3.507
Thermal conductivity		W $m^{-1}K^{-1}$	0.355

System is observed during both switching liquid ejector ON/OFF operation after achieving the steady state (~30 minutes). Variations in various parameters are logged continually in the system. Evaporator temperature, evaporator pressure, superheat at MT evaporator and power consumption by MT compressor in both ON/OFF liquid ejector operation is observed.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Figure (3) compares the temporal variations in the observed pressure and temperature in the MT evaporator when the system was operated with and without the liquid ejector operation. It is observed that as the evaporator gets overfed, the evaporator pressure starts increasing and corresponding to which the evaporator temperature also starts increasing. This is ascribed to the fact that as the mass flow rate of refrigerant in the MT evaporator increases, it further improves the wetness in the evaporator surface and allows the refrigerant to use the maximum heat transfer area effectively.

Also, the increasing MT evaporator temperature projects the overall improvement in refrigeration capacity of the system with higher evaporation temperature. It is also observed that the percentage increment in evaporator pressure is 4.5% during flooding conditions of MT evaporator.

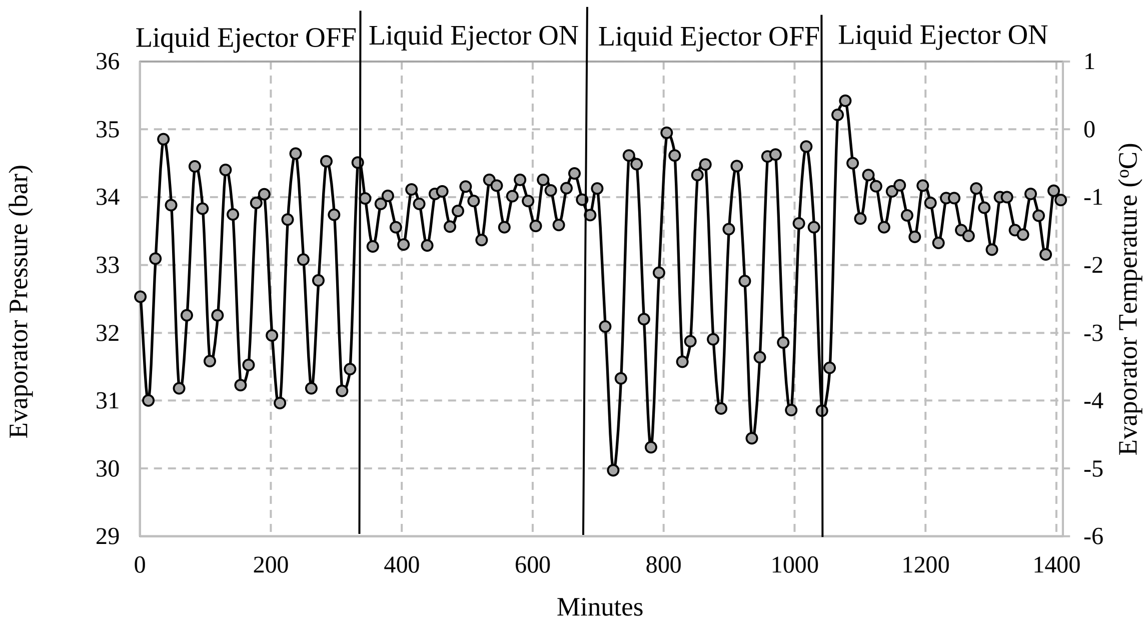

Figure 3. Variation of MT evaporator pressure and temperature with respect to time.

Figure (4) shows the variation of superheat at MT evaporator observed during both with and without liquid ejector operation with respect to time. During overflooding the MT evaporator with respect to liquid ejector, there is no evident of superheat at the evaporator exit. The improved stability in system operation is also observed from the same. However, the reason behind the minimum value of 1K superheat observed is also reported by Huelle, Z.R., (1967), that the superheating cannot be reduce below a minimum value without instability problems in the system.

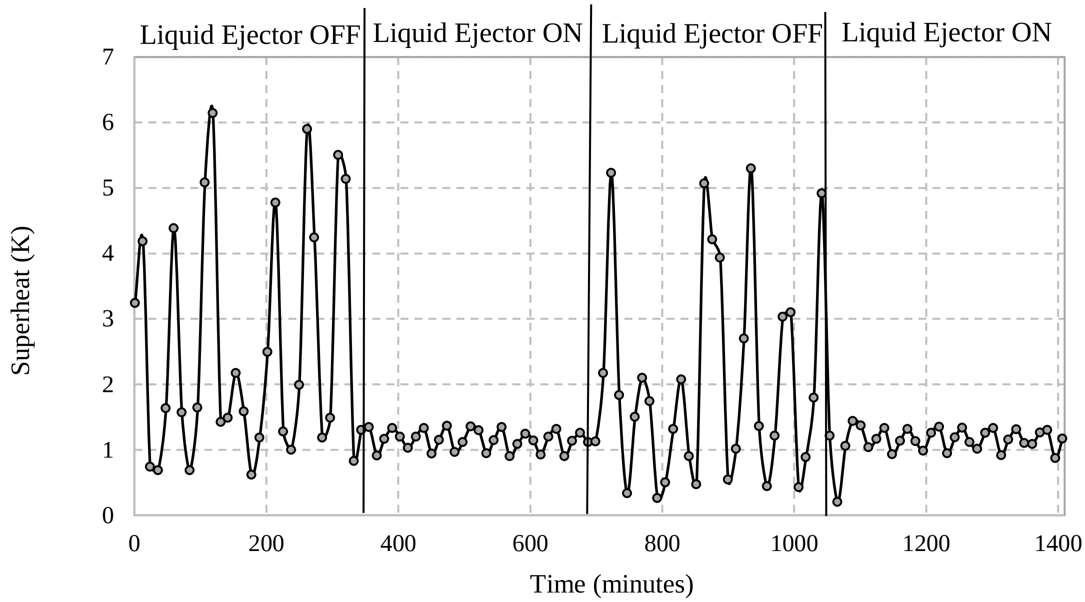

Figure 4. Variation of superheat at MT evaporator with respect to time.

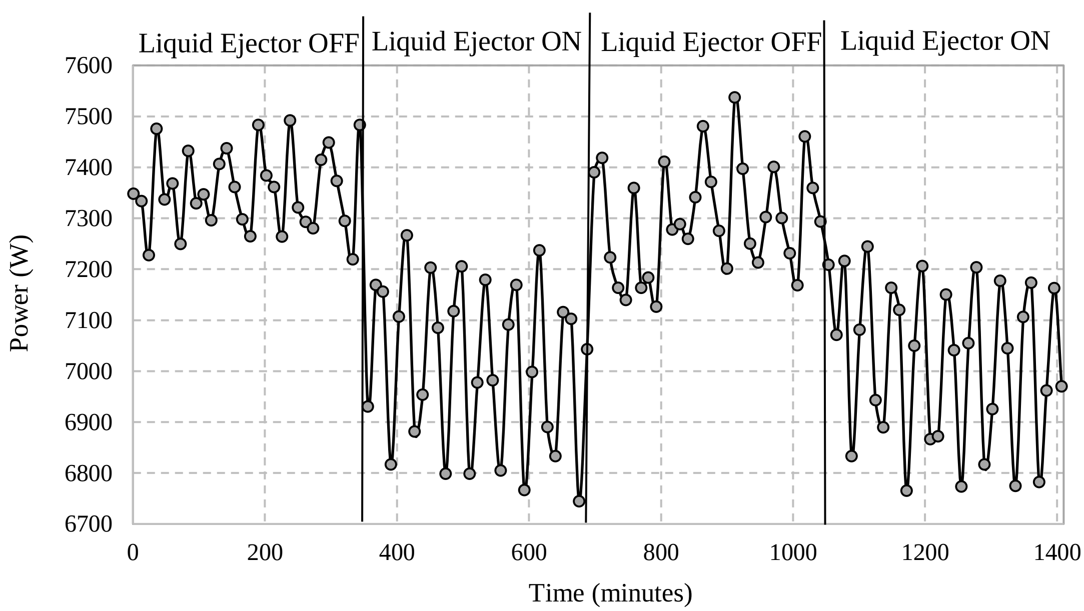

Figure 5. Variation in MT compressor power consumption with respect to time.

Figure (5) shows the MT compressor power consumption variation observed during both with and without liquid ejector operation with respect to time. The compressor power consumption is projected during both switching ON/OFF operation and also the reduction in the consumption during both operations. It is observed that the percentage reduction in compressor power during flooded conditions is 5.5%. The reason ascribed for the same is due to increase in pressure of MT evaporator and which further results in reduced compression ratio of the system.

5. CONCLUSIONS

An experimental evaluation is carried out in order to compute the performance of the flooded evaporator and its stability using the liquid ejector for R744 supermarket system at high temperature climatic context (46^{o}C).

The system is observed in both ON/OFF operation of liquid ejector and the following conclusions are drawn.

- Proposed solution offers improvement in CO_2 cooling system stability and reduction in power consumption for supermarket application and promotes the use of liquid ejector at high ambient context.
- Superheat at the evaporator exit reduced due to increase in the use of available heat transfer area of the MT evaporator by increase in total wetting surface area. The observed percentage increment in evaporator pressure is 4.5% during flooding conditions.
- Minimum 1K superheat can be maintained during flooding conditions of MT evaporator at high ambient context.
- The percentage reduction in compressor power during flooded operation is 5.5% as compare to the normal system operation.
- From the present experimental evaluation, it is evident that, under partial load conditions the liquid ejector is a promising option to reduce the heat energy losses of the system.

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Acronyms

AC	Air conditioning	*HVAC*	Heating, ventilation and Air- conditioning
AUX	Auxiliary		
COP	Coefficient of Performance	*IC*	Inter-cooler
CO_2, R744	Carbon dioxide	*LT*	Low temperature
HCs	Hydrocarbons	*LE*	Liquid ejector
HER	High ejection ratio	*LER*	Low ejection ratio
HFCs	Hydrofluorocarbons	*MT*	Medium temperature

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