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Utilization Of Ethane As Working Fluid At Two-Stage Cascade Vapour Compression System

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ABSTRACT: For supporting future demands of lower temperature, environmental friendly low-temperature refrigerants must be studied and developed to replace halocarbon. Ethane, which is one of hydrocarbon compound, is an environmental friendly refrigerant because it has zero ODP and GWP ~20[per 100yr]. On this study, two-stage cascade refrigeration system was utilized to investigate performance of ethane on the low-stage. By employing R22 at higher stages, energetic performance as well as operating condition of R22/R170 system is compared to R22/R23. At low stage evaporation pressure ranges from 1.10 to 2.74 bar, R22/R170 shows higher COP over R22/R23. Furthermore, at the same range evaporation temperature R22/R170 can reach lower temperature.

Ethane, Cascade refrigeration, R23, Energetic performance

Nomenclature

COP	:	Coefficient of Performance
Cp	:	Specific heat [kJ/kg.°C]
GWP	:	Global Warming Pot. [/100 yr]
h	:	Enthalpy [kJ/kg]
HS	:	High Stage Cycle
LS	:	Low Cycle
$\dot{m}$	:	Mass flowrate [kg/s]
ODP	:	Ozone Depletion Potential
P	:	Pressure [bar]
Q	:	Heat rate[W]
T	:	Temperature [°C]
W	:	Compressor Power [W]

Subscript

c	:	Condenser
e	:	Evaporating
cr	:	Critical
in	:	Inlet flow
out	:	Outlet flow
r	:	Ratio
tot	:	Total
w	:	Water
1	:	HS Compressor inlet
2	:	HS Compressor outlet
3	:	HS Condenser inlet
4	:	HS Condenser outlet
5	:	HS Exp. valve inlet
6	:	HS Evaporator inlet
7	:	HS Evaporator outlet
8	:	LS Compressor inlet
9	:	LS Compressor outlet
10	:	LS Condenser inlet
11	:	LS Condenser outlet
12	:	LS Exp. valve inlet
13	:	LS Evaporator inlet
14	:	LS Evaporator outlet
15	:	Cooling chamber
16	:	Water in
17	:	Water out

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Table 1 Property of Refrigerants (ASHRAE, 1997)

Parameters	CFC13	R503	HFC116	HFC23	HC170
Normal Boiling Point	-81.3	-87.5	-78.2	-82	-88.9
Critical temperature (Tcr)	28.9	184	19.9	25.9	32.2
Critical Pressure (Pcr)	38.8	42.7	30.4	48.4	48.7
ODP	1.000	0.599	0.000	0.000	0.000
GWP	14000	13000	11900	12000	~20

1. INTRODUCTION

Our recently, within few decades, we realized that humanity significantly influences the global environment, in the early 1800s, atmospheric measurement confirm basic concept developed a decade earlier. This basic concept showed that human activities were affecting the ozone layer (Wuebbles, 1999). This threat is followed by international concern, several agreement have been issued to reduce environmental impact which causes ozone depleting

The 1987 Montreal Protocol (UNEP, 2000) is widely seen as a global environmental accord that has produced tangible results in terms of reductions in ozone-depleting substances. For over 50 years, CFCs were thought of as miracle substances, they are stable, non-flammable, low toxicity, and inexpensive to produce. Since the Montreal Protocol is in place, the production and consumption of CFCs, of halons as well as other ozone depleting chemicals have been almost completely phased out in industrialized countries.

There are only small numbers of refrigerants available for lower temperature application ranging from −70 °C to −100 °C. Some of these refrigerants are shown by Table 1. R13 and R503 are among of refrigerants for lower temperature that have been capped due to its contribution to ozone depletion. R23, R116 and its derivatives substances such as R508A and R508B are once considered as best replacement of CFC refrigerants at lower temperature, since these hydro-fluorocarbons (HFCs) refrigerants are chlorine free and ozone safe. Yet, due to a long chemical lifetime, they cause a considerable contribution to the greenhouse effect, because it contains fluorine that contributes GWP to the refrigerant.

Therefore, even the HFCs once viewed as the long-term replacement for CFCs, the application is now under question. Although the production and use of hydro-fluorocarbons (HFC) refrigerants are not regulated by Montral Protocol, yet it is regulated by Kyoto Protocol. Several countries do not consider HFCs as the final solution because concerns about global warming have intensified (Domanski, 1998), some of them have already issued regulation relating with this refrigerant. Denmark has announced a ban of R23 from the beginning of 2006 (DEPA, 2002), and there are reports that Austria and Switzerland may follow suit (BUWAL, 2002). Therefore, because of several ban of this refrigerant, new alternatives refrigerant must be studied and developed.

Natural refrigerants are the best retrofit to meet the future demand of long term environmental friendly refrigerants (Lorentzen, 1995). It is non ozone depleting and green house effect substances. Therefore, research of alternatives refrigerant should be directed to natural refrigerant.

Hydrocarbon refrigerant could become retrofit of the non-environmentally friendly refrigerant. It has zero ODP, since there is no presence of the chlorine, and low GWP, because it is not contain Fluorine that is contribute GWP to the refrigerant.

Alsaad (1998), Hammad (1999) and Wongwises *et al.* (2005) have studied about carbon mixtures of propane−butane−isobutene in the domestic refrigerators, the refrigerator work satisfactory with this refrigerant mixture without need for any modification or adjustment. Halimic *et al.* (2003) shows that R290 (propane) gives best performance compare to R410A and R134A. In addition, R134a pressure drops characteristics has been studied by Lim and Han (2003)

Because of its operating temperature range, in the hydrocarbon group only ethane and ethylene can be applied in the low−pressure stage of cascade refrigerating. At ambient pressure, saturated ethane can reach temperature down to −88.9 °C. Critical temperature of ethane is 32.2 °C at 48.7 MPa (see Table 1), this thermophysical properties is very suitable for low temperature application as future drop−in of HFC as well as CFC refrigerants.

This study is aimed to investigate performance of ethane on the low stage of 2−stage cascade refrigerating system under the various evaporating pressure at the lower stage cycle.

R22 will be employed on the high stage to cool down the low stage cascade condenser. Similar study will be conducted to the R22/R23. Therefore, by the end of this study, the relationship among evaporating temperature of low stage to the characteristics of the cycle (COP, work of compressor, mass−flow rate. etc) of R22/R170, and compare to those of R22/R23 can be described.

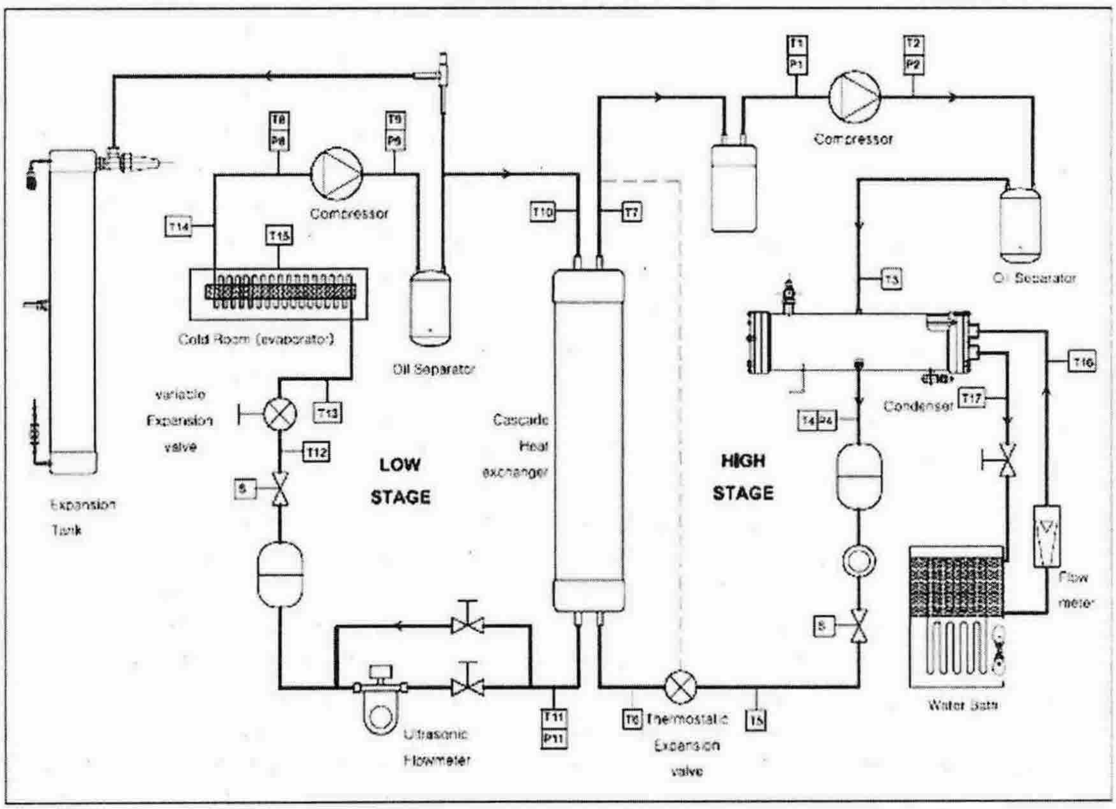

Fig 1. Temperature measurement location of cascade refrigeration system

2. TEST SETUP

The experimental set up consists of two refrigeration circuits. Copper pipe with 9.5 mm of outer diameter is utilized for connecting each apparatus in the refrigerant circuit. Low stage and high stage refrigerant is pumped to the main cycle by utilizing hermetic compressors. High stage cycle refrigerant from compressor outlet is cooled down by water bath system in the shell and tube condenser. The inlet water temperature is maintained at 19−20 °C, while the water mass flow rate is ranging from 0.25−0.275 kg/s. Meanwhile, the lower stage circuit refrigerant is cooled down by evaporating refrigerant of high stage cycle in the cascade heat exchanger. Having condensed, refrigerants are expanded by the thermostatic and variable expansion valve in the high and lower stage respectively. Variable expansion valve ranges from 1.10 to 2.74 bar.

Low stage evaporator is located in a cold chamber. This cold chamber is 1000x180x180 mm^3 copper container covered by adiabatic material.

Figure 1 shows experiment set up. Temperature of refrigerant circuit was measured by 17 thermocouples attached in the specific location shown by Figure 1. T−type thermocouples are employed since this thermocouple is relatively steady for low temperature application −200℃ to −300℃and more suitable for oxidation atmosphere environment. Uncertainty of this thermocouple is 0.5 °C or special tolerance is 0.4%. These thermocouples are attached on the copper tube surface. Meanwhile, RTD type thermocouples are installed at high−stage condenser inlet and outlet. Six pressure transducers are installed in the compressor inlet & outlet and condenser outlet of high stage and low stage. This data input was recorded using data logger every 10 second. To measure flowrate a rotameter and Oval Coreolis effect flow meter are mounted at water bath system and low stage circuit respectively.

3. THEORETICAL CALCULATION

Low stage refrigerant gains heat from evaporator, this evaporation heat changes liquid−vapor refrigerant condenser inlet to superheat refrigerant at condenser outlet before it enters compressor.

Amount of the heat transferred to low stage evaporator is:

$$Q_e = \dot{m}_{ls}(h_{14} - h_{13})$$

This super heat refrigerant subsequently compressed to higher pressure of compression outlet. The compression work for lower and higher stages is:

$$W = \dot{m}\ (h_{out} - h_{in})$$

Super heat refrigerant at higher stages compressor will be condensed by the water condensing system, condensation heat absorbed by water is:

$$Q_c = \dot{m}_w C_p (T_{16} - T_{15})$$

This heat is assumed equal to the heat rejected by condensing high stages refrigerant. Therefore, the mass flowrate of high stage refrigerant is:

$$\dot{m}_{ls} = \frac{Q_c}{(h_4 - h_3)}$$

Finally, performance of cascade system is:

$$COP = \frac{Q_e}{W_{ls} + W_{hs}}$$

4. RESULT AND DISCUSSION

The experiment was conducted for different evaporation pressure at low stage ranging from 1.10 to 2.74 bar. High stage system is condensed by 20 °C inlet-water from water cooling system; meanwhile the evaporation temperature ranges from −21.5 to −30 °C. At this condition, high stage cycle operated at pressure ratio 4.6 to 6. High stage pressure ratio decreases as low stage evaporating pressure increases, in contrast evaporating temperature increases.

Figure 2 shows that at the same evaporation pressure, high stage cycle of R22/R23 gives higher mass flow rate between 1.10 to 1.9 bar. Meanwhile, quadratic regression of low stage mass flow rate shows that R22/R170 system has lower mass flow rate. Compression ratio (Figure 3) of R23 is higher for every evaporation pressure. Pressure ratio decreases as evaporating pressure increase.

Figure 4 shows that both evaporation temperatures are intersecting at 2 bar, from this pressure downward temperature of R170 starts lower than R23 temperature. From figure 4, it can be seen that more low pressure of ethane, evaporation temperature is more lower compare than R23. This is one of thermophysical benefit of ethane (R170) over CFC, HCFC and even HFC refrigerants. We can verify this from thermophysical properties of refrigerants at Table 1. At 1 bar, ethane can obtain -88.9 °C

By using refrigerant data properties of simulation software, thermodynamic properties of refrigerant were obtained. In the operational range low stage compression work of R22/R23 system is much higher than R22/R23. Yet, the higher stages show opposite circumstances with R22/R170 has higher compression work (figure 5).

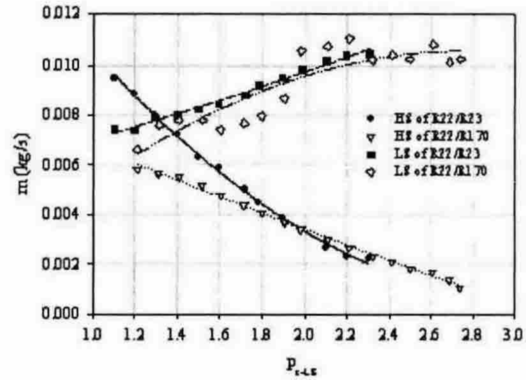

Fig.2 flowrate versus LS evaporating pressure

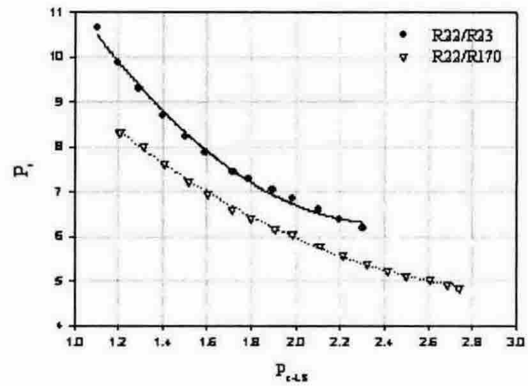

Fig.3 LS pressure ratio versus LS evaporating pressure

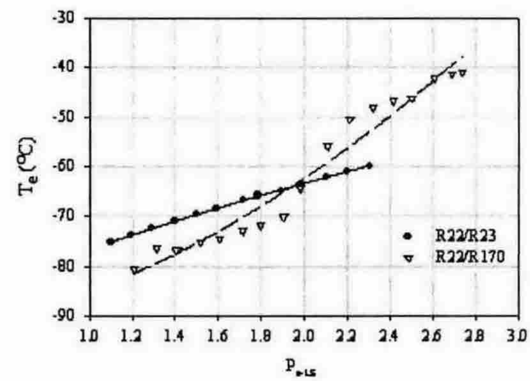

Fig.4 LS evaporating temperature versus LS evaporating pressure

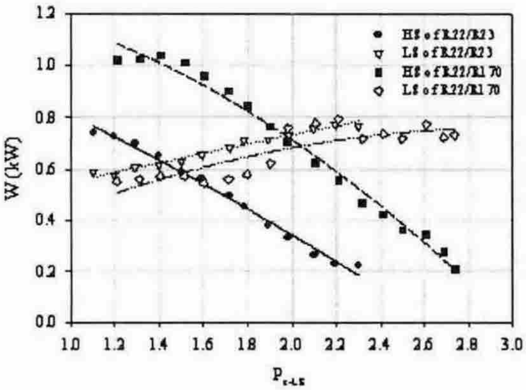

Fig.5 compressors work versus LS evaporating pressure

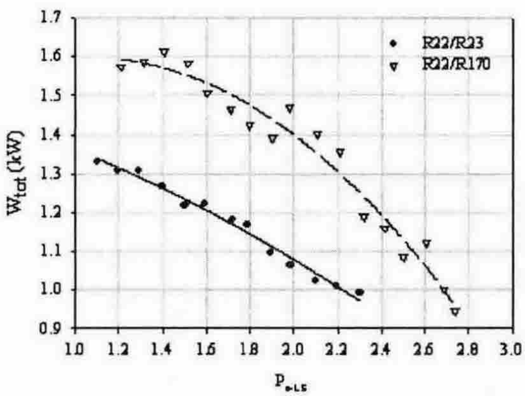

Fig.6 compressors work versus LS evaporating pressure

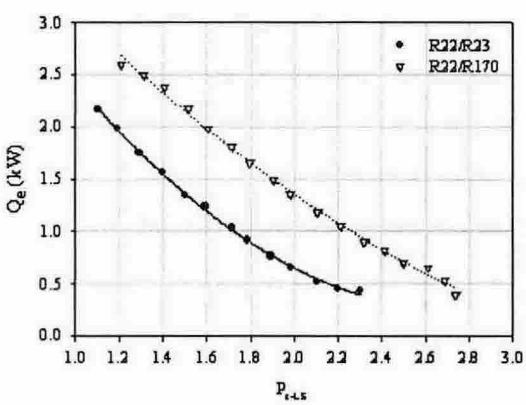

Fig.7 Refrigeration capacity versus LS evaporating pressure

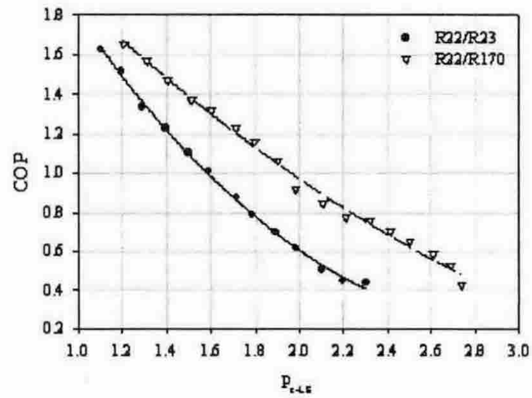

Fig. 8 COP versus LS evaporating pressure

Overall compression work of R22/R170 system is 0.14−0.46 higher than R22/R23 systems (figure 6). This is due to higher heat rejected by the ethane to higher cycle of R22. it can be verified from Figure 7 that refrigeration capacity of R22/R170 system is 0.58−0.84W greater than those of R22/R23. This is because R170 has higher latent heat compare to R23. Therefore, R170 could absorbed more heat compare to R23 at same mass flowrate and evaporating temperature.

finally, Figure 8 shows that at low stage evaporation pressure between 1.10 to 2.74 bars, performance coefficient of R22/170 is always higher in the every evaporating pressure compare than R22/R23.

5. CONCLUSION

In the future, the environmental issue is become most important consideration for selecting refrigerant. Most of halocarbon refrigerant we know today will be capped; consequently environmental friendly refrigerants must be studied to replace it. In this work, ethane as natural refrigerant is compared to the HFC23 refrigerant. The main experimental results are as following:

1. When the performance of ethane in R22/R170 system is studied and

compared to the R23/R170 gives better performance over R23 in every evaporation pressure.

2. Evaporating heat and COP of R22/R170 were represented higher 0.58−0.84 W and 0.14−0.46 respectively compare to R22/R23 system
3. Under the evaporating pressure of 2.0 bars, R22/R170 cascade refrigerating system showed lower temperature down to −10 °C
4. Ethane is expected to be retrofit for lower temperature circuit to replace halocarbon refrigerants.

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