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Fractionating Condenser for Binary Fluid Ejector Refrigerating System.

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Abstract: *Binary Fluid application for Ejector Refrigerating System allows improving the efficiency by 1.5-2.5 times comparing to a Single Fluid one. This is achieved by decreasing the shock losses in the ejector by 30-60% and increasing a ratio of specific cooling capacity to a specific heat input in the vapour generator by 1.2-4.5 times. Binary mixture separation into single fluid components is to be achieved within 1-2% of purity. Fractionating condensation with a directed combination of heat- and mass- exchange processes can perform such separation. The selection of pairs of the components is carried out as a result of fluids PTX diagram analysis, taking into account normal boiling temperatures, concentrations and ejector's outlet mixture parameters. The methods of binary mixture components selection as well as approaches for concentration control were developed.*

Keywords: ejector, binary fluid, fractionating condensation, efficiency

1. INTRODUCTION

The interest to low grade heat driven air-conditioning and refrigerating technologies increases from year to year. The main requirement for these systems is reliable cooling generation at the outstanding energy efficiency. Commercially available absorption refrigerating systems does not meet this requirement at high ambient air temperatures. This is related to absorption process's limitation that leads to system stagnation. The proposed Binary Fluid Ejector Refrigeration System (BERS) demonstrates the performance on a level or even higher than absorption systems, while it is cost-efficient, durable and involve less moving parts. The key elements of BERS are: Fractionating Condenser, Ejector and Feed Pump. But if the last two components were developed and successfully tested earlier [1], the fractionating condenser is yet to be studied along with the selected binary fluid components. This study addresses P-T-X diagram analysis taking into account normal temperatures difference and initial mixture composition after ejector.

2. BINARY FLUID SELECTION FOR BERS FOR AIR-CONDITIONING MODE

The schematic diagram and thermodynamic cycle of the BERS is presented on Figure 1.

Initial researches on binary fluid selection criteria were based on critical sonic velocities difference, including molar mass and other properties. Shock loss in ejector depends on squared velocities difference of working and refrigerant flows as shown in Eq. 1:

$$\delta E = \frac{U}{2(1+U)}\left(w_{wf} - w_{rf}\right)^2 \qquad (1)$$

Since ratio of λ functions of the flows depends on operating conditions, the velocity difference can be minimized by selection of fluid pair with opposite properties of the fluid components (Eq. 2,3).

$$\lambda_{wf} = \sqrt{\frac{k_{wf}+1}{k_{wf}-1}}\sqrt{1-\Pi_{wf}^{\frac{k_{wf}-1}{k_{wf}}}} \qquad (2)$$

$$\lambda_{rf} = \sqrt{\frac{k_{rf}+1}{k_{rf}-1}}\sqrt{1-\Pi_{rf}^{\frac{k_{rf}-1}{k_{rf}}}} \qquad (3)$$

where $\Pi_{wf} = p_{sc}/p_{gen}$, $\Pi_{rf} = p_{sc}/p_{eva}$.

Working fluid should have lower critical sonic velocity, refrigerant fluid – higher sonic velocity. This relation of velocities means that molar mass ratio is also arranged in the inversed manner as stated in Eq.4:

$$a_{crit} = \sqrt{kT\frac{8314}{\mu}} \qquad (4)$$

Considering that fluids in BERS represent quite similar compounds, so Trouton's number differs insignificantly, Eq. 5:

$$\Theta = \mu r_s / T_s \qquad (5)$$

From Eq. 5 it can be derived that ratio of fluid components' latent heat of evaporation in BERS is greater than 1 [2,3,4]. Another study [3] offers coefficient of compressibility *Z* as an additional factor for fluid components selection. Table 1 represents several properties of studied binary fluids that basically represent requirements for its components. Additionally, normal boiling temperatures difference and shape of PTX diagram has a great impact on components' separation during condensation. Figure 2a and 2b represents sample of TX diagram.

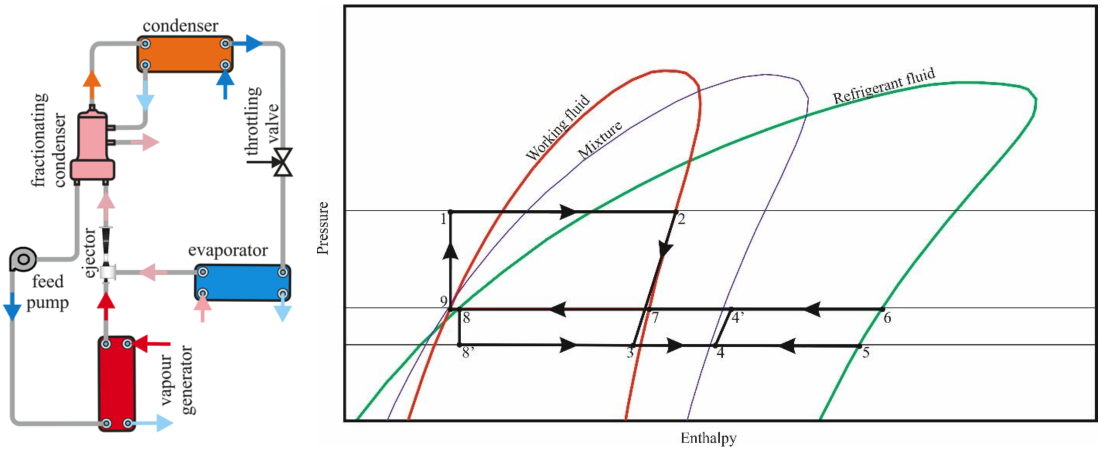
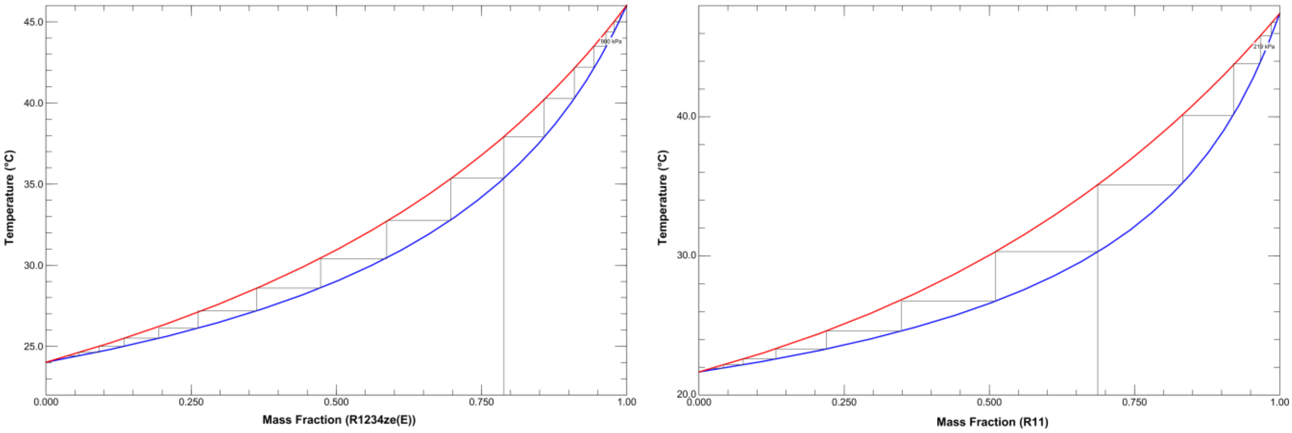


Fig. 1 Schematic diagram and thermodynamic cycle of the BERS. 1-2 – working fluid heating and evaporation in the vapour generator, 2-3 – working vapour expansion in the nozzle, 3-4 and 5-4 – working flow and refrigerant flow mixing, 4-4’ – mixture compression in the cylindrical mixing chamber, 7-8 working fluid condensation in the fractionating condenser, 6-9 refrigerant fluid condensation, 8-8’ – refrigerant fluid throttling, 8-5 – refrigerant fluid evaporation, 9-1 – working fluid pumping into the vapour generator.



a b

Fig. 2 T-X diagram for a) R1234ze/R161 – 24 stages, b) R11/Butane – 12 stages

Table 1. Fluid properties.

Fluid/Mixture	Zwf/Zrf	awf/arf	Molar wf	Molar rf	Tcrit		Pcrit, Mpa	
R11	0.90	1.02	137.37		197.96		4.41	
Butane	0.83	0.94	58.12		151.98		3.80	
R1234ze	0.68	0.81	114.04		109.36		3.63	
R161	0.62	0.80	48.06		102.10		5.01	
R11/Butane	0.93	0.69	137.37	58.12	197.96	151.98	4.41	3.80
R1234ze(E)/R161	0.71	0.51	114.04	48.06	109.36	102.10	3.63	5.01
R365mfc/butane	0.93	0.64	148.07	58.12	186.85	151.98	3.27	3.80
R245fa/DME	0.88	0.56	134.05	46.07	154.01	127.23	3.65	5.34
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R1234ze/R161	0.71	0.51	114.04	48.06	109.36	102.10	3.63	5.01

Shape of the TX diagram showing low difference of normal boiling temperatures means that separation process is complex and requires more precise fractionation though the purity of components is not guaranteed. Those binary fluids can be still applicable in the BERS, since even at high concentrations of the other component in the vapour generator and evaporator COP is greater than of single fluid ERS. Table 2 represents COP of the ERS and BERS with premixes in evaporator, generator.

Alternatively, the binary fluid with significant normal boiling temperatures difference is separated easily, but lower condensation temperature can be equal to evaporation temperature Table 2 and such binary fluid can be only used when other cooling media is available.

The preferable binary fluid is a fluid with optimal normal boiling temperatures difference, when easy to perform separation, while finishing condensation temperature is significantly higher than evaporation temperature.

In addition, at fluid components selection, requirements of Kyoto and Montreal Protocols should be met along with fire safety, toxicity level etc.

Table 2. COP and condensation temperature of the single and binary fluid at t_{gen}=85°C, t_{cond}=35°C, t_{eva}=12°C

Fluid/Mixture	X_{gen}	X_{eva}	X_{cond}	$t_{cond,wf}$	$t_{cond,rf}$	U	COP
R11	-	-	-	-	-	0.48	0.4
Butane	-	-	-	-	-	0.48	0.36
R1234ze	-	-	-	-	-	0.45	0.36
R161	-	-	-	-	-	0.4	0.39
R11/Butane	1	0	0.68	47.45	21.65	0.47	0.86
R1234ze(E)/R161	1	0	0.77	43.55	21.65	0.29	0.59
R365mfc/Butane	0.9	0	0.58	37.25	18.25	0.53	0.58
R245fa/DME	0.8	0	0.54	35.25	19.18	0.46	0.73
R245fa/DME	0.85	0	0.58	36.70	17.44	0.46	0.76
R245fa/DME	0.85	0.1	0.60	35.63	17.29	0.47	0.74
R1234ze/R161	0.95	0	0.72	41.05	22.88	0.31	0.59

3. FRACTIONATING CONDENSER

Fractionating condenser is a unit that provides condensation with simultaneous separation of binary fluid into components [5,6].

The most efficient design of fractionating condenser is a column with a series of packing and heat exchange surface, which rejects condensation heat to environment. Fig. 3 represents schematic of the fractionating condenser. Raschig rings can be used as packing, twisted ribbons with inclined corrugation that creates channels for reflux flow, wire coils etc (Fig. 3.)

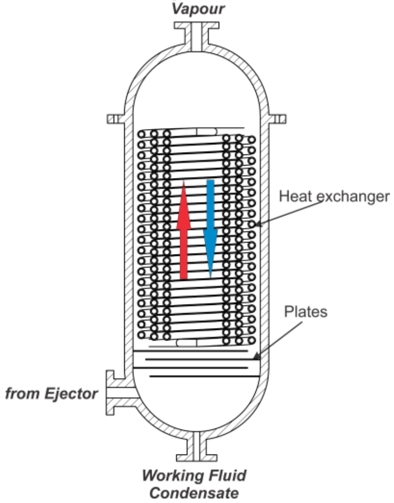

Fig. 3. Cross-section view of the BERS' fractionating condenser for separation of binary fluids components.

During BERS application, a significant angular inclination 30-40° of fractionating condenser is allowed. It makes possible to operate BERS on transport systems.

Calculation and design of heat exchange surface at various sections and temperature gradient in accordance with binary fluid PTX diagram define heat exchange area of each packing element and its composition on inlet/outlet of each section.

Application of water-cooled fractionating condensation in BERS will provide an additional to air-cooling hot water service as a byproduct with temperature of 50-55°C.

4. CONCLUSIONS

1. BERS application allows increasing the efficiency of low-grade heat operated air-conditioning by 1.5-2 times compared to single fluid ERS.
2. Various binary fluids can be selected for designed conditions that simultaneously meet safety and efficiency requirements. The search of new fluids will allow achieving better results in both energy efficiency and technological advantages.
3. BERS simultaneously produce cold and heat that increases their profitability.
4. The design of fractionating condenser is simple and can operate on fixed-site and transport systems.

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