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ABSTRACT

This paper presents the results of the analysis of an ejector refrigeration system operating with Freons as the working substance. Such a system is suitable for operating at subzero evaporator temperatures. The mass of motive refrigerant vapour per hour per ton and the coefficient of performance are calculated for various assumed operating parameters such as boiler temperature, evaporator temperature and condenser temperature with and without subcooling in the condenser. Using these results the performance data of the system is presented. It is found that use of higher boiling temperatures, lower condensing temperatures with some degree of subcooling and higher evaporator temperatures is beneficial. A criterion for comparing the performance with various working fluids is presented. Amongst R-11, R-12, R-21, R-22 and R-113 which are compared, R-21 is found to give best performance. A graphical method for selecting operating parameters for any of these refrigerants is suggested.

INTRODUCTION

Ejector refrigeration system with steam as the working medium is well known. However, it has the limitation of being inapplicable for refrigeration systems operating at below zero degree Celsius. Kalustian [1] examined the possibility of using Ammonia and reported it unsuitable due to higher pressure requirement in the system. Usage of Freons in ejector refrigeration system will have the advantage as it can provide refrigeration below 0°C and the need for vacuum in evaporator may be avoided. Besides, Freons have low boiling point and can be conveniently generated as motive fluid in the system utilising solar energy. Kumar and Charan [2] proposed such a system operated by solar energy and carried out the thermodynamic analysis of the cycle. They compared the coefficient of performance with Ammonia, Steam and Freon-11 as the working medium and reported Freon-11 as the best. A low value of mass of motive vapour (W) and high value of coefficient of performance (COP) is considered advantageous. Taking the case of R-11, Charan [3] showed that W and COP depend upon various operating parameters and recommended use of highest possible boiler temperature, a lower condenser temperature with some degree of subcooling and the system to operate better at higher evaporator temperature. In the present paper, the performance data of the system with various Freons such as R-11, R-12, R-21, R-22 and R-113 is presented and compared.

THE SYSTEM AND CYCLE ANALYSIS

The schematic layout of solar energy operated ejector refrigeration system is given in Figure (1). Hot water from the heat storage tank circulates directly through a heat exchanger placed in the refrigerant boiler. The vapourised refrigerant attains high velocity in the nozzle and entrains the vapour from the evaporator. The combined vapours are then compressed in the diffuser section and discharged into the condenser where they are condensed. A portion of this liquid refrigerant goes to the boiler and remaining in the evaporator to maintain the mass balance. The evaporator is placed in a water tank where it chills the water for refrigeration purpose say for airconditioning in the layout shown. For other applications the evaporator may be kept in a brine tank.

Figure (2) gives the temperature-entropy diagram of the thermodynamic cycle. The initial condition of the motive vapour at A is assumed to be dry and saturated for analysis purpose. The state of the motive vapour after accounting for the nozzle efficiency (e_{AB}), entrainment efficiency ($e_{B'I}$) is at I. This mixes with the flashed vapour at K coming from the evaporator to reach the state C. The mixture then gets compressed in the diffuser and after accounting for its

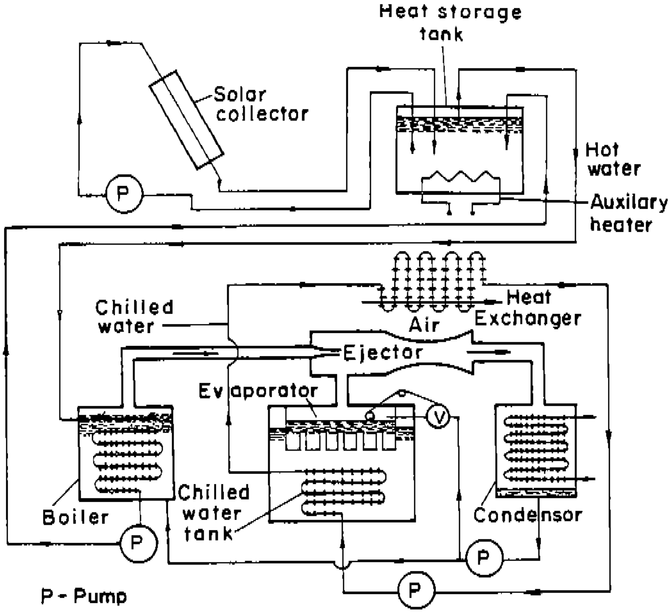

Fig.1 Schematic system layout

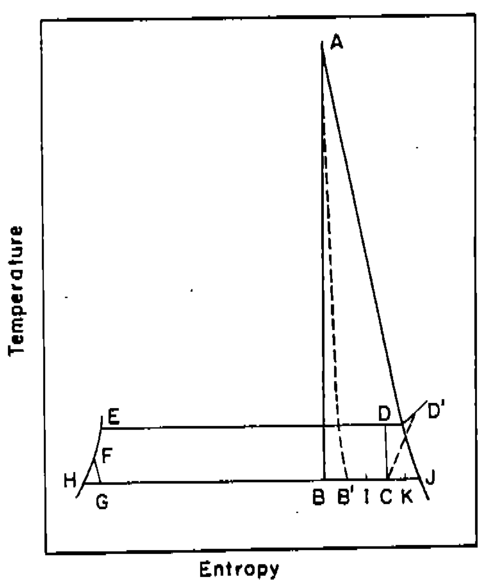

Fig. 2 Thermodynamic cycle

efficiency (e_{CD}) it emerges at D'. The state of the condensate reaching the boiler and the evaporator is at F. Employing usual method of analysis [4], the following relations are used to calculate W and COP.

Mass of motive vapour per unit mass of flashed vapour,

$$n = (h_D - h_C)/[(h_A - h_B)(e_{AB})(e_{B'I})(e_{CD}) - (h_D - h_C)] \tag{1}$$

Mass of motive vapour in kg per hour per ton,

$$W = (3.516 \times 3600)\ (n)/(h_K - h_F) \tag{2}$$

Coefficient of performance,

$$COP = (h_K - h_F)/(n)\ (h_A - h_F) \tag{3}$$

Where, h is the specific enthalpy of the refrigerant at various states represented by the subscripts.

PERFORMANCE PARAMETERS

The parameter taken for the cycle analysis are the boiler temperature, evaporator temperature and the condenser temperature. The boiler temperatures are chosen in the range available from solar collectors. The evaporator temperatures are considered in the range applicable to cold storage and airconditioning. The condenser temperature are assumed in the range available for water and air cooled condensers. All the values chosen for calculation are in steps of 5.5°C (10°F) as given below:

Boiler temperatures ,	°C(°F):82.2, 87.8, 93.3 (180, 190, 200)
Evaporator temperatures	°C(°F):-17.8,-12.2,-6.7,-1.1,4.4 (0,10,20,30,40)
Condenser temperatures	°C(°F): 43.3,37.8,32.2 (110,100,90)
Degree of subcooling in condenser	°C(°F): 0,2.8, 5.5 (0, 5, 10)

Calculations were made first for a selected condensing temperature and for various combinations of evaporator and boiler temperatures. These were repeated at other condensing temperatures for each value of degree of subcooling of the condensate. Thus a large data was generated to study the performance of the system for various operating parameters. However, for discussion only the typical results representing the trend at higher boiler temperature of 93.3°C and 2.8°C subcooling in the condenser is presented in Tables 1 and 2. For all these calculations the values of nozzle efficiency, entrainment efficiency and diffuser efficiency were taken as 95%, 90% and 82%, respectively as recommended in the literature [5]

Table 1 : Variation of COP with evaporator temperature

Boiler temperature = 93.3°C (200°F)
Degree of subcooling in condenser = 2.8°C (5°F)
Condenser temperature = 32.2°C (90°F)

Evaporator Temperatures °C(°F)	Coefficient of Performance (COP)					percent variation between highest & lowest COP
	R-11	R-12	R-21	R-22	R-113	
-17.8 (0)	.223	.168	.216	.165	.209	29
-12.2 (10)	.290	.277	.286	.232	.283	20
- 6.7 (20)	.378	.334	.386	.324	.386	16
- 1.1 (30)	.501	.375	.520	.439	.542	30
4.4 (40)	.744	.793	.717	.631	.771	18

Table 2 : Variation of W with evaporator temperature

Boiler temperature = 93.3°C (200°F)
Degree of subcooling in condenser = 2.8°C (5°F)

Evaporator temperature °C	Mass flow of motive vapour (W) kg/hr/ton				
	R-11	R-12	R-21	R-22	R-113
	Condenser temperature = 32.2°C (90°F)				
-17.8	261	510	233	485	315
-12.2	209	308	176	343	234
- 6.7	161	256	130	247	171
- 1.1	121	227	96	182	122
4.4	82	108	70	126	86
	Condenser temperature = 37.8°C (100°F)				
-17.8	428	987	384	1040	566
-12.2	348	663	279	656	399
- 6.7	260	447	200	404	274
- 1.1	187	311	150	269	193
- 4.4	122	226	110	204	133
	Condenser temperature = 43.3°C (110°F)				
-17.8	1073	4060	894	-	2454
-12.2	702	1727	557	-	1105
- 6.7	387	827	344	1574	628
- 1.1	279	569	247	558	387
4.4	201	382	177	368	257

DISCUSSION OF RESULTS

(i) Table 1 gives the values of COP at boiler temperature of 93.3°C for condensing temperature of 32.2°C with 2.8°C of subcooling in the condenser. An examination of this table shows that the values of COP range from 0.165 to 0.233 at evaporator temperature of -17.8°C and from 0.631 to 0.793 at evaporator temperature of 4.4°C. Thus the system operates better at higher evaportor temperature for all the refrigerants considered.

(ii) Again from Table 1, it is observed that at each evaporator temperature the difference between the highest and the lowest value of COP for the refrigerants under consideration is not substantial. In terms of the percent reduction the calcuated values range from 16 to 29 percent and its average variation is 22 percent.

(iii) In Figure (3), W versus condenser temperature for various evaporator temperatures has been plotted for R-21 at boiler temperature of 93.3°C and 2.8°C of subcooling in the condenser. It is seen that W reduces at lower condenser temperature.

(iv) In Figure (4), W versus evaporator temperature for various refrigerants are plotted. It is seen that at each evaporator temperature, W increases in the sequence commencing R-21, R-11, R-113, R-22 and R-12. The increase in W from R-21 to R-12 range from 120% to 100% from lower to higher evaporator temperatures, respectively.

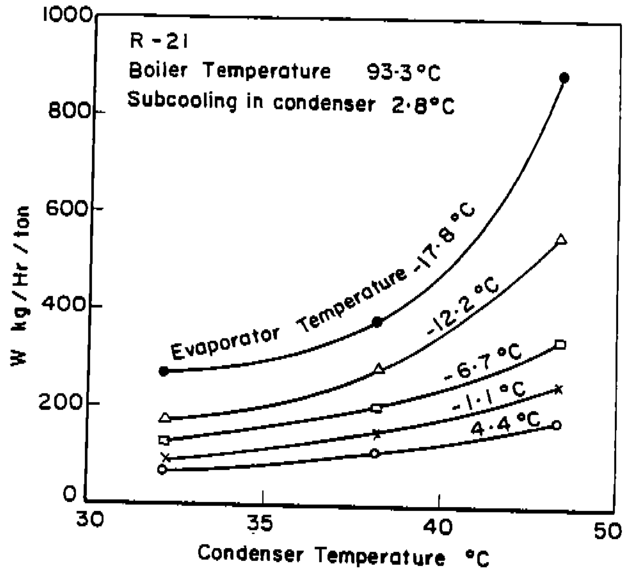

Fig. 3 Showing the effect of condenser temperature on mass of motive vapour

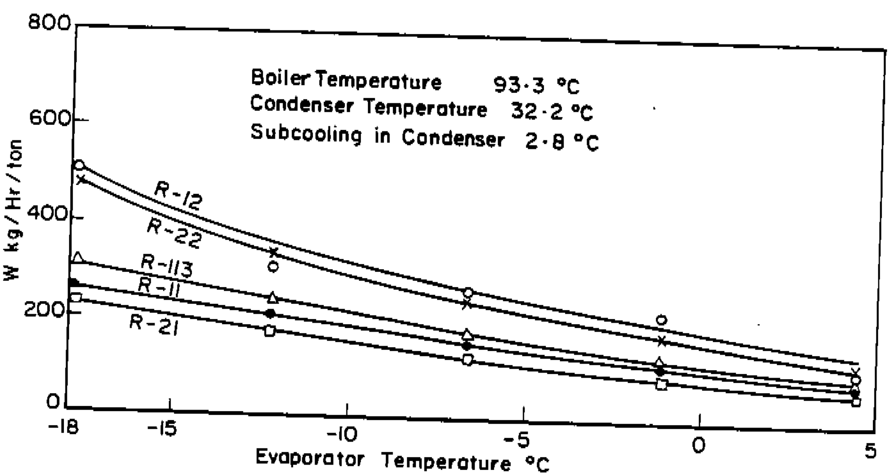

Fig. 4 Showing the effect of evaporator temperature on mass of motive vapour

(v) It is well known that for a compact system, higher values of COP and lower values of W are desirable. As explained in (ii) and (iv) above, the effect of change in the refrigerant is more on W than on COP. Therefore, values of W should be taken as the predominant parameters in selecting the working fluid.

(vi) In order to decide the operating conditions for the system, plots of W versus condenser temperature as shown in Figure (3) may be used. This is for maximum boiler temperature of 93.3°C and 2.8°C of subcooling and for R-21. With the help of this figure it is possible to : (a) determine W for chosen evaporator and condenser temeratures. The values of evaporator temperatures which are not on the curves may be interpolated, (b) determine the evaporator and condenser temperature combination for a fixed value of W. It may be noted that for Freons other than R-21, the data from Table 2 can be plotted similar to Figure (3) and used as suggested above.

CONCLUSION

A solar energy operated Freon ejector refrigeration system has been proposed Such a system operates best at highest possible boiler temperature, a lower condenser temperature with some degree of subcooling in the condenser and the system operating at higher evaporator temperature. The order in which Freons give best performance is R-21,R-11,R-113, R-22 and R-12. The data similar to that as shown in Figure (3) may be plotted and used to determine the operating parameters for designing the system for a chosen refrigerant.

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