PART - B.

CHAPTER - 1.

FREON TURBINES

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F R E O N T U R B I N E S*

1.1 ABSTRACT:

A Freon Turbine is a turbine having freon gas as its working medium. The chapter deals with the theory and applications of Freon turbine. The advantages and disadvantages of a Freon Turbine in comparison to a steam turbine have been explained in this chapter. The important advantages have been shown to be smaller size of turbine and condenser, lesser blade erosion and smaller rotative speed of turbine. The main disadvantage of these turbines is the high initial cost of freon and cost of make-up freon.

1.2 Introduction:

Freon compounds are well known refrigerants. Among them Freon 12 or Dichloro Difluro methane ($CCl_2\ F_2$) is the most widely used refrigerant. Other Freon compounds are also used in different fields of refrigeration.

The Critical properties of steam are T_c = 706.1°F, P_c = 3226.0 psia and V_c = 0.0503 cft/lb.

All Freon compounds have lower critical properties than steam, as shown in Table 5.1 of Part A of this thesis. These compounds are very suitable working media for super critical cycles. This idea was first given by Gokhshtein [30] in 1955. Thereafter an article was published in 1957 [38]

*A paper on this subject was published in 1965 and a reprint has been enclosed. [Appendix C] describing the possibility of using a Freon gas turbine for road vehicles.

The thermodynamic advantage of using a Freon Compound as the working substance in a turbine has been explained below.

1.3 <u>Theory of Freon Turbines</u>:

The temperature-entropy (T-s) diagrams of steam power cycle and freon power cycle will generally be as shown in Figs. 1.1 and 1.2.

The isothermal evaporation of steam from 5 to 6 in Fig.1.1 by receiving heat from AB, results in a large irreversibility thereby leading to loss of efficiency. This irreversibility can be reduced to a large extent by making the line of evaporation follow the line 7-1 of Fig.1.2.

Thus with same temperature difference between A and B, the heat exchange between the cooling flue gas and the evaporating Freon will be more efficient than the heat exchange between cooling flue gas and evaporating steam. The super-critical cycle of Fig.1.2 is, thus, more efficient thermodynamically than the sub-critical cycle of Fig.1.1. If, however, a supercritical cycle is to be chosen for the steam plant, the highest temperature of the gas will have to be about 1200°F and the steam pressure will have to be about 15000 psi. In fact, supercritical steam plants are now being used in U.S.A. and some other countries. For a Freon 12 supercritical cycle, the corresponding values can be as low as 300°F and 1000 psi.

T-S DIAGRAM FOR A TYPICAL STEAM CYCLE

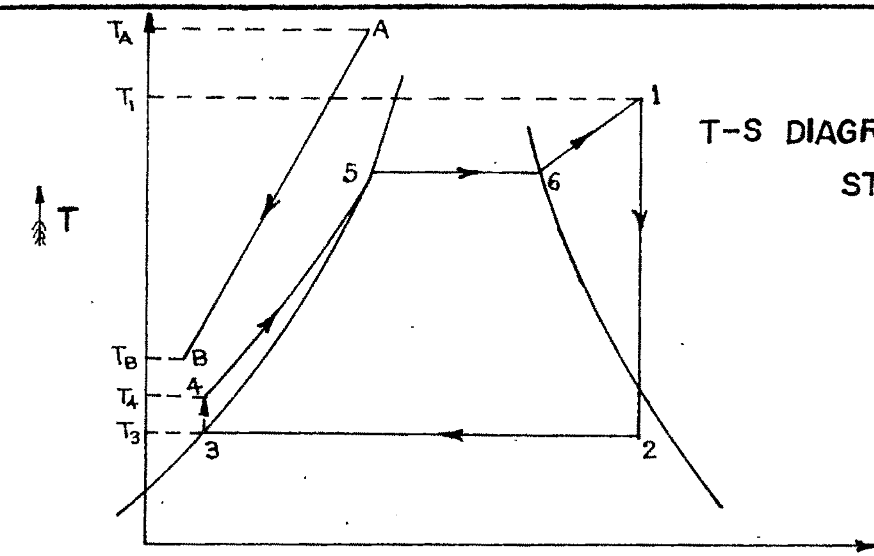

FIG. 1.1

T-S DIAGRAM FOR A TYPICAL FREON CYCLE

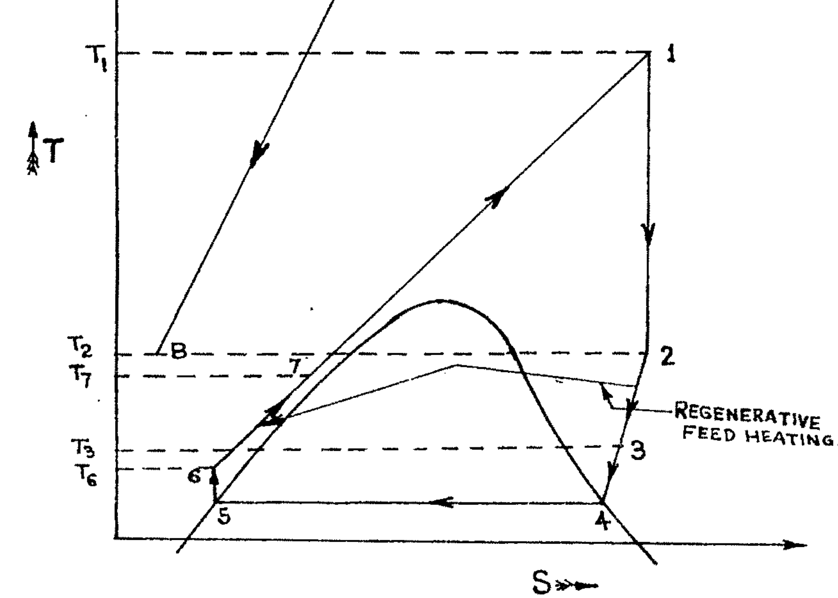

FIG. 1.2

Another disadvantage of a supercritical steam plant in nuclear power stations, is that, steam has to be flame heated to attain the maximum temperature of 1200°F. The realisation of steam cycles at super-critical initial pressures without the use of a flame super heater becomes convenient if the working fluid has a low boiling temperature. It should, however, be noted that lesser temperature difference between the heating fluid and the heated fluid will require a larger heat transfer area for the same amount of heat to be transferred. The greater is the heat transfer area, the greater is the initial cost of the plant. Hence an optimum temperature difference between the heating fluid and the heated fluid will have to be maintained.

1.4 Comparison of performances of a Steam Turbine and Two Freon Turbines.

For comparing the performances of Freon and Steam turbines, a low temperature steam plant, like an atomic power plant, has to be considered. A typical example is shown below:

Steam Cycle:

In Fig.1.1 : Let $T_A = 610^{\circ}F$, $T_B = 110^{\circ}F$, $T_1 = 590^{\circ}F$,

$$T_2 = T_3 = 90^{\circ}F$$

(To suit cooling water temperature)

$$p_5 = p_6 = p_1 = 498 \text{ psi}$$

Other assumptions are:

(a) No reheating of steam

(b) Adiabatic efficiency of turbine taken as 80% as part of the expansion takes place in the wet region.

(c) Pump efficiency has been taken as 80%.

Though the future trend in atomic power stations is likely to be the use of saturated steam cycles with moisture separators [31], we shall limit our discussion to the superheated cycle as shown in Fig.1.1. The thermal efficiency of a saturated cycle steam plant will be 39% as against 30.3% for a superheated cycle steam plant (Ref.App.1). But a saturated cycle steam plant has many well known disadvantages.

Freon 12 Cycle:

The Freon cycle will be as shown in Fig.1.3 for same temperature range as the steam cycle.

The saturation pressure of liquid Freon 12 at 90°F is 114.5 psia. Hence Freon 12 vapour in the turbine can be expanded upto this pressure.

The assumptions for this cycle are:

(a) Efficiency of Freon turbine is taken as 90% as the expansion takes place only in superheated region.

(b) Regeneration efficiency has been taken as 75%.

(c) Pump efficiency has been taken as 80%.

(d) The temperature difference at either end of the heat exchanger has been kept at 20°F.

Freon 11 Cycle:

This will be as shown in Fig.1.4, for same temperature range:

The saturation pressure of liquid Freon 11 at 90°F is 19.7 psia. Hence Freon 11 vapour in the turbine can be expanded upto this pressure.

T-S DIAGRAM FOR FREON 12 CYCLE

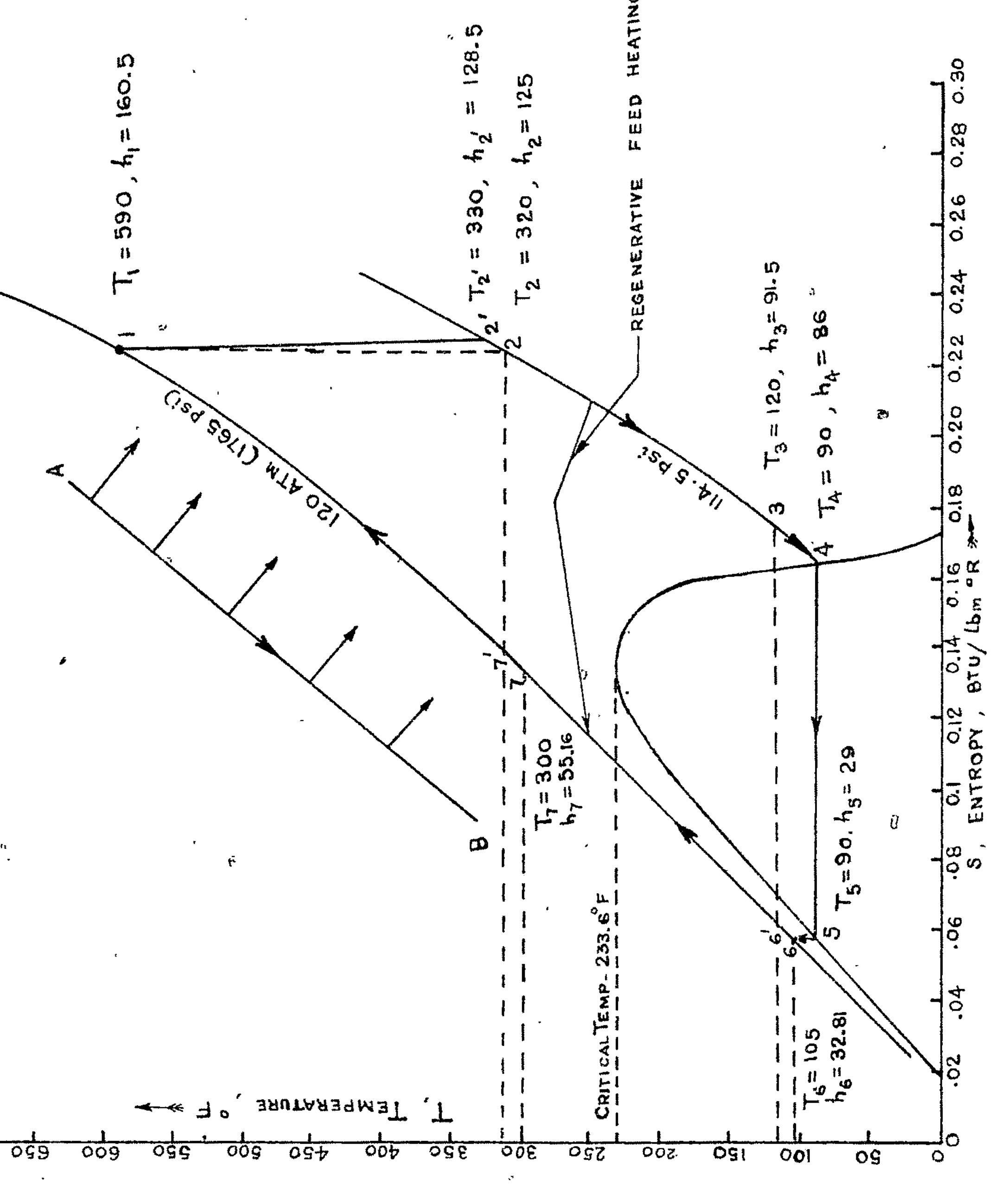

FIG.I.3

The performances of all the above three types of turbines have been summarised in Table 1.1. The calculations have been given in an abridged form in Appendix No.1. Detailed calculations have been shown in the author's M.Tech.thesis (Ref.No 32)

TABLE 1.1

Summary of Performances.

Properties	Steam cycle	F 12 Cycle	F 11 Cycle
Initial pressure, psia.	498	1765	1765
Final pressure, psia.	0.7	114.5	19.7
Initial vapour temperature in tubbine, ^{o}F	590	590	590
Final vapour temperature in turbine, ^{o}F	90	330	155
Vapour temperature in condenser, ^{o}F	90	90	90
Output per lb. of working fluid Btu/lb	374	31.95	38.7
Cycle efficiency, per cent	30.3	27.5	27.4
Volumes of different parts for equal output:			
(a) H.P. end of turbine (cft)	1.15	0.527	0.27
(b) L.P. end of turbine (eft)	407	6.82	22.45
(c) Condenser (cft)	407	4.15	20.20
(d) Liquid pipe line (cft)	0.016	[illegible] 0.146	0.006

1.5 Explanation of the results:

1. Although the cycle efficiency of a Freon turbine is about 3% less than that of a steam turbine, the overall efficiency of the electric power station operated by Freon turbine is likely to be more, due to better heat exchange efficiency in the Freon boiler. Gokhshtein [30] has shown that in going from a steam cycle to a Freon cycle at the Calder Hall atomic power station there would be a saving of 9.76% in heat consumption, i.e. with the same uranium consumption there would be an increase of 9.76% in the electric power generated.

2. Blade erosion in a Freon turbine is expected to be much less in comparison to that in a steam turbine, as Freon vapour expansion will take place only in the super-heated region. Moisture losses and supersaturation losses will not be present in a Freon turbine.

3. The size of the turbine will be much smaller. The H.P. end of a Freon 12 turbine will be less than half and the L.P. end about 1/60th of the size of a steam turbine for same output. The H.P. end of a Freon 11 turbine will be less than 1/4th and the L.P. end about 1/18th of the size of a steam turbine for the same output.

4. The condenser size will also be much smaller. A freon 12 condenser will be about 1/100th and a Freon 11 condenser will be about 1/20th of the size of a steam condenser.

5. Normally a modern steam plant would require two to three stages of reheating and four to five bleeding points for feed

water heating, necessitating complicated layouts. In case of a Freon turbine, these complications will not arise, except for the regenerative feed heating arrangement at the end of expansion, which will be much simpler than the regenerative feed heating of the steam plant.

6. Number of stages of a Freon turbine will be less than that of a steam turbine due to smaller enthalpy drop. Another advantage of the smaller enthalpy drop is that a Freon turbine can be directly coupled to an electric generator, whereas a steam turbine invariably requires an intermediate gear box to drive a generator.

A schematic diagram of a Freon power plant is given in Fig. 1.5.

The disadvantages of using a Freon turbine are, however, as follows:

(i) High initial cost of liquid Freon and make up Freon.

(ii) Higher strength required for Freon boiler, as the pressure is higher than that of superheated steam. In the above example, the pressure of Freon vapour is 1765 psia as against 498 psia for steam.

(iii) Slightly higher cost of liquid pipe lines.

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T-S DIAGRAM FOR FREON 11 CYCLE

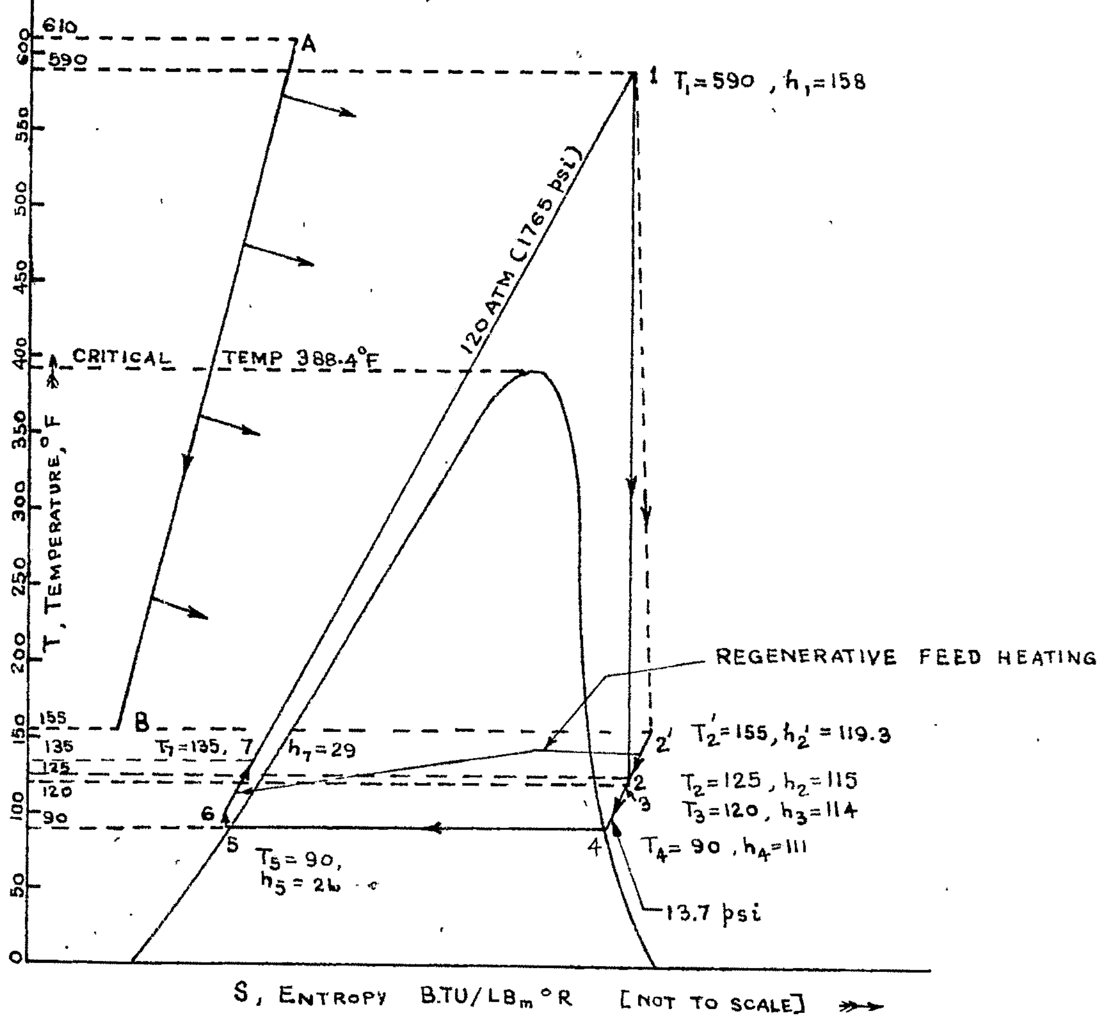

FIG. 1.4

SCHEMATIC DIAGRAM OF A FREON POWER PLANT

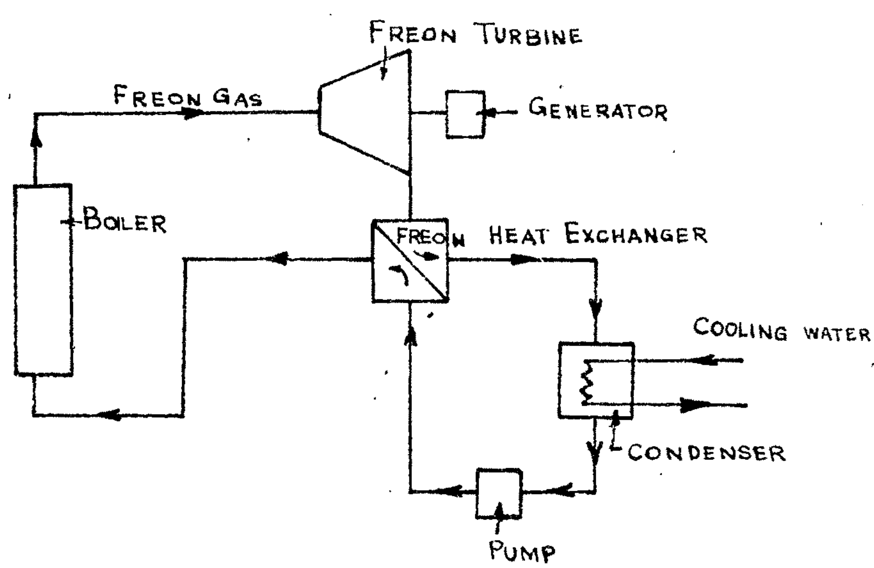

FIG. 1.5

Appendix No. 1

Abridged Calculations relating to Freon Turbines.

The points given below correspond to those indicated in Figs. 1.1, 1.2, 1.3 and 1.4 of Chapter 1, Part B.

A. Efficiency Calculations:

(a) For a saturated steam cycle between 590°F (310°C) and 110°F (32°C)

p_1 = 100.64 ata, h_1 = 651.4 Kcal/Kg,

p_2 = 0.0485 ata, h_2 = 408.0 Kcal/Kg.

p_3 = 0.0485 ata, h_3 = 32.02 Kcal/Kg.

p_4 = 100.64 ata h_4 = 34.38 Kcal/Kg.

s_1 = 1.3431 Kcal/Kg.°K

s_2 = 1.3431 Kcal/Kg.°K

s_3 = 0.1108 Kcal/Kg.°K

s_4 = 0.1108 Kcal/Kg.°K

Pump Work = 2.36 Kcal/Kg.

$$\text{Ideal efficiency} = \frac{651.4 - 408 - 2.36}{651.4 - 32.02 - 2.36} = 39\%$$

(b) For Superheated Steam Cycle (Fig.1.1)

Assuming 80% pump efficiency, pump work = 1.03 Kcal/Kg.

Turbine output = 0.8(716.7 - 472) = 208 Kcal/Kg.

Net Output = 208 - 1.03 ≃ 207 Kcal/Kg.

Heat supplied = 716.7 - 32.03 - 1.03 = 683.6 Kcal/Kg

$$\text{Efficiency} = \frac{207}{683.6} = 30.3\%$$

(c) For Freon 12 Supercritical Cycle (Fig 1.3)

The property values have been taken from ASRE Data book and Freon 12 chart of E.I.Du Pont de Nemours & Co. The Freon vapour in the turbine can be expanded only upto 114.5 psia which is the saturation pressure of liquid Freon 12 at 90°F. The temperature at the end of expansion 1-2 is 320°F. This vapour can be utilised to heat the compressed liquid from 6 to 7 and in the process the gas cools itself from 2 to 3. The temperature difference at either end of the heat exchanger has been kept at 20°F.

Freon turbine output = 0.9(160.5 - 125) = 31.95 Btu/lb.

Actual pump Work = $\frac{3.81}{0.8}$ = 4.76 Btu/lb.

Enthalpy available for feed heating = 0.75(128.5 - 91.5)
= 27.8 Btu/lb.

Net turbine output = 31.95 - 4.76 = 27.2 Btu/lb.

Heat Supplied = 160.50 - 61.56 = 98.94 Btu/lb.

Efficiency = 27.5%

(d) For Freon 11 Supercritical Cycle (Fig 1.4):

Following the same procedure as the Freon 12 cycle, it can be shown that the efficiency of the Freon 11 cycle comes to 27.4%.

B. Comparison of Turbine Size and Condenser size.

(a) Steam Cycle:

Specific volume of superheated vapour at 35 ata and 310°C
= 0.07173 m^3/Kg. = 1.15 cft/lb.

Specific volume of saturated steam at 90°F and 0.87 dry*
= 407 cft/lb.

*The moisture content in the steam turbine is assumed not to exceed 13 percent.

(b) Freon 12 cycle:

Specific volume of supercritical F-12 vapour at 120 atm. (1765 psi) and 590 ^{o}F = 0.045 cft/lb. [from Du point de Nemours chart]

Specific volume of superheated vapour at 330 ^{o}F and 114.5 psia = 0.583 cft/lb. [from ASRE tables] (~~Kcal~~)

To get the same output as one lb of steam, $\frac{208 \times 1.8}{31.95}$ = 11.71lbs. of Freon 1 2 are required.

Hence the Freon turbine volume, for the same output as one lb of steam will be :

High pressure end = 11.7 x 0.045 = 0.527 cft.

Low pressure end = 11.7 x 0.583 = 6.82 cft.

Condenser size = 11.7 x specific volume of saturated F 12 vapour at 90 ^{o}F = 11.7 x 0.355 = 4.15 cft.

(c) Freon 11 cycle:

Specific volume of super critical vapour at 120 atm (1765 psi) and 590 ^{o}F = 0.028 cft/lb [from ASRE chart]

Specific volume of superheated vapour at 155 ^{o}F and 19.7 psia = 2.328 cft/lb. [from ASRE chart]

Specific volume of saturated vapour at 90 ^{o}F = 2.091 cft/lb [ASRE tables]

To get the same output as one lb of the steam $\frac{208 \times 1.8}{38.7}$ = 9.66 lbs. of Freon 11 are required.

Hence the Freon turbine volume, for the same output as one lb. of steam will be:

High pressure end	=	9.66 x 0.028	=	0.27 cft.
Low pressure end	=	9.66 x 2.328	=	22.45 cft.
Condenser sizé	=	9.66 x 2.091	=	20.2 cft.

C. <u>Comparison of pipe sizes for carrying liquid freon and water, for same power output as one lb of steam</u>:-

For Water, volume required = 0.016 cft/lb. of water

For F-12, volume required = 11.7 x 0.0125 = 0.146 cft.

For F-11, volume required = 9.66 x 0.011 = 0.106 cft.

Thus the volume ratios for liquid freon to water are:-

For F-12, $\frac{0.146}{0.016} = 9.14$

and For F-11, $\frac{0.106}{0.016} = 6.63$

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