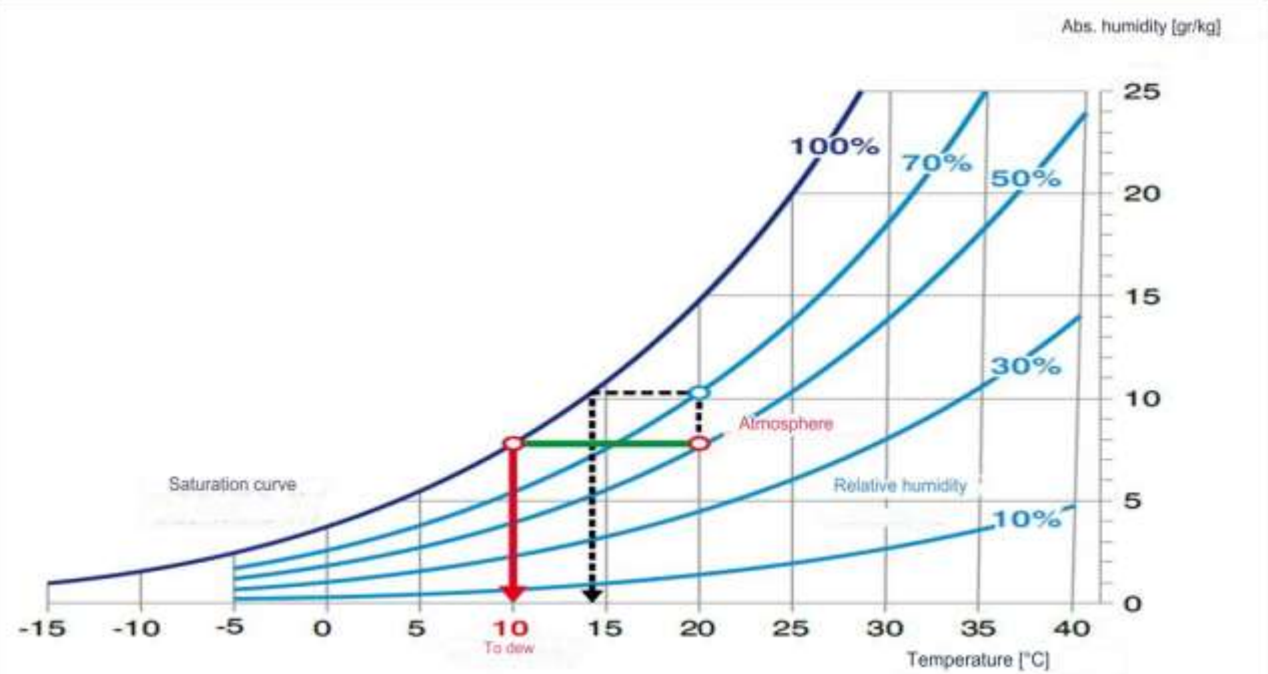
V. Ideal liquefaction cycles and minimal work

Introduction

Liquefaction involves removing energy from it in order to cool it from ambient temperature to its dew point, then condensing the saturated vapor(Fig. 1).

Fig. 1



The dew point : *is the temperature to which air must be cooled for the water vapor it contains to condense into dewor frost.*

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1. Ideal Liquefaction Cycle

An ideal liquefaction cycle is considered ideal if it produces liquid with maximum efficiency, meaning minimum external energy consumption. To achieve this, the cycle must incorporate certain transformations characteristic of the Carnot cycle. The difference is that this will be an open cycle, as the produced liquid is assumed to be continuously removed from the system.

The Carnot cycle includes a compressor, an expander that performs work, an evaporator, a nd a condenser (see Fig. 2

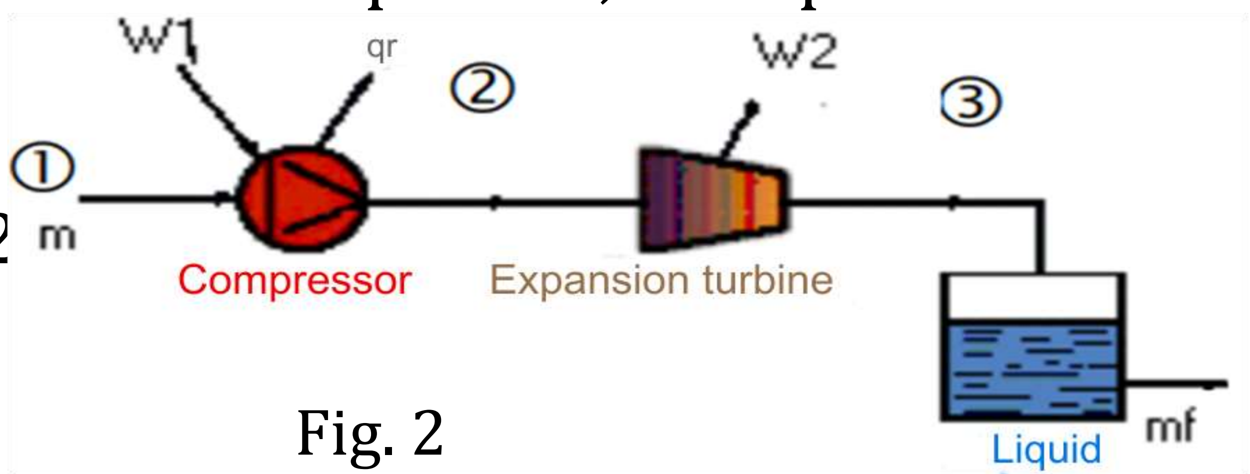

Fig. 2

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The stages of this cycle are as follows: 1-2: Reversible isothermal compression. 2-3: Isentropic expansion; point 2 will be chosen such that so that in 3 the liquefaction stage corresponding to the lowest possible pressure (that of point 1, atmospheric pressure) is reached. This will achieve 100% liquefaction of the compressed gas from 1-2, with the work required for liquefaction represented by the area 1-2-3-4 (see Fig. 3).

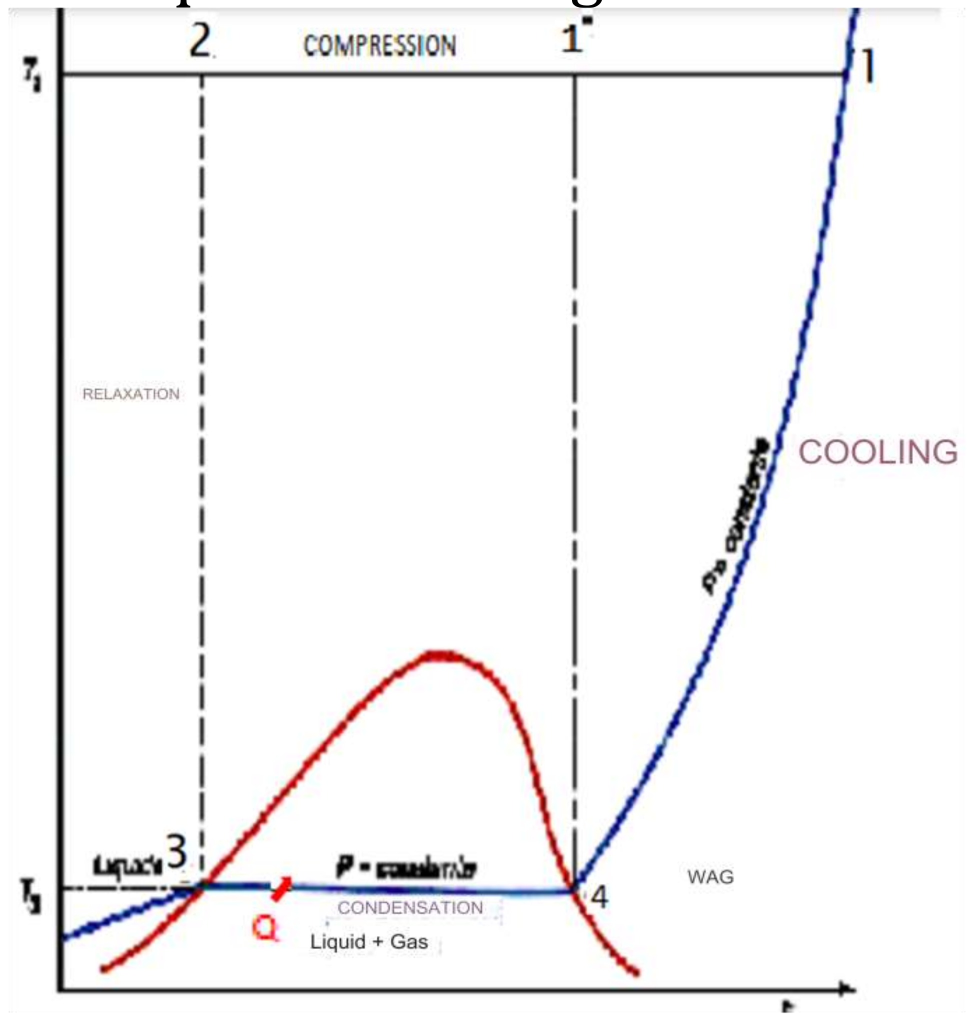

Fig. 3

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<u>Note</u>: It should be noted that this area decomposes into the area 1-1'-4, which represents the heat (or work) required to cool the gas to the liquefaction temperature T_3, and the area 1'-2-3-4, which represents the actual work of liquefaction

2. Minimum liquefaction work

The work W is the value defined by the reversible transition from 1 to 3. The change in internal energy occurs during this process.

$$W - Q = U_3 - U_1$$

The work to be supplied from point 1 (P_1, V_1) to point 3 (P_1, V_3) is represented by the area 123.

$$W = Q + U_3 - U_1 = T_1(S_1 - S_2) + U_3 - U_1$$

A portion of the supplied work

$$W' = P_1(V_1 - V_3)$$

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Note: Point 1 represents the gas conditions under normal ambient conditions, and point 2 is chosen so that the fluid gas reaches the saturated liquid state.

The first law of thermodynamics applied to the system "compressor and expander" is:

$$Q_r - W = m(h_L - h_1)$$

Where:

Q_r: Heat transferred from the compressor [kJ],

W: Work required for liquefaction [kJ],

m: Mass of the fluid flowing through the system [kg],

h_L: Enthalpy of the liquid phase [kJ/kg],

h_1: Enthalpy of the gas [kJ/kg].

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According to the second law of thermodynamics we obtain

$\boldsymbol{Q_r = m\, T_1\, (S_2 - S_1)}$

S_L : Entropy of the liquid[kJ/kg.K],

S_1 : Entropy under normal conditions[kJ/kg.K],

$S_2 = S_L$ Entropy of the gas exiting the compressor[kJ/kg. K].

By substituting 1 into 2, we arrive at the result :

$(Q_r - W) - Q_r = m(h_L - h_1) - m T_1 (S_2 - S_1)$

the work per unit mass is given by: :

$- W/m = (h_L - h_1) - T_1 (S_L - S_1)$

$W/m = (-h_L + h_1) + T_1(-S_L + S_1) = T_1(S_1 - S_L) - (h_1 - h_L)$