

INCREASING THE ENERGY EFFICIENCY OF PLANT FOR TRITIUM AND DEUTERIUM SEPARATION BY USING THE COOLING SYSTEMS WITH ECOLOGICAL FREON

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ABSTRACT: Refrigerants are the working fluid in any refrigeration system. They absorb heat from one source and reject it in another area usually through the evaporation and condensation processes respectively, due to phase changes. The chlorofluorocarbons – CFC's and hydrochlorofluorocarbons HCFC's were developed as a range of non-toxic, stable, and (at normal temperatures) chemically inert refrigerants, and these refrigerants belong to a larger family of substances known as halogens. These refrigerants contained, amongst other elements, chlorine.

Refrigerants known as CFC12 (R12) and HCFC22 (R22) are stable, remain in the atmosphere for many years, and eventually diffuse into the stratosphere. In the upper atmosphere the refrigerant molecules breakdown and release chlorine, which destroys the ozone layer. In the lower atmosphere the molecules absorb infrared radiation and contribute to global warming.

Each chlorine atom released can destroy up to 100,000 ozone molecules before it is removed from the stratosphere. Although the natural cycle of formation and destruction of stratosphere ozone continues, the additional rapid removal of ozone via man-made chlorine (and bromine) containing compounds accelerates the rate of destruction, thus leading to a net depletion.

In real conditions the processes of refrigeration cycles, are accompanied by internal and external irreversibility, which have the effect of consumption need of work, higher than ideal for cold cycle, characterized by the absence of irreversibility. The most representative irreversibility of the refrigeration cycles are:

- External irreversibility due to heat transfer at finite temperature differences;
- Internal irreversibility due to friction, turbulence, mixing, etc..

As the coolant temperature is closer to ambient temperature, the cooling efficiency is higher. Another disadvantage of using refrigeration efficiency in qualitative analysis of refrigeration cycles is that not take account of irreversibility that occurs in refrigeration processes. Reasons presented below, will be considered the irreversibility and losses from them

and will introduce the concept of exergetic efficiency, refrigeration cycle performance indicator that takes into account both the environmental temperature cooled, and the environment, and losses due to thermal processes manifested by irreversibility of component refrigeration cycles. Variable refrigerant flow multi systems are a very cost effective alternative to chiller, both in terms of installed cost, and running costs.

Keywords: refrigeration efficiency, irreversibility, environmentally friendly freon, heat transfer, R407 refrigerant

1. INTRODUCTION

The Montreal Protocol (1987) is a landmark in environmental policy making. It was an international treaty designed on the basis of scientific evidence, to prevent rather than cure the problem. The Montreal Protocol (1990) initially dealt with the phase out of FC's, by the year 2000 including R12, which has an Ozone Depletion Potential index of 1.0. However, subsequent meetings and agreements within the EEC, the phase out date was brought forward to 1995.

Further meetings between the Member Parties of the Protocol and the EEC recognised the burden placed on industry as a whole by the rapid removal of CFC's, and allowed HCFC's as transitional substances. These were added to a list of controlled substances, although refrigerant R22 has an Ozone Depletion Potential index of 0.055, which is 5% of that of R12.

HFC production will increase as HCFC's are phased out. Whilst refrigerant HFC407C (R407C) is at 03/99 some 20% more expensive than HCFC22 (R22), the price of R22 is progressively increasing.

Due to the reduced production of R22, there will no longer be the economies of scale, resulting in a high priced refrigerant, against R407C whereby the economy of scale in production will become effective.

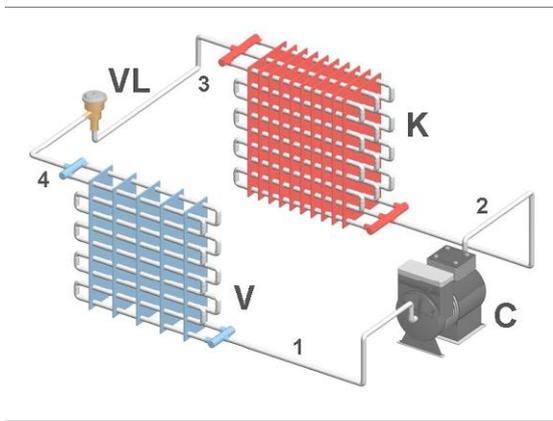


Fig. 1 Working principle of refrigeration systems

- VL – Throttle valve
- V- Evaporator
- K – Condenser
- C – Compressor

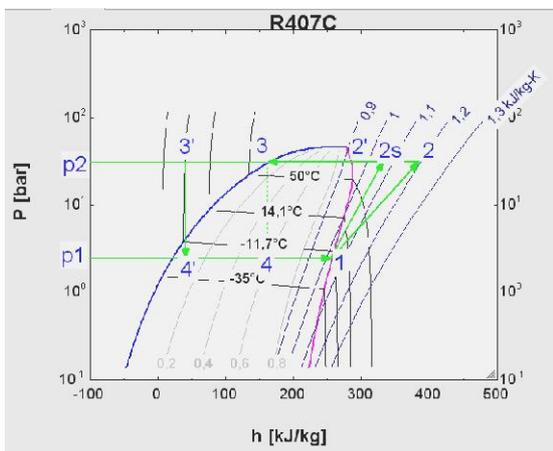


Fig. 2 The real process in p-h diagram, for R407 refrigerant.

2. SYSTEM ANALYSIS

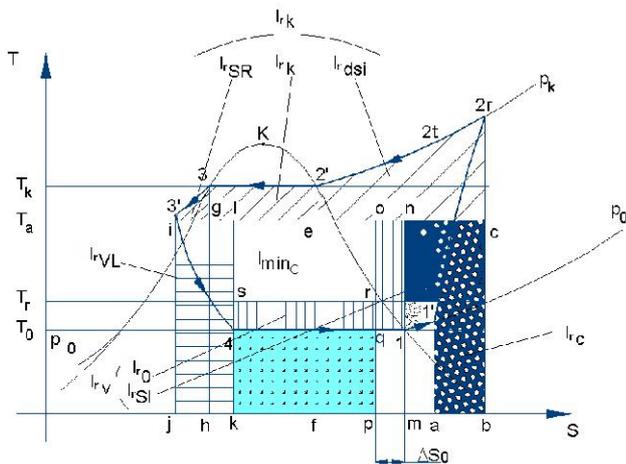


Fig. 3 The irreversibility of refrigeration cycle

Cooling efficiency, provides comprehensive information on the performance level of the cycle, but is a

parameter that does not take into account the cold quality obtained.

In Figure3 is represented in the T-S diagram, a real refrigeration cycle with the subcooled in condenser and overheating in vaporizer, which allows the study of the major irreversibility of the refrigeration cycles.

For the calculation of all losses due to irreversibility and generally denoted by I_r , is used Guy-Stodola theorem, which in mathematical terms can be written as:

$$I_r = T_a \cdot \Delta_{s_sys} \tag{1}$$

where T_a is ambient temperature and Δ_{s_sys} entropy change in thermal system that includes the entropy

change with the environment, Δ_{s_hs} entropy of heat sources and Δ_{s_ra} entropy of refrigerant agent:

$$\Delta_{s_sys} = \Delta_{s_hs} + \Delta_{s_ra} \tag{2}$$

Ideal compression process is represented by the diagram in Figure 3 by adiabatic transformation 1'-2t characterized by a constant entropy and the real process is represented by polytropic transformation 1'-2r characterized by increasing entropy due to internal irreversibility. Irreversibility of this process are internal, and in the absence of thermal interactions with the environment.

Losses due to irreversibility of compressor process can be calculated by the relationship:

$$I_{r_c} = T_a \cdot \Delta_{s_ra} = T_a \cdot (s_{2r} - s_{1'}) \tag{3}$$

area a,b,c,d

Real process of condensation, represented on the chart by isobaric transformation 2r-2'-3-3' (Figure 3), is characterized by external irreversibility due to heat transfer at finite temperature differences. Condensation process can be split into three subprocesses: low overheating 2r-2', 2'-3 condensation and subcooling process 3-3'. For each stage of the condenser heat transfer, we can write Guy-Stodola equation for determining the losses due to irreversibility.

Losses due to irreversibility of the low overheating process are calculated by:

$$I_{r_{loh}} = T_a \cdot (\Delta_{s_HSloh} + \Delta_{s_ra}) = q_{loh} + T_a \cdot (s_{2'} - s_{2r}) \tag{4}$$

area 2r, 2', e, c

where Δ_{s_HSloh} is the change in entropy of hot source after overheating process, because it (the environment) absorbed specific heat of low overheating.

Losses due to irreversibility of the condensation process are calculated by:

$$I_{r_c} = T_a \cdot (\Delta_{s_HSc} + \Delta_{s_ra}) = q_c + T_a \cdot (s_3 - s_{2'}) \tag{5}$$

area 2', 3, g, e

where Δ_{s_HSsc} is the change in entropy of hot source after condensing process, because it (the environment) absorbed specific heat of condensation process.

Losses due to irreversibility of the subcooling process

$$I_{r_{SC}} = T_a \cdot (\Delta_{s_HSsc} + \Delta_{s_ra}) \quad (6)$$

$$= q_{sc} + T_a \cdot (s_3 - s_2')$$

area 3,3',i,g

where Δ_{s_HSsc} is the change in entropy of hot source after subcooling process, because it (the environment) absorbed specific heat of subcooling process.

Losses due to irreversibility of the throttling adiabatic process

$$I_{r_{tv}} = T_a \cdot \Delta_{s_ra} = T_a \cdot (s_4 - s_3') \quad (7)$$

area l,i,j,k

Real process of vaporization 4-1-1'(Figure 3) is accompanied by irreversibility due to heat transferred to finite temperature differences. Vaporization process can be divided into two phases, the vaporization 4-1 and overheating 1-1'.

$$I_{r_0} = T_a \cdot (\Delta_{s_ra} - \Delta_{s_sc0}) = T_a \cdot \Delta_{s_0} \quad (8)$$

area m,n,o,p

$$I_{r_{oh}} = T_a \cdot (\Delta_{s_ra} + \Delta_{s_SCoh}) \quad (9)$$

$$= T_a \cdot (s_1' - s_1) - q_{oh}$$

area n,d,1,1'(Figure 3)

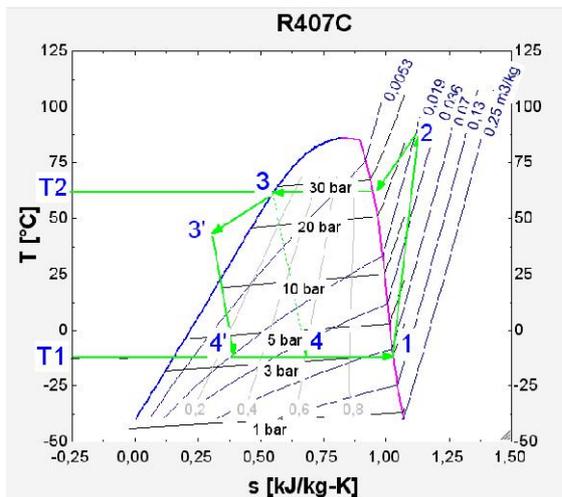


Fig. 4 The real process in T-s diagram, for R407 refrigerant

3. APPLICATION

The experimental Pilot Plant for Tritium and Deuterium Separation, part of National Research and Development Institute for Cryogenics and Isotopic Technologies - ICSI Rm.Valcea, as principal target have to establish the technology of the water-hydrogen

catalyzed isotopic exchange and cryogenic distillation for mixtures of hydrogen and his isotopes diatomic species.

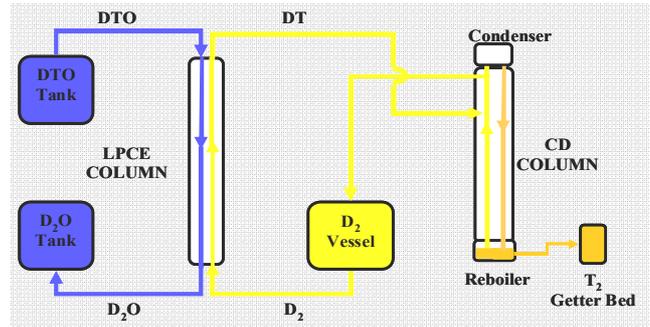


Fig. 5 The flow diagram of a combined LPCE-CD heavy water detritiation process

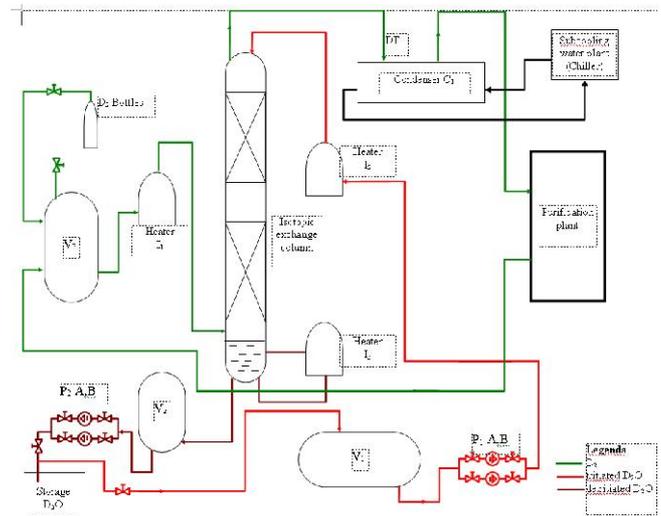
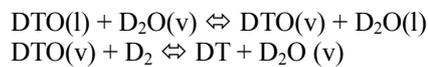


Fig. 6 The Chiller system in isotopic exchange process

In LPCE module the tritium is transferred of water in deuterium flow by catalytic exchange in liquid phase:



l – Liquid phase
v – Vapour phase

Transfer process occurs on hydrophobic catalytic fillers that allow direct contact between water and deuterium gas in liquid form on the catalyst surface. Deuterium, enriched in heavy isotopes, leaving at the top of LPCE column and enter in C1 condenser, where is cooled and condensed the water vapor, cooling circulation achieved by countercurrent flow with subcooled water at temperature 4 - 6°C. Subcooled water system consists of a fully automated Chiller, cooling water being mixed with antifreeze. Of C1 condenser, deuterium is sent to plant 200 for advanced drying.

Table 2.1. Comparative analysis of cycles with and without subcooled

Without subcooled	With subcooled	Comments
specific cooling power $q_0 = h_1 - h_4$	specific cooling power $q_0 = h_1 - h_4' > q_0$	advantage
mass flow of the plant $\dot{m} = \frac{\dot{Q}_0}{q_0}$	mass flow of the plant $\dot{m}' = \frac{\dot{Q}_0'}{q_0} < \dot{m}$	advantage
compression work $l = h_2 - h_1$	compression work $l' = h_2 - h_1 = l$	
power needed to compression $P = \dot{m} \cdot l$	power needed to compression $P' = \dot{m}' \cdot l' < P$	advantage
specific power of condenser $q_k = h_2 - h_3$	specific power of condenser $q'_k = h_2 - h_3 = q_k$	
	specific heat of subcooling $q'_{sc} = h_3 - h_3'$	
thermal load of condenser $\dot{Q}_k = \dot{m} \cdot q_k = \dot{Q}_0 + P$	thermal load of condenser and subcooling $\dot{Q}_k + \dot{Q}_{sc} = \dot{m} \cdot (q_k + q_{sc}) = \dot{Q}_0 + P < \dot{Q}_k$	advantage
cooling efficiency $\varepsilon = \frac{\dot{Q}_0}{P}$	cooling efficiency $\varepsilon' = \frac{\dot{Q}_0'}{P'} > \varepsilon$	advantage
exergetic efficiency $\eta_{ex} = \varepsilon \cdot \left(\frac{T_a}{T_r} - 1 \right)$	exergetic efficiency $\eta'_{ex} = \varepsilon' \cdot \left(\frac{T_a}{T_r} - 1 \right) > \eta_{ex}$	advantage

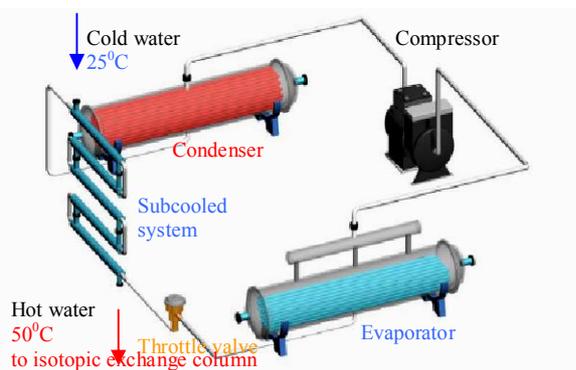


Fig. 7 Use of subcooling system to coupled at isotopic exchange column

4. CONCLUSION

A theoretical comparison, of refrigerant R407C and R22 in the cooling mode is given in Table 3.1

Table 3.1

Refrigerant	R407C	R22
Evaporator Temperature °C	1	1
Condenser Temperature °C	38	38
Compress Efficiency Isentropic %	74	74
Evaporator Outlet	4	4
Cooling Power kW	14.5	14.5
Calculated data		
Condenser Pressure Bar	18	17.5
Evaporator Pressure Bar	3.5	3.1
C.O.P.	3.536	3.536
Compressor Power kW	4.1	4.1
Volumetric Flow into Compressor m3/hr	11.5	11.5

In the heating/cooling mode (Table 3.1) the refrigerants have similar performance properties, and therefore R407C in terms of thermodynamic performance properties is an acceptable alternative to R22.

The most important technical difference between R407C and the hydrochloroflourocarbon R22, is that R22 has chlorine as part of its chemical structure, which now makes it totally unacceptable as a refrigerant for the future.

Of the chiller refrigeration cycle analysis reveals that it is possible to increase the exergetic efficiency by recovery the subcooling heat and reinsertion to circuit of isotopic exchange column(Heater II, fig. 6).

The Chiller system is equipped to R407 refrigerant. Whilst refrigerant R22, an HCFC, is not so environmentally aggressive as a CFC refrigerant, it is being phased-out of production, and will eventually no longer be a viable proposition as a first choice refrigerant for new installations. In the heating mode both refrigerants have similar performance properties, and therefore R407C in terms of thermodynamic performance properties is an acceptable alternative to R22. The most important technical difference between R407C and the hydrochloroflourocarbon R22, is that R22 has chlorine as part of its chemical structure, which now makes it totally unacceptable as a refrigerant for the future.

Can observe that in refrigeration systems, is always advantageous to achieve subcooling and overheating of the system. In this case increase the exergetic efficiency, cooling efficiency, and specific cooling power.

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