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OPERATING PARAMETERS ACCUMULATION OF HELIUM LIQUEFICATION SYSTEM: (H.E & TURBINE)

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ABSTRACT

Present work involves analysis and optimization of the process parameters (like helium flow rate, pressure and temp.) for main components as (eight different heat exchangers as well as three different turbo-expanders) of helium liquefaction plant of refrigeration capacity 1 kW at 4.5 K. Nevertheless, this plant can be operated in mixed mode also as helium refrigerator-cum-liquefier, although it is optimized for refrigeration load. To optimize process of any helium refrigeration/liquefaction system, this is important to consider one independent variable at a time and under valid assumptions, and its effect on the various process. From the analysis, the optimized value of the concerned and considered process variables is taken. The main components of system that affect process parameters are compressor, heat exchangers ,expansion devices or expansion valve besides this basically concerned with the parameters of the heat exchangers as well as expansion engines. Current calculation work mainly total compressor mass flow rate, fraction of total compressor flow of mass diverted towards engines, inlet temperature to many expansion engine and heat exchangers are calculated and accumulated using steady state condition. Present study, analysis and optimization of the important operating parameters is done considering logical assumptions and fulfilling important practical constraints that are explained in this report.

KEYWORDS: Helium Liquefier, Helium refrigerator, Liquefaction system.

INTRODUCTION

The kind of cooling system discussed before is the so-called ‘refrigerator’. We should install a separator (small vessel) after the throttle valve and if some nitrogen liquefies after throttling, this liquid substance will accumulate in this separator. Usually, 6–8% of the nitrogen flow is liquefied, and the rest (~95%), which was already in gaseous form, goes through the heat exchanger and cools the high-pressure stream. If some liquid accumulates in this system, we have to feed the same amount of nitrogen into the system just to balance the cycle. The liquid nitrogen can be taken out from system and can be used. This kind of cycle is known as a ‘liquefier’.

Liquefaction is the process of converting a compressed gas into a liquid under reliable conditions. Liquid helium is required as a working medium in almost all low-temperature laboratories. Usually a large-scale liquefier serves as a central facility for helium liquefaction, for distribution of liquid helium to many cryostats in large transport dewars. With the availability of small closed-cycle cryocoolers a different scheme has become possible, where helium liquefaction may be performed nearby or even in the cryostat, thus allowing operation independent from cryogenic liquids support. Measurements of the pressure dependence of the liquefaction rate are considered. Also liquefaction rate and temperature can be observed by placing resistors in series inside the liquefaction container. There by taking voltage reading we will get liquefaction rate. If cryogenics is to be defined in terms of liquefaction systems, it is science of liquefying the presumed permanent gases mainly air and its major components like nitrogen, oxygen and hydrocarbon gases and other important phenomenon related to same temperature range. Generally preferred temperature point that differentiates cryogenics from normal low temperature phenomena is 123 K. Helium liquefaction is considered tougher than liquefaction of other gases. It is mainly due to its rare availability as compared to other gases and its much lower boiling point temperature. Even though, helium liquefaction is very important. Some of the main aspects and basic need of helium liquefaction systems is explained in the coming sections.

METHOD OPTED TO OPTIMIZE MASS FLOW THROUGH TURBINE A VIS-A-VIS HE 3

For given compressor pressure and mass flow:

HE 2

Hot stream inlet temperature = 80.01
Reason: outlet from liquid nitrogen precooling heat exchanger and 80 K absorber bed.
Hot stream outlet temperature = inlet temperature of turbine A
Cold stream inlet temperature = calculated from HE 3
Cold stream outlet temperature = f (Pcold, hcout)
using formulae I,

$$\sum_{i=1}^{n}\left(m_c \times (h_{cout} - h_{cin})\right) = \sum_{i=1}^{n}\left(m_h \times (h_{in} - h_{out})\right) + \text{ heat leak}$$

Turbine A

Inlet temperature = user defined and fixed while changing mass flow rate to find the optimum mass flow through turbine A vis-à-vis HE 3 and JT valve.
Pressure drop = judicial pressure drop considering the manufacturing or designing factors in view. A separate analysis may be done to optimize the pressure drop.
η = assume certain reasonable efficiency according to manufacturing capability or requirement point of view.
Outlet temperature can be calculated using formulae II as under:
Tin → hin= f (Pin, Tin) → sin=f (Pin, Tin) → hout ideal=f (pout, sin) → hout using formulae II →tout

HE 3

Hot stream inlet temperature = turbine A inlet temperature.
Hot stream outlet temperature = turbine A outlet temperature.
Reason: to keep the temperatures of both high pressure hot stream and medium pressure hot stream inlet temperatures same for efficient heat transfer between the cold stream and hot streams only rather between the two hot streams due to temperature difference.
Cold stream inlet temperature = calculated from HE 4
Cold stream outlet temperature = f (Pcold , hcout)
Using formulae I,

$$\mathrm{h_{cout}} = \mathrm{h_{cin}} + \frac{(\mathrm{m_h} \times (\mathrm{h_{in}} - \mathrm{h_{out}})) + \text{ heat leak}}{\mathrm{m_c}}$$

HE 4

High pressure (from HE 3) Hot stream inlet temperature =turbine A outlet temperature= Medium pressure (from Turbine A) Hot stream inlet temperature
Reason: as explained earlier
High pressure Hot stream outlet temperature =turbine B inlet temperature=medium pressure hot stream outlet temperature
Reason: same as above i.e. to keep the temperature of both high pressure hot stream and medium pressure hot stream inlet temperature same for efficient heat transfer between the cold stream and hot streams only or to check heat transfer between the two hot streams due to temperature difference.
Cold stream inlet temperature = calculated from HE 5(user input)
Cold stream outlet temperature = f (Pcold, hcout)
Using formulae I

$$h_{cout} = h_{cin} + \frac{(m_h \times (h_{in} - h_{out})) + \ heat\ leak}{m_c}$$

Turbine B

Inlet temperature = user defined and fixed while changing mass flow rate to find the optimum mass flow through turbine A vis-à-vis HE 3 and JT valve.
NOTE: Turbine B inlet temperature is also user defined based on one of the many important user objectives like keeping same volumetric flow rate through both turbines etc. Or else a separate analysis may be done to find out an

optimum inlet temperature for turbine B at some optimized turbine A inlet temperature or for an optimum combination of temperature.

Pressure drop =judicial pressure drop considering the manufacturing or designing factors in view. A separate analysis may be done to optimize the pressure drop.

η =assume certain reasonable efficiency according to manufacturing capability or requirement point of view.

Outlet temperature can be calculated using formulae II as under:

Tin → hin= f (Pin, Tin) → sin=f (Pin, Tin) → hout ideal=f (pout, sin) → hout using formulae II →tout

HE 5

Hot stream inlet temperature =hot stream outlet temperature of HE4

Cold stream inlet temperature = turbine B outlet temperature

Reason: for efficient adiabatic mixing of the two streams, one from turbine B outlet and the other from HE 6 cold outlet, both the temperatures have been taken same or as close as possible.

Cold stream outlet temperature =user defined , it is varied along with the mass flow variation through turbine A & B in order to satisfy practical constraints mostly.

1. To keep UA of all the heat exchangers under practical user desired values.(here some base values have been decided for each exchanger) .While varying the mass flow through turbine A ,HE 5 cold outlet temperature is manipulated or adjusted in order to keep the UA of all the exchangers below desired value(generally some multiple of base values.)
2. Sometimes to satisfy efficient heat transfer(avoiding temperature cross)

Hot stream outlet temperature = f (Phot, hout)

Using formulae I,

$$h_{cout} = h_{cin} + \frac{(m_h \times (h_{in} - h_{out})) + \ heat\ leak}{m_c}$$

HE 6

Hot stream inlet temperature =hot stream outlet temperature from HE 5

Hot stream outlet temperature = turbine C inlet temperature

Cold stream outlet temperature =f (pressure, hcout)

Cold stream inlet temperature = f (Pcold, hcin)

Using formulae I and energy balance equation,

$$\mathrm{h_{cout}} \ = \frac{(\mathrm{m_c} \times \mathrm{h_{cin}})_{\mathrm{HE5}} \ - \ (\mathrm{m_c} \ \mathrm{h_{out}})_{\mathrm{Turbine\ B}}}{\mathrm{m_{c\ HE6}}}$$

$$\mathrm{h_{cin}} = \mathrm{h_{cout}} - \frac{(\mathrm{m_h} \times (\mathrm{h_{in}} - \mathrm{h_{out}})) + \ \mathrm{heat\ leak}}{\mathrm{m_c}}$$

Turbine C

Inlet temperature = user defined and fixed while changing mass flow rate to find the optimum mass flow through turbine A vis-à-vis HE 3 and JT valve.

Pressure drop =judicial pressure drop considering the manufacturing or designing factors in view. A separate analysis may be done to optimize the pressure drop.

NOTE: Turbine C inlet temperature is also user defined based on one of the many important user objectives like practical designing and operating problems at that low temperature etc. Or else a separate analysis may be done to find out an optimum inlet temperature for turbine C at some optimized turbine A inlet temperature or for an optimum combination of temperature.

η =assume certain reasonable efficiency according to manufacturing capability or requirement point of view.

Outlet temperature can be calculated using formulae II as under:

Tin → hin= f (Pin, Tin) → sin=f (Pin, Tin) → hout ideal=f (pout, sin) → hout using formulae II →tout

HE 7

Hot stream inlet pressure = turbine C outlet pressure

Hot stream inlet temperature = turbine C outlet temperature

Cold stream outlet temperature =cold stream inlet temperature from HE 6

Cold stream inlet temperature = 4.408 K

Reason:

Pcold = 1.2 bar ,saturation temperature of liquid helium at 1.2 bar is 4.407, so Tcin may be taken as 4.407 or a general superheat of .001 K after the application.

Hot stream outlet temperature = f (Phot, hout)
Using formulae I

$$h_{out} = h_{in} - \frac{(m_h \times (h_{cout} - h_{cin})) - \text{heat leak}}{m_h}$$

JT Valve
Inlet temperature and pressure = hot stream outlet temperature and pressure from HE 7.
Outlet temperature can be calculated as:
Tin →hin = hout ideal →tout=f(Pcold, hout) →vapor fraction & latent heat of liquid helium →liquid fraction → total liquid produced → refrigeration

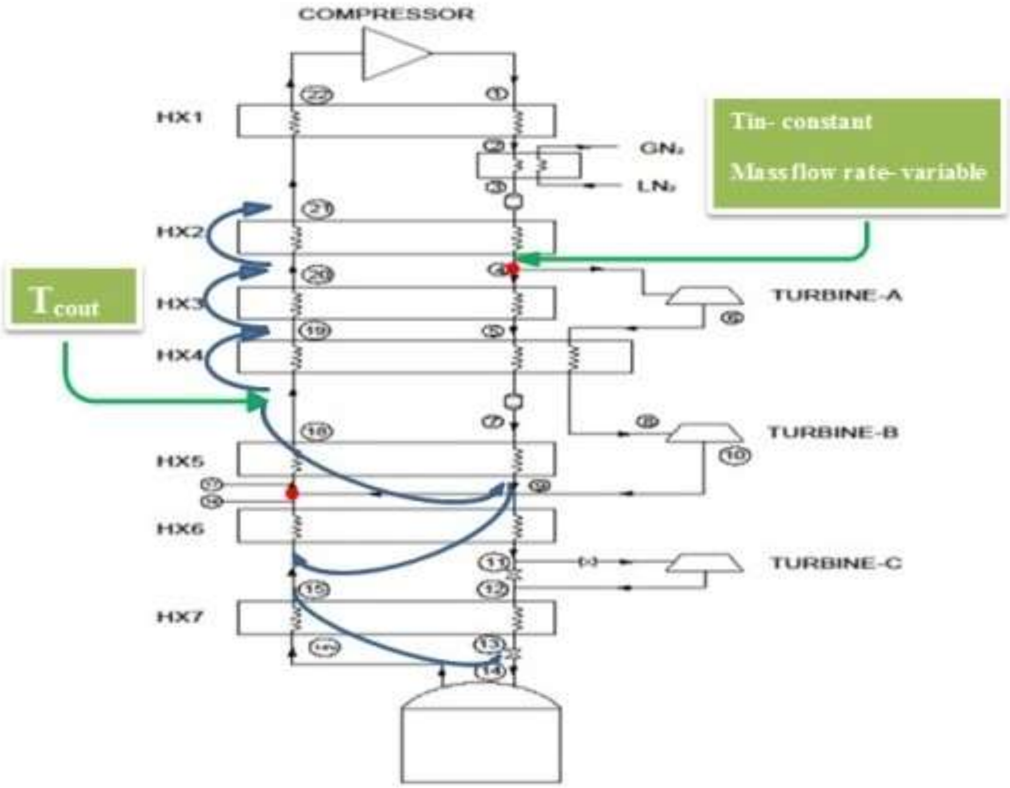

Figure : Schematic diagram for methodology to optimize mass flow through turbine A

CONCLUSION

High reliability, availability, low operational costs and short delivery times have become key requirements for small scale helium liquefier production. In addition, the demands concerning product design and user friendliness have risen. By using standardized components, like heat exchangers, expansion turbines and control software of highest quality, designed, prepared and manufactured according to customer's requirements and specifications maintaining short delivery times.

Among all above discussion, the following points are concluded:
1. For the present target capacity of 1 KW, the optimum mass flow under the mentioned constraints is 45 g/s which is 40 % of the total mass flow through cold box.
2. The optimum inlet temperature of turbine A vis- a-vis HE 3 is 33 K.
3. The optimum pressure at JT inlet vis-à-vis Turbine C outlet under the estimated JT inlet temperature range is 4 bar.
4. Refrigeration with third turbine is almost summation of refrigeration without third turbine and refrigeration due to expansion in third turbine.

5. There is a saturation UA value for each heat exchanger after which increase in UA value does not affect the refrigeration capacity of the plant significantly.

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