ANALYSIS AND IMPROVEMENT METHOD FOR AN EXPERIMENTAL/INDUSTRIAL PROCESS OF HYDROGEN CRYOGENIC DISTILLATION

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Abstract: This paper present an analysis and improvement method for an experimental process of hydrogen cryogenic distillation. The method is based on a software development which uses as input data the information acquired from the process and provides, graphically and as a value, the operating parameters of the plant equipments. It is shown that the LabView platform can ensure the interface between automation (data acquisition) and thermodynamics and it can also be subsequently developed for the industrial model of a cryogenic distillation plant.

Key-Words: Software, cryogenics, data acquisition, tritium, thermodynamics

1. Introduction

Tritium separation has become, in the recent years, an issue to be studied more and more, considering both the need to separate tritium from the moderator heavy water from CANDU NPP and for WDS within the fusion reactor which will be built at ITER.

Within ICIT Rm. Valcea, the technology of tritium separation is currently under development within the pilot plant for deuterium and tritium separation.

The important element within the plant is the cryogenic distillation module, focused on achieving the distillation of D-T mixture for tritium separation and storage.

The main purpose is to propose an improved operation/functioning based on a computation model which can be applied generally for liquid hydrogen distillation plants.

Below is presented the chart of the plant, Figure 1, for the separation of deuterium and tritium from ICSI Rm. Valcea, a pilot plant achieved with the purpose of demonstrating the Romanian technological capacity in the field. [1]

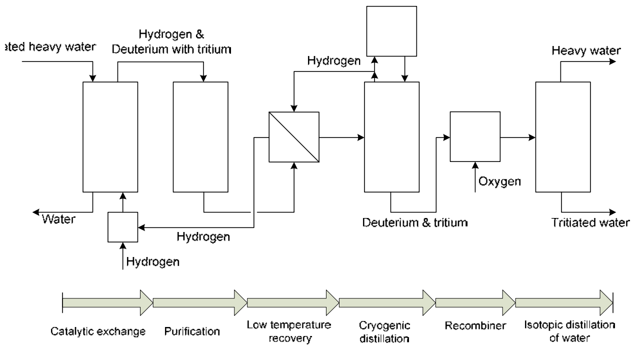

Figure 1.Experimental Tritium and Deuterium Separation

2. Thermodynamic processes in cryogenic distillation

2.1. Theoretical considerations

Below are presented in brief the basic equations involved in the analysis and improvement of a cryogenic distillation process.

It has been considered that, in the case of a cryogenic distillation plant, the operation of individual equipments is based on power conversion processes.

For this, we started with the definition of energy, conceived as being composed of exergy

and anergy. Out of these, the exergy expresses best the process operation, representing the energy which converts itself entirely. Therefore, the operation of a piece of equipment can be analyzed through the exergetic conversion and the exergy losses. [2]
The basic equations are:
Energy:

$$W = E + A = \text{const} \quad (1)$$

Exergy:

$$E = H - T_0 S \quad (2)$$

Exergy losses. Exergetic efficiency

In real, irreversible processes, the exergy is partially or totally converted into anergy. As this cannot convert into exergy, the exergy part converted into anergy within the irreversible processes is considered an exergy loss.
Therefore, the exergetic efficiency is:

$$\eta_e = \frac{E_u}{E_c} = 1 - \frac{\pi}{E_c} \quad (3)$$

2.2. The general expressions of specific measurements
Below are presented the main basic equations for the determination of specific measurements.

General expression of specific enthalpy

The expression of specific enthalpy h = h(T, p), considering the status equation v = v(T,p), and $c_p = c^0_p(T)$ for $p = p_0$ and $p_0 = 0$, becomes:

$$h(T,p) = h_0 + \int_{T_0}^{T} c_p^0(T)\,dT + \int_0^p \left[v - T\left(\frac{\partial v}{\partial T}\right)_p \right] dp \quad (4)$$

where h_0 is the ideal gas enthalpy at T_0 temperature.

General expression of specific entropy

$$s(T,p) = s_0 + \int_{T_0}^{T} c_p^0(T)\frac{dT}{T} - R\ln\frac{p}{p_0} - \int_0^p \left[\left(\frac{\partial v}{\partial T}\right)_p - \frac{R}{p} \right] dp \quad (5)$$

Where s_0 is the specific entropy of ideal gases for the status (T_0, p_0).

General expression of specific exergy

$$de = \varepsilon \cdot c_p \cdot dT + \left[v - \varepsilon \cdot T\left(\frac{\partial v}{\partial T}\right)_p \right] dp \quad (6)$$

Therefore, we have obtained the differential expressions for the status heat measurements of fluids which can be used in the calculation of cryogenic processes, as follows.
We observe the common form of expressions and the term $\left(\frac{\partial v}{\partial T}\right)$, which is common in the above equations.
For its determination, we use status equations in the following form:

$$F(p, v, T, \ldots) = 0 \quad (7)$$

Starting from the equation:

$$pv = RT(1 + Bp + Cp^2 + \ldots) \quad (8)$$

or

$$v = \frac{RT}{p} + RT \cdot B'(T) + RT \cdot C'(T) \cdot p + \ldots \quad (9)$$

by derivation

$$\left(\frac{\partial v}{\partial T}\right)_p = \frac{R}{p} + R\left(T\frac{dB'}{dT} + B'\right) + \ldots \quad (10)$$

Based on the equation (10) there can be determined through a calculation program v, cp, cv in a range of pressures and temperatures appropriate for the process.[3]

3. Experimental basis

In a hydrogen cryogenic distillation plant, it is important to ensure refrigeration power required for the supply of the condenser in the distillation column(s). [4]

The condenser of a hydrogen distillation column can be cooled by means of cryogenic cycles with helium or hydrogen, in the range 18K-22K, according to the operating pressure of the distillation column, so that to achieve a total condensation of hydrogen and its isotopes in the distillation column condenser. Another requirement of the cryogenic cycle is that the minimum temperature of the cycles to be highly stable when fluctuations occur in the nominal operating parameters of the plant.

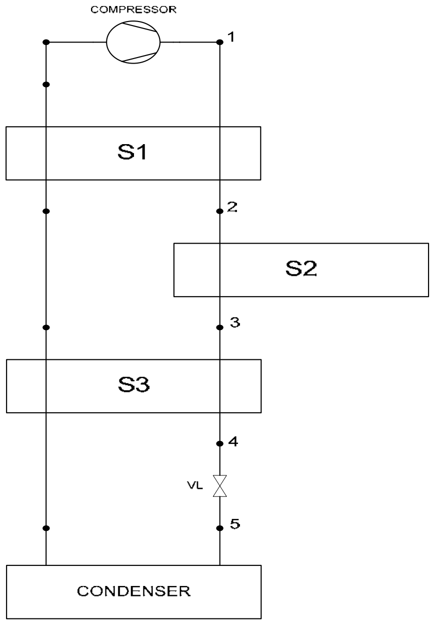

Figure 2. Hydrogen liquefying cycle

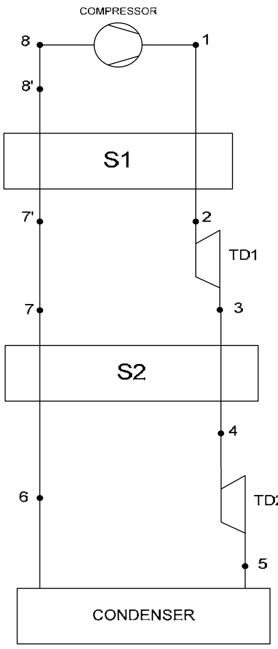

Figure 3. Helium cold gas cycle

Figures 2 and 3 show the existence of some plants and equipments, the operation of which is to be analyzed on basis of the equations presented in chapter 2.

Data acquisition system

Because the TRF is an experimental facility, a flexible hardware and software is required due to many process changes that must be implemented before the technology process is concluded as follows.

The data acquisition system is a fully digital system based on virtual instrumentation, this because of his flexibility and friendly interface (modular I/O architecture and LabView platform).

For an experiment can be monitored up to 50 parameters. Because of the technological processes particularities (liquid hydrogen level, pressure and temperature, fast changes in fluids, vacuum, flow rates) some equipment (hardware) that can assure technical conditions in the facility was chosen.

Taking into account the variation of process parameters, the update rate of 0.8s for monitoring temperatures and 1.4s for the other parameters is sufficient for the characterization of technological process.

The monitoring program writes data from all channels into data files. For data analysis after experiment, it is associated a time item for each value written in data files.

All data monitoring are available to analysis system both online or offline.

4. The process analysis and improvement method

Considering the process example in Figure 2, we envisaged the development of software running adjacent with the general software acquiring the parameters in the plant.

It has as input data the information provided by the process data acquisition system (on the operating status of the equipment), respectively pressure, temperature, flow rate, level values etc. [5]

The program has been developed on a National Instruments platform of visual programming and is based on a logical chart [6].

The program makes calculations of thermodynamic parameters and can display the status parameters of the equipment in its characteristic points[7].

The representation of such parameters characterizes the equipment, allowing the operator to evaluate its functionality and to make decisions in order to adjust the process.

This is allowed by the modular performance and the experimental nature of the plant, which allows the modification of some input parameters in order to achieve the optimum

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process, respectively the reduction of energy/exergy losses.

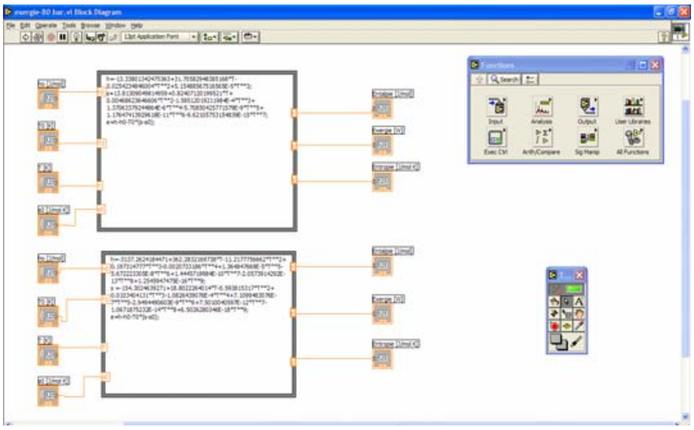

Figure 4. Interface of the computational software

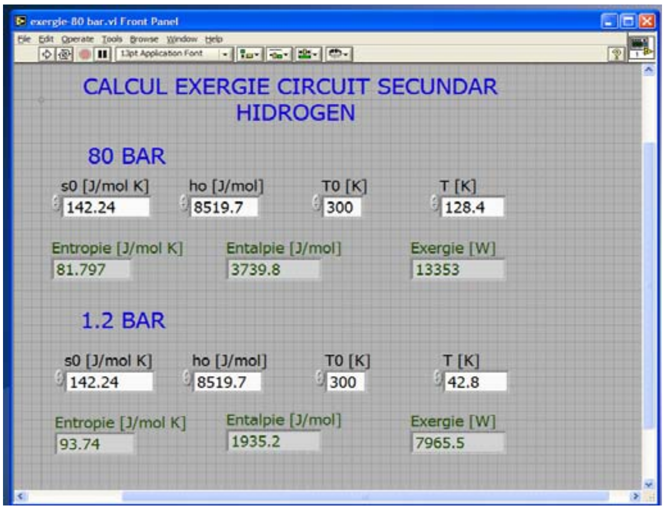

Figure 5. User interface of the computational software for measurements enthalpy, entropy, exergy

5. Conclusions

This paper has presented a method of analyzing and improving an experimental cryogenic distillation process.

The outcome, after validation, can be extended and applied to industrial processes:

The following have been obtained:

- On basis of the thermodynamic process, which is specific for temperatures and pressures in the hydrogen liquefaction cycles, it was highlighted the possibility to introduce the mathematic model in a process analysis software;
- The developed program provides the possibility to analyze the operation of the plant/equipments considering the fact that their physical characteristics are known;
- The method can be developed and implemented for the entire distillation plant;
- the concept of exergetic analysis of a plant or equipment is easy to implement and ensures basic information for the development of an optimum operation.
- the results from this work will be used at the growth and the stability of the capacity of the Tritium Removal Facility from ICIT Rm Valcea, plant that is the researchers' result in the filed of deuterium and tritium isotopic separation.

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