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CONTRIBUTIONS TO THE MONITORING'S OPTIMIZATION OF THE INSTALLATION FOR TRITIUM SEPARATION FROM TRITIATED HEAVY WATER

Carmen Maria MORARU[1], Gabriel IONESCU[2]

Scopul lucrării este acela de a aduce contribuții la dezvoltarea şi perfecționarea sistemelor informatice destinate conducerii, supravegherii şi asigurării siguranței în funcționare, a unei instalații pilot experimentală de separare a tritiului din apa grea tritiată, rezultată în reactoarele nucleare, utilizate pentru producerea energiei electrice. Caracterul pilot al instalației de separare a tritiului implică posibilități de a obține regimuri de operare foarte variate, din observarea şi studierea cărora să se poată desprinde concluzii privind condițiile care maximizează eficiența procesului de separare, menținând şi securitatea instalațiilor şi a mediului la niveluri admisibile.

Paper aim is to set up contributions to the development and improvement of information system for control, supervising and ensuring safety in operation to an experimental pilot installation for the separation of tritium from tritiated heavy water, resulting in nuclear reactors used for electrical energy. The pilot plant features for the tritium separation, involve opportunities to obtain operating regimes very different and from their observation and study to derive conclusions on which is possible to maximize the efficiency of separation and to maintain the security of installations and the environment to acceptable levels.

Keywords: monitoring, LabVIEW, optimization

1. Introduction

The main objectives of this work are to develop and improve an information system corresponding to an experimental pilot plant installation for the separation of tritium from heavy water.

The pilot plant is composed mainly of three major modules, namely: the installation of isotopic exchange, the installation of purification by catalytically burning and the installation of cryogenic distillation.

To satisfy the many requests that claim a pilot plant for research is needed a comprehensive information system consisting of numerous and varied hardware and software such as:

[1] Eng., National Institute of Research - Development for Cryogenic and Isotope Separation Technologies, ICSI-Rm.Valcea, mcarmen@mail.icsi.ro

[2] Prof., Department of Automation and Industrial Informatics, Automation and Computer Faculty, University POLITEHNICA of Bucharest, Romania, gion@clicknet.ro

- hardware parts consisting of sensors and transducers, cable connections, modules for data acquisition, actuators, computers for data processing, display and remote control devices capable to implement various operating conditions;

- software programs for applications that include acquisition, data processing and presenting the information in a form suitable for easier understanding by the operators, programs for performing calculations for the identification, modelling,simulation and optimization, programs for initiating controls, warnings, alarms and for ensuring the communications safety.

2. The information system structure of the pilot installation for the separation of tritium

The information system complexity imposed a structure based on subsystems, as an essential means to increase the operational efficiency. The important subsystems and their roles are listed briefly below:

Interlocking and inter-conditioning system – ensures the control of the plant for the smooth operation with minimum leaks of toxic fluids; it also controls and commands the recovery of fluids from the plant and/or the building after the occurrence of accidents.

System for monitoring the dosimetric and quality of the ***emission***s, secures the personnel's dosage rate, checks the level of toxicity inside the premises as well as the release of gases into the atmosphere; it also supplies signaling values for the concentration levels of radioactive/toxic substances.

System for control, recovery and treatment of toxic gases – allows for the recovery of toxic gases in case of hazards resulting with leakage of toxic gases in concentration levels higher than the maximum admissible threshold.

Control system for plant draining in case of emergency – ensures the drainage of the plant in case of accidents; the system being activated for those values of the technological parameters corresponding to signals emitted from a radioactive fluids detector.

Supervising and control system for the ventilation equipment – ensures the ventilation of the facilities processing toxic fluids as well as the control room with the view to diluting their concentration in the air; it also starts up the gases recovery system in case of failure.

Central system of monitoring and control

The entire process is managed centrally from a control room isolated from the hall of the process. All information are concentrated here and are supplied in appropriate formats, both for computing devices and automatic management, and also for operators in view of manual observation and to start the calculations and the manual controls to obtain the plant operating conditions in accordance with the presetted research programs.

So that the information system to meet the requirements of the various areas described above, it was considered to be beneficial the software issues to make calls on the LabVIEW, a graphical programming language that allows develop applications using icons. Unlike textual programming languages, in which the instructions are those which cause the program execution, LabVIEW is using the flow of data which is highlighted by a suggestive graphic presentation.

Arguments in favor of this option are based on the fact that, more significantly than other programming languages, LabVIEW has extensive libraries of functions and subroutines which can be directly used in many applications, such as acquisition, processing, analysis, presentation and storage of data, measurement and display of various physical quantities, procedures of modeling, simulation and process calculations.

The monitoring system for the technological process of the tritium separation from heavy water installation, based on LabVIEW, implements the following functions:

- display synoptically schemes and instantaneous values of the parameters, as illustrated in Fig.1, Fig. 2, Fig.3 for the three main modules,
- setting and changing the alarm limits for monitored parameters;
- taking the screens from the safety and protection system.

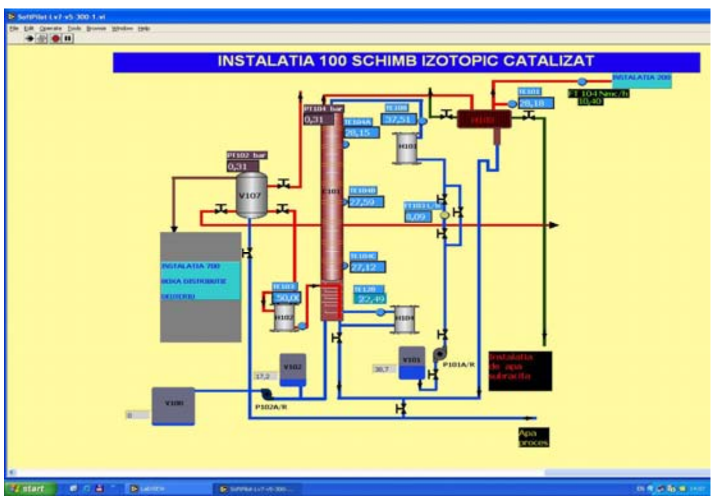

Fig. 1. Monitoring the isotopic exchange installation - front panel in LabVIEW

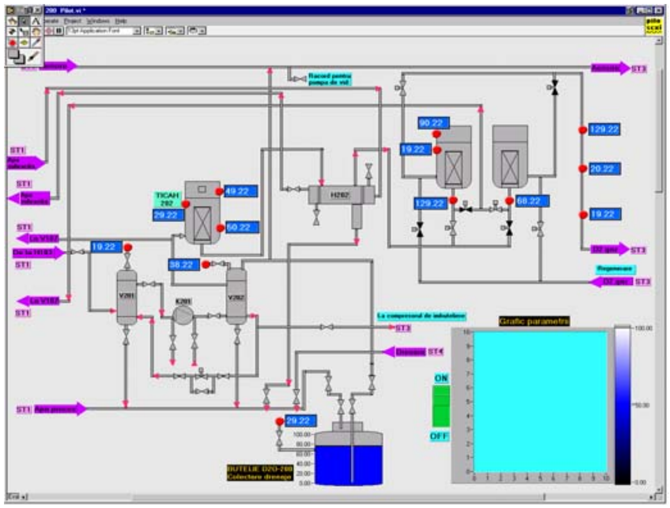

Fig. 2. Monitoring the installation of urification by catalytically burning - Front Panel in LabVIEW

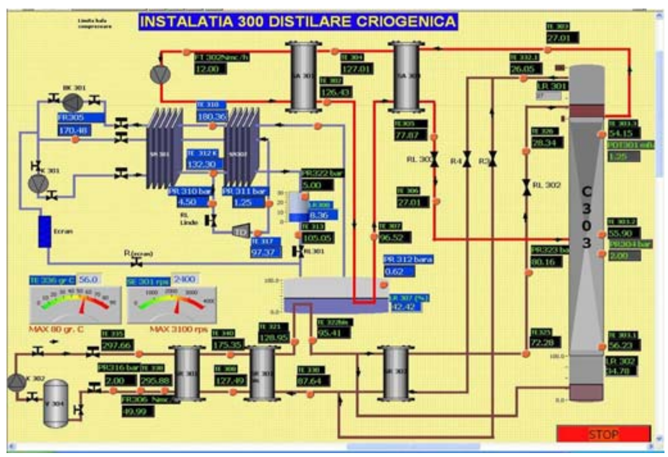

Fig. 3. Monitoring the cryogenic distillation installation in LabVIEW

3. Process modelling and simulation of the cryogenic tritium separation

The modelling process for the separation of tritium from heavy water calls to analyze the physics of phenomena underlying the separation process technology and uses mathematical equations that describe the phenomena in question.

The models used for the simulation, which consists in a graphical LabVIEW representation that displays the process behavior. The facilities that the LabVIEW application offers for modelling and simulation of cryogenic pilot plant are exemplified in the following, referring to the entropy and enthalpy of hydrogen in the cryogenic distillation.

In developing the model the starting point is the state equation of Beattie-Bridgemann:

$$p = \frac{RT}{\upsilon} + \frac{\beta}{\upsilon^2} + \frac{\gamma}{\upsilon^3} + \frac{\delta}{\upsilon^4} \tag{1}$$

where R is the gas constant, υ the specific volume of the gas and the equation coefficients are:

$$\beta = -A_0 + B_0 RT - \frac{cR}{T^2} \tag{2}$$

$$\gamma = aA_0 - bB_0 RT - \frac{cB_0 R}{T} \tag{3}$$

$$\delta = \frac{bcB_0 R}{T^2} \tag{4}$$

A_0, B_0, a, b, c are specific gas constants and are determined both theoretically and experimentally.

In (υ, T) relationship the differential entropy is expressed by:

$$dS = \frac{1}{T} c_\upsilon dT + \left(\frac{\partial p}{\partial T} \right)_\upsilon d\upsilon \tag{5}$$

Taking into account with the equation (5) the enthalpy becomes:

$$dh = c_\upsilon dT + d(p\upsilon)_T - \left[p - T \left(\frac{\partial p}{\partial T} \right)_\upsilon \right]_T d\upsilon \tag{6}$$

Equations (5) and (6) allow the calculation of the enthalpy variation between two states determined by the gas pressure and temperature on the path through the cryogenic distillation module. With this aim programs, in LabVIEW, dedicated to the numerical integration were developed and the pressure and temperature value are taken from the files of the monitoring system.

In Figure 4 is shown the LabVIEW front panel corresponding to the calculations of the enthalpy and entropy, for certain values of pressure and temperature (specified in the figure). Also is represented the saturation curve at hydrogen equilibrium and the T-s, temperature–entropy graph dependence.

Using T-s diagram is needed to determine the heat absorbed or released during a transformation, especially to study the thermodynamic cycles. In the front panel one can see also the values of enthalpy, entropy, temperatures in the primary circuit of hydrogen and constants included in the above equations (1-6),

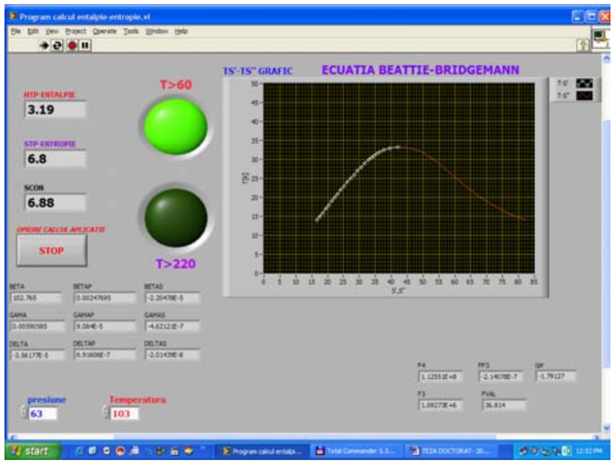

Fig. 4. Determination of the enthalpy and entropy for tritium separation installation - Front Panel in LabVIEW

4. Optimizing the cooling system of the cryogenic distillation module. Computing the turbodetentor efficiency using LabVIEW

The tritium separation is based on the cooling to very low temperature, e.g. 21K at the peak of cryogenic distillation column. For this purpose it is used the nitrogen as a cooling liquid, obtained from a turbodetentor. The turbodetentor performs, through relaxation, a drop of gas temperature, accompanied by an enthalpy decrease as a consequence of the mechanical work. The optimization refers to determining the values of pressure and temperature on the nitrogen liquefaction cycle at the input and output of the turbodetentor, which maximize the cooling power and efficiency. Starting from the equations of thermal balance on nitrogen liquefaction cycle, the relationship between gas temperature at the input and output of turbodetentor (Fig. 5) can be in the form:

$$T_{317} = T_{312}(1-\alpha) \tag{1}$$

$$\alpha = \frac{T_{312} - T_{317}}{T_{312}} \tag{2}$$

After several transformations based on physics of gases relationships the following equations are obtained:

$$\alpha = \eta \frac{\left(\frac{p_{312}}{p_{317}}\right)^{(\gamma-1)/\gamma} - 1}{\left(\frac{p_{312}}{p_{317}}\right)^{(\gamma-1)/\gamma}} \tag{3}$$

$$\eta = \frac{\alpha \cdot \left(\frac{p_{312}}{p_{317}}\right)^{\frac{(\gamma-1)}{\gamma}}}{\left(\frac{p_{312}}{p_{317}}\right)^{\frac{(\gamma-1)}{\gamma}} - 1} \tag{4}$$

η represents the turbodetentor efficiency and must be maintained at a value greater than or equal to 63%.

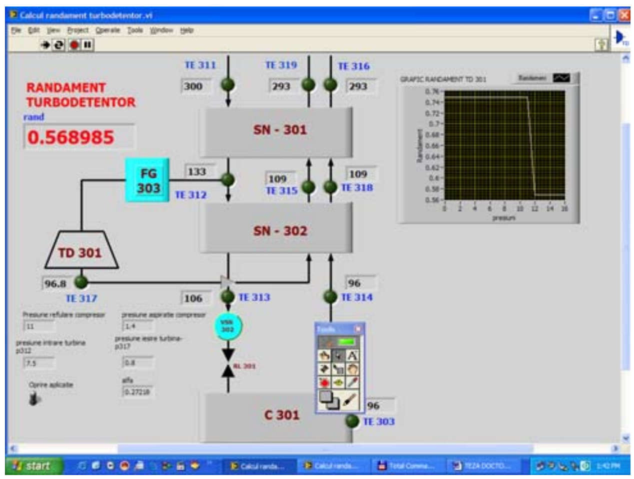

Fig. 5. Front panel of the application for calculating the turbodetentor efficiency at p_{312}=7.5 bar and p_{317}=0.8 bar, also T_{312}=133 K and T_{317}=96.8 K

It was observed that at the lower pressures to the input and output of the turbodetentor, with temperatures T312 and T317 constant, the turbodetentor efficiency decreased. At the lower temperatures T312 and T317 with p312 and p317 pressures constant, the efficiency of the turbodetentor increases, but not very much.

Following the calculations performed with the program developed in LabVIEW, it was found that the most influence in maximizing efficiency of the turbodetentor have the pressures at the input and the output of the turbodetentor p312 and p317.

5. Conclusions

In the paper were presented, briefly, some solutions developed by the authors for the information system to accomplish the monitoring and control of a pilot plant installation for the tritium separation from heavy water produced in nuclear reactors. In terms of hardware, the solutions aimed to the increasing the number of sensors and transducers and to the introduction of data acquisition systems of the last generation that provide more benefits in monitoring of performance parameters and also of the installation equipments. A special attention was given to the software issues, in this respect is emphasized the introduction of LabVIEW graphical programming that has proven to be particularly advantageous, having adequate facilities for applications as monitoring and control of processes, also including capabilities for modelling, simulation and optimization. The authors consider that by implementing solutions, partially illustrated in this paper, there are satisfied at an appropriate level the requirements of a pilot installation to ensure the flexibility of operating modes and to increase the quantity and quality of information necessary to perform complex research programs in the field of tritium separation.

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