USING LABVIEW AND FIELD POINT I/O MODULE FOR CATALYTIC ISOTOPIC EXCHANGE COLUMN CONTROL AND OPERATORS TRAINING

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***Abstract* – This paper presents the main advantages of using the programmable automation controller (PAC) and LabVIEW software in the operation of an isotopic exchange column which is part of ETRF (experimental tritium removal facility) from ICIT Rm. Valcea. Taking in account the advantages of Compact FieldPoint for using in industrial control application (advanced embedded control, data logging, headless operation and Ethernet-based data acquisition) personnel are able to operate an experimental catalytic isotopic exchange column under manual or automatic control. The very friendly interface and an alarm management system help operators to manipulate the performance of the control loops (TIC, FIC, PIC) in order to improve the operation of the column. The operators can visualize all parameters of the process, to check/modify the conditions of the all control loops, to identify/change the on/off status of dynamic equipment. For young engineers is easy to understand the PAC graphic interface as well as to investigate control loops behavior during PID tuning process. The time required to train the engineers to operate and control the column by our PAC system is minimal. Also, in the paper it is presented a short description of the mathematical model (based on Shimizu equations) of the isotope transfer along the column length used for package evaluation performances during the experiment.**

Keywords: *PAC, PID, control, monitoring*

1. INTRODUCTION

At ICIT Rm. Valcea was built an ETRF (experimental tritium removal facility). The TRF has the purpose to process heavy water with high content of tritium in order to reduce tritium concentration. A TRF mainly consist of three technological processes: catalytic isotopic exchange, purification and cryogenic distillation. Each process has its own particularities and monitoring and control requirements.

The initial data acquisition system based on analogue instruments is now upgraded to a fully digital system.

Virtual instrumentation has become lately very used for monitoring and controlling parameters in plants. In the specific case of ETRF there are a lot of process parameters which have to be monitored and controlled.

Taking into account the experimental character of catalytic isotopic exchange column a flexible hardware and software is required due to many process changes that must be implemented before the technology process is concluded. Therefore we used Compact Field Point which is a programmable automation controller (PAC) and LabVIEW software. PACs combine the specifications and reliability of programmable logic controller (PLC) with the software, flexibility, RAM, functionality of a PC resulting a great advantages for the users of this of technology [1]:

- flexible hardware architecture and software tools which come with advanced algorithms of optimization, modeling and control;
- Ethernet communication;
- capabilities for manage alarms and abnormal events;
- integrated diagnostic features in hardware, communications and control;
- ability to create historical data bases and efficient manipulation;
- security by having limits on the access to the parts of the control system;
- user friendly graphic tools that are useful in manipulating the system.

Furthermore, by taking advantage of historical data bases, operators can analyze the trends of the main variables of column: temperatures, pressures, the steam flow rate, etc.

The paper is organized into 5 sections. After the introduction, the second section presents a brief description of the catalytic isotopic exchange column. The third section illustrates how the PAC display options and control management system can provide easy operation of the column by operators.

Next, in the fourth section, it is presented a short description of the mathematical model of the isotope transfer along the column length and PID tuning.

Finally, the conclusions of this paper are found in the 5 section.

2. CATALYTIC ISOTOPIC EXCHANGE PROCESS

2.1. Description of the process

In Figures 1 and 2 is shown the P&ID diagram and system skid respectively. The main equipments from catalytic isotopic exchange system from ETRF are:

- catalytic isotopic exchange column (C101)
- water and gas heaters (H101, H102, H104)
- water transfer pumps (P101A/R, P102A/B)
- one condenser (H103)
- deuterium gas compressor (K201)

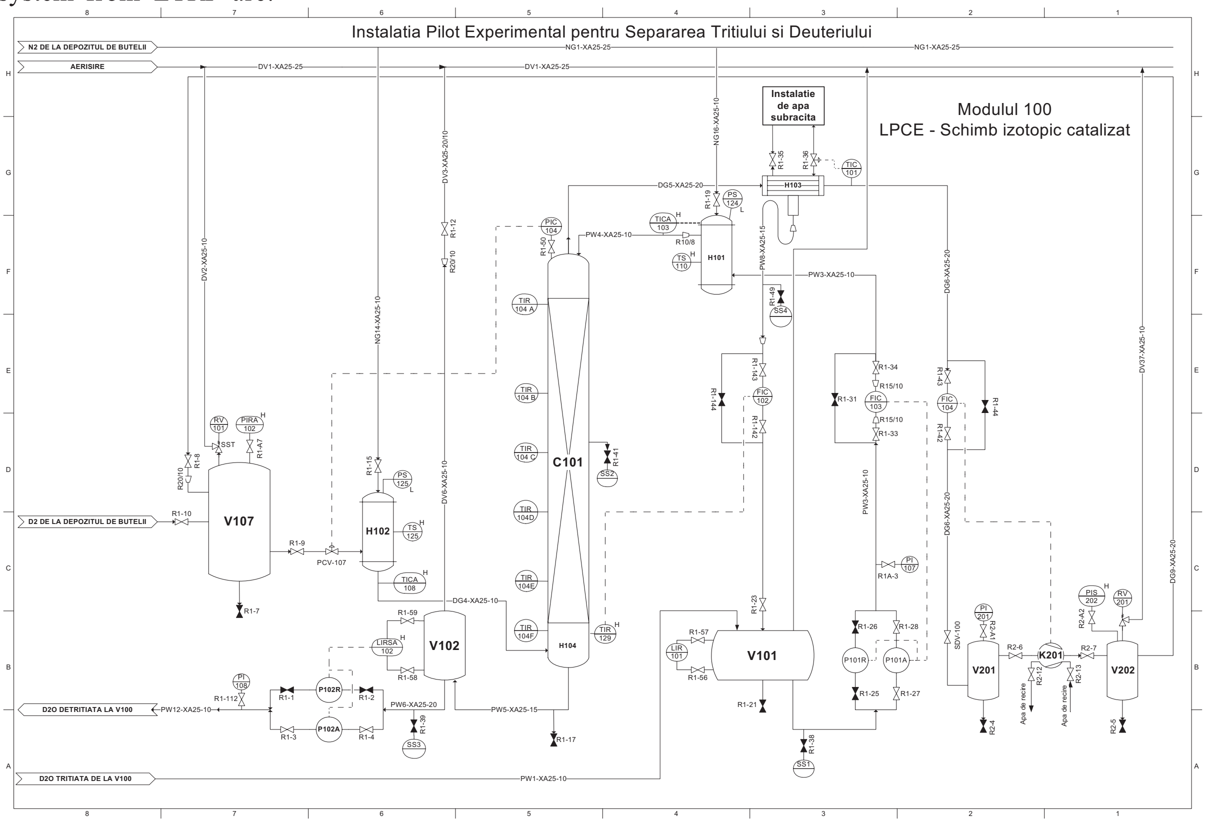

Figure 1. LPCE P&ID

In the LPCE process tritium is transferred from heavy water to deuterium gas into C101 column. The water and gas are circulated in counter-flow with gas inlet at the column bottom.

To operate the catalytic isotopic exchange column there are the following control loops that need to be working simultaneously: heavy water column feed temperature (TIC108) and flow rate (FIC103), hydrogen gas column feed temperature (TIC103), flow rate (FIC104) and pressure at the top of the column (PIC104), water vapor flow rate (FIC102), hydrogen gas temperature at the output of the condenser (TIC101). Also, transfer pumps and the compressor must be operated.

Figure 2. LPCE Skid

2.2. Objectives

There are three objectives:

1) to perform tests to assess the functional parameters of the column and compare by theory data;
2) to help young engineers to configure, test and understand how PAC system can control process.
3) to train the operators and familiarize them with the operation of the PAC system and the control of the catalytic isotopic exchange column, in order to operate an ETRF;

To accomplish the first objective, the column has to be operated al different operating points.

To evaluate the catalyst and ordered packing performances the temperature along the column, water and gas flow rate must remain constant for a time period. ETRF is an experimental facility and therefore, LPCE system is operated at different temperatures and flow rate values in order to investigate the separation efficiency and catalyst material performances. These requirements imply that is important to evaluate the performance of the control loops before make data acquisition in order to assure conditions for conclusive tests.

Table 1 shows the operating points of all control loops for the entire experiment

Parameter	Value
TIC108	60-90 ºC
TIC103	60-90 ºC
TIC101	12ºC
FIC102	0-5 kg/h
FIC103	0-12 Kg/h
FIC104	0-12 Nm^3/h
PIC104	0,5 bar

Table 1. Operating points

To meet the second goal, the engineers are taught how to manipulate a PAC system and to see how things are going for different configurations.

To achieve the third objective, control room operators receive training to how to control the process using HMI interface.

2.3. Safety hazards

Another important point regards the safe operation of the process. So, pumps and compressor has to be protected to membrane breaking, low suction and high discharge pressure. Also, compressor must have protective loops for cooling water flow and oil pressure. To avoid heaters to rich high temperature, supplementary temperature protective loops has to be implemented.

3. HUMAN MACHINE INTERFACE (HMI) OF PAC SYSTEM

The use of the PAC graphics interface makes isotopic exchange process operation easier for personnel (operators and researchers). The HMI has the following functions: (1) to provide visualization of process parameters; (2) to enable interaction with the process; (3) to provide alarms and event notification to operator about abnormal situation in the plant.

Figure 3 shows the overview graphic display of the catalytic exchange process, which provides a representation of the process and makes it easier for operators to visualize what is happening. Through this overview display, it is possible to monitor the main parameters of the column, check the conditions of the most important control loops, and identify the on/off status of the discrete components which are operating in the process. For instance, the temperature over the column can be monitored by checking the tag numbers TI104A to TI104E. Moreover, the key variables of the control loops can be viewed. Finally, the pump and compressor status is identified by their color, as it showed in Table 2.

According with Table 2, the pump P101R from Figure 3, is stopped, no alarm present, in manual mode, power circuit available and can not be started (start permissive OFF).

To interact with the process, detailed displays which contain specific control functions to operate the column, can be used. Figure 4 shows one of these detailed displays available in the LPCE column.

Pump Symbol	Red Green	Running Stopped
Fault Symbol	Not visible Yellow	Normal Alarm
Auto/ Manual	A (green) M (orange)	Auto Mode Manual Mode
Power availability	Not visible UN yellow	Available Unavailable
Permissive Start	Not visible NP yellow	Start permissive ON Start permissive OFF

Table 2. Pump/compressor mimic display

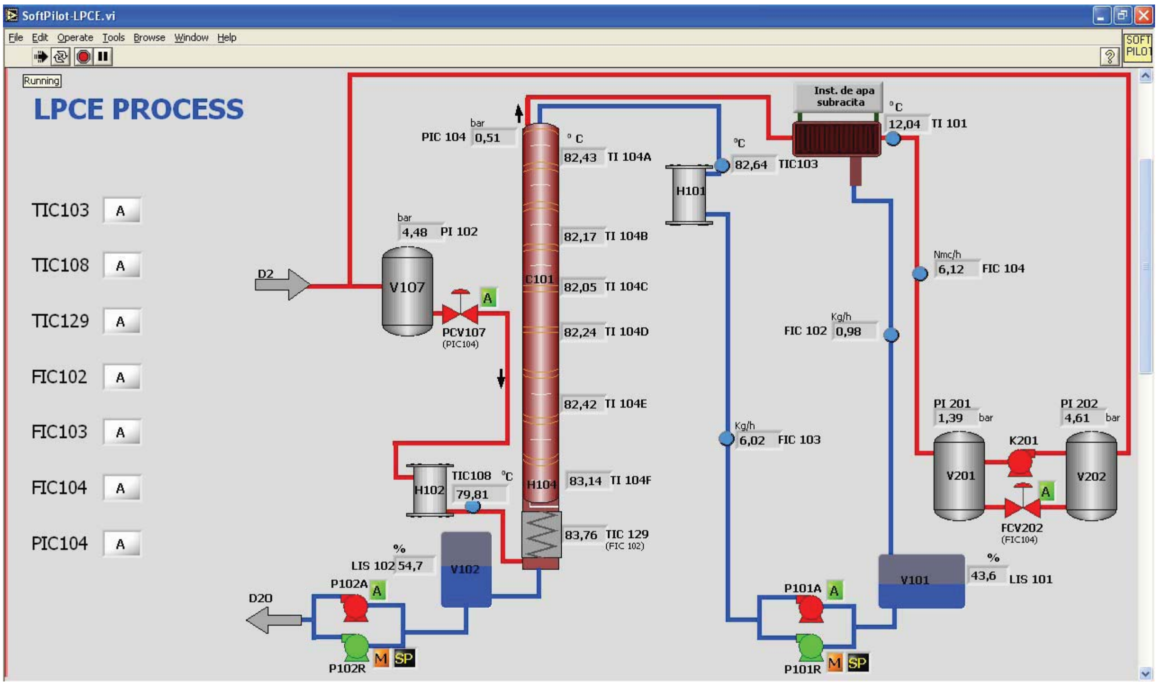

Figure 3. HMI -LPCE Display

With this detailed display it is possible to control the functioning of 4 pumps and one compressor. This print-screen shows us that pumps P101A and P102A are working, in AUTO mode, command given by PAC (not from local button), since that P101R and P102R are not working, they are in MANUAL mode and controlled also by PAC. For both pump groups 101 and 102, there are an start-permissive button which set the active pump.

Figure 4. Control Display- LIS102

Also, there are available detailed displays, to control the level of the V102 tank by setting up a control loop. The operator has the choice to configure the set point levels (LSH, LSL) and in AUTO mode, level LIS102 loop commands pump start at maximum level (LSH) and stops it at minimum level (LSL).
Also, the operator is able to manipulate the opening of the valve FCV202 from the control loop FIC104, which determines the deuterium flow-rate in the column, or PCV107 of control loop PIC104 for top column pressure. In automatic mode (AUTO), the final control element is manipulated automatically through a PID controller and the set point for the control loop is manually set by the operator. A cascade mode control between FIC103 (master) and TIC129 (slave) is operated. The master controller sets the set point for the slave controller. The set point for the master controller is set by the operator. It is also possible to control independently these two loops, by disabling cascade mode control.

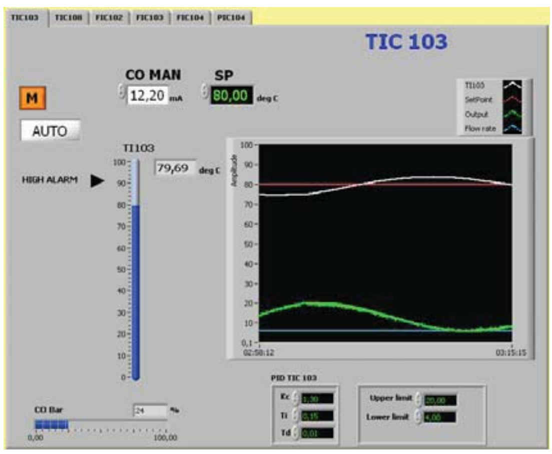

Figure 5. Control loop TIC103 faceplate

On the other hand, with the idea of having specific information about the separate loops that are operated in the isotopic exchange column, Figure 5 illustrates a typical faceplate display. This faceplate corresponds to feed water temperature control loop TIC103. Usually, the faceplate display shows the controlled process variable and the output of the control loop. Furthermore, the set point and the operating mode of the control loop can be changed. Additionally, detailed information is available related to the parameters of PID controller and the different alarms that can be authorized in this control loop with its respective values of activation.

4. EXPERIMENTAL DATA ANALYSIS

The following formula (1) shows the practical model of the PID controller:

$$u(t) = K_c\left[(SP - PV) + \frac{1}{T_i}\int_0^t (SP - PV)dt - T_d \frac{dPV_f}{dt}\right] \quad (1)$$

The default ranges for the parameters **SP**, **PV**, and **output** correspond to engineering units. The parameters T_i and T_d are specified in minutes. In the manual mode, you can change the manual input to increase or decrease the output. To perform the manual to automatic transfer it is better to manually drive the process variable until it meets or comes close to the set point.
We used LabVIEW PID advanced VIs for control loop which utilize the following formula represents the current error used in calculating proportional, integral, and derivative action.

$$e(k) = (SP - PV_f)(L + (1 - L) \cdot \frac{|SP - PV_f|}{SP_{range}}) \quad (2)$$

where SP_{range} is the range of the set point, and L is the linearity factor that produces a nonlinear gain term in which the controller gain increases with the magnitude of the error. If L is 1, the controller is linear.

In Figure 6 the faceplate for TIC103 has a very good control behavior, with small error and a approximate linear curves for the process value (PV) and controller output signal (CO). In first case (Figure 5), we used Ziegler - Nichols heuristic method for manually determining PID parameters, since that in second case, LabVIEW autotuning module was used.

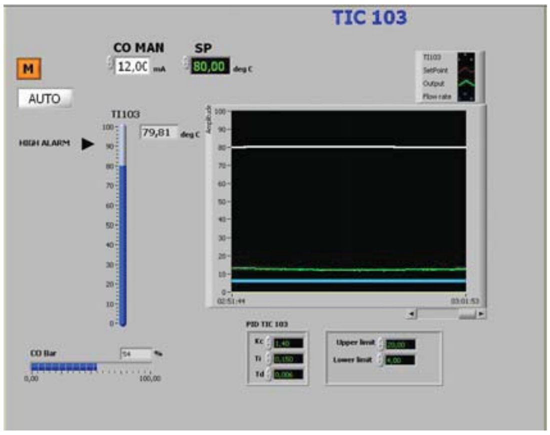

Figure 6. Control loop TIC103 optimized

Based on operating points from Table 1, the experimental set-up and data acquisition, the operator can determine the efficiency of the mass transfer. In Figure 7 is presented the diagram of the mathematical model for LPCE process. The model presents the isotopic transfer between the three phases in contact: liquid, vapor and gas.
The mathematical model of the isotope transfer along the column length is reported to the differential system which describes the successive isotope exchange. This model is based on Shimizu [3] equations which in the infinitesimal height of the column dz produces the isotope transfer τ:

$$L \cdot \frac{dx}{dz} = \tau_d = k_d A_d[x - \alpha_d \cdot v_d] \quad (3)$$

$$V \cdot \frac{dv_d}{dz} = -\tau_d = k_d A_d[x - \alpha_d \cdot v_d] \quad (4)$$

$$V \cdot \frac{dv_d}{dz} = \tau_c = -k_s A_s[v_c - \alpha_s \cdot y] \quad (5)$$

$$G \cdot \frac{dy}{dz} = \tau_s = k_s A_s[v_s - \alpha_s \cdot y] \quad (6)$$

where y,v,x are the isotopic concentrations in gas, vapor and liquid; α_d, α_s are the separation factors for distillation and catalytic exchange; A_d, A_s are the area of the interfaces gas-vapor and vapor-liquid; k_d and k_s are the mass transfer coefficients from distillation and catalytic exchange respectively.

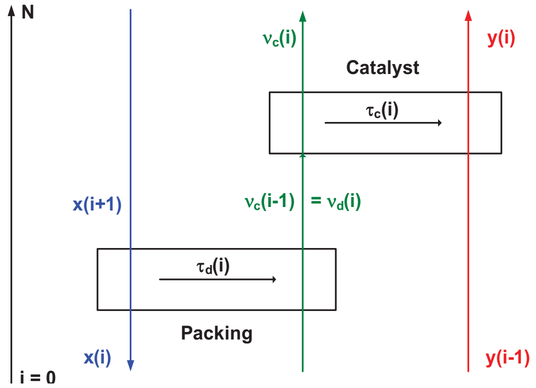

Figure 7. LPCE model diagram

In Figure 8 are presented the values for the mass transfer coefficient on each isotopic exchange process and distillation and also flow-rate (liquid, gas and vapor) for this experiment.

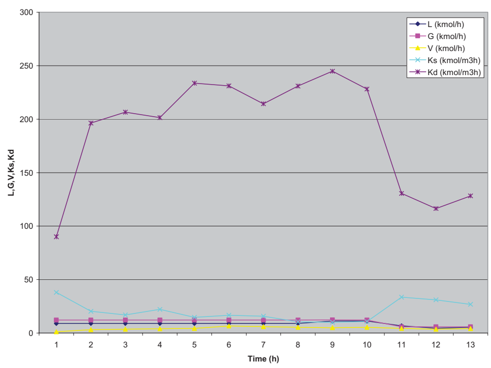

Figure 8. Variation of k_s, k_d

One can observe that k_d is decreasing and k_s has an opposite behavior when flow-rate decrease.

In Table 3 is presented the mass transfer coefficient k_{med} expressed like function of k_s and k_d for different values of molar rate G/L, over one month experiment.

T(°C)	G/L	HTO Con. (Ci/kg)		k_{med}
		top	bottom	(kmol/m^{3}h)
60.5	0.15	1.111E-7	1.084E-7	8.0
60	0.24	1.034E-7	9.865E-8	24.0
60.5	0.40	1.080E-7	1.008E-7	23.5
61	0.77	1.112E-7	9.814E-8	37.0
61	0.92	1.110E-7	9.654E-8	37.3

Table 3. Experimental results

The experimental results show us the performances of the catalytic package used at tritium transfer from water in gas. Comparing these results by previous data obtained at deuterium transfer from water in gas [4], it was remarked a decrease of exchange performances with 60%.

5. CONCLUSIONS

The experimental data computed with Shimizu mathematical model offer us an image about mass transfer coefficients for catalytic isotope exchange, respective for distillation which characterize the performances of catalytic package at low tritium concentration.

The second conclusion is that the time required to train personnel to use an advanced HMI interface for monitor and also to control the process is not so long. Basically, the training took few hours, and was proved by practice.

The last conclusion and maybe the most important regarding the scope of this paper is that using a PAC system for set-up experiments in research environment allows to young engineers to have a large amount of data available to observe the performances of control loops. Furthermore, there is flexibility to change standard control methods in the process with the option of modifying the PID parameters.

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