AUTOMATION OF ION EXCHANGE PROCESS USED FOR DESALINATION OF WATER

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Abstract: The problem for automation of an ion exchange process for desalination of water is considered. The paper describes first the process technology and the necessity to automate the process behaviour in order to achieve the needed quality of water with minimum consumption of resin and chemicals for regeneration. The instrumentation needed for measurement, data acquisition and control implementation is described.

The algorithm for whole control sequence implementation is given. The control sequence realization depends on different logical conditions imposed by the process technology. These conditions are shown and included in the control sequences.

LabVIEW program realizing the control sequences is described. The results are presented. *Copyright © 2003 IFAC*

Keywords: algorithms, automation, computer control, conductivity, control, diaphragm valves, hardware, optimal control, sensors.

1. THE ION EXCHANGE PROCESS

The ion exchange (IX) is a very convenient chemical process for wastewater desalination. The considered ion exchange is a counter current (resin/liquid) process with the up flow period (*T*) considered as a control action (Dube and Tzoneva, 2001; Project, 1982; Slater, 1974).

Ion exchange is a chemical process that involves replacement of ions of the same charge from a liquid phase to a solid phase. The ion exchange as used for water purification removes salts from the water (desalination), which are the main constituents of sewage water.

In water treatment application, ion exchange resins (charged beads of micrometers in diameters) are coated with replacement ions H^+ (hydrogen ions) and OH^- (hydroxide ions) for two main phases of the ion exchange process respectively. In the cation phase the H^+ ions will exchange with Na (sodium) ions from sodium chloride (NaCl) salt in the water being processed. During the anion phase the Cl^- (chloride) ions exchange with OH^- ions (Dube and Tzoneva, 2003).

The basic ion exchange counter current (CCIX) configuration consists of four columns, two for cation phase and two for anion phase. The columns are operated in a multistage approach (Dodds, *et, all* 1973; Dube, 2002). In the cation phase, salts in water being purified are converted to a weak acid solution, by exchanging positive ions. In the anion phase the weak acid solution is stripped off the acid by exchanging negative ions and only pure water remains. The desalination mechanism is to convert the salt into acid using a strong acid cation exchange (cation load column) and subsequently remove the weak acid by absorption using weak anion exchange (anion load column). The secondary columns are for regeneration of partially exhausted resins (Horn, F. J. M. 1967; Dube and Tzoneva, 2003).

The ion exchange pilot plant is built at Peninsula Technikon, Department of Chemical Engineering. The paper describes part of the work done in design and implementation of personal computer (PC) system, developed in the Department of Electrical Engineering, for monitoring and control of the cation part for the plant (Dube, 2002; Dube and Tzoneva, 2001; Project, 1982).

Associated with each column is the system of pumps, valves and pipes, which enables the liquid and resins flows to be switched as required at various operation stages. pH and conductivity sensors are used to determine acidic strength and ion concentration of the solutions at different strategic points. These measurements are in turn used in determining control actions of the plant (opening and closing of valves).

Columns are divided into eight stages by multi orifice plates and each stage is half a meter high thus, each column is four meters high. The load columns and regeneration columns are 400 mm and 160 mm in diameter respectively (Dube, 2002; Dube and Tzoneva, 2001; Dube and Tzoneva, 2003; Rosen, 1980; Slater, 1974).

The main objective of the process is to maintain the operating conditions such that the required quality of water is produced at constant throughput for the minimum consumption of regenerant chemicals. This aim is achieved by introduction of a modern instrumentation and PC system for full automation of the process. The instrumentation and algorithms for implementation of the control sequence are described in the paper.

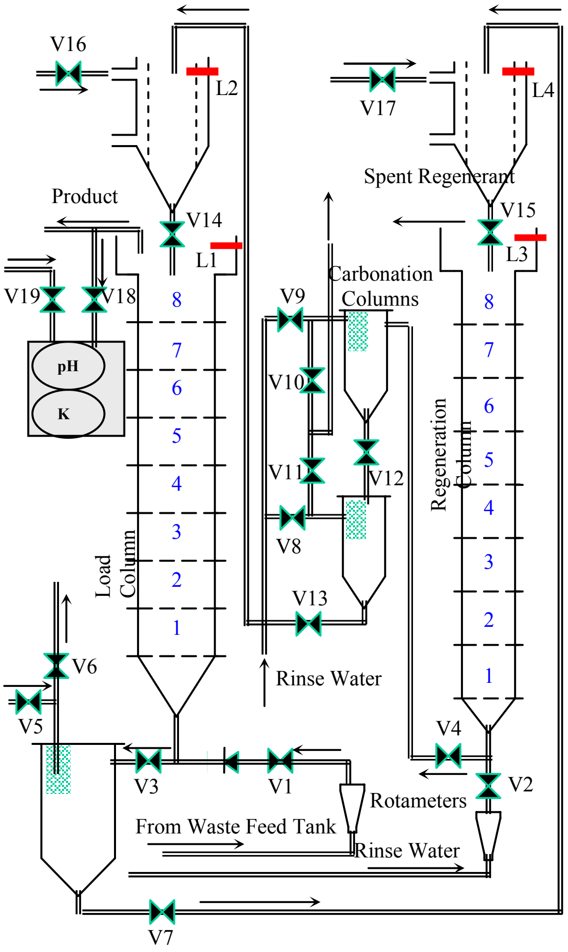

Fig. 1. The Ion Exchange Pilot plant (cation phase) as built at Peninsula Technikon Chemical Engineering Department.

2. CONTROL STRATEGY

Careful control operating conditions are necessary to ensure that for a given desalination level, maximum water output is produced with minimum regenerant chemicals consumption. This is achieved by designing an optimal control for the two main regimes of work: 1) start-up requirement to be done for a minimum time to reach steady state and 2) steady state operation under the influence of slowly varying disturbances.

To achieve optimal control a PC based control system is developed, whereby the column cycle times and regenerant feed rates are automatically optimized on the basis of salinity as determined by the measurement of pH and conductivity at different points on the plant (Fig. 2). These measurements are then processed and used for the calculation of the sodium (Na) concentration at the output stream (cation load output stream for this investigation) using criterion for minimum of the salt concentration in the output flow and special multistage model of the IX column. Based on the calculation, a control action is then activated which involves the switching of relevant valve for the relevant control required. The calculated control is included in the automatic control sequence implementation described in sections 4 and 5. The following streams are currently used for measurement and monitoring of the plant: feed-water input stream (cation input), and cation output (acidic stream).

The computer control also performs on-line monitoring function with a comprehensive measurement and record keeping for the plant variables. Computer based monitoring and record keeping further helps in plant operation while eliminating the need for highly skilled operator (Randall, 1984; Thurston, C. W. 1980).

3. DATA ACQUISITION AND CONTROL INSTRUMENTATION

The hardware system is designed such that it provides an operator with interactive data display including the values of the analog measurements of pH and conductivity of flows, status of levels and valves in the plant. The system must also realize manual or fully automated control of the flows in the process. The construction of instrumentation with the main goal in mind is to develop a system that does not require any sophisticated processing technologies but be able to achieve a high level of water purification (Fig. 2).

Data acquisition is very important for implementation of any control system. Prior to the implementation of any control system for process automation, reliable data should be acquired by the computer system and data should be available to the computer in a convenient form. Most of the data acquisition (DAQ) systems would require that a signal conditioning be used to convert the voltage or current produced by the sensors to a convenient signal that the computer can use. The developed data acquisition system consists of the following parts: the PC, signal conditioning (amplification, isolation, filtering, excitation and linearization), analog and digital inputs and digital output channels. This section is composed of, the DAQ board (PC30GA_ADV), ADPT5050 adapter connector, Current to Voltage Converter (PC71 card), pH sensor (pH S-mA), Conductivity sensor (**bürkert** CONDUCTIVITY 8225) and a power supply (Fig. 2).

The DAQ card (PC30G_ADV) is used for acquisition of both analog and digital signals (input and outputs) and then for the processing of the received data. The signals from the pH and conductivity sensors are a low current signal. These signals are connected via the current to voltage converter card, the PC71. The pH sensor is used to measure pH in the input feed and output stream of the cation load column. The conductivity sensor is used to measure conductivity of the feed stream and the output stream of the cation load column. Data acquired from both sensors is then used for calculation of the concentration of salt in the input and output column flows.

The adapter 5050 features three connectors, IDC-50 male type, the DB-50 male connector and 51-pin screw terminal blocks, for use with external devices. All three connectors are mapped one – one. A 24V external power supply is used for powering the pH sensor with its meter and the conductivity sensor with its meter.

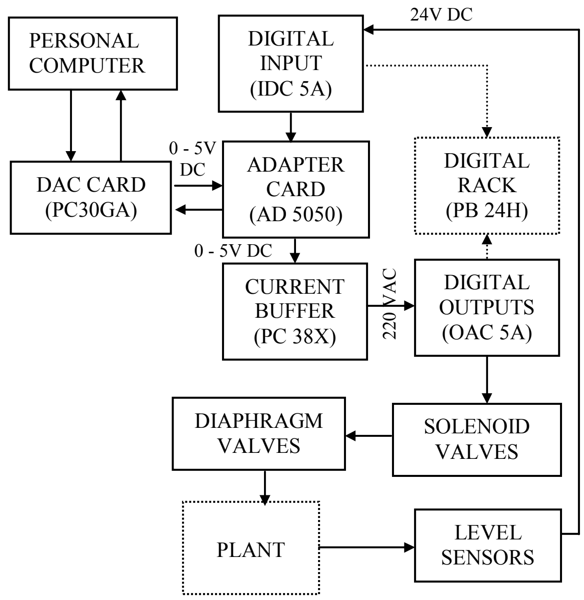

Fig. 2. Digital Inputs and Outputs to and from the Computer to Valves and from Level Sensors.

The digital section of the plant is composed of the following: DAQ (PC30G ADV) card, interface adapter (ADAPTER 5050 card), current buffer (PB 38X) card, digital (Input/Output) module mounting rack (PB 24H), Digital Input Modules (IDC 5A), digital output modules (OAC 5A), level sensors (**electro-**LV1 LIQUID LEVEL CONTROLLER), solenoid valves (Bulletin 2830), diaphragm valves and external power supplies. Two 5V external DC power supply are provided for use with the digital IO mounting rack (PB 24H).

The IDC 5A digital input module converts digital signals into a numerical value that can be interpreted by the computer. The module output is a TTL logic digital signal of 0–5V (ON or OFF). The digital output modules (OAC 5A) use 0–5V signals to switch its output of 220V AC to control the AC solenoid valves. This module connects to the mounting rack which supplies it with the necessary 5V to drive its output. The level sensors here are used to give information about the levels in catchpots and hoppers.

4. OPERATION SEQUENCE OF THE CCIX COLUMN

There are three distinct operational cycles, the up flow, resin settle and pull down periods for both the cation and regeneration columns which allow the liquid to be switched as required at various operational stages. The regeneration flows are obviously much faster than the load flows due to its small volume (i.e for the regeneration column a number of operational cycles would lapse while the load column is still busy with up flow period).

Step1: Liquid Up flow

During the up flow period water to be treated (feed water) is fed through the bottom of the load column via V1. The solution flow rate into the column is controlled through an automatic sensing device based on the position of a float within a rotameter tube. The up flow period typically lasts for about 30 minutes to 1h 30 minutes depending on the flow rate. During this up flow period, the resin on each stage of the contactor is fluidized as the feed passes through each stage. The sodium chloride salt which is the main constituent of feed water is split is then split. On completion of the up flow period, the feed flow is switched off and the resin is allowed to settle.

Step2: Resin Settle

The length of this period is set to allow complete settling of the fluidized column with each stage of the column. It is typically 30 seconds but varies from column to column with the plant design.

Step3: Resin Pull down

Each resin settle cycle is followed by a much shorter down flow cycle to transport resin from one stage to the stage below. This period is only operational in the control of the column and it is not based on a time cycle. Instead a sensor placed on top stage of the column (L1, L2 and L3, L4) causes switching to occur when the liquid level in the column has dropped by a certain preset volume. In this manner, the volume leaving the bottom of the column can be accurately controlled. The resin at the bottom stage is first moved to a catchpot below the column. From the catchpot it is pumped to the top stage of the next column, regeneration if the resin is from the load column and to the load column if the resin is a regenerated resin. After the pull down period the resin occupies about half the stage height, this means that each stage is fluidized at 50%. When the liquid level sensor terminates pull down, the up-flow commences.

Various periods in a column cycle may be summarized as follows, primary cycles (up flow, settling, pull down) and secondary cycles (resin transport, rinse). The first flows, primary cycles are regulated on the basis of time. On commencement of the next up flow period, resin that was pulled down to both the cation and anion regeneration catchpots is immediately transferred to the load columns. At the entry of each catchpot is a slotted resin screen which allows solution but not resin to pass through the screen opening.

The same sequence is followed for each column with only difference in timing since the regeneration column has small capacity.

The resin stage volume is the volume which when expanded by the set flow rate fluidizes to fill the particular stage under consideration. If the pull down volume is less than the stage volume, then a degree of backmixing is introduced. Alternatively if the pull down volume is greater than the stage volume resin bypass occurs (efficient utilization of resin). The pull down volume and resin capacity together determine the resin equivalent flow per cycle (Project, Vol. 3, 1982).

5. CONTROL SEQUENCE ALGORITHM

The principal control variable is the up flow time for the load column. The control and monitoring of valves is used to achieve the automation control sequence as shown by the tables (Table 1, 2) and algorithms below (Fig. 3, 4).

Level sensors are connected such that the high levels (L2 and L4) are monitored from the top catchpots and low levels (L1 and L3) are monitored on the hoopers.

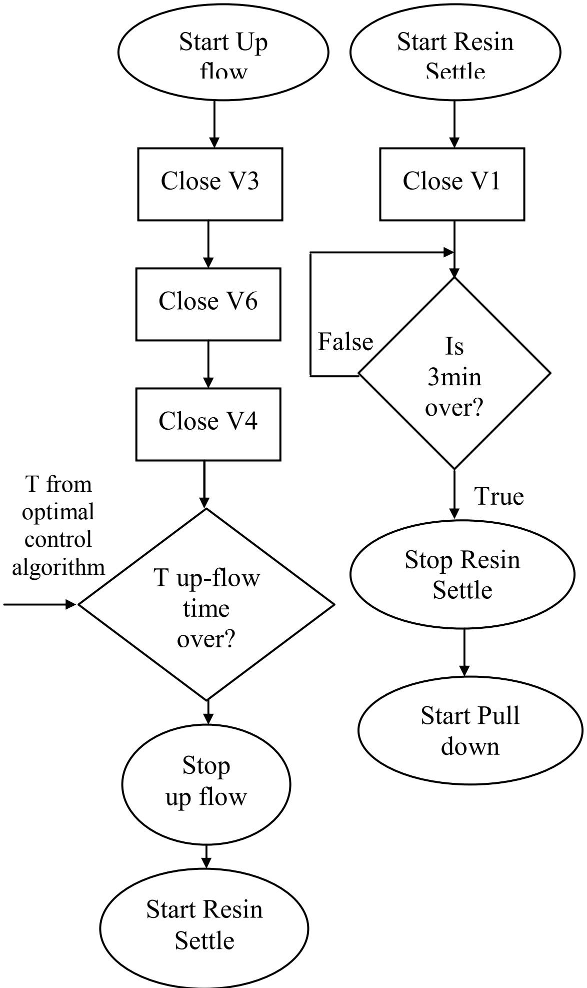

Fig. 3. Flow chart diagrams for Cation Load Up flow and Resin Settle periods.

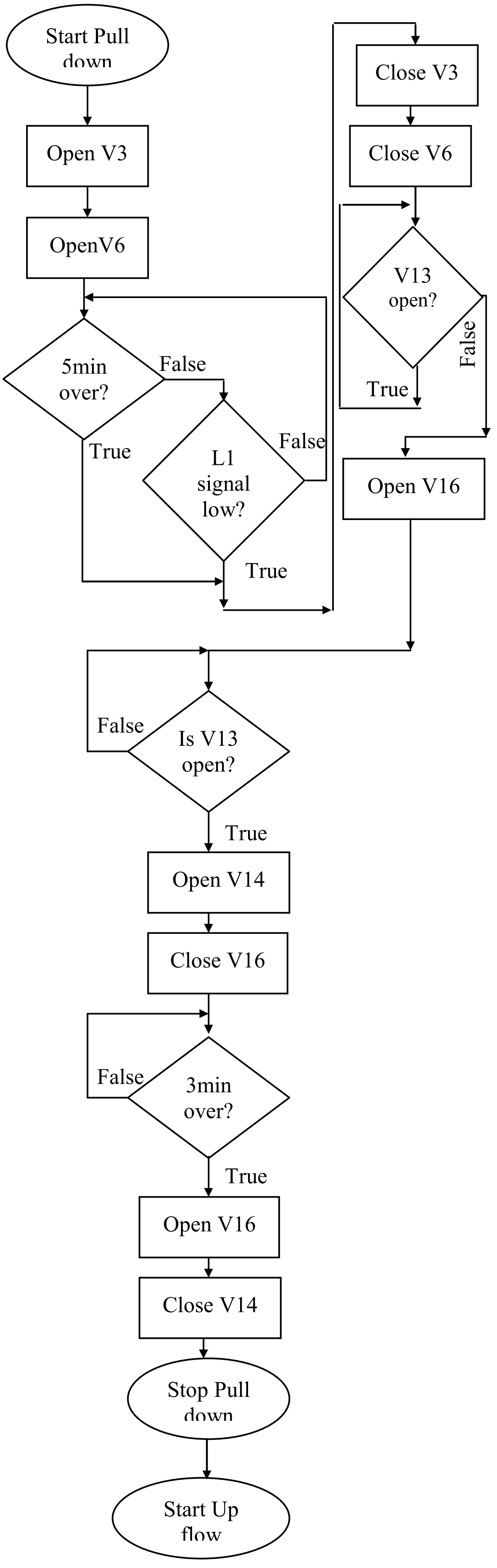

Fig. 4. Flow chart diagrams for Cation Load Pull down period.

Table 1a. Cation Load valve sequence.

O – Open
X – Open/Close
C – Close

CATION LOADING PERIOD	Valve Number																	
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18
Up flow	O	X	C	X	X	C	C	X	X	X	X	O	X	C	X	X	X	X
Settle	C	C	C	C	C	C	C	C	C	C	C	O	C	C	C	C	X	X
Pulldown	C	C	O	C	C	O	C	C	C	C	C	O	C	C	C	C	X	X
Fluidization	X	X	X	X	X	X	X	X	X	X	X	O	C	C	X	O	X	X
Transport	X	X	C	X	O	C	O	X	X	X	X	O	X	X	C	X	X	X

Table 1b. Cation Regeneration control valve sequence

CATION REGENERATION PERIOD	Valve Number																	
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18
Up flow	X	O	X	C	X	X	X	C	C	C	C	O	C	X	C	X	X	X
Settle	X	C	X	C	X	X	X	C	C	C	C	O	C	X	C	X	X	X
Pulldown	X	C	X	O	X	X	X	C	O	C	C	O	C	X	X	X	X	X
Fluidization	X	C	X	C	X	X	X	X	C	X	X	O	X	X	C	X	O	X
Transport	X	X	X	C	X	X	X	O	C	O	O	O	O	C	C	X	C	X

The control sequences are developed according to the requirements of the process technology. The time for settling down and pull down can be adjusted according to the calculate values of the up flow period.

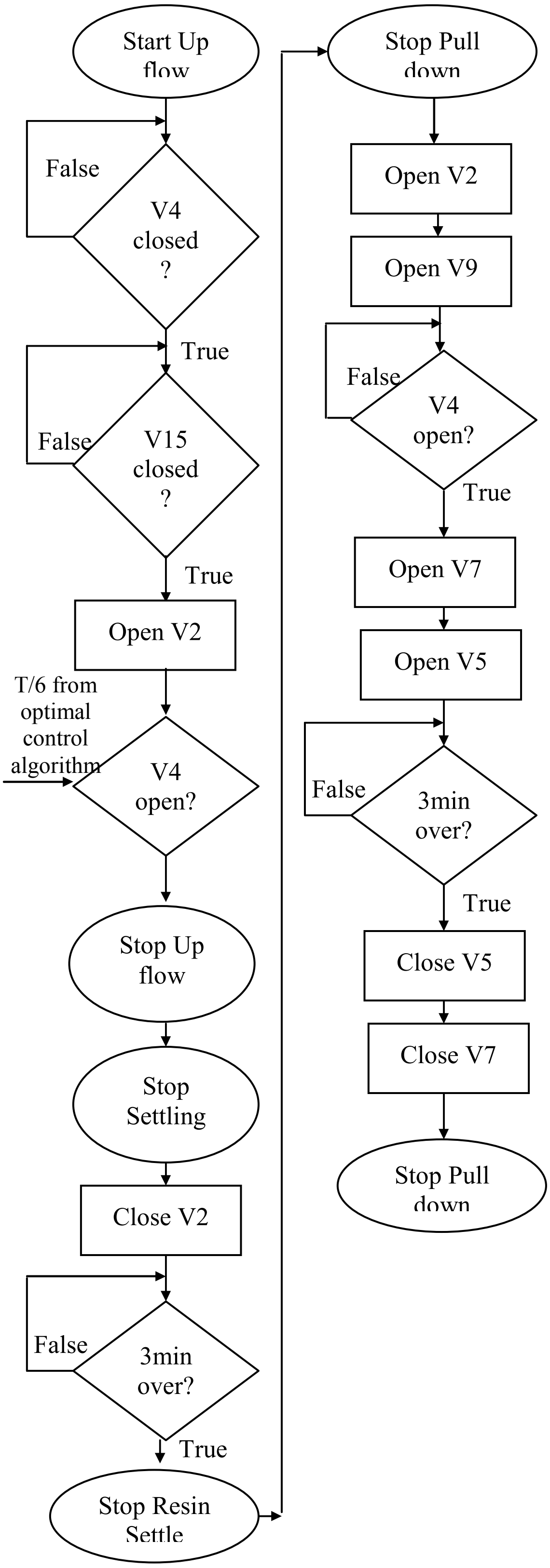

Fig. 5a, b. Flow chart diagrams for Cation Regeneration up flow and pull down periods.

6. LABVIEW PROGRAM FOR DATA ACQUISITION

The real time control of the process is implemented in the programming environment of LabVIEW (Fig. 6). The system functions in the regime of repetitive optimization where the value of the control action: 1) up flow period is recalculated according to the values of the measured main disturbance for the process and 2) the concentration of sodium into the input flow.

The value of the control action is sent to the subroutine for implementation of the control sequence. The front panel and diagram of this programme are shown on Fig. 7a,b.

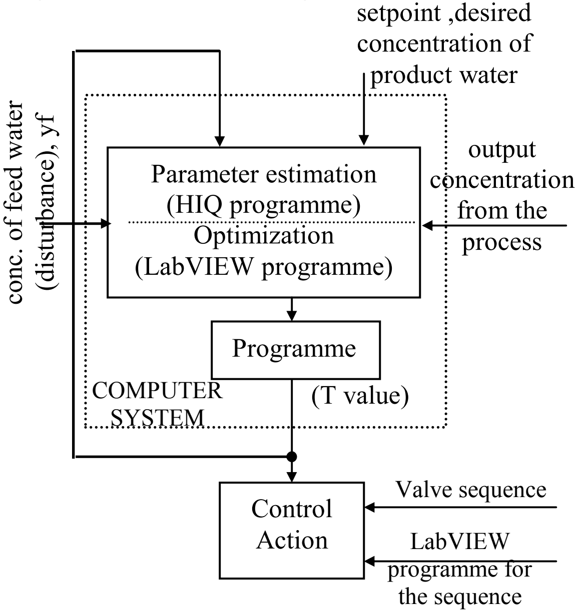

Fig.6. The real time control sequence implementation with the PC control.

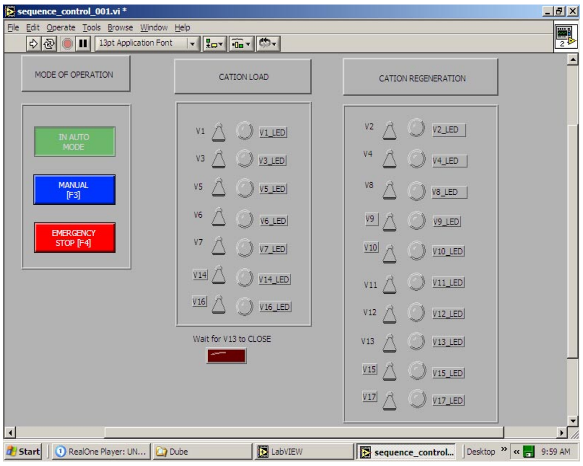

Fig. 7a. LabVIEW subroutine for implementation of the control sequence, the front panel.

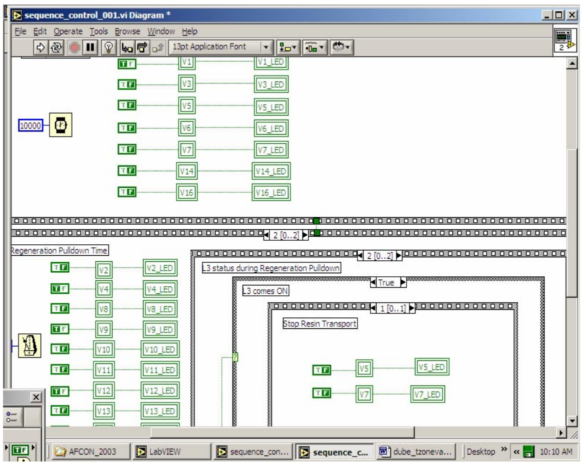

Fig. 7b. LabVIEW subroutine for implementation of the control sequence, the block diagram.

7. CONCLUSION

Instrumentation and control sequences designed and used automation of the ion exchange process desalination of water are described. They are part of a system for automatic control developed in the environment of the programming technology LabVIEW. The control system can work in two modes, manual and automatic. Manual control can be implemented in two ways, from the control panel and from the screen on the by directly clicking on the corresponding valve.

The automation of the control sequence allows the problem with interlocking of the valves to be overcome, due to the flexibility of the developed algorithms and programmes.

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REFERENCES

Athans, M. (1971). On the design of PID using Optimal Linear Regulator Theory. *Automatika,* **Vol.7**, pp. 643–647.

Dodds, R., Hudson, P. I., Kershenbaum, L. and Streat, M. (1973). The Operation and Modelling of a periodic, countercurrent Solid-liquid Reactor. *Chemical Engineering Science* **Vol.28**, pp. 1233–1248.

Dube, N. M. and Tzoneva, R. (2001) Method for Optimal Control of Ion Exchange Process for Desalination of Water. *The Third International Conference on Control and Automation* (ICCA '01). CD FAO1–4, pp. 579–583.

Dube, N.M. (2002). Modelling and Optimal Control of Ion Exchange Process. *Dissertation*, pp. 53–69, pp. 142–150, 215–269, .

Dube, N. M. and Tzoneva, R. (2003) Development of a Mathematical Model for Ion Exchange Process for Desalination of Water. *The Fourth International Conference on Control and Automation* (ICCA '03). CD WM05–6, pp. 579–583.

Horn, F. J. M. (1967). Periodic Countercurrent Processes, *I and EC Process Design and Development,* **Vol. 6** No. 1, pp. 30–35.

Project, (1982). Ion Exchange for Desalination and Tertiary treatment of Effluents, *Department of Chemical* Engineering, University of Cape Town (UCT), **Vol. 1–5**.

Randall, E.W. (1984). A microprocessor-Based Data Monitoring and Control System for a Continuous Ion Exchange Plant. *Desalination,* **Vol. 49**, pp. 169–184, Amsterdam: Elsevier Science Publishers B.V.

Rosen E.M., (1980). Steady State Process Simulation: A State of the Art Review, in Computer Applications to Chemical Engineering (R.G. Squires and G.V Reklaitis, Editions; ACS Symposium Series **Vol.124**, *American Chemical Society*, Washington DC).

Thurston, C. W. (1980). Computer-aided Design of Distillation Column Control, Part 1 and Part 2. *Hydrocarbon Processing*, 65–77.

Slater, M.J. (1974). Continuous Ion Exchange in Fluidized Beds. *The Canadian Journal of Chemical Engineering*, **Vol. 52**.