

# CONTROL OF FLOW CYCLES IN AN ION EXCHANGE DESALINATION PILOT PLANT USING LabVIEW™

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## ABSTRACT

The paper presents an algorithm and a program implementation for real time control of flow cycles in an ion exchange desalination pilot plant using a personal computer and LabVIEW™ as driver software. The pilot plant and the control systems are designed, developed and implemented by students for the purpose of student education and research using recent computer and control technologies. Hardware and software components of the control systems are described and discussed. The relevant LabVIEW™ code is presented. The program fully automates the operation of the plant. The implementation is inexpensive, safe, reliable and stable and may be replicated in other educational environments.

**Keywords:** Ion exchange process, process cycles, Control system components, LabVIEW™ software.

## 1. INTRODUCTION

Modern control and computer technology has given rise to an increased demand for engineers who are required to be competent to apply their interdisciplinary knowledge to specified tasks. The education process needs to take current technology tendencies into account and as an answer to this necessity the lecturers and final year undergraduate and post graduate students from the Departments of Chemical and Electrical Engineering at Peninsula Technikon, South Africa, decided to combine their knowledge in building an ion exchange pilot plant for desalination of water together with its modern control system as an educational tool for the undergraduates and as a research tool for the postgraduate students.

The plant comprises of two cation columns (load and regeneration) and two anion columns (load and regeneration). Presently the cation load and regeneration columns have been built and are operational (see Figure 1). The mechanism for desalination is to convert the salt into acid by strong cation exchange (in the cation load column with strong cation resin) and subsequently to remove the acid by absorption on a weak anion resin (in the anion load column) (Hendry, 1982), (Hendry, 1985). Firstly, each column operates with counter current flow of the resins and solutions. The salt water enters at the bottom stage and the resin at the top of the columns. Secondly, operation is cyclic - with phases of operation being: (a) Liquid up-flow, (b) Resin settle and (c) Resin pull-down and transport. Associated with each cycle is a series of diaphragm valves and pumps, which enable the liquid and resin flows to be switched in a timed sequence as required by various stages of operation. Sensors, for pH and conductivity measurements are used in order to determine the water salinity in the input and output column flows.

The complexity of the timing sequence for realization of the cycles required a feasible design and implementation of a stable control for switching the diaphragm valves. The previously used mechanical switching system was not very reliable and caused interlocks (see Hendry, 1982). Modern control hardware and software technology like LabVIEW™ allows cheaper and easier solutions (Wells, 1997). Lately LabVIEW™ is used in many control laboratories at various universities for development of courses, practical experience and research projects of the students,

(Egarievwe *et al.*, 2000), (Hennessey *et al.*, 2000), (Henry and Knight, 2000). Some of the educational applications of LabVIEW™ are presented in special issues of the IJEE in 2000 and 2004. Previously published results, combined with the experience in the Department of Electrical Engineering with LabVIEW™ courses and applications (see Tzoneva, 2000) and the possibility to use not very expensive hardware with the modern software have resulted in selection of LabVIEW™ as a platform for building of the ion exchange control system.

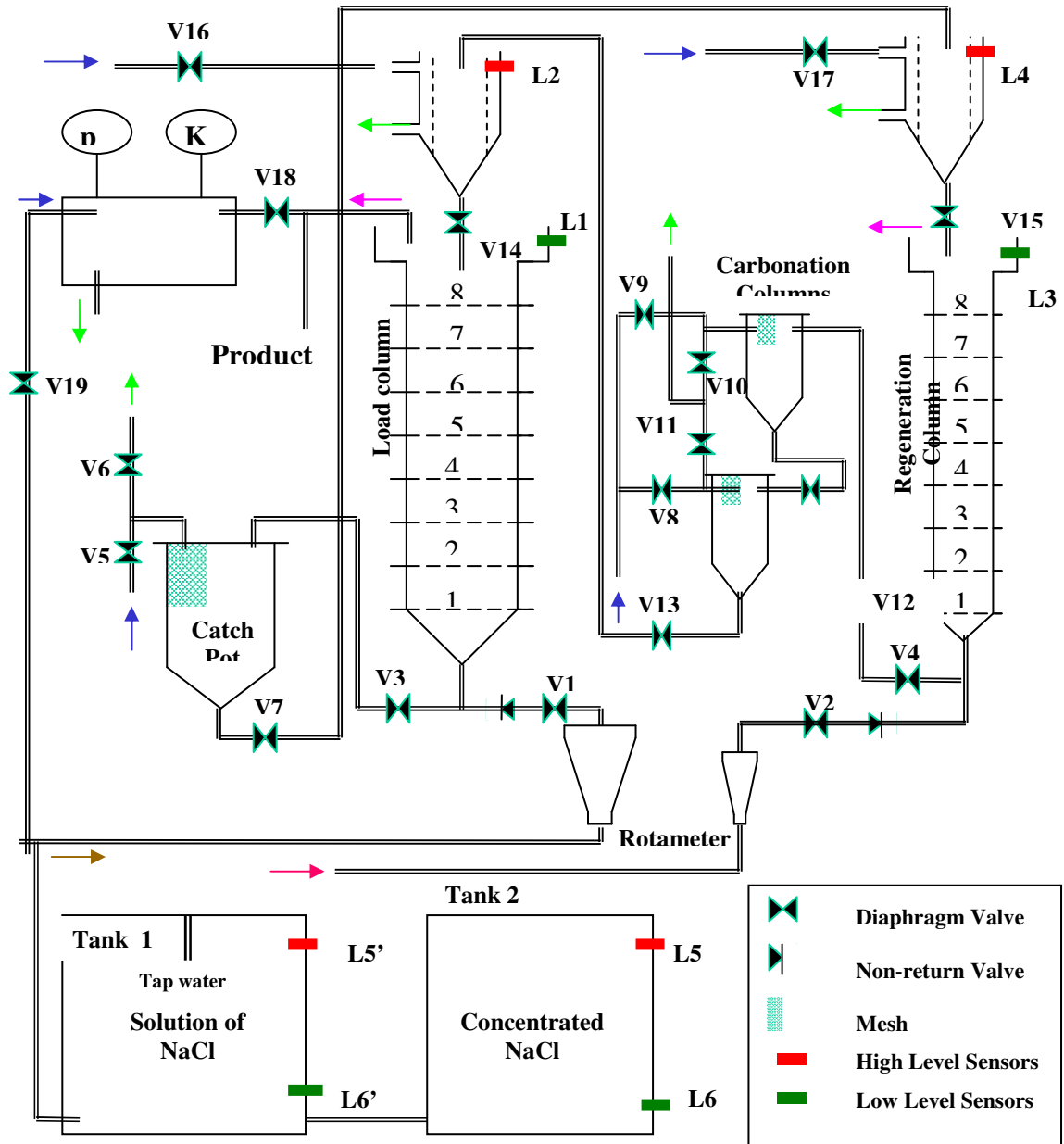


Figure 1. The implemented ion exchange pilot plant

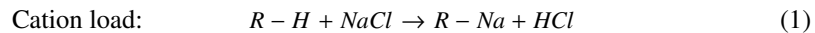
The developed control system fully automates the operation of air actuated diaphragm valves and pumps and optimizes the timing sequences using the methods of the modern control theory. This paper describes the hardware and software for implementation of the control sequences in real time. The developed software uses the output of the software for optimal control calculation, operator decisions and the ion exchange process technology requirements to implement the switching sequences for the process flows. Algorithms and programmes realizing the switching sequences have been developed using graphical programming language 'G'. They form a part of the built system for two-layer optimal control of the ion exchange plant based on measurement of pH and conductivity of input and output load column flows, model parameter estimation, steady state optimization and nonlinear control design and implementation (Tzoneva, 2003). The control action to the process is the time of the Up-flow phase. It is realized by switching of the valves for the corresponding flows. The program and control systems are implemented on a standard PC, running Windows 95 with LabVIEW™ as driver software. The connection between the PC and the plant is based on PC30GA\_ADC data acquisition card (Eagle Technology, 2000), OPTO22 racks and signal conditioning modules and solenoid valves.

The paper first describes the ion exchange process and the sequences of operation, represented by the switching of the corresponding valves. Then the hardware structure of the control system is presented. The software development is described by the programme algorithm, the hierarchy, front panel and a diagram. Some implementation issues of the programme in the pilot plant are discussed and a conclusion is given at the end of the paper.

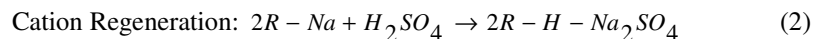
## 2. ION EXCHANGE PROCESS CYCLES

### 2.1 The ion exchange process

The considered ion exchange process is for desalination of water containing sodium chloride. The counter-current contact of the liquid and resin results in an exchange between the ionic species in the feed liquid with the counter species on the resin. In case of the cation load column the sodium ion  $\text{Na}^+$  exchanges with the hydrogen  $\text{H}^+$  of the regenerated resin. The  $\text{Na}^+$  concentration in the liquid thus decreases in each successive stage up the column. A corresponding increase in  $\text{Na}^+$  concentration in the resin phase occurs at each stage progressing down the column. The overall degree of exchange obtained and the concentration profile, which are established at steady state, are determined by measurement of pH and conductivity of the input and output column flows. The reactions occurring in the cation couple of columns are:



Since the resin gets exhausted during the loading column (ion exchange) operation there is a need for it to be regenerated and the latter is achieved by contacting the loaded cation resin with about 20% strength of acid ( $\text{H}_2\text{SO}_4$ ) according to the reaction :



The extra set of columns (labeled "carbonation") are used for the dual; purpose of resin catchpots and intermediate storage, for additional rinsing of the resin if needed or for another special flowsheet involving recovery of sodium carbonates using anionic resins instead of the cationic resins in straightforward desalination. The series of diaphragm valves and pumps, enable the liquid and resin flows to be switched as required during the stages of operation mentioned above. The valve switching is performed according to the values of the Up flow periods of the load and regenerated columns, generated by the environment program developed in LabVIEW™ for real time optimal control of the process. These values of the Up-flow periods are inputs for the described algorithm and programme.

## 2.2. Load column valves operation

According to the schematic diagram shown in Figure 1, the process starts with the Up-flow phase. The salt water is pumped into the lowest stage, flows up the column, fluidizing the resin beds and contacts the regenerated cation resin entering the column from the top hopper. The diaphragm valve V1 must be opened during this cycle. In between each stage is a perforated plate with a number of holes small enough to distribute the liquid evenly across each bed. At the end of the Up-flow phase the feed flow is shut off (V1 closed) for some short period of time (pre-determined by the operator) and the resin beds are allowed to *settle* onto their respective perforated plates. Only a small percentage of resin falls through each plate during this interval due to bridging of the particles across the holes. Thus, most of the resin remains in its own stage.

After the resins have finished settling, the Pull-down phase is started by opening V3 and V6 and the resin slurry is allowed to flow into the receiver i.e. catch pot. After the Pull-down phase (V3 and V6 closed) has completed, the transport of the resin from the regeneration column is done (via the "carbonation" columns used as catch-pots) using valves V9, V11, V10, V12 and V13. The resin extracted from the load column is then transported (V5 and V7 opened) to the regeneration column hopper and the load column Up-flow commences again. The actual transport should, however, not be initiated unless the receiving hopper can accommodate it. The level detectors are included to make sure that there is no resin overflow. High resin levels for the hoppers are measured by level sensors L2 and L4 and low resin level for the column last stages are measured by the level sensors L1 and L3 respectively for the load and regeneration column.

## 2.3 Regeneration column valves operation

The operation is similar to that for the load column. The difference is in the valve numbering and in the length of the cycle times. The regeneration column has 5 to 6 times shorter cycle times than the load column because of its smaller dimensions. These are smaller because of the higher solution concentrations and smaller flow volumes that are employed in regeneration than in the loading columns.

## 2.4 Requirements for the control of the pilot plant.

The proper operation of the plant requires resin flow balance between the load and regeneration columns. In order to maintain stable physical column operation and maintain and set optimal steady state working conditions, both liquid and resin flows must be accurately set. The liquid flow rate is easily set by use of metering pumps. The resin flow rate depends on the liquid Up-flow time, type of resin used and the type of stage in operation. Optimal resin flow rate of the load column is determined through the developed control system by optimization of the process according to the specifications for the output quality of the desalinated water and the values of the input water salinity measured in real time. The results are then transformed to Up-flow time on the basis of the resin mass balance of the entire column. The value of the Up-flow time is used as a control action, implemented as a part of the switching sequence of the valves.

## 3. HARDWARE IMPLEMENTATION OF THE CONTROL SYSTEM

The program and control system is implemented on a standard PC. The connection between the PC and the plant is based on PC30GA\_ADV DAQ card, OPTO22 racks and signal conditioning modules, AC switching box and solenoid valves. The solenoid valves switch ON and OFF the air pressure to the diaphragm valves via the whole control system using digital outputs from the PC. All parts of the control system (see Table 1), are discussed step by step in the next paragraphs.

### 3.1. Personal Computer (PC)

The platform for the system is the standard PC running Windows 95 as the operating system. LabVIEW<sup>TM</sup>5.1 has been installed as driver software.

Table 1. Control system components

Personal computer with LabVIEW software
PC 30GA_ADV
ADPT 5050
PC 38X
PB24 with DO AC
AC switching box
Solenoid valves
Diaphragm valves

### 3.2 PC30GA\_ADV DAQ card

The card is plugged into the ISA slots of a standard PC or any compatible machine (Eagle Technology, 2002). The card comes from a family of different models, half size, low cost high accuracy analog and digital I/O boards. The card characteristics are: 100kHz or 330kHz conversion rates, 8 differential or 16 single-ended inputs, 12 bit Analog resolution, Programmable gain, Simultaneous sample and hold option available, 4x12 –bit Analog outputs with flexible ranges, 24 Digital I/O lines (3 ports), One 16-bit user Counter timer. It is clear that there are a lot of functions where the card can be utilized. The design is utilizing all the digital ports; as a result a brief summary of all the ports is given in the next paragraph. The configuration of the card is performed using both software and hardware (Eagle Technology, 2002), (National Instruments, 2002). Hardware setting involves setting the mini jumpers that are used to set the DMA levels, IRQ, DRQ, +5V/DGND, 10/20V span select, etc. The DIP switches that are found within the card set the base address of the board. If a specific address needs to be set refer to User manual for the PC30F and PC30G Series Boards (Eagle Technology, 2000). The base address is set to 700H by factory default.

### 3.3. Adaptor interface card (ADPT-5050)

The PC30GA\_ADV data acquisition card has all its outputs on the DB50 female connector as seen from the rear of the card. The outputs include 16 analog channels, 3 X 8 bit digital ports being port A, B and C, +- 5V, digital ground, analog ground, etc. According to the card design, there should be no current that must be drawn from the DAQ card directly. The latter implies that the outputs coming from the DAQ card has to be isolated, so that the current from the DAQ card can be increased. The adaptor 5050 is added to achieve the isolation in the connections so that the required lines can be selected, in this case digital I/O lines. The ADPT-5050 features IDC 50male and DB50male connectors as well as 51 pin screw terminal blocks. These three connectors are mapped i.e. (1:1). The output of the ADPT5050 is fed to the PC38X which is explained in the next paragraph.

### 3.4. PB38X Interface card

The PB38X is a 24 Channel TTL I/O driver card. The PB38X card is an industrial interface card, used to provide increased current driving capability to all 24 I/O lines of PC30GA\_ADV DAQ card. A custom screened multi-core cable using DB type connector which matches the type of DAQ card used has to be developed to link the DAQ PC30GA\_ADV to PB38X cards.

### 3.5. Signal conditioning modules

The PB24 rack can accommodate up to 24 single channel I/O modules (Opto22, 2002). The PB24 mounting rack features a 50-pin header connector for easy interface using any device via the ribbon cables more especially the interface with computers. In the design the rack is used for mounting of output modules (OAC). The modules isolate the PC with the DAQ

(PC30GA\_adv) (DC current) from the solenoid valves with AC current. The PC38X card increases the DC current so that it is sufficient to drive the OAC modules.

### 3.6. AC Switching box

The box is designed so as to allow the operator to bypass the PC at any time as may be required for valve repairs etc. or in the event of the PC not functioning properly. The box has three modes of operation being: Manually ON; Manually OFF; and Automatically operated using the PC. In manual ON mode, the valve is switched ON manually using the switching box, that is, without using the PC. In manual OFF the valve is completely OFF, meaning it cannot be switched ON by the PC. Lastly in Automatic mode, the PC is in control of the switching of the valves either ON or OFF depending on the operator directly using the front panel or the program. The plant is fully automated in this mode.

### 3.7. Solenoid valves and Diaphragm valves

Solenoid valves are electrically controlled three-way air control valves, (Liptak, 1999). The specifications (ASCO™) are 220VAC with maximum power of 9Watts. The maximum pressure that they can handle is 7bars (7000Kpa). Diaphragm valves are air-operated valves, normally open. The pressure from the compressor via the solenoid valves outlet controls the diaphragm valves. Alternative valves that are normally (spring) closed, (air to open) types may be substituted but would require appropriate switching logic changes.

## 4. SOFTWARE IMPLEMENTATION OF THE CONTROL SYSTEM

The software is developed in LabVIEW™ 5.1 running on Windows 95 OS. LabVIEW™ is selected as a proven programming system in use in science, engineering and factory process control all over the world (National Instruments, 2000). LabVIEW™ differs from textual languages in several ways:

- The source code is entirely graphical “G”, resembling a circuit schematic.
- Execution order is data driven, i.e. a node begins execution when data is available at all of its input controls, i.e., “dataflow”.
- It has inherent parallelism of loops and control flow.
- Syntax errors are inherently minimized in LabVIEW™.

All these characteristics helped for realization of the programme for control of different types of processes.

### 4.1. Description of the program code

The program is written following the Algorithm, shown in Figure 2 and Figure 3. The Algorithm is developed on the basis of the process technology requirements.

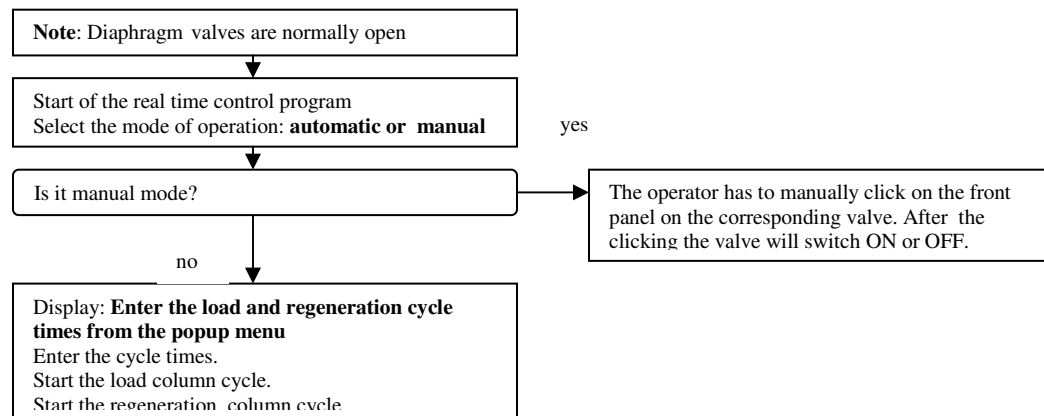


Figure 2. Real Time control Algorithm – selection of mode of operation

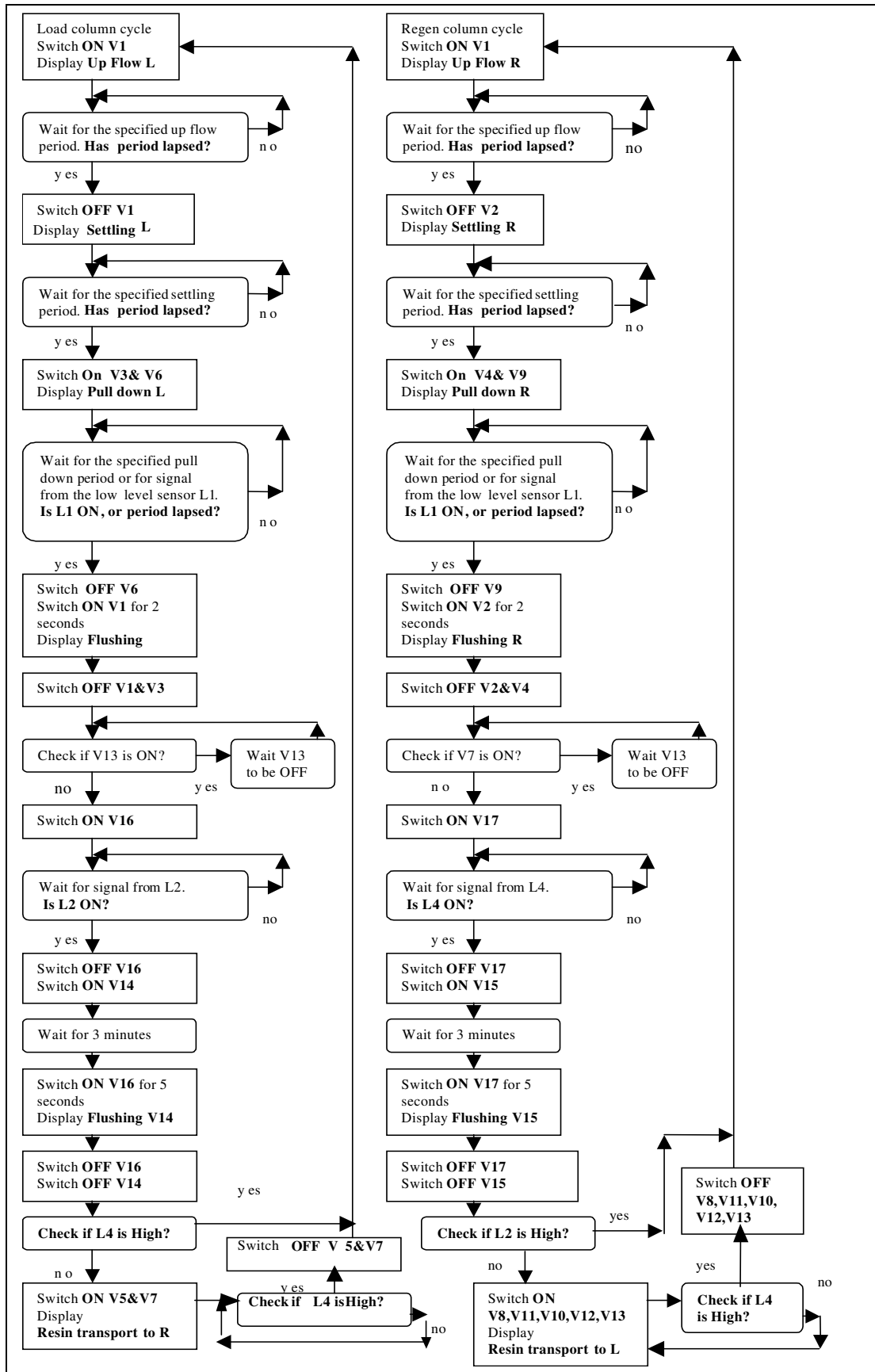


Figure 3- Real time control algorithm- column cycles

The program as described in the introduction is written using a graphical programming language allowing the icons to be dragged and dropped to define functionality. The icons have input parameters that are used for calculations or processing of data and output parameters that are sent to other functions. The subVI's in this program perform more complex functions with input and output parameters.

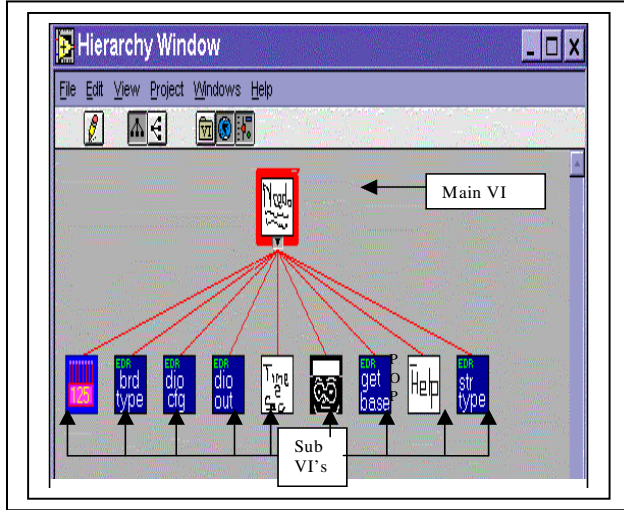


Figure 4. LabVIEW™ program hierarchy

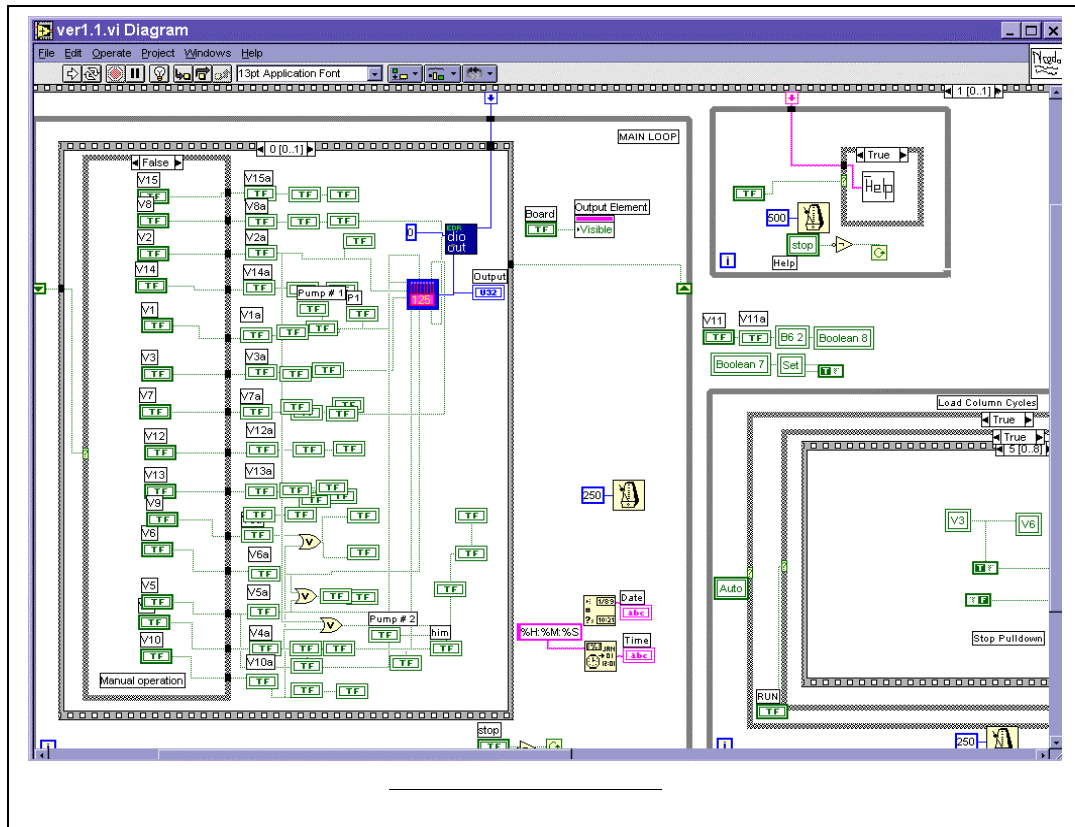


Figure 5. LabVIEW™ programme code

As an example, a pop up menu, subVI (POP.vi), passes the time entered by the operator to the main VI (Ncedo.vi) that switches the valves on or off based on the times that have been specified. The other subVI's like brgtype.vi, diocfg.vi, dioout.vi, getbase.vi, strtype.vi get the information about the DAQ card and configure the cards DI/O. The base address information and the type of card installed are received through the subVI's and are then passed to the main VI.

The hierarchy and the subVI's are shown in Figure 4. A part of the programme code is shown in Figure 5.

#### **4.2. Joint operation of the two columns**

Load and regeneration columns have the same algorithm (see Figure 3). The difference is the cycle time. The regeneration Up-flow time is 5 to 6 times shorter than that of the load column, the latter is due to the difference in the column sizes. The former implies that for one Up-flow period on the load column there are 5 –6 complete cycles on the regeneration column, the cycles being liquid Up-flow, resin Settle, resin Pull-down and resin transport. The above can result in valve interlocking between the load column and the regeneration column, because the load column hopper needs to be monitored by the level sensors to make sure that there is enough space for the next volume of resin that has been regenerated.

#### **4.3. Operation of the plant**

The plant has two modes of operation i.e. Manual and Automatic.

- Manual mode of Operation. In this mode the operator specifies the cycle times, that is, Up flow, Settle and Pull down, from the pop up menu. The program waits for the operator to switch the valve associated with the cycle. The valve will be switched for the period of time that has been specified from the pop up screen. Each valve is associated with the cycle operation i.e. Up-flow, Settle and Pull-down. The cycle that the load and regeneration columns are at is shown on the mimic columns seen from the front panel, Figure 6. The process time is stored in a text format and displayed on the User interface for viewing the elapsed times.
- Automatic mode of operation. In this mode the operator enters the cycle times from the pop up menu and the plant runs itself automatically, in this mode the plant is fully automated. The process time is also recorded.

Other features are the help menu, and the stop button. The experiments were conducted using the load and regeneration column of the ion exchange process. Both modes of operation were checked. The hardware and software work properly and according to the requirements of the operator. No interlocks of the solenoid valves were observed. The phase of work and the time sequences of the valves for every of the phases can be seen on the front panel (see Figure 6).

It is important to note that the column cycle times that are required in the ion exchange process depend mainly upon the application. Thus, the mass balances for the particular resins, feed water composition and strength, and the required performance in terms of percentage salt removal all influence the process times. Even the type of acid and acid regenerant strength employed affects the optimal economic operation in which the objective is usually to maximize the recovery of purified water while at the same time discharging concentrated waste salt solutions from which salts can still be recovered to avoid secondary pollution.

Consequently, the control algorithm and its implementation are major factors in attaining these process efficiencies. The ability to re-program the process sequences via software offers the advantage of being able to adapt the process to different feed waters and to different process characteristics. A number of new applications in water and wastewater treatment in the biotechnology industry are being studied. Large scale adsorptive treatment and protein separations are among these.

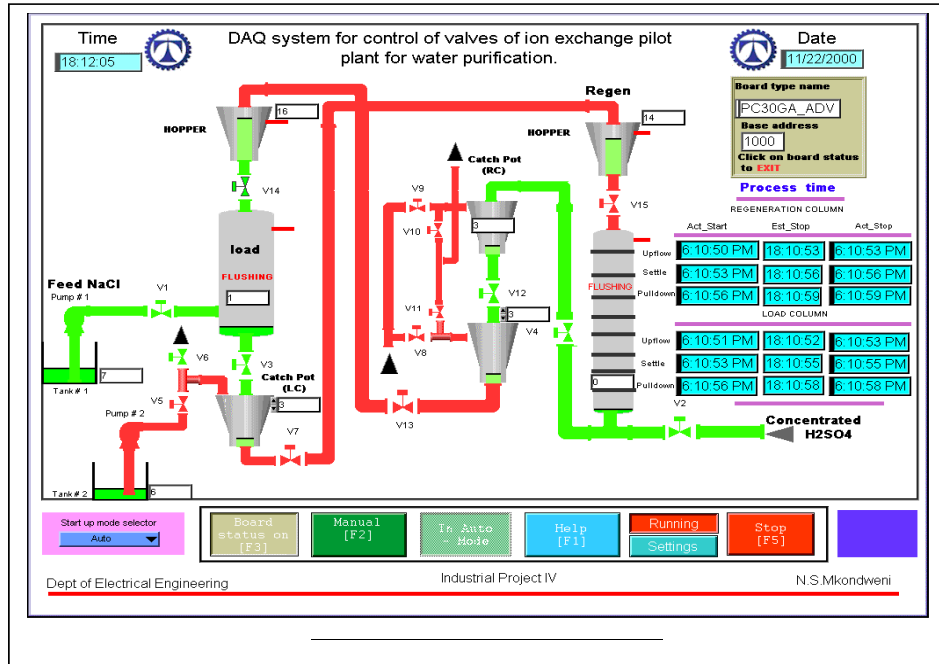


Figure 6. Front panel of the control system.

## 5. CONCLUSION

The complexities of controlling an ion exchange plant in existing applications and in various new ones, as mentioned above, demand flexibility and robustness in order to optimize the operation of the plant. The implemented program is very effective in that respect. It helps to overcome the difficulties with the interlocking of the valves in automatic mode of operation and allows fast starting or stopping of the flows in the process according to the commands of the operator. The developed LabVIEW™ program makes the implementation of the control actions easy. The control system integrates the extensive possibilities of LabVIEW™ programming with affordable hardware. In this way it is applicable for different ion exchange processes in water treatment, bioprocessing, mining and many other industries.

The collaborative work between the students from the Chemical and Electrical Engineering Departments at Peninsula Technikon on one common project has resulted in an increase of the student interdisciplinary knowledge and in deeper understanding of the principles of their own fields of study. At the same time the students learnt one of the modern industrial control and computer technologies such as LabVIEW™ and in this way they were getting better prepared to be more useful at their future industrial work places.

## ACKNOWLEDGEMENTS

The work was funded by the National Research Foundation of South Africa under the grant No: 2042812 "Control of ion exchange process for desalination of water".

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**Received:** 11 November 2003

**Accepted in final form:** 15 April 2004 after one revision

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