Engineering Thesis

Tjuntjuntjara Groundwater Desalination

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1 Abstract

The Tjuntjuntjara Groundwater Desalination Thesis was conceived to solve the operational faults of a Vacuum-Multi-Effect-Membrane-Distillation (VMEMD) Pilot Plant. The National Centre for Excellence in Desalination (NCED), Murdoch University and other contributing parties intend to power the plant with renewable energies in order to supply the Tjuntjuntjara indigenous community with water.

The thesis involved research into VMEMD technology and an assessment of the control system and instrumentation that operated it. During the assessment process, operational faults as well as potential improvements in the operation of the plant were recorded. It was found that the control system had a number of software based faults. The design and implementation of a new Programmable Logic Controller (PLC) operating code was undertaken to correct these faults. In parallel to this work, the design and implementation of systems to improve the operation of the plant was also undertaken.

When all upgrades to the plant were complete, the vigorous process of validating the new additions commenced. As well as testing the new code and system improvements, a series of continuous trial periods was conducted. These proved that the plant can now operate continuously and at varying system temperatures for over 100 hours. During the trial periods, operating point data was collected and methods for increasing distillate output were found.

The plant has been brought up to a stable operating standard and the additional systems installed to improve the plant have further increased its reliability. A number of recommendations have been provided to stimulate further development of the VMEMD pilot plant.

2 Acknowledgments

The writer would like to thank Murdoch University, the National Centre of Excellence in Desalination, friends and family for the continuing support of this thesis project.

3 Terminology and Abbreviations

NCED – National Centre for Excellence in Desalination VMEMD – Vacuum-Multi-Effect-Membrane-Distillation MEMSYS – VMEMD module manufacturer

P&ID – Piping and Instrumentation Diagram

PLC – Programmable Logic Controller

HMI – Human-Machine Interface, a computer display for monitoring and control

CV – Control Valve

SV – Solenoid Valve

B&R – Bernecker and Rainer, a German based Automation Company

Code – Written on a PLC to operate various instrumentation

Flash – Change of state from fluid to vapour

JSA – Job Safety Analysis

KNF – Vacuum pump manufacturer

Gemu – Valve manufacturer

DRAM – Dynamic random-access memory

SCADA – Supervisory Control and Data Acquisition

VNC – Virtual Network Connection

I/O – PLC electrical inputs and outputs

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6 Background

The Tjuntjuntjara indigenous community is located 800 km north-east of Kalgoorlie in Western Australia. As of January 2012, the facilities at Tjuntjuntjara currently support a population of 180 community members [1]. The community is slowly growing and there is a need for supplementation of the current water supply, to meet this growth. It is estimated that the current requirement is 11,000 – 15,000 L/day, with the maximum capacity of the groundwater supply capped at 24,800 L/day [1]. There have also been concerns raised about the quality of the current water supply, specifically with regard to the high levels of nitrates [1]. A collaboration between Murdoch University, the National Centre for Excellence in Desalination (NCED) and other industry and academic partners have come together to provide water for the remote community.

The project aims to provide a cost effective, renewable energy driven, desalination technology for the supply of drinking water to remote areas. It was proposed by Murdoch University, with Trevor Pryor from the School of Energy and Engineering at Murdoch taking the position of Principal Investigator [2]. One of the industry partners, MEMSYS, manufactures a desalination technology known as Vacuum-Multi-Effect-Membrane-Distillation (VMEMD). This technology was chosen for the project due to its relatively low cost and high efficiency. The process of VMEMD also has the ability to remove chemicals that standard desalination technologies cannot. A 1 m^3/day VMEMD pilot plant was provided by MEMSYS for the project. The plant serves as a prototype to be implemented at Tjuntjuntjara and if successful an upgrade to a 20 m^3/day would follow.

The premise was that the plant would be fully functional and simply have to be integrated with a renewable energy source. When the plant was received by the NCED and assembled, it was found to be faulty. The VMEMD module had not been properly commissioned and eventually had to be replaced. George Horvath, from the NCED, then tested the plant for a number of months to see if it could operate continuously, as required by the project. On numerous occasions the plant faulted and had to be manually shut-down in order to avoid damage. This was a major set-back for the project because the technology could not satisfy the need for reliability. To progress forward, the control system operating the VMEMD module needed to be assessed and the cause of the problems identified.
The Tjuntjuntjara Groundwater Desalination Thesis was proposed in order to complete these tasks.

7 Problem Definition

7.1 Problem Scope

The nature of the environment that the unit will operate in and importance of the commodity that it will provide requires that it is reliable and sustainable for long periods of time. Testing carried out by the NCED has proven that the current instrumentation and controller cannot operate the VMEMD module safely for more than 8 hours and that it is not rugged enough to withstand the transport to the community or the conditions in which it must operate in.

7.2 Problem Details

A trial run of the MEMSYS unit was carried out by George Horvath and during this period a number of problems were encountered:

- Various temperatures and pressures spiked beyond set-point which led to unsafe conditions and the trial had to be stopped.
- The CPU of the B&R PLC averaged an operating point of 88%. This indicates that the PLC is under heavy load while operating the plant in standard conditions.

Inspection of the unit has led to other problems that need to be rectified:

- The control system may not comply with Australian Standards for wiring and should be further investigated.
- The tubing throughout the system is flimsy, not secured and may be knocked out of the push- lock joints.
- It is not protected from environmental factors (dust, dirt, animals . . . etc.)

While setting the unit up for trial runs it was noted that the priming procedure is far too complicated:

- Manual valves have to be operated as well as the HMI to prime the heater tank, cooling tank and feed line.
- A good understanding of the process equipment and terminology is required in order to complete the start-up procedures.

7.3 Resources

A weekly teleconference with staff from MEMSYS was organised so that their extensive knowledge of the system could be drawn upon. The control/operation manual and functional description for the VMEMD plant was located and this documentation was crucial in the initial research phase of the project.

8 Proposed Work

8.1 Assessment of the B&R Code

The coding of the B&R controller needed to be interrogated in order to properly understand how the system is being driven. The NCED did not have access to the Automation Studio software, for the controller, and therefore it needed to be acquired. With the use of the software the system could be put into normal operation and the code monitored to determine the functional pieces of code and problem areas. If needed, the code could be stripped back to the basic requirements in order to make the system more robust.

8.2 Re-coding or New Design

Once a closer look had been taken at the controller, code and instrumentation a decision had to be made as to whether the system would be suitable for the Tjuntjuntjara project. If it was decided that it was not suitable then steps would have had to be undertaken to design, acquire, install and test a new control system. However, if the code of the current system could be modified to stabilise it then this would lead to a much more simple solution.

8.3 Automating the Start-Up Procedures

Whether the project led to a re-design or simply a re-coding of the PLC, the start-up procedures of the plant needed to be more streamlined. With the aid of a couple of additional pieces of instrumentation the start- up procedures could be fully automated. In this case, all that will be required to start the plant is simply to connect the feed, distillate and brine lines and initiate the operation via the HMI. This instrumentation would need to be sized and installed and the appropriate routine coded into the PLC.

8.4 Instrumentation and Control Standards

The instrumentation and controls within the plant needed to be brought up to Australian Standards for Electrical Installations (AS/NZS 3000:2007).

This could be carried out primarily to properly secure and label the wiring, outside of the control cabinet, and the piping between instrumentation. This would aid in making the plant more robust and suitable for use in a commercial sense.

9 VMEMD Technology

Distillation is a simple principle that has been practiced over many years. The general process of distillation involves a saline water feed being heated to produce a vapour of fresh water that is then collected and condensed. This results in the separation of fresh water from saline and is also known as desalination. A new distillation technology, known as Vacuum-Multi-Effect-Membrane-Distillation (VMEMD), has been developed by MEMSYS Clearwater Pty Ltd. VMEMD is a thermally driven separation process which is utilised to desalinate saline water. With the addition of multiple distillation effects, porous membranes and a reduction in pressure, the process becomes more efficient. The efficiency of the technology, its thermally driven nature and ability to remove chemicals that other desalination technologies cannot were the reasons it was chosen for the Tjuntjuntjara project [2].

9.1 Functional Description

9.1.1 MEMSYS Module

The V-MEMD module consists of 6 modular blocks that are held together by an adjustable bracket. The first of these blocks is the steam raiser. Heated water flows through the steam raiser which is exposed to the system vacuum. The lower pressure reduces the boiling point of the water and causes it to flash. The steam produced can then move through a porous membrane to the next block. After the steam raiser, comes the first of 4 effects. Each effect consists of a foil and membrane frame with the saline feed flowing between them, as shown in Figure 1.

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Image Link

Figure 1 - VMEMD module flow diagram [3]

The vapour from the previous block condenses against the foil frame and the latent heat of condensation is transferred to the other side of the frame. The transferred energy then heats the feed flowing between the frames and the vapour produced is passed through the membrane frame, into the next effect. Energy is transferred through the entire module in the same fashion (heat > vapour > condensation > heat . . .). After the last of the effects, the final block is the condenser. Cold water is circulated through this block to condense the vapour from the final effect and remove any excess heat. The module is designed to operate on a thermal energy water feed between 50 – 80 ˚C. The transfer of heat through the module can be observed in Figure 2. Heat is slowly lost as it is transferred which is represented by the varying colours of the thermal image.

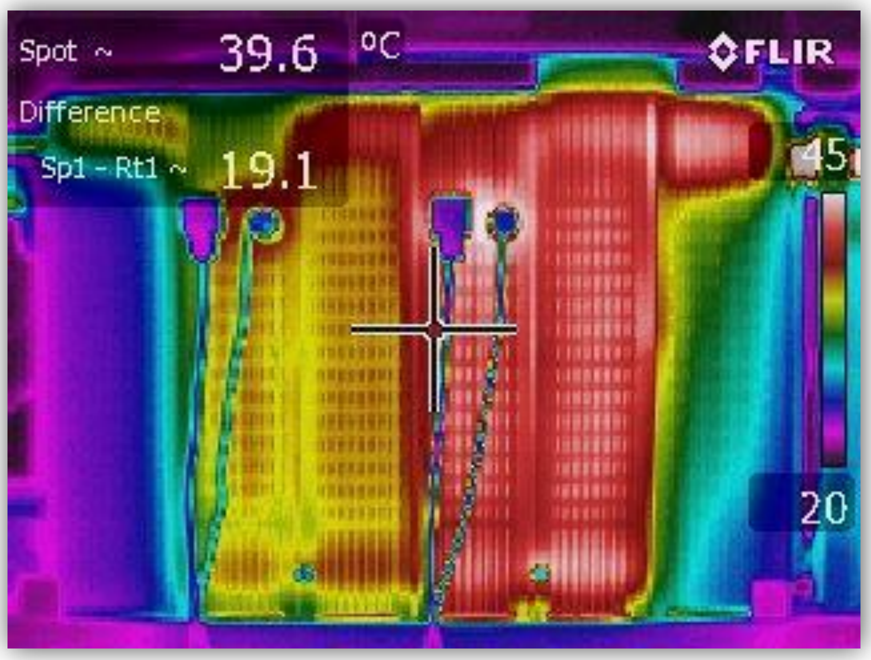

Figure 2 - Infra-red photo taken of the VMEMD module at the NCED

9.1.1.1 Block Composition

The blocks of the VMEMD module are made up of three different frames. There are empty frames with an open grid, membrane frames and foil frames [3]. Channels between the frames allow vapour, feed, distillate and brine to flow through the module. A different combination of frames is used for each type of block. The steam raiser is made out of empty and membrane frames, an effect out of foil and membrane frames and the condenser out of foil and empty frames [3]. The alternating foil and membrane frames that produce an effect block can be observed in Figure 3.

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Figure 3 - Composition of a single effect in a VMEMD module [3]

9.1.2 Supporting Instrumentation

There are a number of key physical parameters that must be monitored and controlled in order to operate the V-MEMD module. The temperature and pressure as well as feed, distillate and brine flows are a few of these. MEMSYS does not specialise in this area and therefore the design of the control system was out-sourced to Bernecker and Rainer (B&R). The choice of PLC for the project was a B&R Power Panel 45, seen in Figure 4. This model of PLC has a built in touch screen Human- Machine Interface (HMI) but does not include any inputs and outputs (I/O) on-board. Therefore, B&R's X20 remote I/O unit is used via a proprietary X2X communications link. The X20 system contains modularised analogue and digital I/O units that can be connected together on a single bus. This facilitates the control of pumps and valves as well as monitoring flow, pressure and temperature.

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Figure 4 - B&R Power Panel 45 PLC [4]

One of the major difficulties in achieving VMEMD is maintaining a vacuum throughout the module while fluids are flowing through it. This is achieved by having the supply to, or discharge from, the module flowing via a vessel that is also exposed to the system vacuum. The VMEMD plant therefore has 5 storage vessels that are all exposed to the system vacuum. These vessels contain the heating and cooling water, brine and distillate outputs and heating water top-up. The level in all vessels is monitored via float switch, indicating high or low level. Brine, distillate and heating water top-up levels are controlled via outlet pumps and the cooling and heating levels via inlet valves. Pumps are activated when a high level is reached and de-activated when reaching a low level. Valves are opened when a low level is reached and closed when a high level is reached. The low system pressure forces water to flow from atmospheric conditions to the low pressure inside the vessel, when an inlet valve is opened. The system vacuum is produced by a vacuum pump which is attached to the module and all vessels through a series of flexible tubing. Since water vapour that is not condensed properly in the condenser block can enter the vacuum tubing, an inline sump is installed. The sump collects any water vapour that condenses in the lines before it reaches the vacuum pump.

The process is currently driven by a 3 phase heater which is controlled by the PLC. Water is circulated from the heating water vessel through the heater and into the steam raiser block of the module, in a closed loop. Thermal energy is then transferred from block to block by means of convection and conduction. The energy is finally removed by cooling water circulated, in a closed loop, through a heat exchanger and into the condenser block of the module. A detailed P&ID can be found in Appendix D – Electronic Documents (Electronic Source Number: TGD-B0001) and a photo of the plant has also been provided in Appendix A – MEMSYS Plant Photo for the reader to gain a greater understanding of the piping and instrumentation that has just been described.

10 Plant Assessment

The NCED had previously completed a number of trial operations of the VMEMD plant. During the trials several problems resulted in the plant having to be manually stopped and because of this it was not able to continuously operate for more than 8 hours. To confirm these problems and gain a better understanding of where they arise from and how they can be resolved, the plant needed to be properly assessed.

This involved researching and understanding the control system and instrumentation, trial operation of the plant and consultation with members of the NCED and MEMSYS.

10.1 Piping and Instrumentation

10.1.1 Process Piping

There are two different types of piping used to transport the process materials around the plant. The first is a standard PVC that is used for the flow of cooling and heating water, distillate and brine around the plant. The second is applied to supply the system vacuum for the module and storage vessels. The two different types can be seen in Figure 5, below.

Figure 5 - PVC process piping and polyurethane vacuum tubing

The main concern with the PVC piping is its rigidity compared to strength. In transportation the tendencies for things to be vibrated would likely lead to the piping being fractured. Therefore, it would need to be disassembled before transportation and re-assembled onsite. Since the vacuum lines are flexible polyurethane tubing the only concern would be the push fit connections. However, after working with these connections they have been found to be strong and maintain a good seal.

10.1.2 Pumps

The choice of pumps for the VMEMD plant is quite crucial because the corrosive process fluid and low pressures are not ideal conditions for a pump to operate in. Furthermore, the distillate and brine pumps are started and stopped very frequently. The pumps selected for the distillate and brine outputs are Iwaki magnetic drive turbine pumps and the cooling loop and heating loop top-up pumps are Iwaki magnetic drive pumps. Magnetically driven pumps are advantageous in this situation because the pumping chamber is separated from the motor, there are no drive seals and frictional losses are minimised.

The saline water is not exposed to any metallic components in these pumps and therefore no corrosion can occur. With minimal friction the magnetic drive pumps are easier to start and more reliable. A Grundfos pump, of the canned rotor type, was chosen to circulate the heating loop. Still magnetically driven, the canned rotor pump offers the same advantages as the Iwaki pumps. Finally, a KNF diaphragm vacuum pump is used to lower the system pressure. In Figure 6, below, the Iwaki pumps and KNF vacuum pump can be viewed.

Figure 6 - 4 green Iwaki pumps and KNF vacuum pump (with cover removed)

10.1.3 Valves

There is a combination of manually operated ball valves and GEMU solenoid valves (SV) installed on the plant. SV's are used to automate the top-up of both the heating and cooling loops as well as regulate the vacuum and feed flow. These valves are suitably sized for the application and the correct valve body materials are adopted to reduce corrosion. The solenoid valves operate on a 24 V supply voltage and are normally closed.

10.1.4 Sensors

Pressure, temperature and flow are measured with the aid of different sensors which convert their physical measurements to an electrical signal. This signal is then interpreted by the PLC for control and monitoring. The level in all vessels is indicated via the use of float switches. High and low level float switches are positioned to maintain the fluid level at roughly three quarters full. Maintaining the level at this height keeps a head of fluid between the system vacuum and ambient air pressure. Float switches can fault quite easily because of the hinge action on which they rely upon. They are also submerged in the fluid being monitored which can lead to corrosion.

Since the fluids being monitored in this application are free of particulate matter and the selected float switches are made of suitable materials this should not be a problem. Temperature and pressure sensors are mounted in each block of the module and on the cooling and heating loops. Flow sensors are also placed to monitor feed, heating loop and cooling loop flow.

10.1.5 PLC and Electrical

The electrical equipment that operates the plant is placed in one of two cabinets. The first cabinet contains the control components and the second contains electrical power components. Figure 7 shows the control cabinet (external and internal), with the B&R PLC mounted on the door of the cabinet so that the display is accessible.

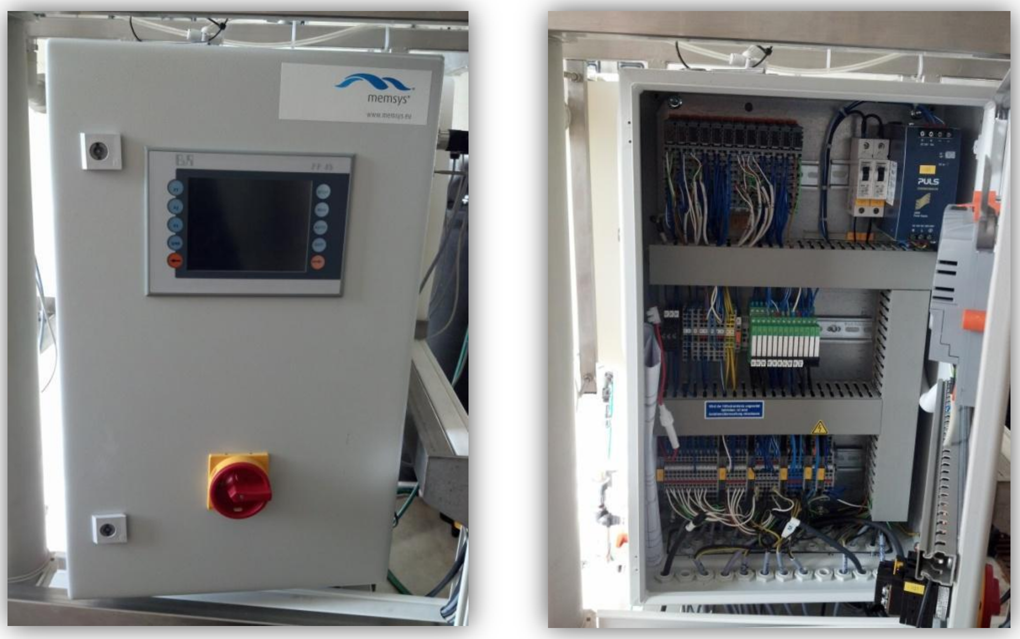

Figure 7 - Control cabinet externals and internals

B&R PLC's are manufactured to be very compact and the PP45 is no exception. It is in the form of a standard HMI however it also contains on-board processing capabilities. Its touch screen display measures 5.7" across and the on-board processor is clocked at 100 MHz with 64 mb of DRAM [5]. The memory is upgradable with the application of a compact flash card and communication with the PP45 can be achieved by Ethernet or X2X link. To facilitate the operation of the valves and pumps and monitoring of flow, level, pressure and temperature an X20 remote I/O system is adopted. The PP45 communicates to the X20 system via X2X link and can operate and monitor the digital and analogue I/O modules of the system. The X20 system currently contains 1 X20 bus receiver/transceiver module and 11 I/O modules.

These modules, as well as the PP45, are powered by a 24 V transformer and the digital I/O receives or outputs 24 V's. Analogue inputs can be configured to receive a +/- 10 V, 0 – 20 mA or 4 – 20 mA signal. One of the concerns with the I/O modules on this system is the use of push-lock fittings. After inspecting the I/O and testing the strength of the fittings it was found that they were not very reliable. For a detailed description of the PLC and remote I/O the reader should refer to Appendix D – Electronic Documents (Electronic Source Number: TGD- B0100). The other concern that has been noticed is that the electrical wiring does not meet Australian standards. Three-phase power is wired to the colour of European standards, there is little ventilation for the control and power cabinets and there is insufficient labelling. Since the plant is a prototype it is not a major problem for now however the wiring should be brought up to standards before it is operated in a commercial application. Since the Tjuntjuntjara site is located in a region of very hot and dry weather the lack of ventilation within the control box may cause problems.

10.2 Plant Operation

10.2.1 Trials

Over the space of approximately two weeks the plant was operated and all significant parameters recorded manually.

Parameters such as;

- Feed, Brine and Distillate Conductivities
- System Operating Temp
- Cooling, Heating and Feed flow rates
- Vacuum Pressure

Each time the unit was brought up to steady operating conditions, measurements of the distillate flow rate were taken over an hour long period and the percentage recovery from feed was calculated. Observed fluctuations in operating conditions and system faults were also recorded. The reader should refer to Appendix B - Trial Operation of the VMEMD Plant for a record of the trials.

10.2.2 Plant Faults

There were a number of faults encountered while conducting plant trials. One of the most concerning was the lack of a safe shut down sequence.

Once the stop button was pressed, to shut the plant down, the heater would be turned off and the plant exposed to atmospheric pressure. Following this, level control would be continued for 5 minutes and then all control would be switched off. The issue observed when this shut down sequence was initiated is that the heating loop temperature would increase to levels above 80 ˚C. It was determined that this was due to the latent heat produced from the water vapour, now being exposed to atmospheric pressure, condensing within the module. Although this is a major concern due to the possibility of damaging the module, it is also concerning with regard to a safety point of view.
Further testing revealed that if the heating loop temperature was brought below 50 ˚C, before being exposed to atmospheric conditions, the latent heat produced would be small enough to prevent any further temperature rise. Therefore proper shut down of the plant could only be commenced once the heating loop temperature was 50 ˚C or less.

Another problem that occurred was the accumulation of condensate in the vacuum lines of the condenser stage. The MEMSYS plant has a sump connected to these vacuum lines to collect the condensate. However, if the plant is to run non-stop the sump needs to be able to drain itself without disturbing the vacuum pressure. The cause of the condensate in the vacuum lines was investigated further and it was determined that if the heat exchanger fluid rose above 28 ˚C the condensing stage of the module would not operate as desired. Vapour within the module would then not condense until it got into the vacuum lines and cooled down, causing the build-up.

Problems with the PLC operation of the plant were also observed. On a number of occasions the PLC would enter an unknown state, during automatic operation, in which the vacuum pump would switch off and not turn back on. The plant would then have to be switched over to manual mode and shut down. The alarming of the plant also caused some issues as on some occasions the plant would be forced to shut down due to an alarm condition that was not outside normal operating conditions.

When the PLC was able to operate the plant without faults, measurements were taken of the distillate output and the percentage recovery was calculated. The results of a maximum of 23 L/h (at a system operating temperature of 65 ˚C) and average of 18 L/h were far short of the 41 L/h rated output of the plant. After consulting MEMSYS about the rated output of the plant, it was highlighted that this rating was a maximum rather than the average.

It was also noted that at higher salinity of feed and lower operating temperatures the output would dramatically decrease. Further testing revealed that the output did increase at higher temperatures.

10.3 MEMSYS Consultation

A weekly meeting was organised with MEMSYS so that the problems with the plant could be discussed. The expertise from MEMSYS was drawn upon during these meetings to develop an understanding of the plant operating points. During one of the meetings with MEMSYS it was determined that the rated output of 1 m^3/day could only be achieved while operating the plant at high temperatures with a low feed salinity. This meant that with the high salinity of the Tjuntjuntjara bore (~ 60 mS/cm) the plant will not be able to yield the 1 m^3/day output. It was also noted that with a higher salinity feed the flow rate should be reduced so that a good recovery percentage can be achieved. While discussing the build-up of condensate in the vacuum lines, MEMSYS stated that the heat exchanger fluid should not go above 25 ˚C. This presents another problem with the Tjuntjuntjara site as the ambient temperatures in the region will make it difficult to keep fluid below 25 ˚C.

11 B&R Program Assessment

11.1 Automation Studio

In order to assess the PLC code the B&R programming environment, Automation Studio, had to be acquired. The closest distributor of the software was DaaNet Pty Ltd in Victoria and after some inquires the company provided an evaluation copy. Shortly after receiving the software it was discovered that B&R PLC's do not allow the upload of PLC code. A request of the code from MEMSYS was then communicated to finally acquire the means to assess and modify the PLC code. An Ethernet connection to the PP45 provides the communications necessary to monitor the code in real-time. This provided a better platform for understanding how the PLC operates the plant.

11.2 General Code

It was hoped that the code could simply be altered to rectify the problems uncovered during operation of the plant however this was not possible. On first interrogation of the code it was discovered that all comments and variables were written in German. While the comments could be translated, the large number of variables could not.

Furthermore, the code was written for a much larger MEMSYS project (Marina Barrage) and a lot of it was simply unused. There were also a number of functional issues with the coding of the plant. One example of this was the external and internal top-up of the heating loop being allowed to operate independently of each other. The external top-up could fill the heating vessel to a high level and then if the internal top-up vessel reached a high level it would also begin to fill the heating loop. The two top-up methods filling the loop at the same time meant that the heating vessel would be overfilled and cause high pressure and level alarms. These factors led to the decision to re-code the PLC. In doing this, the unused code can be removed and the addition of new functionality becomes much simpler.

11.3 HMI

Automation studio allows the design of visualisations, otherwise known as a HMI or operator screen, for the B&R Power Panels. The HMI is used to operate the plant and monitor plant parameters. Figure 8 shows the HMI design for the plant with vessels, valves, pumps, flow lines and the VMEMD module displayed on the main screen. There are screens for changing PLC variables, monitoring plant parameters and others for configuring the PLC. The vast amount of configurability demonstrates that the HMI was designed for testing purposes. With the amount of information displayed by the HMI only a person very familiar with the plant would be able to understand configuration displays.

Figure 8 - VMEMD plant HMI

12 Re-Code of the B&R Program

12.1 Design

Re-coding of the PLC first commenced by creating a state diagram, seen in Figure 9, which describes how the plant will operate. This diagram was used to code the plant with the state machine methodology. The idea is that the plant has four main states; start-up, automatic, manual and shutdown. With the state machine methodology, the plant can only be in one state at any time. This approach was taken in order to remove the unknown operating states seen during plant trials.

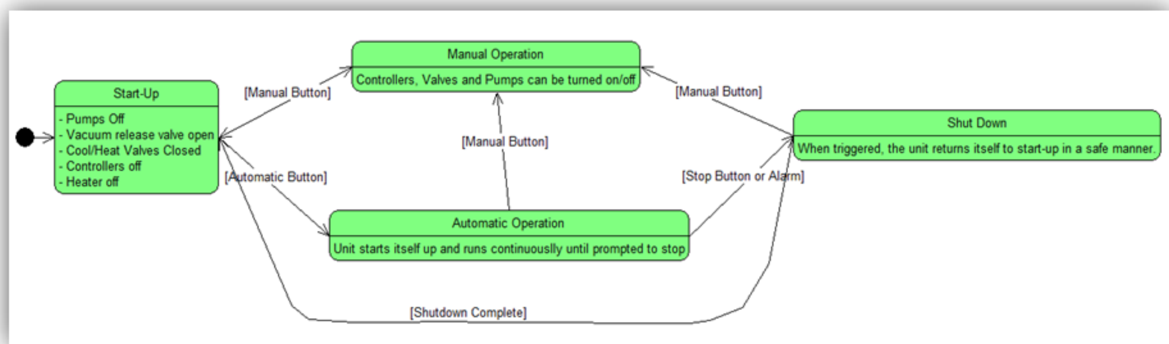

Figure 9 - State-Machine design of MEMSYS plant

The automatic state can be further broken down into the preparation procedures for automatic operation. The steps involved can be viewed in Figure 10, below. When the plant moves into the automatic state the first step is to check if the heating and cooling vessels are full. Next level control is introduced and the vacuum pump is started. The vacuum pump runs until the system vacuum reaches 450 mBar and then it is switched off. At this point, the heating loop pump is started and if the heating vessel is full and the flow through the loop is larger than 10 L/min the heater is turned on. The plant will remain in this state until the heating loop temperature reaches 50 ˚C in which the vacuum pump and cooling pump will be turned on and 60 seconds later the feed valve (V2) will be opened. At the end of these steps the plant will be in a state of automatic operation.

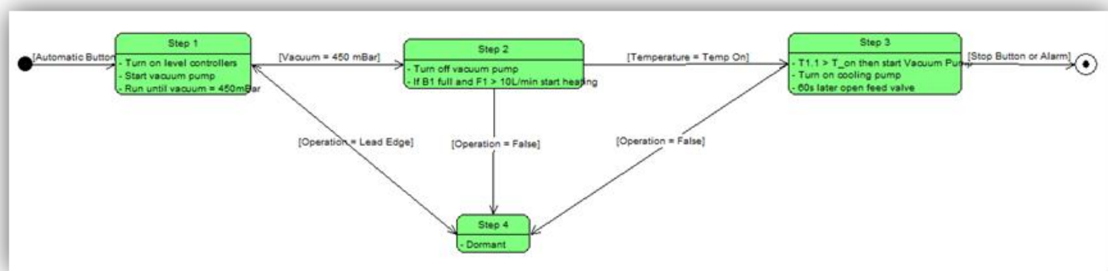

Figure 10 - Automatic Operation state-flow

Similarly the shut-down state can be broken down into a series of steps. The design of the shut-down procedure had to be thought about quite carefully as this state is used to shut-down the plant in the case of a fault or alarm and for general shut-down. In both cases the main priority is removing the thermal energy from the module. It was determined through testing that the heating loop should be brought down to 50 ˚C before complete shut-down. In order to bring the temperature down as quickly as possible there are 3 objectives; firstly the heater should be switched off, secondly the system vacuum should be maintained to avoid latent heat being released and thirdly the feed should be maintained as this will provide further cooling to the system. So therefore, in the event of a shut-down the heater should simply be switched off and all operations maintained until the heating loop temperature is less than 50 ˚C. When reaching 50 ˚C the plant is then exposed to atmospheric pressure and following this all further control is released. The plant will then return to the start-up state. Figure 11 shows the procedure for the plant to go from automatic operation to the start-up state.

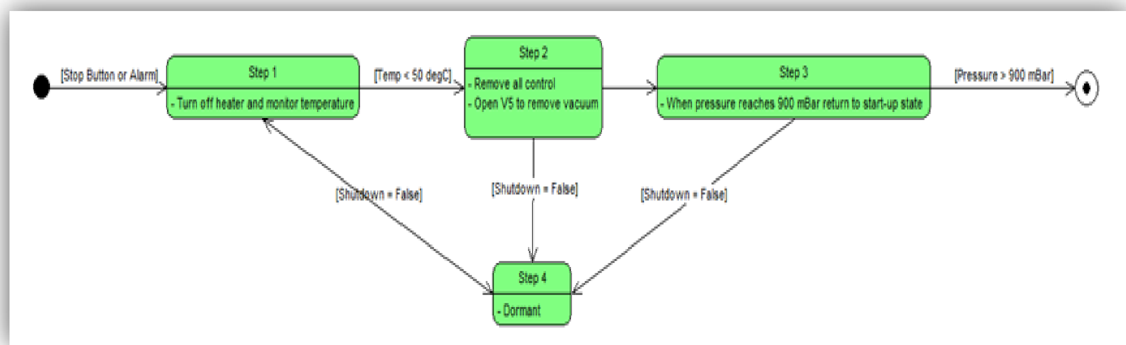

Figure 11 - Shutdown state-flow

12.2 Implementation

The previous PLC code was investigated again for useful functions and areas that did not need to be re-coded. In this respect the analogue scaling functions that were used in the previous code were adopted for the new code and the HMI design was also adopted. Since these areas were relatively small it meant that a significant amount of code had to be produced. To implement the state-machine design the code was broken into 9 programs, each having a specific purpose. There is a program for each type of control instrumentation (pumps, valves. .etc.), automatic start, shut-down, level control, analogue scaling, alarming and a higher level program which controls the 8 other programs. All programs are written in ladder logic except for alarming which is written in Automation Studio Basic and analogue scaling which is written in Function Block Diagram.

12.2.1 Higher Level Code

The higher level program that was developed manages the state of operation of the whole plant. States were designated through state machine design, as seen above, in which the code moves between states only if certain transition conditions are met. Having the higher level program allows the PLC to switch on/off control to certain programs depending on which state the plant is operating in. An example of this is if the plant is in the automatic operation state all level control is enabled but if in the start-up state then all level control is disabled.

12.2.2 Pump, Valve and Level Control

Different control instrumentation was grouped together in separate programs to maintain clarity of the overall plant code. Pump control is implemented in the fashion seen in Figure 12. The manual state in this case allows the pump to be switched on if the HMI pump button is pressed or if level control (d4.control) is activated. Operation and shutdown states only allow the operation of the pump via level control. In the manual state, there are also interlocks in place which only allow the pump to activate if the distillate vessel low level float switch is true. The operation and shutdown states have interlocks which only allow one of the switching pumps to be active at once. This reduces the larger current draw that can occur from the pumps switching on at the same time. Valves are controlled the same way as pumps however the interlock is not a low level in this case but a high level.

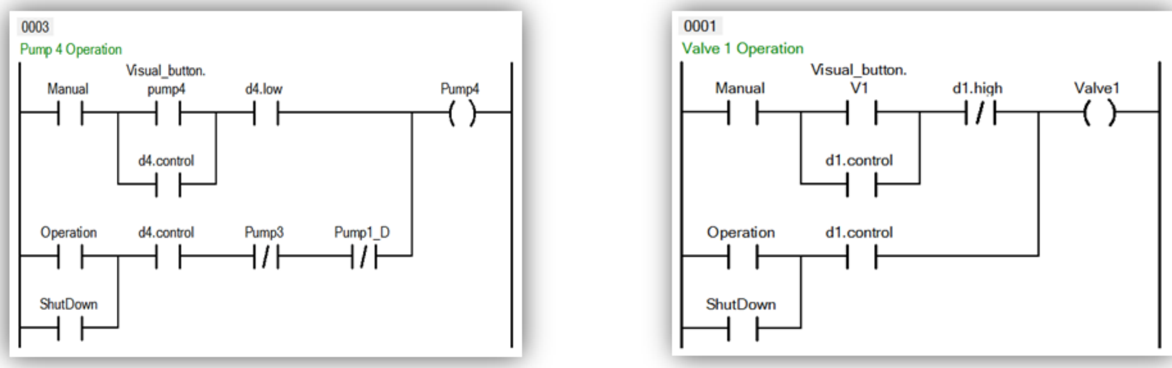

Figure 12 - Pump (left) and Valve (right) ladder logic control code

Level control is implemented to either drain or fill a vessel. An example of this can be seen in Figure 13. The control of level in the heating loop vessel is facilitated by activating Valve 1 (through d1.control) when there is a low level in Vessel 1 and Vessel 1D (internal top-up) and de-activating Valve 1 when a high level is reached in Vessel 1. With the new code, the external top-up will only be activated if the internal top-up is empty. The control of level in Vessel 1D therefore activates Pump 1D when Vessel 1 reaches a low level or if it reaches a high level. This resolves the overfilling issue experienced in the previous code. Level control for each vessel is timed so that if a control element is activated and vessel is not drained or filled in specified amount of time it will de-activate that element. When the timer runs out it's an indication that the pump or valve that was activated is not operating correctly because the vessel's level has not changed. De-activation stops the control element from being further damaged. An alarm is also triggered and the plant goes into the shut-down state.

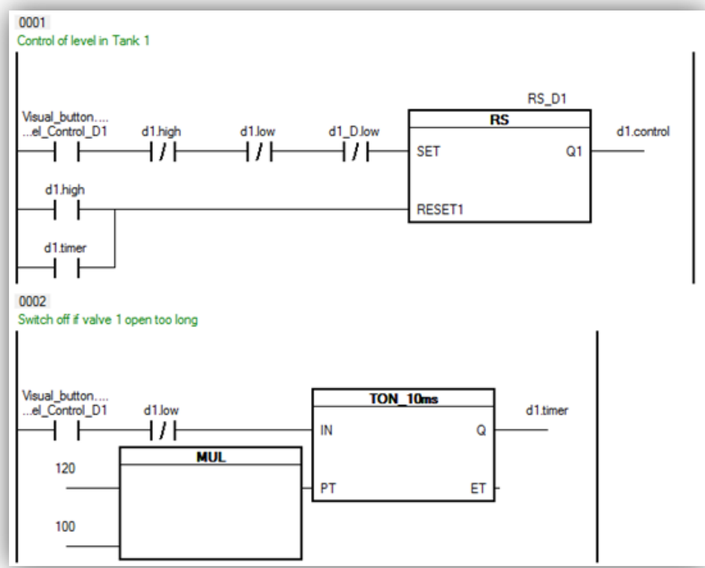

Figure 13 - Level control of Vessel 1 and corresponding timer

12.2.3 Automatic Operation and Shut-down

Both the automatic operation and shut-down states contain a sequence of events that must be executed in order. The program for each of these states operates in a ring structure. When the state is not active the program stays in a dormant state and when activated it will move around the ring until deactivated again. These two programs were again executed with state machine coding techniques and written in ladder logic. An example of one step in the automatic operation state can be viewed in Figure 14, below.

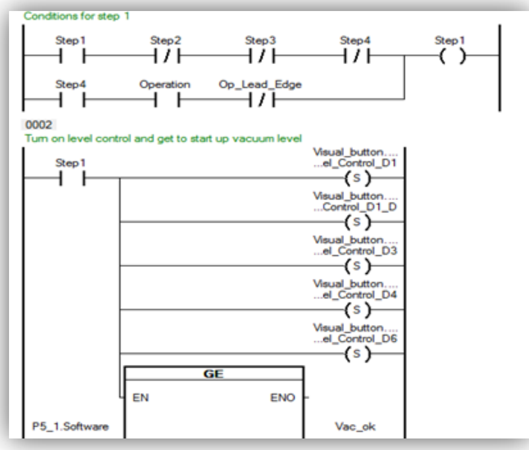

Figure 14 - State-machine coding for automatic operation

This step, being the first step in the automatic operation sequence, is activated when there is a leading edge (low to high) in the higher level state, operation.

Step 4 in the ring structure is the dormant state in which the state doesn't execute any extra code. Therefore, the first step is activated when the code is in the dormant state of automatic operation and a leading edge occurs in the higher level state operation. Step 1 then executes the code seen on the second network of ladder logic in Figure 14. Following this, Step 2 and Step 3 will be activated when their entry conditions are met and they will execute their designated code. Step 3 signifies the final step in which automatic operation is achieved and the plant will stay in this state until it is shut-down. When the higher level shutdown state is activated, either by HMI stop button or alarm, the automatic operation sequence will enter the dormant state and the shutdown sequence will go from its dormant state to Step 1 of its sequence.

12.2.4 Alarming and Interlocks

The implementation of the alarming conditions was written in Automation Studio Basic, as seen in Figure 15. There are 11 conditions which include high temperature and pressure, low flow, instrumentation fault and power failure. When an alarm is triggered the plant is sent into shut-down mode and the alarm condition is registered as an integer. The HMI will also display that there has been an error and that the plant is shutting down. The operator can move to the error page of the HMI display in order to view the condition of plant shut-down. The interlocks were included in the instrumentation code as described in 12.2.2. Constraints for the alarms and interlocks were selected to keep the plant operating at a safe level and to indicate any malfunctions with equipment.

```
PROGRAM _CYCLIC

    IF Operation = TRUE THEN

        // Set check variable that pressure has gone under 400mmBar
        IF (P1_2.Software <= 400) AND (Press_Check = FALSE) AND (T1_1.Software > (Visual_value.Heater_SP*10))  THEN
            Press_Check = TRUE;
        ENDIF

        // If pressure goes back above 800mmBar trigger emergency stop and note condition
        IF (P1_2.Software >= 800) AND (Press_Check = TRUE) THEN
            EmergencyStop = TRUE;
            Emergency_Cond = 1;
            Visual_value.Alarm = TRUE;
        ENDIF

        // If the temperature gets to high then trigger emergency stop and note condition
        IF T1_1.Software >= 850 THEN
            EmergencyStop = TRUE;
            Emergency_Cond = 2;
            Visual_value.Alarm = TRUE;
        ENDIF

        // If flow goes above 10 L/min in operation set flag
        IF (F1_1.Software >= 1000) AND (Heat_Check = FALSE) THEN
            Heat_Check = TRUE;
        ENDIF
```

Figure 15 - Alarming code written in Automation Basic

12.3 Code Assessment

As with all software design, once the programming has been finished there is a period of de-bugging that commences. This is even more crucial when it is applied to a PLC that is operating physical instrumentation. If the code doesn't operate as expected there is a chance for the instrumentation to be damaged or, in the case of more hazardous equipment, physical harm to occur.

De-bugging the new code involved downloading it to the PLC and monitoring the operation of the plant via Ethernet connection. Starting in manual operation, each piece of instrumentation was tested to see if the I/O was matched correctly and if scaling of the sensor signals was correct. Automatic operation was the next state to be de-bugged. The steps that bring the plant up to automatic operation were more critical as there was a sequence of events that had to occur correctly. The bugs encountered were removed by carefully monitoring the code while these steps were carried out and making adjustments where an error had occurred. These bugs were generally small mistakes that could be fixed relatively quickly. The final section of code to de-bug was the shut-down sequence which had very little problems. Further testing of the code involved following the state machine design transitions, seen in Figure 9. Moving between different states tested that the transitions were working correctly, so that the plant could not be stuck in an unknown state as seen in the original trials. Alarming conditions were then tested by physically altering the plant. An example of this would be closing a hand valve to simulate a low flow fault. Each condition was tested with this methodology while monitoring the code to ensure the right fault condition was registered and the plant moved into the shut-down state. A check list of the alarming conditions and their corresponding test result can be found in Appendix C - Alarm and Shut-down Test (3/10/12). A functional description was also produced in order to instruct an unfamiliar operator on the operation of the plant. The functional description will have to be updated as further development of the plant occurs however the current version can be found in Appendix D – Electronic Documents (Electronic Source Number: TGD- E0201).

13 Plant Improvements

The numerous hours spent operating the plant, have led to some key improvements. These improvements were brought into fruition to solve operational problems.

One of the main problems experienced while operating the plant was the build-up of condensate in the vacuum lines. A sump had been installed to collect the condensate that built-up. However, when the sump was full the condensate would simply overflow out through the vacuum pump. Even though the pump is designed to be able to extract condensate, it should not sustain this for long periods of time. Therefore a way to extract the condensate from the sump was required. A condensate dump chamber was designed to remove the condensate from the sump without compromising the system vacuum. The P&ID of this design can be seen in Figure 16.

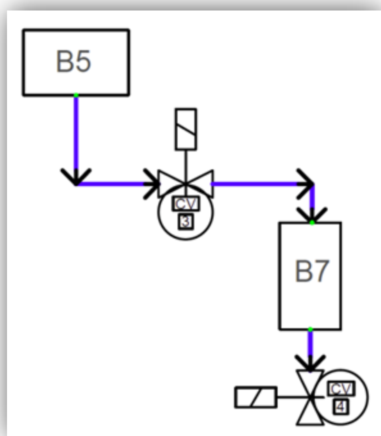

Figure 16 - Condensate dump system

Two solenoid valves were used to separate the chamber from atmospheric pressure and the sump. In order to remove condensate, the valves operate in a cascade effect. Valve 3 opens first, with Valve 4 closed, allowing condensate to flow into the chamber and then Valve 3 closes with Valve 4 open to allow the condensate to flow out of the chamber. This process is programmed to occur every 30 minutes, with the whole procedure taking 10 minutes, and the distillate removed can be collected.

The VMEMD plant currently runs off a three-phase power supply. It was identified that if that supply was cut off that the plant would be severely compromised. All control would be lost and the system vacuum exposed to atmosphere. This therefore would cause the temperature to rise dramatically and potentially damage the module. The main priority if the supply was cut off would be to have a backup supply that would power the PLC and valves. With the PLC and valves still powered a fault could be registered and the system vacuum maintained until the module temperature was brought below 50 °C. Since the PLC and valves operate on 24 volts two 12 volt batteries were connected in series to supply the backup.

Before connecting the backup to the 24 volt transformer the transformer specifications were reviewed. It was discovered that the current transformer could not charge batteries and therefore a new transformer was procured. With the new transformer installed, the backup batteries were connected in parallel with the transformer. This model of transformer also provides an indication of the state of the three-phase supply by means of an inbuilt relay. If the three-phase supply was to cut out the relay would open. The inbuilt relay was connected to a digital input of the X20 system so that a power failure could be identified by the PLC.

The addition of these improvements to the plant contributes towards the reliability required for the Tjuntjuntjara site. It has been noted that the H/E fluid may not be able to be kept below 28 ˚C and therefore a significant amount of condensate may be produced. The addition of the dump chamber ensures that this will not affect the operation of the plant for long periods of time. Power supply for the VMEMD plant instrumentation will be produced by a generator which powers the community. The backup power supply installed will guarantee that if the generator were to fault or be turned off the VMEMD plant can identify the problem and shut-down safely.

14 Continuous Operation Trial

The goal of the trial was to prove that, due to the re-code of the PLC and additional improvements, the plant is capable of operating continuously for an extended period of time. This was a crucial step in the progression of the project. Once it was proven that the plant could operate continuously without monitoring, the focus shifted towards ruggedizing the plant and designing the renewable energy source to power it.

14.1 Planning

The NCED has a pilot plant area in which the VMEMD plant is situated. The facilities which had been used for testing the plant were a ~2 m^3 feed tank and buckets for the distillate and brine output. Fluid for the H/E was also circulated from the feed tank which, due to the size of the tank, after a couple of hours of operation would heat up to over 30 ˚C. The feed supply tank was filled from a saltwater bore, on-site at the NCED, which provided a feed conductivity of ~ 50mS/cm.

Due to the longevity of the trial, the small capacity of these tanks meant that they had to be upgraded and the H/E fluid circulated through a separate tank.

The NCED had tanks available that fitted the required size and these were to be plumbed securely to the plant. To position the tanks and plumb them the use of a forklift and plumbing tools was required. Since the trial required the use of potentially hazardous equipment and would operate with high voltages and temperatures, a Job Safety Analysis (JSA) was completed. The reader should refer to Appendix D – Electronic Documents (Electronic Source Number: TGD-F0002) for a record of the JSA.

A much larger tank was selected for the H/E fluid in order to dissipate the heat better. Three 200 L tanks were positioned for the distillate and brine output and the heating and cooling loop top-up. The setup of the trial can be viewed in Figure 17 in which the H/E tank (left), feed tank (middle), 3 200L tanks (right) and the plant can be seen.

Figure 17 - Continuous trial setup at the NCED

A timeline of 5 days, Monday 15th of October to Friday the 19th, was set aside for the trial to be conducted. The feed tank had to be filled at the end of business hours each day and the output tanks emptied. As stated above, the goal of the trial was to prove that the plant could run continuously and therefore the system operating temperature was kept at 65 ˚C for the duration of the trial.

This is the average of the range of operating temperatures (50 – 80 ˚C) for the plant and if the trial was successful a second trial would test continuous operation with temperature variations.

14.2 Trial Operation

The plant was started at 0900 hours on October the 15th and ran for a total of 4 hours before it shutdown. A Pump 4 (distillate pump) fault was recorded by the PLC and displayed on the HMI. Pump 4 was then tested in the manual state and found to be operating well. The plant was started again the following day and after 2 hours of operation abnormal noise started emanating from Pump 4. Once power was applied to the pump it would produce this noise for a few seconds before actually pumping any fluid. It was thought that this could be cavitation however the possibility of an electrical fault had to be ruled out first. The PLC controls the Pumps, which operate on 240 VAC, by applying 24 VDC to a relay. Monitoring the Pump 4 digital output from the PLC showed that Pump 4 was being activated when required. Testing the relay proved that is was being provided 24 VDC and switching 240 VAC, as it should.

Next, the amount of current being drawn from Pump 4 was tested to check if it was being supplied the correct power. The current drawn was found to be identical to that of Pump 3 (brine pump) and within the ranges provided by the pump manual. With the electrical components ruled out as a possible cause for the malfunction, it was decided to remove the pump and disassemble it.

As stated in 10.1.2, Pump 4 is a magnetic drive pump which is considered to be very reliable and contain relatively few troublesome parts. The pump was disassembled and found to have some small fibrous material inside the turbine chamber. It is believed that the material may have been left inside one of the frames of the module during the manufacturing process and slowly flowed out of the module in the distillate stream. The material was removed and the rest of the pump investigated. After finding no other problems, the pump was reassembled and installed. The trial was started again and after a 6 hour period the plant shutdown, recording the same fault. Both the electrical control and the pump had been disproved as the cause of the fault and therefore the only other consideration was the piping and flow characteristics of the distillate line. To test this, Pump 3 and Pump 4 which are identical pumps were swapped.

The brine vessel is situated at a higher position than the distillate vessel and it was considered that smaller head of water that the distillate pump is provided may be partially to blame. The plant was started again and after 3 hours a shut-down occurred however this time the fault was registered as the brine pump. Since the pumps had been swapped the actual fault was caused by Pump 4 again. This indicated that the fault was definitely with the pump and not any other part of the plant. The resulting option was then to either disassemble the pump again or procure a new one. Once again, pump 4 was disassembled and checked for possible causes. While disassembling the pump, it was noticed that the O-ring that sealed the turbine chamber was not greased properly. No signs of wear and tear or possible causes of the fault were found except the poorly greased O-ring and therefore the O-ring was greased and the pump reassembled.

The trial was started again on the 18th of October after 3 days of troubleshooting the faulty pump. Operation of the plant was maintained throughout the day and the decision was made to leave it operating over-night, to properly test Pump 4. The plant ran through till the 19th in which the planned trial period was scheduled to finish. Since the supply tank had to be filled every 24 hours and the output tanks emptied, the plant was shut down over the weekend.

A new trial was started on the 22nd of October and scheduled to finish on the 26th. During the first day of the trial the temperature of the H/E tank rose from 21 ˚C to 25 ˚C. This severely decreases the effectiveness of the condenser stage of the module and hence a larger amount of condensate built up in the newly installed dump system. On the 23rd the plant shut-down due to a high pressure alarm. The heating loop top up tank had run dry and therefore when Valve 1 opened to top up the heating loop the system had been exposed to atmospheric pressure. This fault was recorded in the trial log as human error and the trial continued. Water in the H/E tank rose to a temp of 30 ˚C and appeared to reach an equilibrium position for the remainder of the trial period. This again increased the build-up of condensate in the dump system. The remainder of the trial period was completed and the plant was shut-down on the 26th. A log of the trial can be found in Appendix D – Electronic Documents (Electronic Source Number: TGD-F0001).

A second trial commenced on the 29th of October to run until the 2nd of November. Throughout this trial the system operating temperature was varied to simulate the conditions that the plant would experience at site.

The operating temperature was varied between 60 – 75 ˚C and the overnight temperature set at 55 ˚C. Operating point data was collected for 4 hour periods at 65, 70 and 75 ˚C. The plant ran continuously for the duration of the trial totalling over 100 hours of operation.

14.3 Results

The first trial period was carried out simply to prove that the plant could operate continuously for an extended period of time. Since the system operating temperature was kept constant no operating point data needed to be collected.

The trial was visually inspected at two hour intervals (0900 – 1700), as specified by the JSA. While monitoring the plant it was noticed that the sump was filling at a greater rate as the trial progressed. This was correlated with H/E water temperature rising which reduced the effectiveness of the condenser. Distillate output was also notably reduced as the trial progressed. The H/E fluid did however reach an equilibrium temperature of roughly 30 ˚C, on the second day of the trial.

Since it had been proven that the plant could continuously operate, the second trial was carried out to confirm the result of the first and to collect plant operating data. A number of operating parameters were recorded each hour for 4 hour periods. The data was recorded to an excel spread-sheet which can be found in Appendix D – Electronic Documents (Electronic Source Number: TGD-F0003). Operation of the plant during the first day of the trial provided a good correlation between distillate output and H/E water temperature, as seen in Figure 18. A linear line was fitted to the data and, by extrapolating, it can be deduced that at lower temperatures of H/E water the distillate output would be much higher.

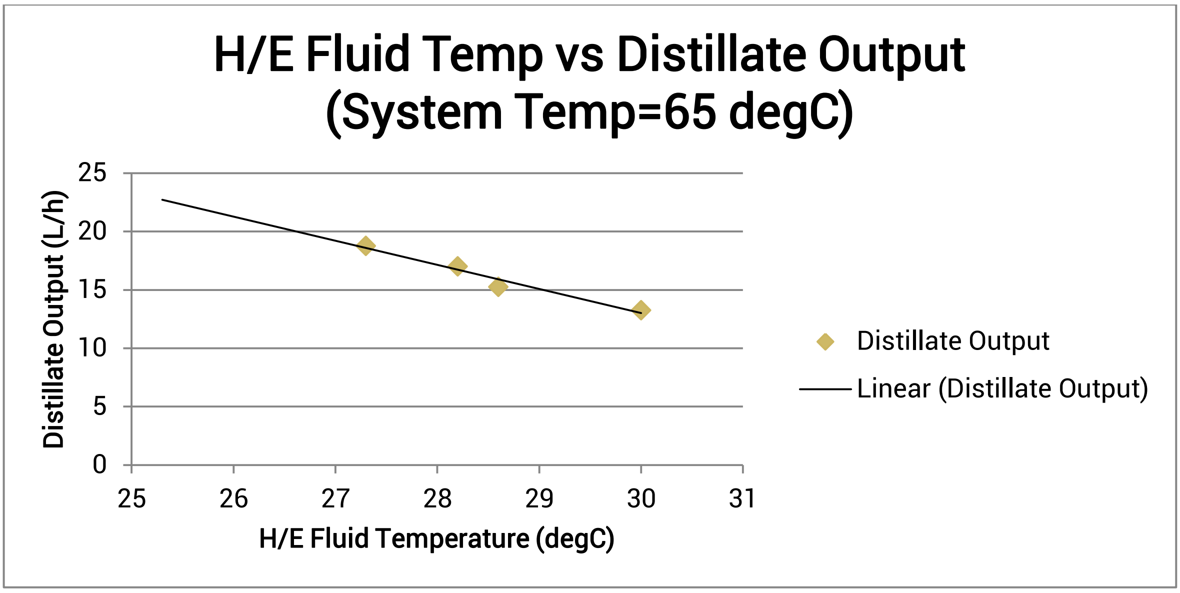

Figure 18 - Correlation between distillate output and H/E water temperature

The results found in earlier trials of the plant (see Appendix B - Trial Operation of the VMEMD Plant) which produced 23 L/hour at an H/E temperature of 25 ˚C, confirm this correlation.

Further distillate output results from the data were tarnished by the uncontrolled rise in the H/E water temperature. The rise reduced the output however there was still a larger recovery percentage seen at higher temperatures.

The image has been removed.

Figure 19 - Distillate output compared with system operating temperature [6]

The Marina Barrage project, which also utilised a MEMSYS VMEMD module for desalination, achieved the results seen in Figure 19. A recovery percentage increase at higher temperatures during the continuous trial confirmed these results.

An average drop in pressure of 29 mBar and drop in temperature of 3 ˚C between effects was recorded throughout the continuous trial. These results can be viewed in Figure 20 in which the averages for a system operating temperature of 70 ˚C can be seen.

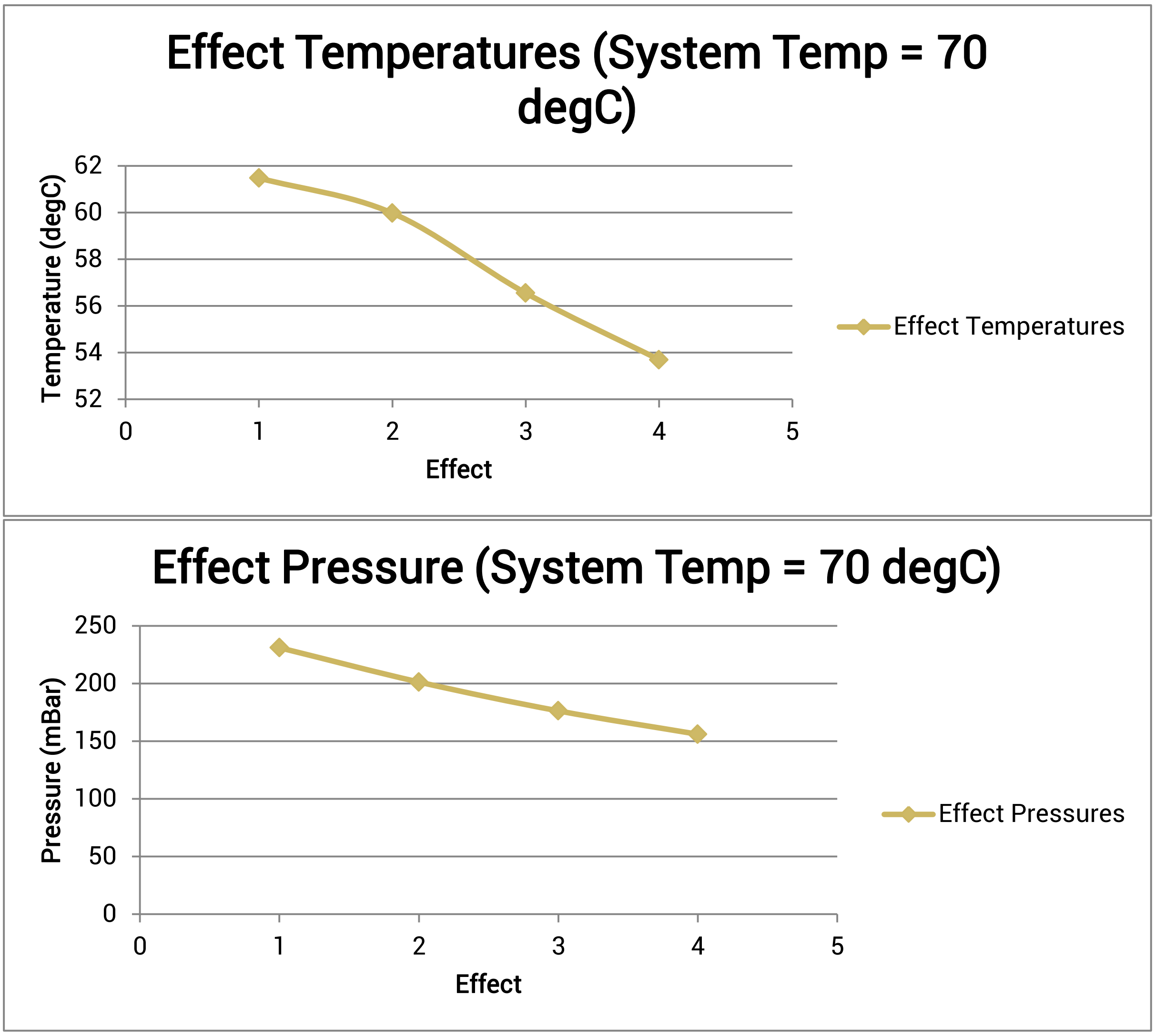

Figure 20 - Effect pressure and temperatures for an operating temp of 70 ˚C

A gradual increase in the amount of water required to top up the heating loop was also observed. This is due to the excess steam losses through the steam raiser membrane, at higher temperatures. The trend can be viewed in Figure 21.

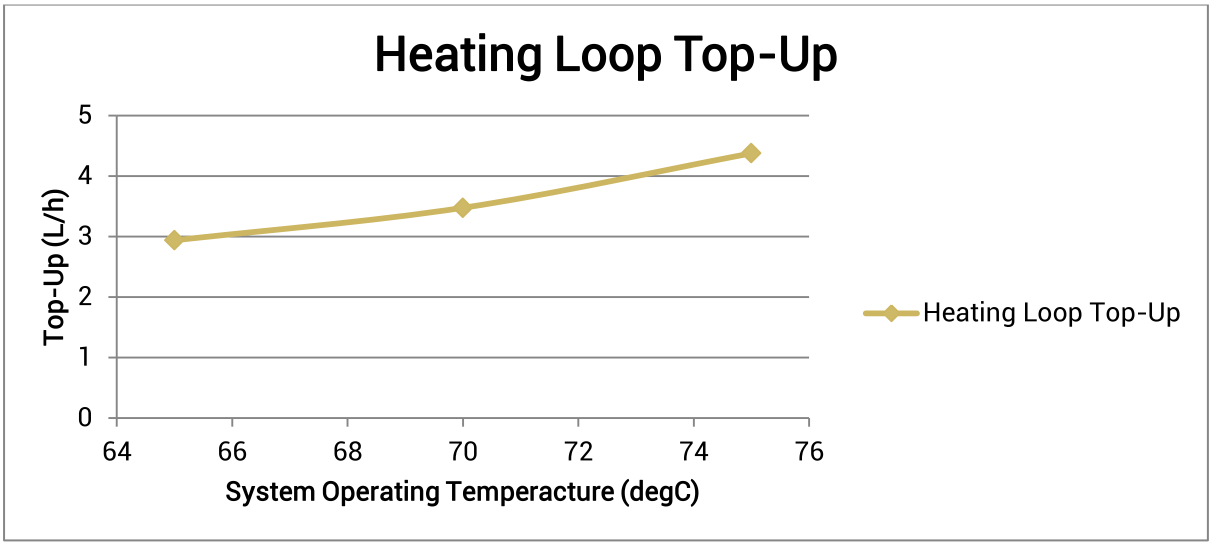

Figure 21 - Heating loop top up trend

The continuous operation trial of the VMEMD plant was a milestone in the progress of the Tjuntjuntjara project. It has shown that, in order to increase the effectiveness of the plant, the thermal input to the system will need to be at the higher range of operating temperature and the H/E fluid will need to be kept lower than 28 ˚C. Prior to the trial it was considered that the technology chosen for the project may not be reliable enough to proceed. Achieving continuous operation for over 100 hours has proven that the technology is reliable enough for the project and has allowed the project to progress forward. When the solar driven thermal input to the system has been developed and integrated further testing will be required to confirm the reliability of the entire system.

15 Recommendations

The work completed for the Tjuntjuntjara Groundwater Desalination Thesis was carried out during the early stages of the project and although the VMEMD plant has reached a good standard of operation, further development is required.

15.1 Tjuntjuntjara Research

There have been preliminary works completed to investigate the site at Tjuntjuntjara and this has provided an introduction to some of the challenges that may be experienced. Further research into the unknown factors that may affect plant operation must be completed. The main concern is the climate at Tjuntjuntjara. Based on the weather records for Kalgoorlie [7], the maximum temperature in the warmer months may average between 30 – 36 ˚C and 15 – 25 ˚C in the cooler months. Peak temperatures can reach maximums of 46 ˚C and minimums of -3 ˚C.

These extreme conditions may make it difficult to maintain stable operation of the VMEMD plant. Further research into the temperatures that will be experienced and their effect on plant operation should be conducted. The security of the plant itself should be considered and it is suggested that it is installed into some form of container for transport and security at site. This would protect the plant from environmental factors such as dirt, sun damage and animals. The quality of the feed bore water also needs to be thoroughly analysed. A preliminary visit to site has provided some details of the water quality however a more conclusive analysis should be undertaken. These details are crucial in ensuring that the plant will be able to operate well at site and will help the development of the plant for this challenge.

15.2 System Flush Capabilities

MEMSYS recommends that the VMEMD module is flushed with fresh water after operation with hyper-saline feeds in order to reduce fouling of the membranes. This recommendation has been followed for the short trials conducted however there have been no investigations into the effect extended continuous operation has on the membranes of the module. As a pre-caution it is recommended that a mechanism for flushing the module with fresh water, without shutting down the plant, is installed. To achieve this, a 3-way SV could be installed in the feed line to switch the feed between groundwater and distillate while keeping the plant in automatic operation. The flush could occur for an hour or so every couple of days. A proper study of the effect of extended continuous operation on fouling would have to be completed to provide an evidential based schedule. The installation of the flush mechanism is a very simple process and therefore it would be worthwhile even if it was discovered that there is minimal fouling.

15.3 Stable Coolant

Maintaining a low temperature of the H/E water throughout all trials of the plant has proven to be a major problem. The data collected has shown that the H/E water temperature has a large influence on the effectiveness of the condenser stage of the module. With a poorly functioning condenser the condensate collected in the vacuum lines increases and the distillate output decreases. These are undesirable operating conditions and therefore some way of maintaining the H/E water temperature must be developed. Ideally the temperature of the H/E water should be held below 28 ˚C, the lower the better.

There have been a number of concepts hypothesised to solve this problem; however, it is made increasingly difficult by the conditions found at the Tjuntjuntjara site. The high temperatures seen during the summer months will make it difficult to store a body of water below 28 ˚C even without using it to remove excess heat from the plant. Drawing from the bore, which should be at a much lower temperature, and running the loop underground could be one possible solution to the problem. Early inspection of the site has shown that the feed bore is situated roughly 70 m from the proposed plant location [8]; however, whether it is possible to facilitate this design is unknown. A more educated decision on how to solve the problem will be possible once further research of the site conditions is completed.

15.4 Supervisory Control and Data Acquisition

SCADA systems provide a platform for remote monitoring, data-logging and control. The control system on the VMEMD plant has been configured for remote monitoring and control via a Virtual Network Connection (VNC) viewer. Automation Studio was utilised to configure the virtual network connection on the PLC. The configuration allows the PLC to be connected to the internet by way of an Ethernet connection and therefore it can be monitored and controlled from anywhere in the world. Depending on the facilities on site, this may be a viable option or some form of auto-dialler may have to be designed. An auto-dialler could call or message a phone number if an alarm occurred and, coupled with a 3G modem, logging of operating points could also be set up over a 3G or satellite connection to dump the data logged on the PLC's compact flash card once a day. An example of a suitable auto-dialler and 3G modem can be found in Appendix D – Electronic Documents (Electronic Source Number: TGD-B0500). The complexity of the system is really determined by the amount of data that is required to meet the project requisites. However, some form of supervisory control is required so that if the plant were to shut-down it could be brought back up to operation as quickly as possible.

15.5 Testing

The majority of the operational testing of the VMEMD plant has been successfully completed. From this testing, it has been concluded that the current system is fully operational. There are a number of additions to be made to the plant and after each addition is made further testing will be required to confirm its operational status.

Once the plant has been developed to a state in which it is ready to go out to site, it is recommended that the plant go through a large trial period onsite at the NCED. The test should be arranged, to as closely as possible, mimic the conditions found at Tjuntjuntjara.

Feed water quality should resemble that of the Tjuntjuntjara bore, however, this may be difficult to replicate. To ensure the reliability of the plant under these conditions the trial should operate for an extended period of time, possibly a month or longer, during which time the arrangements can be made for transportation out to site. By this time the remote logging capabilities of the plant should be operational and could be used to analyse the results of the trial. It is hoped that from this trial any problems that could be experienced at site will occur and can be dealt with accordingly.

16 Conclusion

The Tjuntjuntjara Groundwater Desalination Thesis was proposed to work with the NCED, Murdoch University and other partners in the development of a VMEMD pilot plant for the desalination of groundwater. The specific area of investigation in which the thesis undertook was the control system and instrumentation that operates the VMEMD technology. When proposed, the VMEMD plant could not be operated for more than a few hours and in doing so led to unsafe conditions. The project progress was halted because of this and hence the thesis aimed to resolve these issues.

It was believed that the control system operating the plant was the reason it was not operational, however, to properly understand the problem research into the operating principles of VMEMD technologies was required. The project had a plethora of information, supplied by MEMSYS, that was consulted to fulfil this requirement. The control system and instrumentation operating the VMEMD module was interrogated by sourcing datasheets and wiring diagrams. This provided the information required to differentiate between whether a hardware or software caused faults were occurring. The understanding that was gained during this research phase was crucial in moving onto testing the VMEMD plant. After gaining better knowledge of the plant function and capability through testing, an assessment of the plant's control system and instrumentation was conducted to determine if it was suitable for the projects application. The PLC operation was identified as the major area of fault and, as such, it was the place to investigate for a solution. The code investigations led to the conclusion that the PLC was not operating the plant in a safe and effective manner. All research and works completed up until this point were conducted to identify the cause of the problems experienced.

The early stages of the thesis provide the information required to solve the problems experienced and develop the plant further. It was found that the PLC required re-coding to correct a number of inadequacies experienced in the operation of the plant and remove unused Marina Barrage code. The re-coding had to be completed with a more stable methodology so that the unknown operational states of the PLC would no longer be experienced. A safe shutdown sequence needed to be included as it was not provided by the previous code. Level control of the heating loop top-up required a re-designed to remove the overfilling of Vessel 1 which caused functional problems.

While the re-code was required to bring the plant up to a good operational status, a number of other area's that could be improved were also found. The build-up of condensate in the vacuum lines was one of these areas.

A system needed to be developed to remove condensate from the lines so that it did not flow out through the vacuum pump. Similarly, a system had to be developed to cope with the event of a power supply outage. A number of other improvements including a SCADA system and module flush capabilities were identified as future improvements.

Once work had completed to resolve and develop these findings, a method of validating the operational improvement in the VMEMD plant was required. One of the major requisites of the project is the continuous operation of the plant over extended periods of time and therefore a trial period of 5 days was planned as validation. The plant was continuously operated for these 5 days except for a short period of time that was due to human error and not operational fault. A second five day trial was completed with varying operating points to further validate the improvement in the plant and gather data. This trial had the plant operating continuously for over 100 hours and the data gathered provided a good insight into plant parameters at different system operating temperatures. The trials demonstrated that the operational stability of the plant has vastly improved and the crucial operating points that must be controlled in order to optimise the effectiveness of the plant.

The Tjuntjuntjara Groundwater Desalination Thesis was conceived to solve the operational faults of the VMEMD pilot plant. The thesis has rectified these operational faults and designed and installed additions to the VMEMD plant in order to ready it for operation at site. A number of recommendations have been put forward to ensure the reliable operation of the plant and further stimulate the projects progress. It is hoped that the project will progress forward with these recommendations in mind and that the VMEMD pilot plant is a stepping stone to solving a number of other water management problems.

17 Appendices

17.1 Appendix A – MEMSYS Plant Photo

17.2 Appendix B - Trial Operation of the VMEMD Plant

17.2.1 28/8/12 Trial

- Started at 9:15 am
- B6 control when topping up seems to overfill the tank and flick the valve on and off erratically
- 35 min trial completed (producing 11L)
- Having to refill B6 quite often (B1D not refilling effectively)

17.2.2 29/8/12 Trial

- New code put onto CF card
- HMI is much more responsive
- Ran unit with feed of 1L/min and achieved a recovery rate of 30%
- Ran unit with feed of 1.4L/min and achieved a recovery rate of 25%
- Higher the feed = more condensate in the vacuum lines

17.2.3 30/8/12 System Flush

- 55 deg C system operating temp
- Ran unit with fresh water until the brine conductivity < 250uS
- Started at around 50mS
- Produced much less distillate per hour with fresh water feed?

17.2.4 31/8/12 Trial

- Monitoring PLC code at the same time
- Under standard operating conditions at 0930
- Feed Conductivity: 52.2 mS
- Distillate Conductivity: 2.8 uS
- Operating Temp: 65 ˚C
- Cooling Flow Rate: ~10 L/min
- Heating Flow Rate: ~17 L/min
- Feed Flow Rate: ~1.35 L/min
- Vacuum 0950: 55-60 mBar
- 1hr Test: Distillate – 18.5 L Refill – 3.5 L

Recovery: [(18.5 - 3.5)/(60*1.35)]*100 = 18.5 %

- 1hr Test (Cooling Loop 18 L/min): Distillate – 20 L Refill – 3 L

Recovery: [(20.5 - 3)/(60*1.35)]*100 = 21.6 %

- NOTE: Sump full by end of trial
- Changed P1D and P6 off times

17.2.5 4/09/12 Trial

- Feed Conductivity: 50 mS
- Distillate Conductivity: 1.7 uS
- Brine Conductivity: 65 mS
- Operating Temp: 65 ˚C
- Cooling Flow Rate: ~17 L/min
- Heating Flow Rate: ~17 L/min
- Feed Flow Rate: ~1.39 L/min
- Vacuum 0920: 40 - 50 mBar
- 1hr Test (0920): Distillate – 21 L Refill – 3.5 L

Recovery: [(21 - 3.5)/(60*1.39)]*100 =21 %

- 1hr Test (system temp 65-67 deg C): Distillate – 23 L

Recovery: [(23)/(60*1.30)]*100 = 29.5 %

17.2.6 17/9/12 Trial (after re-code)

- Feed Conductivity: 50 mS
- Distillate Conductivity: 1.8 uS
- Brine Conductivity: 65 mS
- Operating Temp: 65 ˚C
- Cooling Flow Rate: ~17 L/min
- H/E Fluid Temp: ~20 oC
- Heating Flow Rate: ~17 L/min
- Feed Flow Rate: ~1.18 L/min
- Vacuum 1030: 50 - 60 mBar
- 1hr Test (1030): Distillate – 23 L Refill – 3.5 L

Recovery: [(23 - 3.5)/(60*1.18)]*100 = 27.5 %

- 1hr Test (system temp 70oC and H/E fluid ~ 27oC 1230): Distillate –25 L Refill – 3.5 L

Recovery: [(25 - 3.5)/(60*1.1)]*100 = 32.6 %

- NOTE: Vacuum much more stable

17.3 Appendix C - Alarm and Shut-down Test (3/10/12)

17.3.1 High Pressure P1.2

Test: Open gate valve 1.2

Result: Completed in safe conditions

17.3.2 High Temperature T1.1

Test: Raise heater set-point above alarm condition

Result: Completed in safe conditions

17.3.3 Low Flow F1.1

Test: Hand valve 1 closed

Result: Completed in safe conditions

17.3.4 Low Flow F2.1

Test: Hand valve 2 closed

Result: Completed in safe conditions

17.3.5 Low Flow F6.1

Test: Hand valve 6 closed

Result: Completed in safe conditions

17.3.6 High Temperature T6.1

Test: H/E pump turned off

Result: Completed in safe conditions

17.3.7 Pump 4 Fault

Test: Fault occurred by itself

Result: Tripped multiple times led to the pump having to be removed multiple times until fault was fixed.

17.4 Appendix D – Electronic Documents

Electronic Source No.	Title	Description
TGD-B0100	B&R Control System	Data-sheets and manual concerning the B&R control system.
TGD-B0001	VMEMD Pilot Plant P&ID	Detailed P&ID of the pilot plant.
TGD-F0002	JSA002_Vmemd Trial	Job Safety Assessment of continuous operation trial.
TGD-F0001	VMEMD Continuous Operation Trial Log	Log of the 1st trial period.
TGD-F0003	VMEMD Continuous Operation Trial	Data recorded to an excel spread sheet from the 2nd continuous operation trial.
TGD-B0500	Remote Monitoring	Data-sheets of suggested auto-dialler and 3G modem.
TGD-E0201	Operation Manual	VMEMD plant operation manual.

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