**UNIVERSITY OF NAIROBI**

**DEPARTMENT OF MECHANICAL ENGINEERING**

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**F56/76054/2014**


**PROJECT REPORT**

**MSc. (ENG) Energy Management**

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# TITLE: Energy Efficiency Assessment of Cooling Water System Using Variable Speed Drives at Tetra Pak Converting Factory-Nairobi

*Submitted in partial fulfilment for the Degree of Master of Science in Energy Management*

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# Declaration

## A. Student's Declaration

I declare that this project report is my original work and it has not been submitted to any other College or University for academic credit.

Signed ______________________________ Date________________________

**Dennis Khaemba Masungo F56/76054/2014**

## B. Supervisors Declaration

I confirm that the above student carried out this project work under my supervision for the entire period of the project.

Signed ______________________________ Date___________________________

**Prof. Cyrus Wekesa Project Supervisor**

I confirm that the above student carried out this project work under my supervision for the entire period of the project.

Signed ______________________________ Date___________________________

**Dr. Reuben Kivindu Project Supervisor**

# Abstract

This project assessed the potential of implementing electrical variable speed drives in flow control on a pumping system of a cooling system. Various studies have documented the energy savings from retrofitting variable speed drives in pumping systems. This formed the basis for the need to evaluate a cooling system with thermostatic mixing control and throttling on pumping system running full capacity. Thereby regulating the flow of chilled water and eliminating the need for throttle valves in chilled water line.

The study was conducted at Tetra Pak Limited a packaging manufacturing plant in Nairobi's industrial area. The focus of the study was narrowed to four pumps, three supplying water to the cooling loads (laminators 1, 2 and 3) labelled pump 1, 2, 3 (all rated 22 kW) and the other (pump 4, 30 kW) circulating water between the cooling tower and the chiller condenser which was water cooled.

The research objective of establishing energy and related cost losses from the current installed system was met by following laid out procedures in the methodology. The key steps that followed were; establishment of energy consumption of the existing cooling system, determination of load variance and energy saving and economic analysis of the project. Data was collected through measurement and historic data recorded manually and electronically through a SCADA (Supervisory Control And Data Acquisition) system.

The findings from the project showed that application of variable speed drives would result in substantial saving in the three water pumps supplying the laminators due to the variance in the cooling load. Pump 1 was observed to have a potential of 48.3 per cent energy savings, Pump 2 was observed to have a potential of 61.8 per cent savings, Pump 3 was observed to have the highest saving potential of 72.9 per cent savings. Pump 4 did not have any potential for application of the variable speed drive. Detailed analysis is provided in the report.

Acknowledgement

I wish to extend my sincere gratitude to the following; first to the Almighty God for giving me the opportunity to study at the University of Nairobi without which this project would not have been possible.

I would like to acknowledge with appreciation my supervisors the Prof. Cyrus Wekesa and Dr. Reuben Kivindu for their guidance throughout my project.

I would also like to thank Tetra Pak Ltd management for allowing me to conduct my research project at their company and time to advance my studies.

I extend my gratitude to my colleagues at work Mr. Jude Songok, George Omondi and Chrispinus Obilo for going out of their busy schedules to facilitate me in taking measurements, answering questions and providing details for the plant equipments.

Finally, yet importantly, I am indebted to my family for their support in my master's studies.

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# List of Symbols and Abbreviations

| | |
|---|---|
| ***AC*** | Alternating Current |
| ***COP*** | Coefficient of Performance |
| ***I*** | Current |
| ***DC*** | Direct Current |
| ***E*** | Energy |
| ***EC*** | Energy Cost |
| ***Q*** | Flow Rate |
| ***H*** | Head |
| ***HVAC*** | Heating Ventilation Air Conditioning |
| ***Hz*** | Hertz |
| ***HP*** | Horsepower |
| ***kWh*** | Kilowatt Hours |
| $\dot{m}$ | Mass Flow Rate |
| ***P*** | Power |
| ***pf*** | Power Factor |
| $C_p$ | Specific Heat Capacity |
| ***N*** | Speed |
| ***SCADA*** | Supervisory Control and Data Acquisition |
| $\Delta T$ | Temperature Difference |
| ***VSD*** | Variable Speed Drive |
| ***V*** | Voltage |
| ***RT*** | Refrigeration Tons |
| ***TBA*** | TetraBrikAseptic |
| ***TFA*** | Tetra Fino Aseptic |
| ***PLC*** | Programable logic controller |
| ***PID*** | Proportional Integral Derivative |

# CHAPTER 1

# Introduction

This chapter describes the project site and operations, the cooling plant under study, overview of variable speed drives, project problem statement and research objectives.

## 1.1 Project Site and Packaging Paper Manufacturing

The research project was conducted at Tetra Pak Limited located on Likoni/Enterprise Road Industrial area Nairobi, Kenya. Tetra Pak deals in packaging materials for use in food industries. The packaging is mainly for dairy products, juices and nectars, ice cream, cheese, food and vegetables. To realise its manufacturing and business objectives, Tetra Pak has invested in machinery for production processes which demand a range of utilities. These utilities include; electricity, water, natural gas and compressed air. The utilities drive process motors, fans, pumps, air compressors, refrigeration, as well as building lighting and HVAC systems. Some of the energy consuming machines and equipment are cooling towers, chillers, general lighting, printers, laminators, slitters, doctors, shrink tunnels, stretch wrappers, ventilation fans and conveyors. The key raw material is paper delivered as rolls. First, the paper undergoes printing as desired, then creased/punched to reduce stiffness thereby improving folding. Thereafter, lamination is done to ensure the paper does not experience any leakage nor will the packaged product be exposed to sunlight UV radiation. This protection is achieved by using aluminium foil for protection. Finally, the packing material is slit and sized as per the consumer requirement, at this point the packaging material is ready for dispatch.

The production process is an energy intensive operation. According to the records maintained at the plant, the biggest energy consumers are the laminators. Figure 1.1 shows how the process of manufacturing flows before and after the laminator. It can be observed that the laminators take in various inputs which include; printed paper, polymers and aluminium foil hence demand for substantial energy. The laminators require electricity, chilled water and natural gas for its operation, which is supported by the chillers under study, and cooling tower, which constitute about 92% of the chilled water demand. The energy used by the cooling system was found to be significantly high in spite of decline in input over the years. Hence the energy consumed by the cooling plant was not reducing in proportion as decline in product output.

This necessitated a study to be commissioned on the cooling plant to establish what needs to be improved.

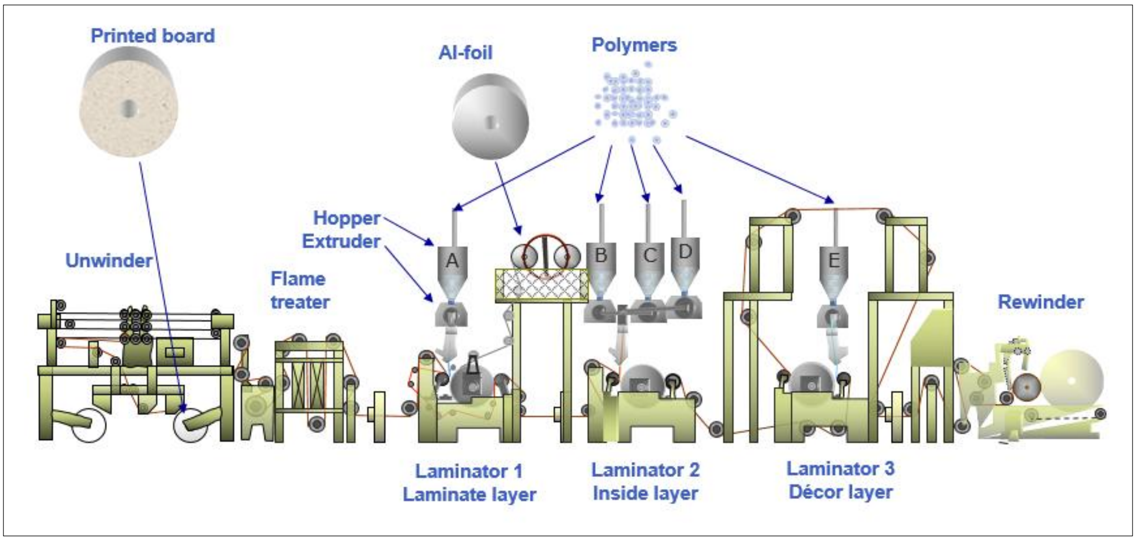



**Figure 1.1**: **Packaging material machinery layout [1].**

## 1.2 Cooling Plant

The laminators operate with a continuous supply of chilled water which forms a closed loop. Figure 1.2 is a configuration of a model for cooling the laminators, due to upgrade and redesign of the system at the project location, the schematic is not the current one however, they are similar. The differences shall be highlighted that distinguishes the two [1].

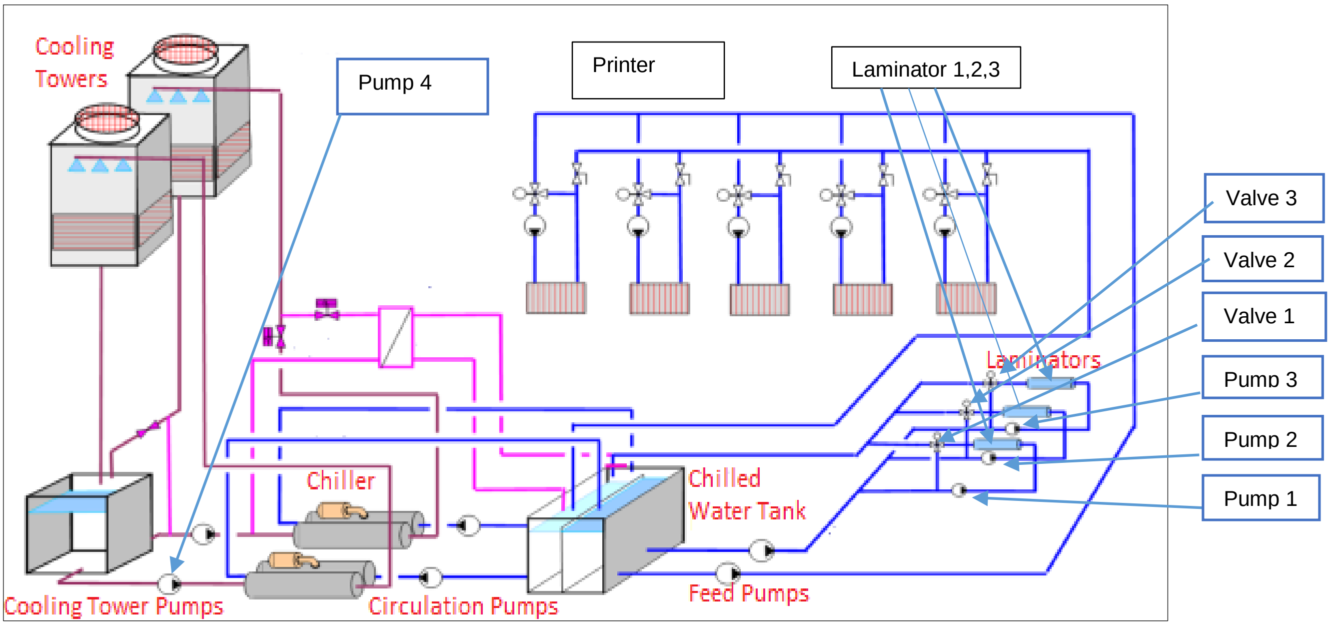



**Figure 1.2a: Laminators cooling system as installed currently.[1]**

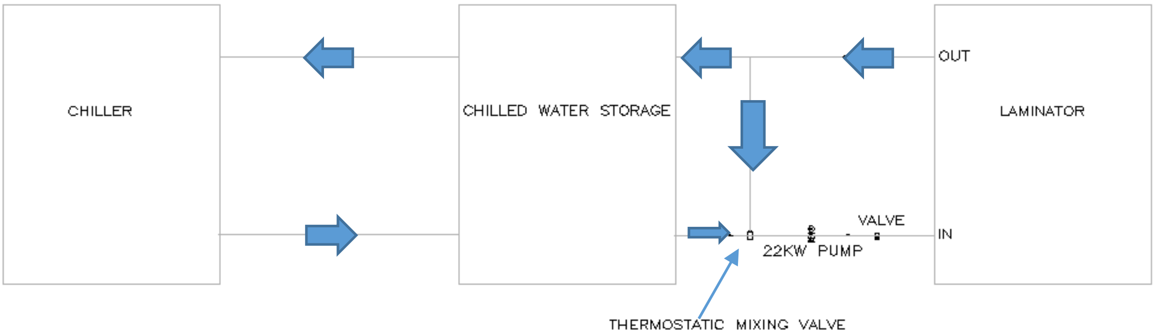



**Figure 1.2b: Laminators cooling system as installed currently.**

Fig 1.2a show the current laminator cooling system flow diagram. The laminator is supplied with chilled water from the reservoir tank through a 22KW induction motor pump as shown in Fig 1.2b, there is a thermostatic 3-way mixing valve that is pneumatically actuated on the return line from the laminator that is used to regulate the ratio of chilled water and warm water returning thus to achieve the desired set point. There is a manual throttle valve after the pump in line to the laminator. The supply water going into the three laminators described above is pre-set temperatures between 10 °C and 17 °C (refer appendices 1-7) these temperatures have been determined to produce the right quality of packaging materials. Undercooling lead to deformity phenomenon in packaging material called strip break whereby the polymer layers peels off due to weak bonding while overcooling leads to phenomenon called water marks where packets of water spots are visible on the material. The system monitors both inlet and outlet temperatures to determine corrective measures through the PID controlled valves with feedback loops. The amount of cooling required at any given time is controlled automatically through an algorithm program in the SCADA as well as operator input based on observation of the results. The purpose of the thermostatic mixing valves is to regulate the return warm water from the laminator and mixing it with chilled water from the reservoirs in proportional ratios thereby achieving desired inlet temperature.

Once the laminators are cooled, the outlet water from the heat exchangers, flows back to the chiller water tank and discharged at the top while chilled water is drawn from the bottom to the plant. This causes mixing of warm returned water with chilled water held in the tank. There are two pumps, one standby circulating water from the chilled water tank to the chiller. The circulation pump maintains the chilled water temperature at 8 °C in the tank by pumping water through the chiller to lose heat and storing in the insulated tank.

The screw compressor chiller installed is a water-cooled type thereby operates with a cooling tower to extract heat from the condenser. The pump is rated 30 kW with an average flow rate of 161 $m^3$/hr.

## 1.3 Problem Statement

While, production industries cannot control the rise of energy prices, they can control the consumption of energy by adapting various energy conservation techniques in their plants. The current operational cooling system at Tetra Pak is such that the pumps, fans and motors run at full capacity throughout the operation period whereas the cooling load varies with production. Scientifically, this nature of operation expends energy that could be saved by implementing variable speed control mechanism with feedback loops from the cooling loads thus varying performance of the motors subsequently energy demand.

In light of the established findings of energy conservation in modern motor-process control, this research aims at reviewing the current cooling system for the laminators and establish the impact of retrofitting the existing control mechanism operating on pneumatically controlled throttling valves on the chilled water supply line with electrical variable speed drive for the motor pump.

## 1.4 Research Objectives

The main objective of this project is to assess the existing cooling system and establish energy and related cost losses due to throttling valve flow control mechanism while proposing application of electrical variable speed drive. The specific objectives are:

1. To establish energy consumption of the existing pumping system on the laminator cooling circuits.
2. To determine energy savings in retrofitting electrical variable speed drives on pumps and eliminating throttle valves.
3. To determine payback period of the retrofit project

# CHAPTER 2

# Literature Review

## 2.1 Introduction

This chapter presents detailed literature on industrial pumping and flow control mechanisms, application of variable speed drives on pumping systems, performance of cooling systems, and economic analysis.

## 2.2 Pumping and Flow control

Industrial pumps can be categorised in two broad categories i.e positive displacement pumps and dynamic (centrifugal) pumps. The positive displacement pumps apply mechanical means to vary the size (or move) of the fluid chamber to cause the fluid to flow. On the other hand, centrifugal pumps impart momentum on the fluid by rotating impellers immersed in the fluid. This momentum hence produces an increase in pressure or flow at the pump outlet [2].

The other characteristic of positive displacement pumps is that they have a constant torque profile, while centrifugal pumps have a variable torque. Rockwell Automation corporation highlights the two common methods applied in varying flow in centrifugal pumps. The first is throttling which changes the system curve by use of a control or throttling valve and the other is to vary the speed of the pump, which modifies the pump curve. [2]

### 2.2.1 Throttling Control

Throttling controls flow by obstructing fluid flowing thereby increasing the head pressure. This is shown on Figure 2.1, which shows the performance curve of a throttled system and a fully open system [2].

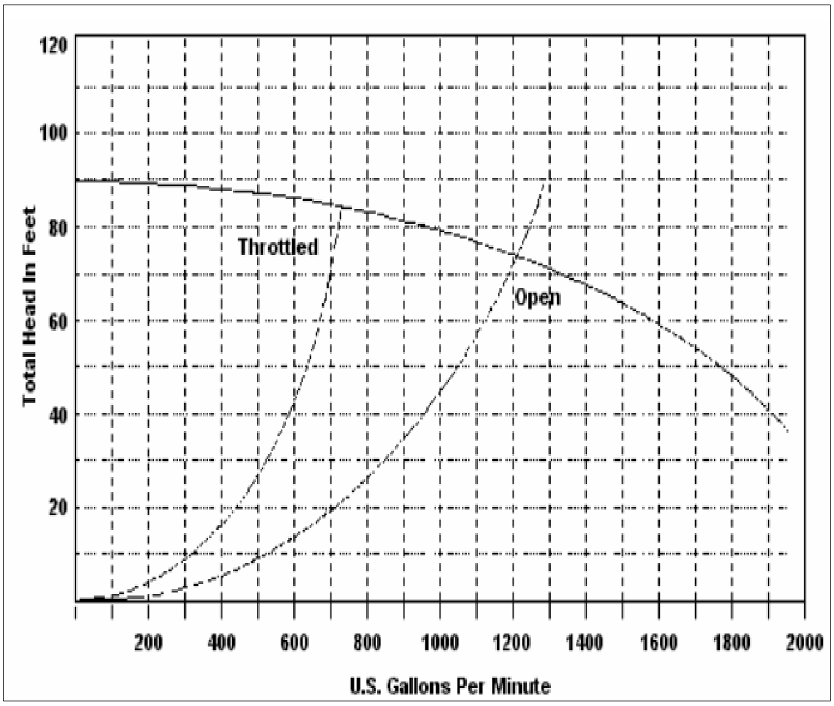



**Figure 2.1: Throttling head against flow chart. [2]**

### 2.2.2 Variable Speed Control

Variable speed drives also referred to as variable frequency drives are electronic motor speed controllers that facilitate the variance of AC induction motor speed. Considering the constant motor speed in various applications, response to changing process conditions would result in energy wastage if the same is not matched by altering the motor speed. In applications where induction motors are prime movers of pumps, fans and compressors, the mechanical power required for operation is cube of the fluid flow rate.

Therefore, a reduction of flow to 80% of the nominal value would half the mechanical power to meet the demand. Conventional mechanisms of flow control like dampers or valves result in loss of the energy savings, whereas application of variable speed drives would enable proportional response to changing flow continuously thereby translating to direct energy and cost savings [3].

As it was noted by Rockwell Automation on the impact of variable speed on centrifugal pumps, Figure 2.2 demonstrates the changes in the head with speed variance. The variable speed system takes advantage of the change in pump characteristics that occur when the impeller speed is changed [2,3].

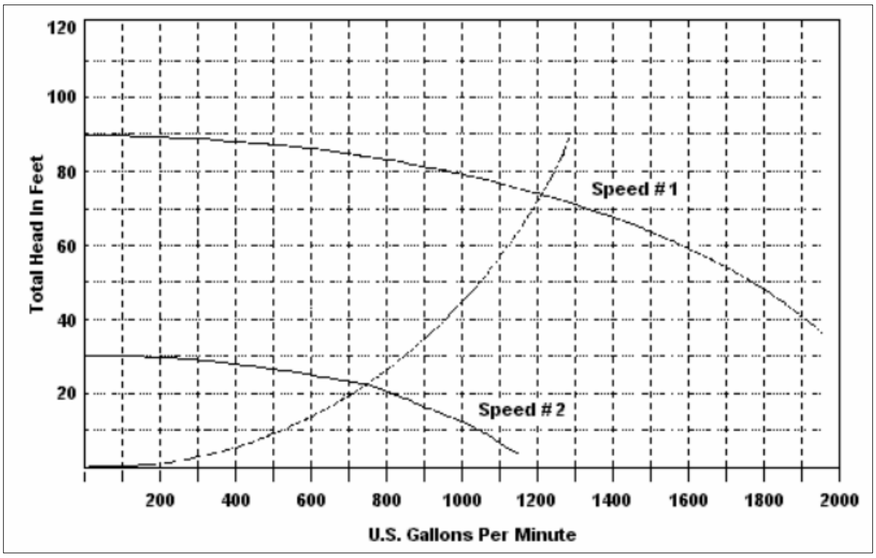
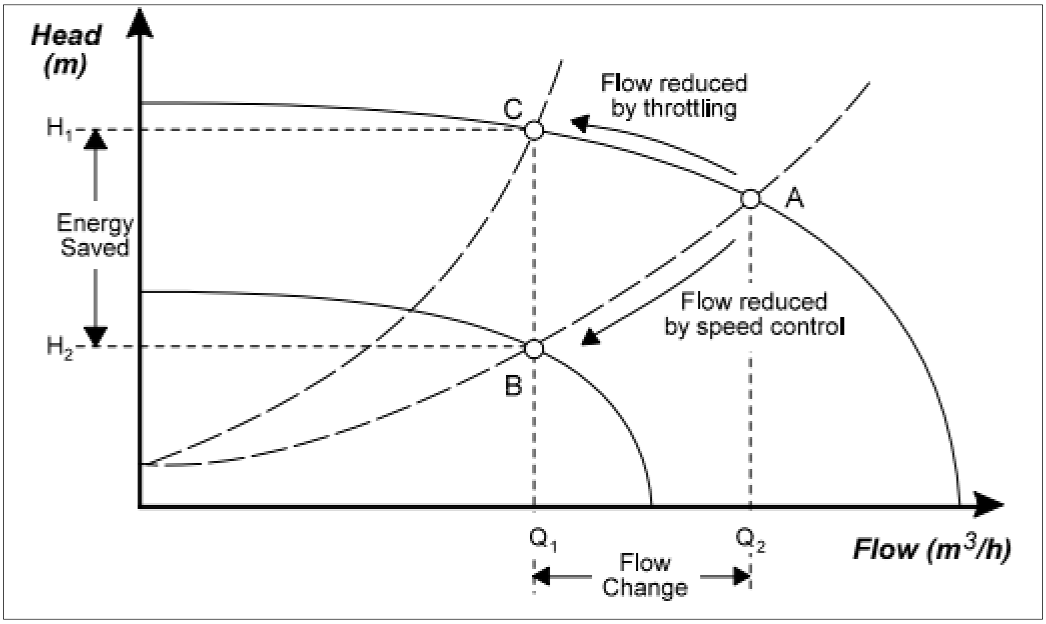



**Figure 2.2: Speed Control Head Pressure against Flow chart. [2]**

Following the observation of the changes in system parameters with the two flow control mechanisms, Figure 2.3 summarises the two scenarios.




*Flow Rate (m³/h)*

**Figure 2.3: Typical Q-H curves for a Centrifugal Pump. [3]**

The reduction of flow from $Q_2$ to $Q_1$ can be achieved either throttling or speed control. To compare the impacts of both mechanisms, Figure 2.3 highlights the profiles from which the following can be deducted [3];

1. **Speed control**, flow decreases along the curve A–B and to a point on another Q–H curve. As the speed falls, the pressure/head reduces mainly due to the reduction of friction in the pipes. A new stable flow of $Q_1$ m$^3$/h is reached at point B and results in a head of $H_2$.

2. **Throttle control**, an upstream valve is partially closed to restrict the flow. As the pressure/head is increased by the valve, the flow decreases along the curve A–C. The new stable flow of $Q_1$ m$^3$/h is reached at point C and results in a head of $H_1$.

The power consumption as a result of varying flow rate can be expressed using equations below [3];

$$\boldsymbol{Pump\ Power}\ (kW) = \boldsymbol{Flow}\ (m^3/h) \times \Delta\boldsymbol{Head}\ (m) X \boldsymbol{\rho}(Density)\mathbf{XG}(Gravity) \ldots 2.1$$

$$\boldsymbol{Pump\ Power}\ (kW) = \mathbf{Qx\rho xgxH} \ldots\ldots 2.2$$

$$\boldsymbol{Absorbed\ Energy}\ (kWh) = \mathbf{Qx\rho xgxH} \times \boldsymbol{t} \ldots\ldots 2.3$$

*Where;*
*P: Pump power, in Watt*
*ρ: Fluid Density, in kg/$m^3$*
*Q: Flow Rate, in $m^3$/s*
*H: Head difference, in metre*
*g: The acceleration due to gravity,*
*t: time*

### 2.2.3 Application of Variable Speed Drives

Since the invention of VSDs in 1983, there have been significant technological advancements in the field of variable speed drives. The desire is to reduce energy consumption squandered by motors, centrifugal pumps and fans has been the main driver. There are several methods which the speed is controlled [3,4,5]. These can be categorised into three namely: electrical, hydraulic, and mechanical drives. These three different methods have mechanisms, which can be used to realise speed control, which include;

1. Mechanical variable speed drives
   - Belt and chain drives with adjustable diameter sheaves
   - Metallic friction drives

2. Hydraulic variable speed drives
   - Hydrodynamic types
   - Hydrostatic types
3. Electrical variable speed drives
   - Schrage motor (AC commutator motor)
   - Ward-Leonard system (AC motor – DC generator – DC motor)
   - Variable voltage DC converter with DC motor
   - Variable voltage variable frequency converter with AC motor
   - Slip control with wound rotor induction motor (slip-ring motor)
   - Cycloconverter with AC motor
   - Electromagnetic coupling or 'Eddy Current' coupling
   - Positioning drives (servo and stepper motors)

The variable speed drives are best suited for control of flow and pressure in systems driven by AC induction motors. This is based on the correlation between flow and speed of the motor. Such systems include;

1. **Fans and pumps**: In applications where the flow of fluid is variable, considerable energy savings can be achieved by replacing existing throttling valves and dampers with VSDs.
2. **Conveyors**: For conveyors with varying speed or with varying material flow, a VSD can adjust to the changing load requirements.
3. **Compressors and chillers**: In the same manner as fans and pumps, compressors can take advantage of the energy saving that is achieved by varying the flow with a VSD.

### 2.2.4 Variable Speed Drive Control Loops

A drive that controls both voltage and frequency is referred to as variable voltage variable frequency (VVVF) controller. The digital control system therefore automates the process. The type of control used in a variable speed drive system influences the accuracy and response of the system to the changing variable. There are three main types of control loops that can be adopted [3]. These are:

1. Simple open-loop control, no feedback from the process
2. Closed-loop control, feedback of a process variable
3. Cascade closed-loop control, feedback from more than one variable

### 2.2.5 Variable Speed Drives in Cooling Systems

Various studies have shown that application of variable speed drives reduce energy consumption. In a study conducted by Song and Zhao in 2017, application of variable speed drive on a closed system show that by keeping the throttling valve fully open and regulating the flow using a speed drive reduced the power demand of a 2.2 kW motor substantially. Table 2.1 show the trend of speed control by varying frequency against power [5].

**Table 2.1: Trend of speed control by varying frequency against power [5]**

| Frequency (Hz) | Total power (kW) | Frequency (Hz) | Total power (kW) |
|---|---|---|---|
| 50 | 2.448 | 25 | 0.402 |
| 45 | 1.818 | 20 | 0.252 |
| 40 | 1.314 | 15 | 0.156 |
| 35 | 0.918 | 10 | 0.102 |
| 30 | 0.618 | 5 | 0.069 |

Moreover, in another study conducted by Narkhede and Naik in 2016 application of variable speed drive on a boiler feed pump resulted in power consumption reduction of 25 per cent through a reduction of operating speed by 10 per cent (Table 2.1). Furthermore, other benefits noted by Narkhede and Naik, include reduction in noise and vibration. Lee, et al. cite other benefits which include;  soft starting and stopping, reduction in “water hammer effect,” the probability of the motor efficiency optimisation and enhanced precision in the flow and temperature control. While the study by Narkhede and Naik highlights the reduction in flow rate with reduced operating speed, it demonstrates that there is slight decrease in head with little effect on flow rate and slight reduction in pump efficiency when compared with fixed speed operation. This forms an assumption for this study where the impact on the pressure head is assumed to marginally vary and impact minimally on the water flow delivery [6,7].

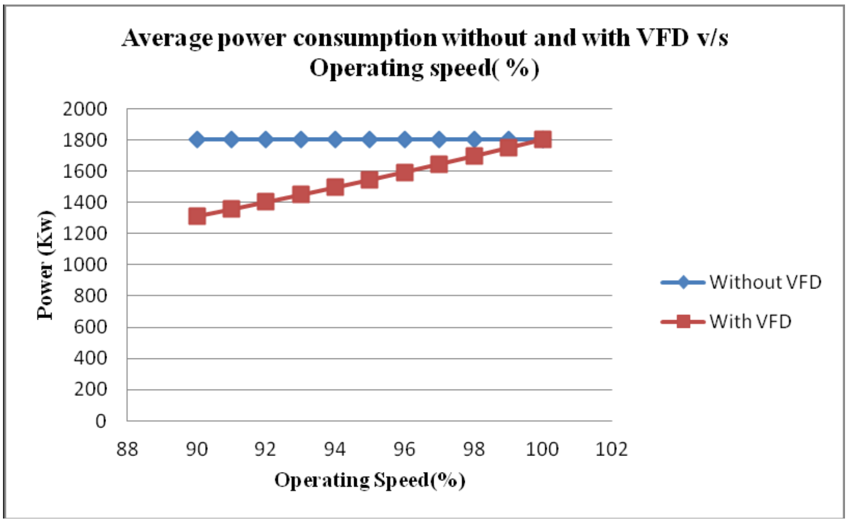



**Figure 2.4: Power without and with VFD v/s Pump operating speed % [6].**

In a study conducted by Lee, et al in 2014, a valve operated ship cooling system, it was observed that a three-way valve regulates temperature by passing fresh water from the high temperature circuit with an aim of maintaining the fresh water (FW) outlet temperature at 36 °C; this is characterised as energy wasting. Figure 2.5 show the profile of valve operating position and temperature over time. In the current research, similar wastage is intended to be mitigated [7].

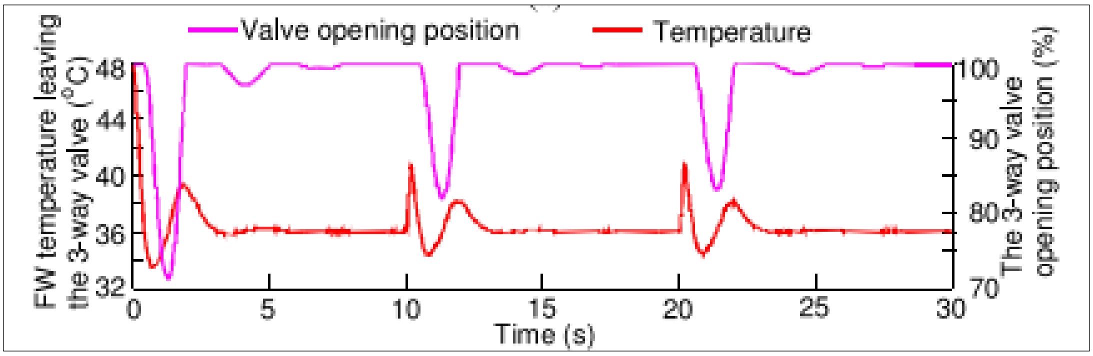



**Figure 2.5: Characteristics of FW temperature leaving the 3-way valve and the 3-way valve opening position[6].**

The study further demonstrate the increment in energy savings with reduction in frequency of the variable speed drive on voyages with sea water temperature of less than 32 °C. this achieved energy savings of almost 70 per cent for sea water temperature of 15 °C.

Considering the constant motor speed in various applications, response to changing process conditions would result in energy wastage if the same is not matched by altering the motor speed. In applications where induction motors are prime movers of pumps, fans and compressors, the mechanical power required for operation is cube of the fluid flow rate. Therefore, a reduction of flow to 80% of the nominal value would half the mechanical power to meet the demand. Conventional mechanisms of flow control like dampers or valves result in loss of the energy savings, whereas application of electrical variable speed drives would enable proportional response to changing flow continuously thereby translating to direct energy and cost savings.

According to a report by Natural Resources Canada on variable frequency drives, a case study at a dairy facility where a vacuum pump whose control mechanism was through bleeding air to the atmosphere was retrofitted with VFD demonstrated significant savings. The project involved replacement of existing motor with a high efficiency one with lower rating and a VFD. This resulted in 30% saving of the system's total capacity without any reducing vacuum pressure nor system capacity. Through the project implementation, there was a saving of $5,520 and 55,000 kWh at a cost of $8,200 which paid back in 1.5 years. [9].

## 2.3 Justification of Saving

According to a research performed, a 20 HP motor operating 24 hours, 365 days a year at 100% speed assuming Rs. 5/kWh would result in an operating cost of Rs. 653,496. Considering the pump load schedule is: 20% of the time at 50% full speed; 50% of the time at 80% full speed; and 30% of the time at 100% full speed, installing a VFD would result in a saving of Rs. 273,816 which is equivalent to 42% cost savings [4].

## 2.4 Performance of Cooling System

Fans like pumps follow affinity laws. This means that the air flow is proportional to the speed. The fan's power usage is half when speed is reduced by 20% and cooling capacity is reduced to 87%. A similar case is demonstrated on pump study shown on Figure 2.6. The savings realised using variable speed drives follows affinity laws. The laws are expressed in equation 2.4: [10]

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \ or \ \frac{H_1}{H_2} = \left[\frac{N_1}{N_2}\right]^2 \ or \ \frac{P_1}{P_2} = \left[\frac{N_1}{N_2}\right]^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 2.4$$

*Where;*

*Q* = *flow rate*

*N* = *Speed*

*H* = *Head*

*P* = *Power*

As the laws are applicable to centrifugal pumps, the same pump type are under study in this research. Ultimately, the strategies for operating an efficient cooling system is relative to outdoor temperature and humidity and water temperature thus the need to control water flow and air flow [8,9]. The projected optimised design is as shown in Figure 2.7.

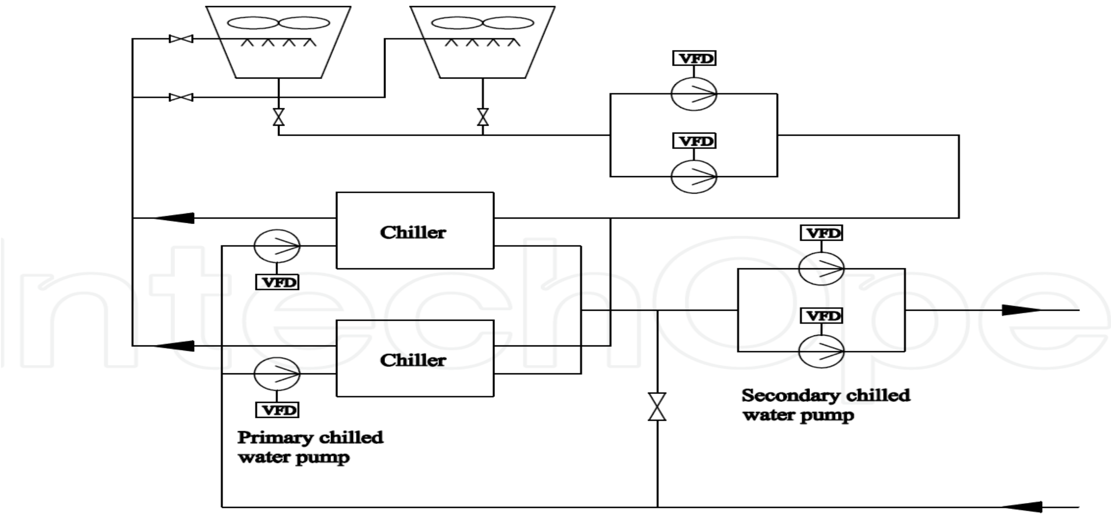



**Figure 2.6: Optimised cooling design.**

## 2.5 Performance of a Chiller

Chillers have the same coefficient of performance (COP) at 100 per cent load regardless if the chiller is equipped with VSD or not, the big difference is at part load down to 25 per cent of the total capacity. This is demonstrated in Figure 2.7 [1].

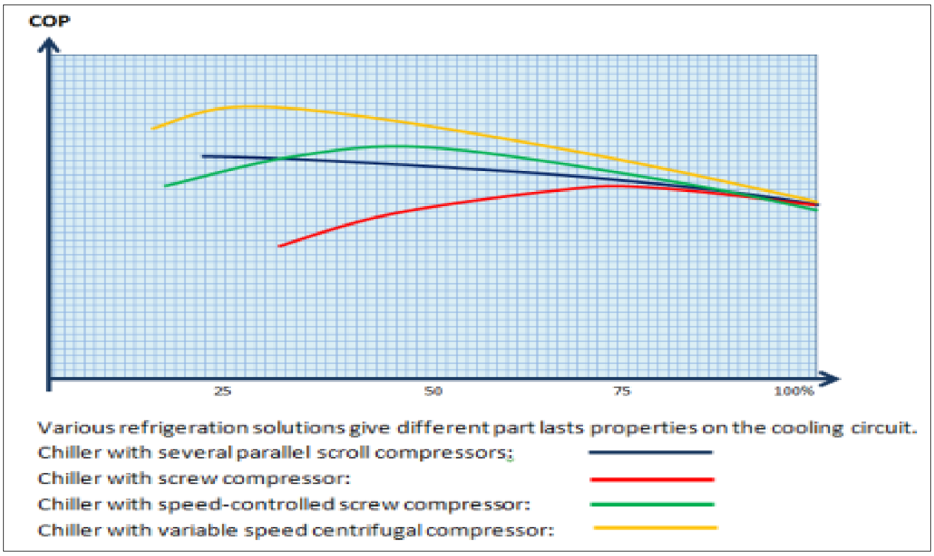



**Figure 2.7: Chillers COP curve [1].**

Due to the fact that the cooling system in most cases is designed to cope with the toughest conditions and that only occurs a limited number of hours a year. The remaining hours over the year the cooling system in oversized and not able to run effective. The single biggest user of electrical power in the cooling system is the chiller and if to lower power below the design power, it can be equipped with a variable speed drive. Chillers with VSD have much better performance at part load and become more efficient at part load. The setup requires full control of cooling tower fan and circulation pump [8,10].

## 2.6 Chiller Design Limitation

There are parameters that limits the chiller's ability to operate at low condensing temperature. One thing is poor lubrication, which limit the capacity of the expansion valve; this must be taken into consideration when floating condensing is applied. Manufacturers usually specify the minimum permitted inlet water temperature to the chillers condenser from cooling tower. Typical value for screw compressor chillers is 15 °C and for centrifugal chillers 13 °C [1].

# CHAPTER 3

# Methodology

## 3.1 Introduction

This chapter describes the procedures that were applied towards realisation of the project objectives. This study analysed energy consumption of the cooling system and performance, which was used to determine benefits that could be realised by implementing a VSD controlled pumping.

Measurements and analysis of the key operational parameters of the cooling system were therefore evaluated. Engineering calculations based on the equations (2.1-3.3) assumptions (see section 3.5) and established scientific data were applied to determine energy consumption, savings and performance. The outcome was quantified in monetary terms to determine viability of the project. The cooling system was evaluated under steady state conditions to establish consumption of electricity and performance.

## 3.2 Characteristics of existing cooling pumping system.

The laminators 1,2 and 3 are supplied with cooling water from identical pumps which are coupled to motors rated 22kW. The motors have a constant speed of 2940 rpm with star connections.

## 3.3 To establish energy consumption of the existing cooling pumping system.

Energy consumption was derived from electrical energy that was drawn for the pumps supplying chilled water to the laminators;

i. The electrical energy to achieve the cooling was to be determined by measuring the energy consumption at the distribution board using a power logger. This was determined by measuring the actual current drawn by the pumps using a Fluke 1735 Three Phase Power Logger shown in Figure 3.1. Total active power was recoded for 24 hours production on 8/11/2018-9/11/2018 to determine any vitiation in consumed power.

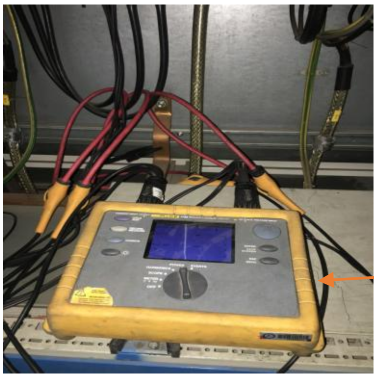



**Figure 3.1: Power logger taking readings from the pump circuit.**

The main specifications of the power logger are:

- Fluke 1735 Three Phase Power Logger
- Error due to power factor PF
- Maximum range with voltage range 830 V delta connection and 3000 A current range
- Intrinsic error ± (0.7 % of m.v. + 15 digit)
- Resolution 1 kW
- Operating error ± (1.5 % of m.v. + 20 digit)

ii. The cooling load was determined by; First measuring the inlet and outlet temperature of water to the chiller and secondly the flow rate. This was realised using non-contact Flexim Ultrasonic flow meter Fluxus F601 shown if Figure 3.2 and infrared thermometer.

**Figure 3.2: Flexim Ultrasonic Flow meter clamped on water line to cooling tower.**

The main specifications of the ultrasonic meter are:

- Transmitter type-F601
- Quantities of measurement- Volume flow, mass flow
- Accuracy-0.01m/s
- Range-0.01-25m/s

## 3.4 To determine load variance and energy saving

To establish the load variance, temperature data was used whereas, energy saving was based on flow rates, valve modulation data, operating hours and motor data (motor power and efficiency). These parameters were obtained from the SCADA (Supervisory Control and Data Acquisition) system that is the user interface and controls the production. These data were analysed to establish;

i. The operating time by estimating running hours per annum based on daily operation time and number of operation days per year. An approximation of the running hours per day's shift and number of days operated in the previous year were referenced from records.

ii. The duty cycles at different flow rates using pre-set temperatures and machine SCADA system as shown on Table 3.1.

iii. The power consumption from the motor name plate and power logger

**Table 3.1: Sample SCADA data parameters.**

| | | m/min | % | C | C | C |
|---|---|---|---|---|---|---|
| | **Sno.** | **Line Speed** | **Lam3: Cooling Water Controller Output** | **Lam3: Inlet Cooling WaterTemperature** | **Lam3: Outlet Cooling Water Temperature** | **Lam3: Cooling Water Temperature Setpoint** |
| **2018-11-07 13:28:00.000** | **1** | 219.4 | -78.83 | 17.73 | 21.2 | 17 |
| **2018-11-07 13:38:00.000** | **2** | 219.4 | -67.66 | 17.17 | 19.52 | 17 |
| **2018-11-07 13:48:00.000** | **3** | 219.4 | 0 | 14.26 | 17.84 | 17 |
| **2018-11-07 13:58:00.000** | **4** | 219.4 | 0 | 13.14 | 18.4 | 17 |

iv. The data extracted from the SCADA system contained Controller output which describes the position of the mixing valves that ranges from 0 to -100% where 0% is fully opened and -100% is fully closed this is relevant in determining the duty cycle by the flow rate.

v. The line speed describes the speed in m/s at which the packaging material is produced which is required when benchmarking energy used versus product output.

vi. Inlet cooling water in ºC into the cooling drums of the laminator, while outlet is the temperature at with the water leaves the cooling drums.

vii. The Data obtained from the SCADA is recorded at 10mins interval. The intervals are pre-set in the program algorithm.

## 3.5 Implementation of VSD on the system using 4-20mA Siemens 30hp VFD Box, 6SL3710-1BJ24-5AR0.

From equation 2.4, the relationship between speed and flow rate is a direct proportional relationship. Therefore, reduction of pump speed will result in reduction of fluid flow to an equal proportion. The speed of the pumps was observed using a Tachometer to establish if it conforms with the rated specifications on the nameplate.

To implement the VSDS on the system, Various parameters from the calculated load variance and duty cycle will be used. A PLC output from the controller will be configured to give analogue signal of 4-20mA that can be used to regulate the speed of the motor.

These outputs will be assigned as follows.

I. The VSD will operate with 4-20 mA signal from the PLC Analogue output

II. 4mA will be equivalent to 0 rpm or 0% flow rate and 20mA will be equivalent to 2940 rpm or 100% flow rate.

III. Analysis of the output will be based on calculated theoretical values from affinity law.

IV. Once the proposal is implemented the energy consumption will be evaluated by taking measurements of power consumptions on each drive and comparisons made with current status.

## 3.6 Economic Analysis

The economic analysis was performed based on the outcomes of technical assessment and feasibility;

i. The energy savings on a motor system is determined using three main parameter Motor power consumed, operating hours and duty cycle.

ii. Equation 3.1 below is used to determine the savings;[4]

$$E = P \times T \times N \text{ ……………………………………………3.1}$$

Therefore, to establish the resulting cost savings, equation 3.2 is applied;

$$EC = P \times T \times N \times C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

*Where;*

*E* = *energy*

*P* = *power*

*T* = *operating time*

*N* = *pump duty*

*C* = *unit energy cost*

*EC* = *total energy cost*

iii. The energy saved is computed by determining the difference in energy consumed without a VSD and with a VSD. The resulting energy saved is multiplied by unit energy cost to establish the energy cost savings. To determine the payback period within which the initial investment (includes cost of cables, VSD and installation) is recouped, Equation 3.3 is used;[4]

$$\text{Payback period} = \frac{\text{Cost of Investment}}{\text{Annual savings}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

iv. Determining electricity price per kWh based on the average unit price for the past 3 months (August, September and October 2018).

v. Total energy cost while using modulating valves and VSD and subsequent cost saving.

vi. Investment cost of the project inclusive of cost of VSD, installation and auxiliaries.

vii. Determining payback period of the project.

## 3.7 Assumptions

Due to uncertainties, the following assumptions were taken into consideration while conducting the research;

i. Electric energy conversion within the system has limited losses.

ii. The heat exchange surfaces were fairly free from fouling

iii. Steady state conditions

iv. The factory is in production 24 hours a day (2 shifts), each shift is 8hours 300 days in a year = 4800 hours

# CHAPTER 4

# Technical Analysis

## 4.1. Introduction

This chapter details the outcomes of the research findings. The objectives of the study are met through quantification of cost, power and energy usage in pumping with and without variable speed drive following the methodology outlined and calculations based on the equations in literature review.

The four pumps on site were analysed independently where three had similar characteristics therefore analysis was performed using the same approach. The three similar pumps operating with throttling valves as flow control mechanism have been referred to as pump 1 (for laminator 1), pump 2 (for laminator 2), pump 3 (for laminator 3) and the other as pump 4 (for cooling tower). The measured full flow rate from the pump was found to be $80m^3$

To acquire a broad range of data to analyse the pumps, two data sets for each of the similar pumps were taken for October and November 2018 under similar operating conditions. These have been analysed in depth below. Calculation on how the results were arrived at have been done for pump 1 and pump 4 while the rest have been evaluated in a similar fashion.

## 4.2. Data Set 1 obtained between 15-10-2018 and 19-10-2018 running TFA packaging material Results

### 4.2.1. Pump 1

The temperature profiles of inlet water, outlet water and set point at laminator 1 were reviewed to establish variance due to the control mechanism in place. The profile was as shown on Figure 4.1. The time scale is numbered to represent time in intervals of 10 minutes between 2018-10-18 09:21am for designation 1 and 145 for 2018-10-19 08:41am the parameters were recorded in the PLC. The data presented in this chapter is summarised from actual data that is recorded in Appendices 1-7.

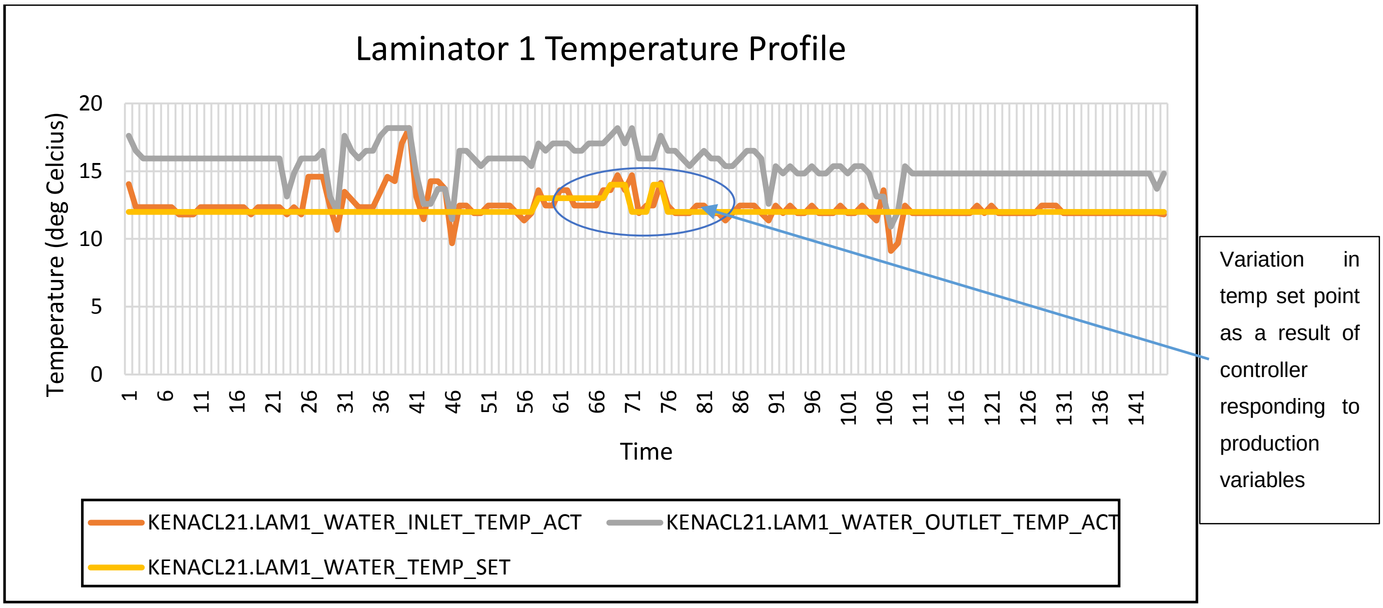



**Figure 4.1: Laminator 1 Temperature Profile**

It was observed that the variances of the temperature were correlated to the position of the valve stem at every point such that; btw 0 - (-20) the valve is mostly recirculating return water since the set point is higher than the actual inlet water temperature and btw (-80) - (-100) the valve is closing, drawing inlet water from the reservoir tank since the set point temperature is lower than the actual inlet temperature. Between -20 to -80, the modulating valve mixes return line warm water with water from laminator in respective proportion i.e. 20% of warm water in the return line is mixed with 80% of chilled water from the reservoir to constitute 100% and at -40, 40% of warm water from the laminator is mixed with 60% of chilled water from the reservoir. The negative sign on the valve position represents the position where the valve is operating in the PID (proportional integral derivative) spectrum this enable the PLC program to determine the actual position. For the purposes of this study the negative sign is ignored. Graphical representation of the same is as shown on Figure 4.2. The variation in temperature set points is mainly due to controller responding to other production variables e.g. laminator speed, stops and paper splices. The operator will adjust the set points depending on quality of the material being produced. This is done to achieve desired bonding parameters.

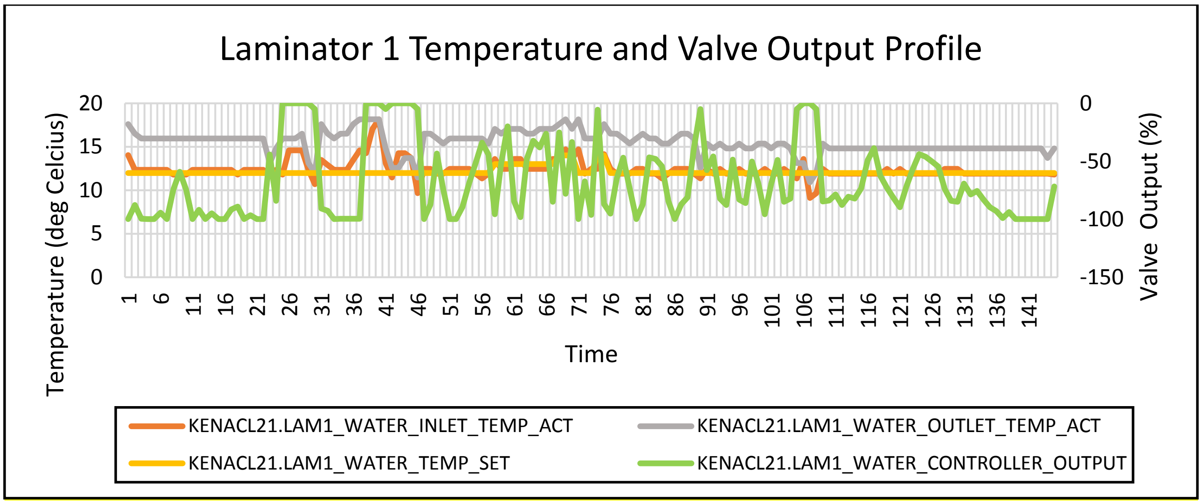



**Figure 4.2: Laminator 1 Temperature and Valve Output Profile**

The first data set of laminator 1 was taken between 15/10/2018, 09:21:00 and 19/10/2018, 09:21:00 giving a total of 145 data points at an interval of 10 minutes. A sample Table 4.1.

**Table 4.1: Laminator 1 valve output, inlet, outlet, pre-set temperatures**

| | | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling WaterTemperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Setpoint |
|---|---|---|---|---|---|
| | | % | C | C | C |
| time | Sno | KENACL21.LAM1_WATER_CONTROLLER_OUTPUT | KENACL21.LAM1_WATER_INLET_TEMP_ACT | KENACL21.LAM1_WATER_OUTLET_TEMP_ACT | KENACL21.LAM1_WATER_TEMP_SET |
| 2018-10-18 09:21:00.000 | 1 | -100 | 14.04 | 17.62 | 12 |
| 2018-10-18 09:31:00.000 | 2 | -87.86 | 12.36 | 16.5 | 12 |
| 2018-10-18 09:41:00.000 | 3 | -99.66 | 12.36 | 15.94 | 12 |
| 2018-10-18 09:51:00.000 | 4 | -99.74 | 12.36 | 15.94 | 12 |
| 2018-10-18 10:01:00.000 | 5 | -100 | 12.36 | 15.94 | 12 |
| 2018-10-18 10:11:00.000 | 6 | -94.41 | 12.36 | 15.94 | 12 |
| 2018-10-18 10:21:00.000 | 7 | -100 | 12.36 | 15.94 | 12 |

A further evaluation of the data by drawing a histogram was used to determine the distribution of percentage opening of the valve using bins of 20 data points signifying valve positions. The bin size was selected to be 20 to simplify the analysis. The histogram is a statistical approach to analyse the distribution of valve positions. This is significant as it will indicate the flow rate. The occurrence indicates how many times the valve was operating at those positions. From Figure 4.3 the valve was at position (-100,-80) 73 times from the same data set and between (-20,0) the valve was operating 22 times. This facilitated analysis of application of a VSD instead of a valve to control temperature. The outcome is shown in Figure 4.3.

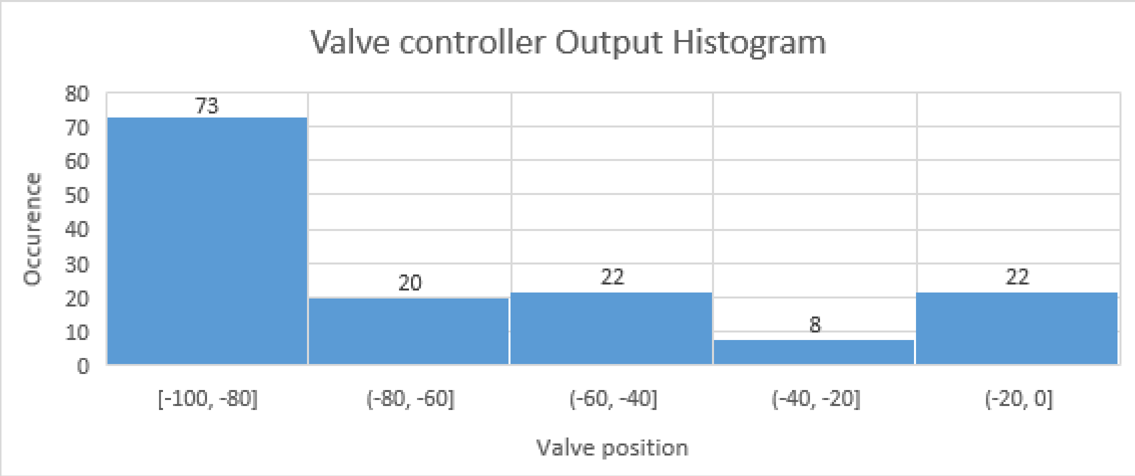



**Figure 4.3: Valve 1 Output Histogram**

## Summary of data analysis for laminator 1

From the histogram, data was Tabled (see Table 4.2), into bins corresponding occurrence and percentage frequency of occurrence for the total data points. The percentage frequency indicates the operating period within the opening percentage of the valve.

**Table 4.2: Laminator 1 operation frequency distribution**

| Bins | Frequency | % Frequency |
|---|---|---|
| 0 - (-20) | 22 | 15% |
| (-20) - (-40) | 8 | 6% |
| (-40) - (-60) | 22 | 15% |
| (-60) - (-80) | 20 | 14% |
| (-80) - (-100) | 73 | 50% |
| | **145** | **100%** |

By applying affinity laws from Equation 4.1 and selecting average bin size, data was analysed to establish; cube of the flow rate ratio and corresponding power demand that should be drawn when the system is on VSD, Table 4.3 summarises.

$$\frac{P_1(Power\ W)}{P_2(Power\ W)} = \left[\frac{Q_1}{Q_2}\right]^3 \ldots\ldots\ldots\ldots\ldots\ldots\ 4.1$$

$P_2 = \left[\frac{10}{100}\right]^3 \times P_1$ Where 10 is % flow rate ratio to full flow rate. The actual full flow rate measured is 80m³/hr equivalent to 100%

$$P_2 = 0.001 \times P_1$$

**Table 4.3: Laminator 1 flow rate analysis**

| Average Bin Size % (Bin mid points) | Cube of flow rate ratio |
|---|---|
| 10% | 0.001 |
| 30% | 0.027 |
| 50% | 0.125 |
| 70% | 0.343 |
| 90% | 0.729 |

The average power and percentage frequency of operation was used to determine the weighted power using Equation 4.2 and 4.3 and summarised in Table 4.4.

$$Power\ demand = Cube\ of\ flow\ rate\ ratio\ \times\ Motor\ power \ldots..4.2$$

From the motor name plate, the rating was stated at 22kW and efficiency (ƞ) of 0.93.
However, from the measured data there were slight deviations.
The power logger was giving 23.9kW.

$$Power\ demand = 0.001 \times 23.9/0.93 = 0.0257\ kW$$

Hence;

$$Weighted\ power = Power\ demand\ \times\ \%\ frequency \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..4.3$$

Therefore;

$$Weighted\ power = 0.025699 \times 0.15 = 0.003855\ kW$$

Applying the same formulae on the rest of the bins and using Microsoft excel for calculations the results are as Table 4.5

**Table 4.4: Summarized data on weighted power at different bins.**

| | BINS | Frequency | %Frequency | Avarage Bin (Mid point) | Cube of flow rate ratio | Power Demand | Weighted Power |
|---|---|---|---|---|---|---|---|
| 1 | 0 - (-20) | 22 | 15% | 10% | 0.001 | 0.025698925 | 0.003899147 |
| 2 | (-20) - (-40) | 8 | 6% | 30% | 0.027 | 0.693870968 | 0.038282536 |
| 3 | (-40) - (-60) | 22 | 15% | 50% | 0.125 | 3.212365591 | 0.4873934 |
| 4 | (-60) - (-80) | 20 | 14% | 70% | 0.343 | 8.814731183 | 1.215824991 |
| 5 | (-80) - (-100) | 73 | 50% | 90% | 0.729 | 18.73451613 | 9.431859844 |
| | | 145 | 100% | | | | **11.17725992** |

**Table 4.5: Laminator 1 power analysis**

| % Frequency | Power demand | Weighted power |
|---|---|---|
| 15% | 0.025699 | 0.003899 |
| 6% | 0.693871 | 0.038283 |
| 15% | 3.212366 | 0.487393 |
| 14% | 8.814731 | 1.215825 |
| 50% | 18.73452 | 9.43186 |
| **100%** | | **11.17726** |

The weighted power of **11.17726kW** represents the theoretical total power that will be drawn by the system based on the data collected when fitted with VSD.

### 4.2.2. Pump 2

The first data set of laminator 2 was taken between 18/10/2018, 09:21:00 and 19/10/2018, 09:21:00 giving a total of 145 data points at an interval of 10 minutes. Table 4. 6 highlights the sample data; actual data is recorded in appendix 2. Using the same method of analysis as in pump 1. The following results were achieved.

**Table 4.6: Laminator 2 valve output, inlet, outlet, pre-set temperatures**

| | Cooling Water Valve Controller Output | Inlet Cooling Water Temperature | Outlet Cooling Water Temperature | Inlet Cooling Water Temperature Set point |
|---|---|---|---|---|
| Time | % | °C | °C | °C |
| 2018-10-18 09:21:00.000 | -5 | 12.25 | 14.26 | 15 |
| 2018-10-18 09:31:00.000 | -5 | 13.37 | 17.62 | 15 |
| 2018-10-18 09:41:00.000 | -78.3 | 15.04 | 17.06 | 15 |
| 2018-10-18 09:51:00.000 | -42.82 | 14.49 | 16.5 | 15 |
| 2018-10-18 10:01:00.000 | -98.92 | 15.6 | 17.62 | 15 |

Corresponding temperature profiles of inlet water, outlet water and set point of laminator 2 is shown on Figure 4.4.

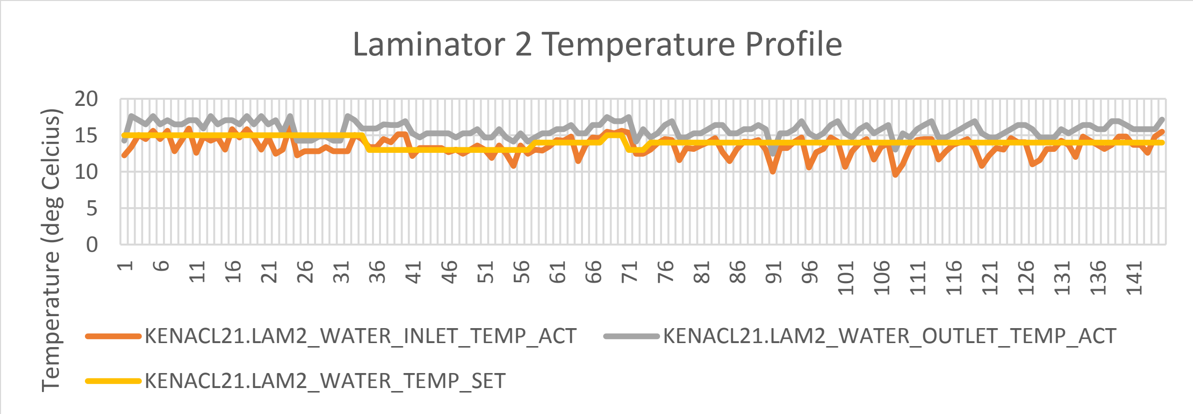



**Figure 4.4: Laminator 2 Temperature Profile**

Corresponding valve output profile, temperature profiles of inlet water, outlet water and set point of laminator 2 is shown on Figure 4.5.

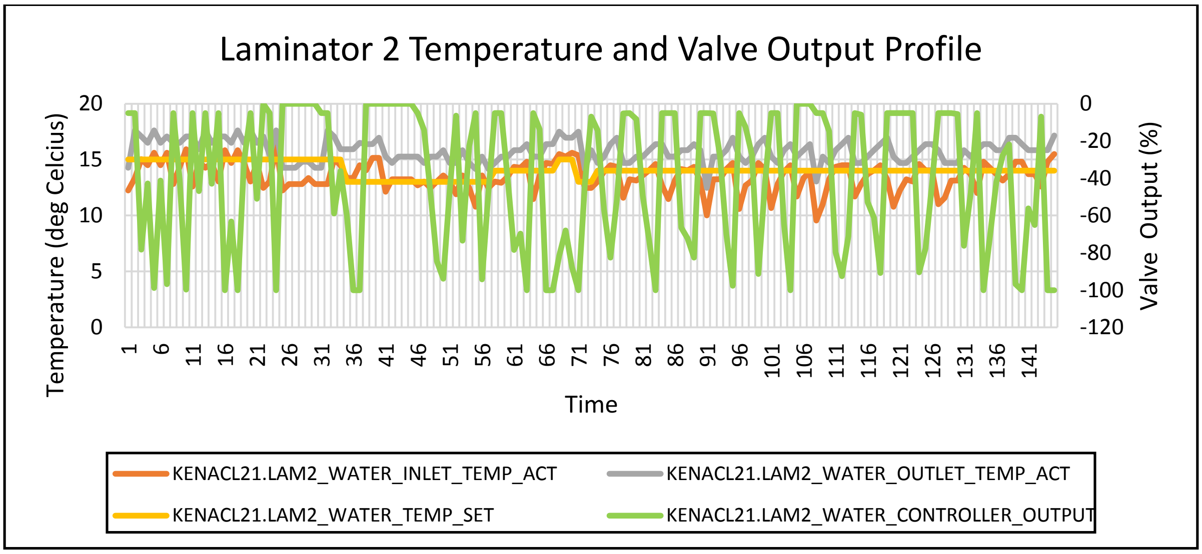



**Figure 4.5: Laminator 2 Temperature and Valve Output Profile**

Representation of valve output data for laminator 2 on a histogram is shown on Figure 4.6.

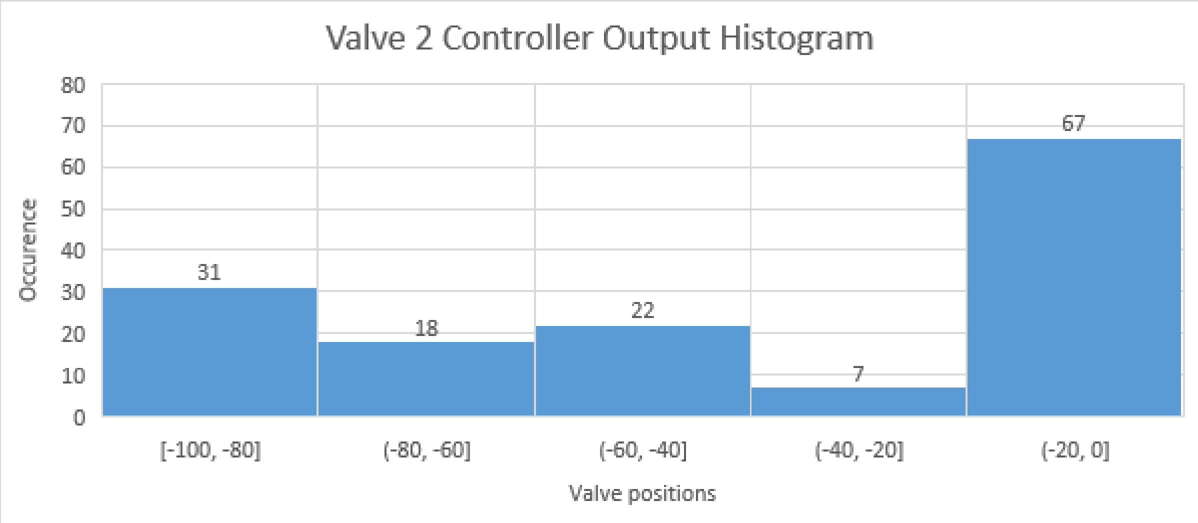



**Figure 4.6: Valve 2 Output Histogram**

**Summary of data analysis for laminator 2.**

From the histogram, data was tabled (see Table 4.7), into bins corresponding occurrence and percentage frequency of occurrence for the total data points.

**Table 4.7: Laminator 2 operation frequency distribution and power analysis**

| | BINS | Frequency | %Frequency | Avarage Bin (Mid point) | Cube of flow rate ratio | Power Demand | Weighted Power |
|---|---|---|---|---|---|---|---|
| 1 | 0 - (-20) | 67 | 46% | 10% | 0.001 | 0.023656 | 0.010931 |
| 2 | (-20) - (-40) | 7 | 5% | 30% | 0.027 | 0.638710 | 0.030834 |
| 3 | (-40) - (-60) | 22 | 15% | 50% | 0.125 | 2.956989 | 0.448647 |
| 4 | (-60) - (-80) | 18 | 12% | 70% | 0.343 | 8.113978 | 1.007253 |
| 5 | (-80) - (-100) | 31 | 21% | 90% | 0.729 | 17.245161 | 3.686897 |
| | | 145 | 100% | | | | **5.184561** |

### 4.2.3. Pump 3

The first data set of laminator 3 was taken between 18/10/2018, 09:21:00 and 19/10/2018, 09:21:00 giving a total of 145 data points at an interval of 10 minutes. Table 4.8 highlights the sample data; actual data is recorded in appendix 3.

**Table 4.8: Laminator 3 valve output, inlet, outlet, pre-set temperatures**

| | Cooling Water Controller Output | Inlet Cooling Water Temperature | Outlet Cooling Water Temperature | Cooling Water Temperature Set point |
|---|---|---|---|---|
| Time | % | °C | °C | °C |
| 2018-10-18 09:21:00.000 | 0 | 12.81 | 16.05 | 17 |
| 2018-10-18 09:31:00.000 | 0 | 14.37 | 18.29 | 17 |
| 2018-10-18 09:41:00.000 | -49.9 | 17.17 | 19.97 | 17 |
| 2018-10-18 09:51:00.000 | 0 | 16.05 | 21.09 | 17 |
| 2018-10-18 10:01:00.000 | -21.46 | 16.61 | 19.97 | 17 |

Corresponding temperature profiles of inlet water, outlet water and set point of laminator 3 is shown on Figure 4.7.

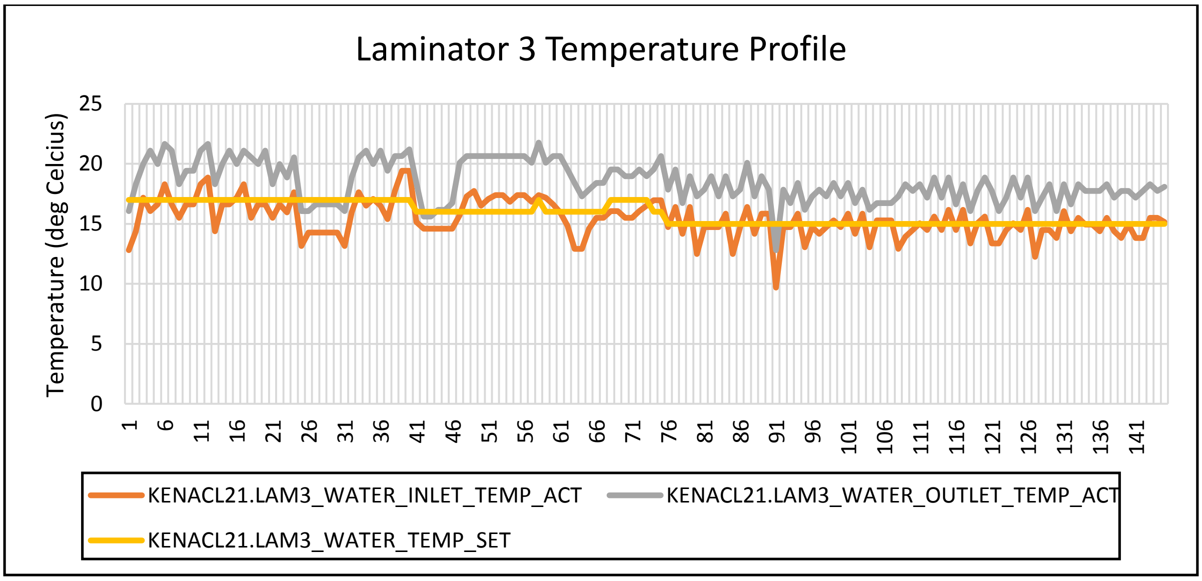



**Figure 4.7: Laminator 3 Temperature Profile**

Corresponding valve output profile, temperature profiles of inlet water, outlet water and set point of laminator 3 is shown on Figure 4.8.

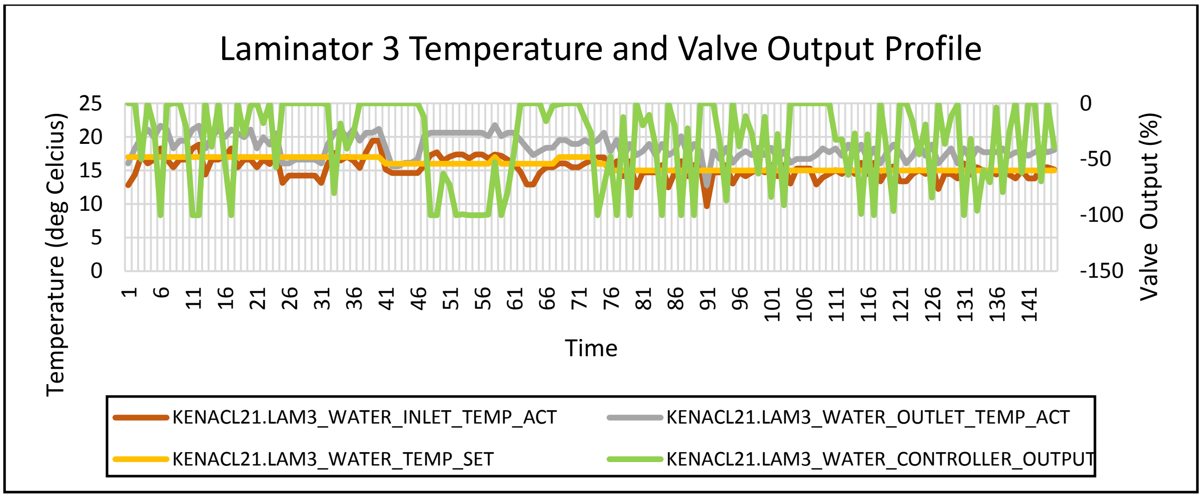



**Figure 4.8: Laminator 3 Temperature and Valve Output Profile**

Representation of valve output data for laminator 3 on a histogram is shown on Figure 4.9.

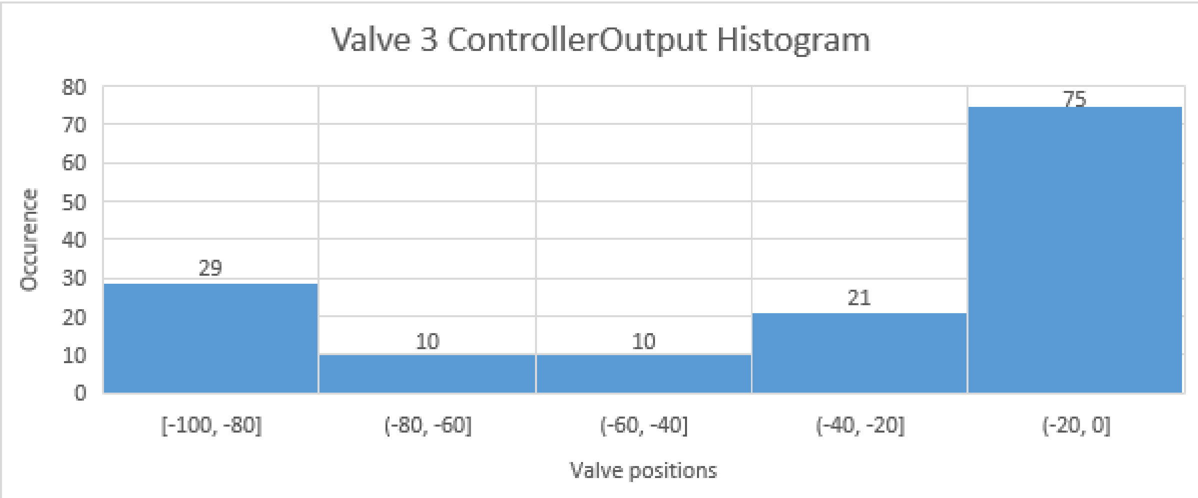



**Figure 4.9: Valve 3 Output Histogram**

## Summary of data analysis for laminator 3.

From the histogram, data was tabled (see Table 4.9), into bins corresponding occurrence and percentage frequency of occurrence for the total data points.

**Table 4.9: Laminator 3 operation frequency distribution and power analysis**

| | BINS | Frequency | %Frequency | Avarage Bin (Mid point) | Cube of flow rate | Power Demand | Weighted Power |
|---|---|---|---|---|---|---|---|
| 1 | 0 - (-20) | 75 | 52% | 10% | 0.001 | 0.023656 | 0.012235818 |
| 2 | (-20) - (-40) | 21 | 14% | 30% | 0.027 | 0.638710 | 0.092502781 |
| 3 | (-40) - (-60) | 10 | 7% | 50% | 0.125 | 2.956989 | 0.203930293 |
| 4 | (-60) - (-80) | 10 | 7% | 70% | 0.343 | 8.113978 | 0.559584724 |
| 5 | (-80) - (-100) | 29 | 20% | 90% | 0.729 | 17.245161 | 3.449032258 |
| | | 145 | 100% | | | | **4.317285873** |

## 4.3. Data Set 2 obtained between 06/11/2018 and 09/11/2018 running TBA packaging material Results.

This analysis was relevant to compare the results obtained in data set 1 that was obtained when a different product was produced. TBA (Tetra Brick Aseptic) is a different type of product that is suitable for larger volumes of products.

### 4.3.1. Pump 1

The second data set of laminator 1 was taken between 07/11/2018, 13:28:00 and 08/11/2018, 23:08:00 giving a total of 171 data points at an interval of 10 minutes. The intent was to have a confirmatory result when production scenario is changed. Table 4.10 highlights the data. This is a sample data; the actual data is recorded in appendices 4-6.

**Table 4.10: Laminator 1 valve output, inlet, outlet, pre-set temperatures**

| | Cooling Water Controller Output | Inlet Cooling Water Temperature | Outlet Cooling Water Temperature | Cooling Water Temperature Set point |
|---|---|---|---|---|
| Time | % | °C | °C | °C |
| 2018-11-07 13:28:00.000 | -100 | 11.24 | 15.49 | 10 |
| 2018-11-07 13:38:00.000 | -100 | 11.8 | 16.05 | 10 |
| 2018-11-07 13:48:00.000 | -100 | 11.8 | 16.05 | 10 |
| 2018-11-07 13:58:00.000 | -100 | 11.8 | 16.05 | 10 |
| 2018-11-07 14:08:00.000 | -100 | 11.8 | 16.05 | 10 |

Corresponding temperature profiles of inlet water, outlet water and set point of laminator 1 is shown on Figure 4.10.

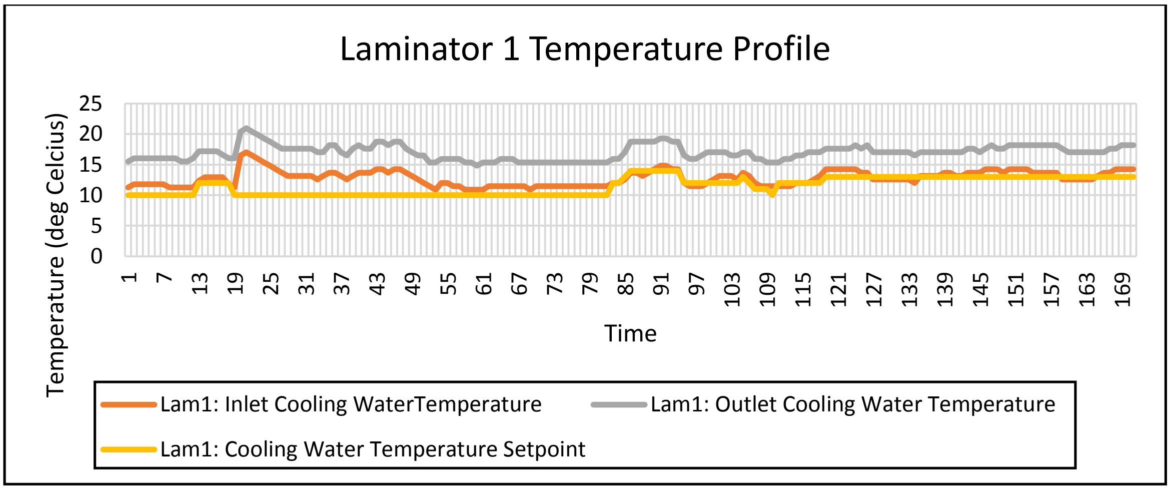



**Figure 4.10: Laminator 1 Temperature Profile**

Corresponding valve output profile, temperature profiles of inlet water, outlet water and set point of laminator 1 is shown on Figure 4.11.

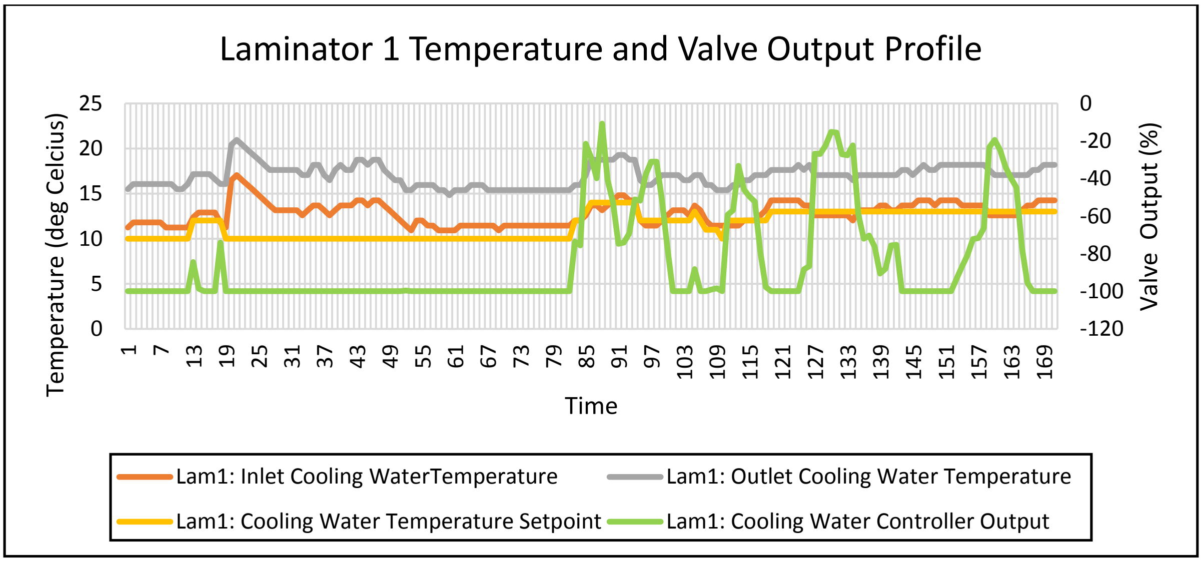



**Figure 4.11: Laminator 1 Temperature and Valve Output Profile**

Representation of valve output data for laminator 1 on a histogram is shown on Figure 4.12.

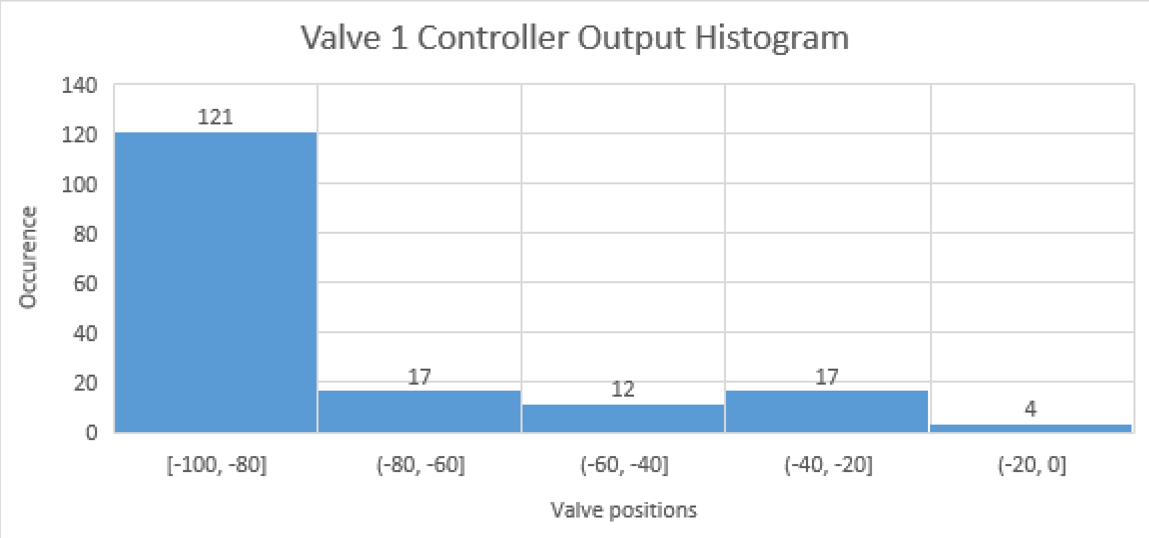



**Figure 4.12: Valve 1 Output Histogram**

## Summary of data analysis for laminator 1.

From the histogram, data was tabled (Table 4.11), into bins corresponding occurrence and percentage frequency of occurrence for the total data points. Table 4.12 summarises savings from Laminator 1

**Table 4.11: Laminator 1 operation frequency distribution and power analysis**

| Bins | Frequency | % Frequency | Average Bin Size % | Cube of flow rate ratio | Power demand | Weighted power |
|---|---|---|---|---|---|---|
| 0 - (-20) | 4 | 2% | 10% | 0.001 | 0.022 | 0.000515 |
| (-20) - (-40) | 17 | 10% | 30% | 0.027 | 0.594 | 0.059053 |
| (-40) - (-60) | 12 | 7% | 50% | 0.125 | 2.75 | 0.192982 |
| (-60) - (-80) | 17 | 10% | 70% | 0.343 | 7.546 | 0.750187 |
| (-80) - (-100) | 121 | 71% | 90% | 0.729 | 16.038 | 11.34853 |
| | **171** | **100%** | | | | **12.35126** |

**Table 4.12: Laminator 1 savings**

| Control Type | Power | Annual Operating Time | Annual Operating Energy | Unit Cost (KShs/kWh) | Annual Operating Cost (KShs) | Annual Savings (KShs) |
|---|---|---|---|---|---|---|
| None | 23.9 | 4800 | 114720 | 14.84 | 1,702,444 | 0 |
| VFD control | 12.35 | 4800 | 59286.06 | 14.84 | 879,805.18 | 822,638.82 |

### 4.3.2. Pump 2

The second data set of laminator 2 was taken between 07/11/2018, 13:28:00 and 08/11/2018, 23:08:00 giving a total of 171 data points at an interval of 10 minutes. Table 4.13 highlights the data.

**Table 4.13: Laminator 2 valve output, inlet, outlet, pre-set temperatures**

| | Cooling Water Controller Output | Inlet Cooling Water Temperature | Outlet Cooling Water Temperature | Cooling Water Temperature Set point |
|---|---|---|---|---|
| Time | % | °C | °C | °C |
| 2018-11-07 13:28:00.000 | -75.89 | 12.47 | 14.82 | 12 |
| 2018-11-07 13:38:00.000 | -70.89 | 11.91 | 14.82 | 12 |
| 2018-11-07 13:48:00.000 | -100 | 12.47 | 14.82 | 12 |
| 2018-11-07 13:58:00.000 | -100 | 12.47 | 14.26 | 12 |
| 2018-11-07 14:08:00.000 | -56.67 | 11.91 | 14.26 | 12 |

Corresponding temperature profiles of inlet water, outlet water and set point of laminator 2 is shown on Figure 4.13.

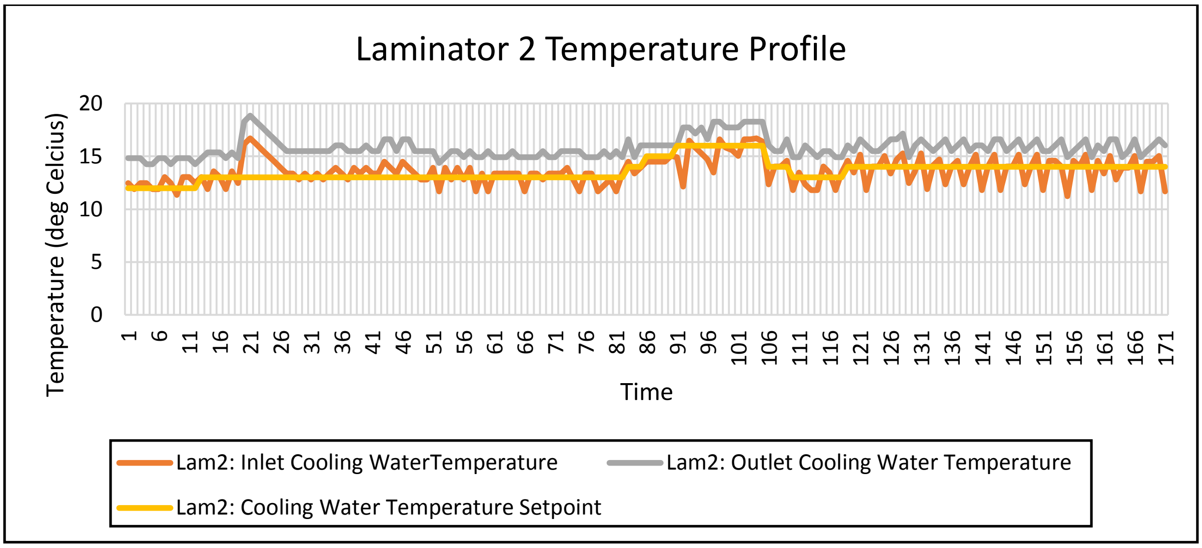



**Figure 4.13: Laminator 2 Temperature Profile**

Corresponding valve output profile, temperature profiles of inlet water, outlet water and set point of laminator 2 is shown on Figure 4.14.

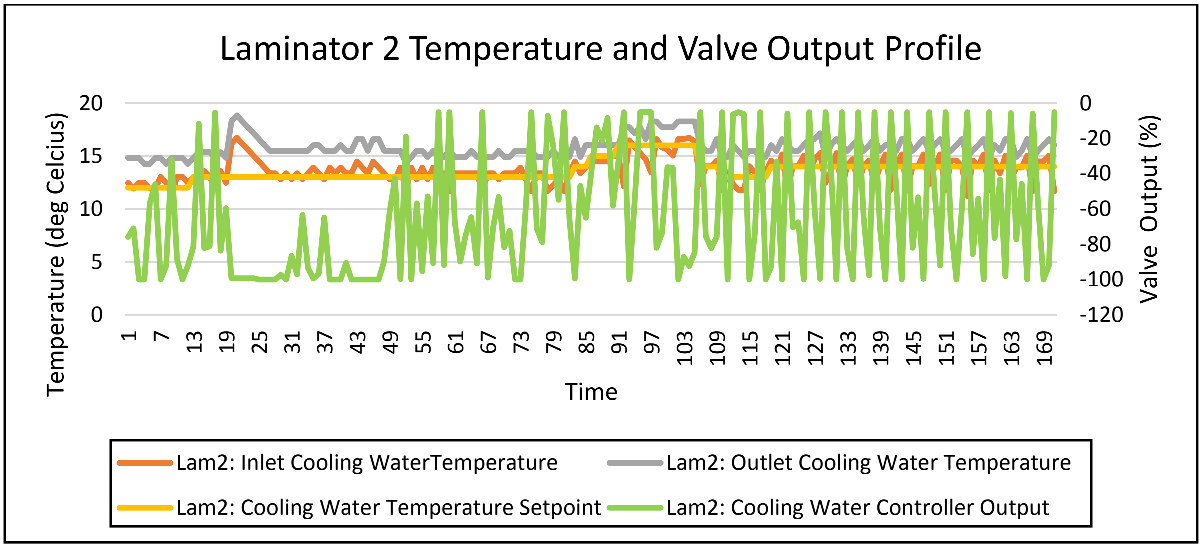



**Figure 4.14: Laminator 2 Temperature and Valve Output Profile**

Representation of valve output data for laminator 2 on a histogram is shown on Figure 4.15.

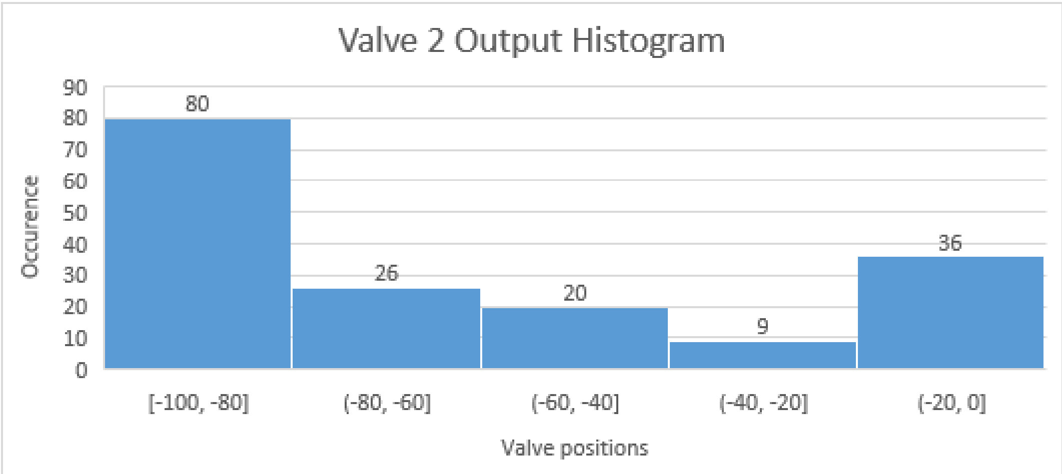



**Figure 4.15: Valve 2 Output Histogram**

## Summary of data analysis for laminator 2.

From the histogram, data was tabled (see Table 4.14), into bins corresponding occurrence and percentage frequency of occurrence for the total data points. Table 4.15 summarises Laminator 2 savings.

**Table 4.14: Laminator 2 operation frequency distribution and power analysis**

| Bins | Frequency | % Frequency | Average Bin Size % | Cube of flow rate ratio | Power demand | Weighted power |
|---|---|---|---|---|---|---|
| 0 - (-20) | 36 | 21% | 10% | 0.001 | 0.022 | 0.004632 |
| (-20) - (-40) | 9 | 5% | 30% | 0.027 | 0.594 | 0.031263 |
| (-40) - (-60) | 20 | 12% | 50% | 0.125 | 2.75 | 0.321637 |
| (-60) - (-80) | 26 | 15% | 70% | 0.343 | 7.546 | 1.147345 |
| (-80) - (-100) | 80 | 47% | 90% | 0.729 | 16.038 | 7.503158 |
| | **171** | **100%** | | | | **9.008035** |

**Table 4.15: Laminator 2 savings**

| Control Type | Power | Annual Operating Time | Annual Operating Energy | Unit Cost (KShs/kWh) | Annual Operating Cost (KShs) | Annual Savings (KShs) |
|---|---|---|---|---|---|---|
| None | 22 | 4800 | 105600 | 14.84 | 1,567,104 | 0 |
| VFD control | 9.008 | 4800 | 43238.56 | 14.84 | 641,660.36 | 925,443.64 |

### 4.3.3. Pump 3

The second data set of laminator 3 was taken between 07/11/2018, 13:28:00 and 08/11/2018, 23:08:00 giving a total of 171 data points at an interval of 10 minutes. Table 4.16 highlights the data.

**Table 4.16: Laminator 3 valve output, inlet, outlet, pre-set temperatures**

| | Cooling Water Controller Output | Inlet Cooling Water Temperature | Outlet Cooling Water Temperature | Cooling Water Temperature Set point |
|---|---|---|---|---|
| Time | % | °C | °C | °C |
| 2018-11-07 13:28:00.000 | -78.83 | 17.73 | 21.2 | 17 |
| 2018-11-07 13:38:00.000 | -67.66 | 17.17 | 19.52 | 17 |
| 2018-11-07 13:48:00.000 | 0 | 14.26 | 17.84 | 17 |
| 2018-11-07 13:58:00.000 | 0 | 13.14 | 18.4 | 17 |
| 2018-11-07 14:08:00.000 | 0 | 15.38 | 21.2 | 17 |

Corresponding temperature profiles of inlet water, outlet water and set point of laminator 3 is shown on Figure 4.16.

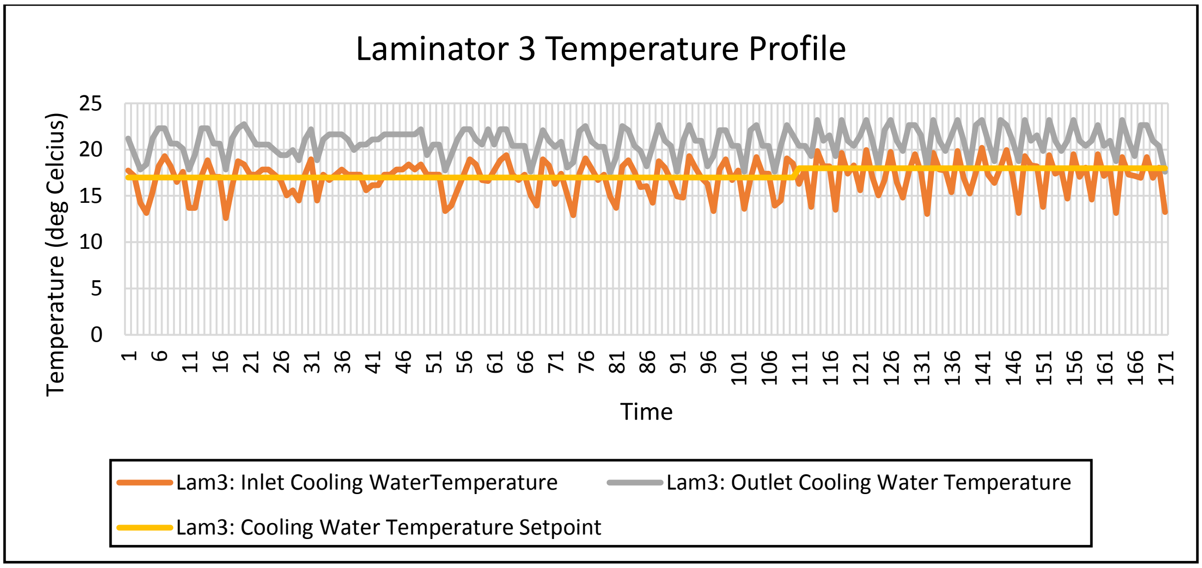



**Figure 4.16: Laminator 3 Temperature Profile**

Corresponding valve output profile, temperature profiles of inlet water, outlet water and set point of laminator 3 is shown on Figure 4.17.

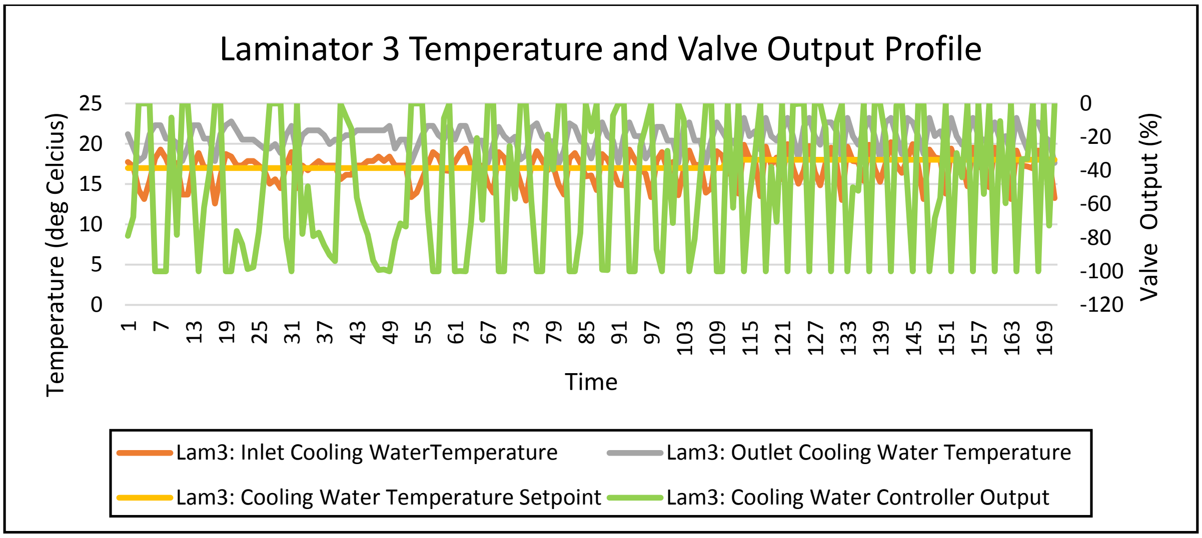



**Figure 4.17: Laminator 3 Temperature and Valve Output Profile**

Representation of valve output data for laminator 3 on a histogram is shown on Figure 4.18.

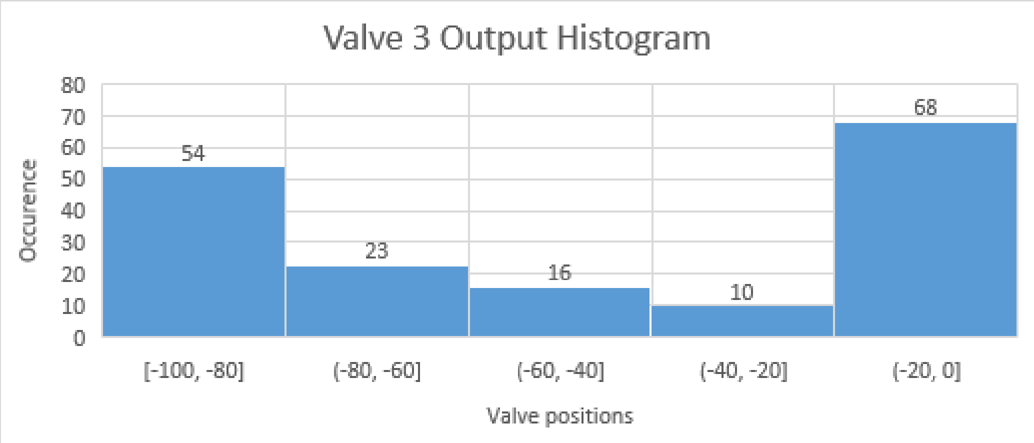



**Figure 4.18: Valve 3 Output Histogram**

## Summary of data analysis for laminator 3.

From the histogram, data was tabled (see Table 4.17), into bins corresponding occurrence and percentage frequency of occurrence for the total data points. Table 4.18 summarises Laminator 3 savings.

**Table 4.17: Laminator 3 operation frequency distribution and power analysis**

| Bins | Frequency | % Frequency | Average Bin Size % | Cube of flow rate ratio | Power demand | Weighted power |
|---|---|---|---|---|---|---|
| 0 - (-20) | 68 | 40% | 10% | 0.001 | 0.022 | 0.008749 |
| (-20) - (-40) | 10 | 6% | 30% | 0.027 | 0.594 | 0.034737 |
| (-40) - (-60) | 16 | 9% | 50% | 0.125 | 2.75 | 0.25731 |
| (-60) - (-80) | 23 | 13% | 70% | 0.343 | 7.546 | 1.014959 |
| (-80) - (-100) | 54 | 32% | 90% | 0.729 | 16.038 | 5.064632 |
| | **171** | **100%** | | | | **6.380386** |

**Table 4.18: Laminator 3 savings**

| Control Type | Power | Annual Operating Time | Annual Operating Energy | Unit Cost (KShs/kWh) | Annual Operating Cost (KShs) | Annual Savings (KShs) |
|---|---|---|---|---|---|---|
| None | 22 | 4800 | 105600 | 14.84 | 1,567,104 | 0 |
| VFD control | 6.3804 | 4800 | 30625.85 | 14.84 | 454,487.65 | 1,112,616.35 |

### 4.4. Results of pump 4- Circulating water between condenser unit and cooling tower

The temperature data set of cooling tower pump was taken between 14/11/2018, 15:00:00 and 14/11/2018, 15:45:00 giving 46 data points at an interval of 1 minute. Table 4.19 highlights the data.

**Table 4.19: Pump 4 inlet/outlet temperatures data sample-Actual data on appendix 7**

| S.No | Time | Temperature Out °C | Temperature In °C |
|---|---|---|---|
| 1 | 14/11/2018 15:00 | 26.1 | 21.8 |
| 2 | 14/11/2018 15:01 | 25.1 | 21.7 |
| 3 | 14/11/2018 15:02 | 25.1 | 21.8 |
| 4 | 14/11/2018 15:03 | 24.9 | 21.7 |
| 5 | 14/11/2018 15:04 | 24.7 | 21.6 |

Corresponding temperature profiles of inlet water and outlet water of cooling tower was plotted is shown on Figure 4.19.

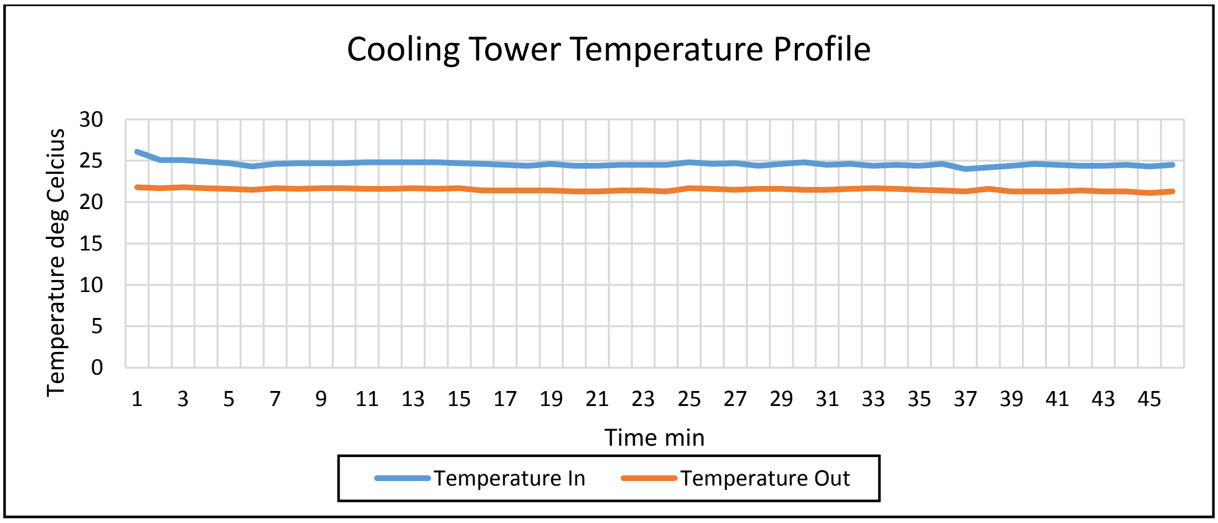



**Figure 4.19: Cooling Tower Temperature Profile**

The flow rate of cooling tower pump was taken between 11/14/2018, 3:10:38 PM and 11/14/2018, 3:20:37 PM was measured using ultrasonic flow meter, giving a total of 369 data points at an interval of 2 minutes. Table 4.20 highlights the data.

**Table 4.20: Pump 4 flow rate**

| S.No | Time | Volume flow m3/h |
|---|---|---|
| 1 | 11/14/2018 3:10:38 PM | 159.95 |
| 2 | 11/14/2018 3:10:40 PM | 159.75 |
| 3 | 11/14/2018 3:10:42 PM | 159.87 |
| 4 | 11/14/2018 3:10:43 PM | 159.86 |
| 5 | 11/14/2018 3:10:45 PM | 159.83 |

Corresponding flow profile was established and a graphical representation of the flow is shown on Figure 4.20.

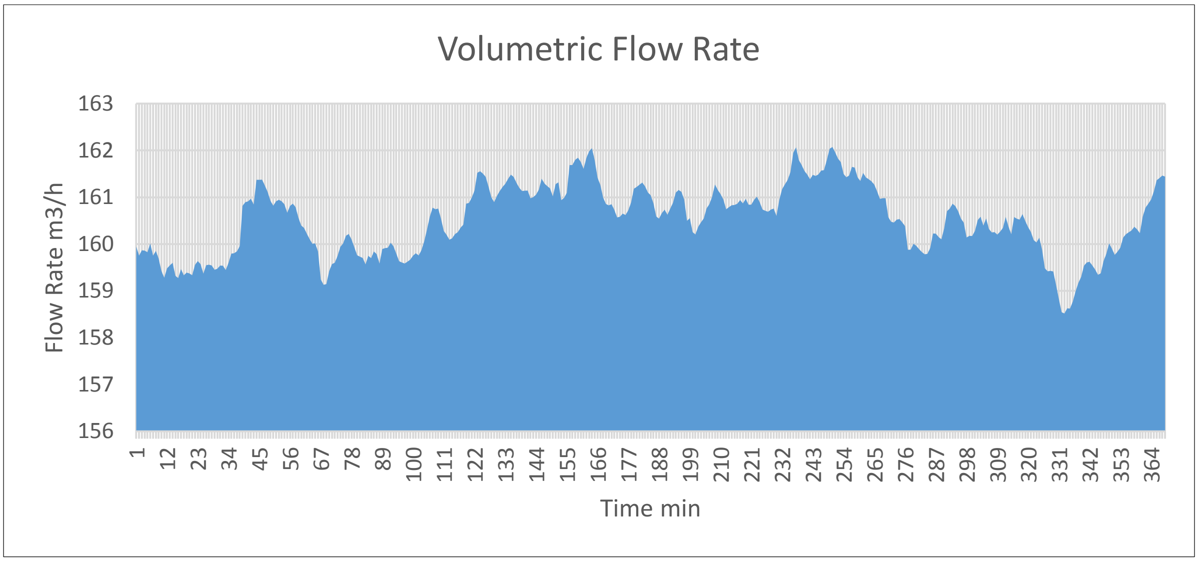



**Figure 4.20: Volumetric Flow Rate**

## 4.5. Results of Chiller Performance

The performance of the chiller would be determined as a ratio of the thermal energy (using Equation 4.4) in the water to electrical energy (using Equation 4.3) drawn by the chiller.[10]

Electrical load

$$Electrical\ power\ = \sqrt{3} \times V \times I \times pf \ \ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

*Where;*

*V* = *voltage*

*I* = *current*

*pf* = *power factor*

Thermal load

$$Cooling\ capacity\ =\ \dot{m} \times C_p \times \Delta T\ \ldots\ldots\ldots\ldots\ldots\ldots\ 4.4$$

*Where;*

$\dot{m}$ = *mass flow rate kg³/s*

$C_p$ = *specific heat capacity*

$\Delta T$ = *temperature difference*

Chiller performance: Ratio of cooling capacity out to power supplied

$$COP\ =\ \frac{Cooling\ capacity}{Electrical\ power}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4.5$$

It was established that the flow rate was average 160.51 $m^3$/hr equivalent to 160.51 kg/hr assuming water density of 1000 kg/$m^3$. Furthermore, the inlet and outlet temperatures were determined as shown on Table 4.21.

**Table 4.21: Chiller average inlet/outlet temperature**

| Average inlet temperature °C | Average outlet temperature °C |
|---|---|
| 12.9 | 8.7 |

Therefore, thermal load becomes;

160.51$m^3$/h is equivalent to 0.044586$m^3$/sec

Using the density of 1000kg/$m^3$

The mass flow rate= 1000×0.044586

=44.586kg/sec

$$Thus\ Cooling\ capacity\ =\ 44.586 * 4.2 * (12.9 - 8.7) = 786.5kW$$

The electrical load could not be determined due to the nature of electrical connection that was split to two breakers hence totalizing the consumption using the simple metering devices that were available could not be used.

## 4.6 Discussion Summary

From the results of the three laminator pumps; pump 1, pump 2 and pump 3, it was observed that there was a variance in temperature profiles for inlet and outlet water where the objective was to attain the set temperature point. This is demonstrated in the graphs on Figure 4.1. To achieve the set temperature, modulating valves-controlled inlet water to the pumps. The set temperatures were approximately; 11.51 °C, 13.60 °C and 17.36 °C respectively. This is shown on Figures 4.2, 4.5 and 4.8. On the other hand, the chiller maintained the chilled water reservoir tank at 8 °C for TBA packaging material and 12 °C for TFA packaging material. The different set points temperatures for the laminators resulted in different modulations by the valves.

The modulation of valves presented an opportunity to implement VSDs on the pumps and this was evaluated using affinity laws. The variance in demand for chilled water was mapped to variance in flow rate as summarise in the Table 4.22. It shows that reduction in flow demand less power compared to maximum flow.

**Table 4.22: Pumps power analysis**

| % Flow | Pump 1 (kW) | Pump 2 (kW) | Pump 3 (kW) |
|---|---|---|---|
| 10% | 0.003899 | 0.004632 | 0.00874854 |
| 30% | 0.038283 | 0.031263 | 0.03473684 |
| 50% | 0.487393 | 0.321637 | 0.25730994 |
| 70% | 1.215825 | 1.147345 | 1.01495906 |
| 90% | 9.43186 | 7.503158 | 5.06463158 |

A graphical representation of power demand is illustrated on Figure 4.21. The graphs demonstrate exponential correlation of power as a result of varying flow rate. Pump 3 presented the highest power saving opportunity due to the least set temperature requirement.

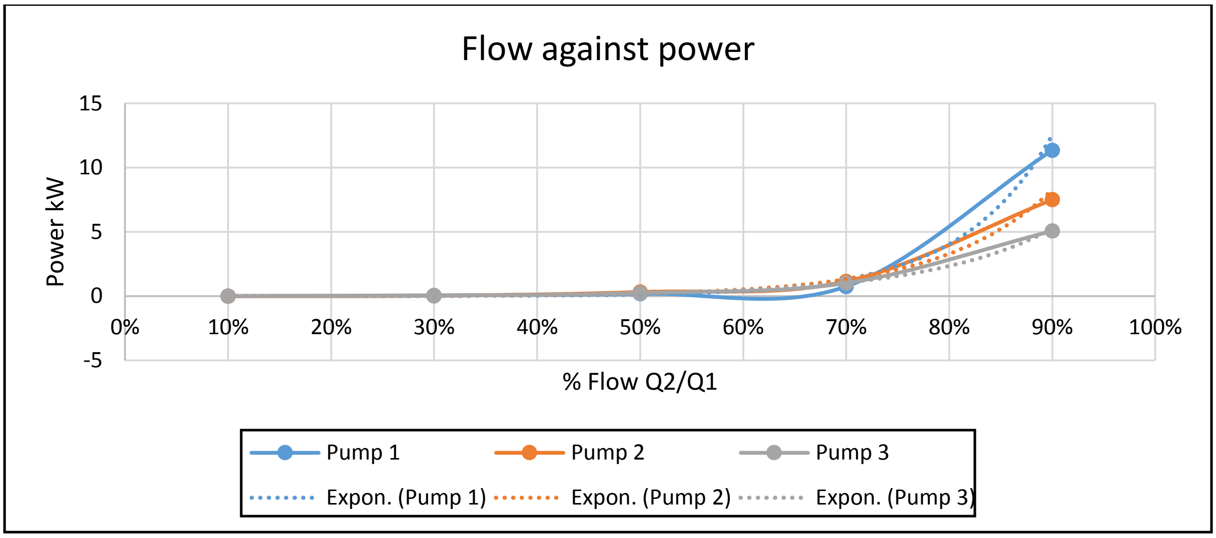



**Figure 4.21: Flow against power**

Following the determination of flow rate profile, the duty at different flow rates was key to determine energy saving. It was observed that pump 1 operated at 71 per cent of its operating time drawing chilled water at 12 °C since the pre-set temperature was the same. On the other hand, pump 3 operated 40 per cent of its time recirculating return water since its pre-set temperature was high 17 °C. Table 4.23 highlights the summary of pump duty.

**Table 4.23: Pumps duty**

| Flow | Pump 1 | Pump 2 | Pump 3 |
|---|---|---|---|
| 10% | 2% | 21% | 40% |
| 30% | 10% | 5% | 6% |
| 50% | 7% | 12% | 9% |
| 70% | 10% | 15% | 13% |
| 90% | 71% | 47% | 32% |
| | **100%** | **100%** | **100%** |

The average temperatures into the laminators were determined to vary as shown on Table 4.24:

**Table 4.24: Laminators average inlet/outlet temperatures**

| Laminator | Avg Temperature In °C | Avg Temperature Out °C |
|---|---|---|
| Laminator 1 | 12.42 | 15.51 |
| Laminator 2 | 13.63 | 15.84 |
| Laminator 3 | 15.69 | 18.49 |

These influence significantly how the operations could be altered to achieve savings where the outlets of laminator 1and 2 could be the inlet water to laminator 3 thereby eliminating pump 3 altogether.

Further, result of application of VSDs was estimated as shown in the Table 4.25. Pump 3 presented the highest opportunity of 72.96 per cent saving due to the operation at a least pre-set temperature.

**Table 4.25: Pumps power savings based on data set 1**

| Pump | Full load (kW) | VSD control (kW) | Saving (kW) | % Saving |
|---|---|---|---|---|
| Pump 1 | 23.9 | 12.3513 | 11.5487 | 48.3% |
| Pump 2 | 23.6 | 9.008 | 14.592 | 61.8% |
| Pump 3 | 23.6 | 6.3804 | 17.2196 | 72.9% |

Whereas, it was expected that pump 2 would present higher savings than pump 1, the second set of data did not indicate the same. This can be explained by inconsistency in modulation of the valve thereby introducing errors. The graph on Figure 4.22 shows the modulation effect.

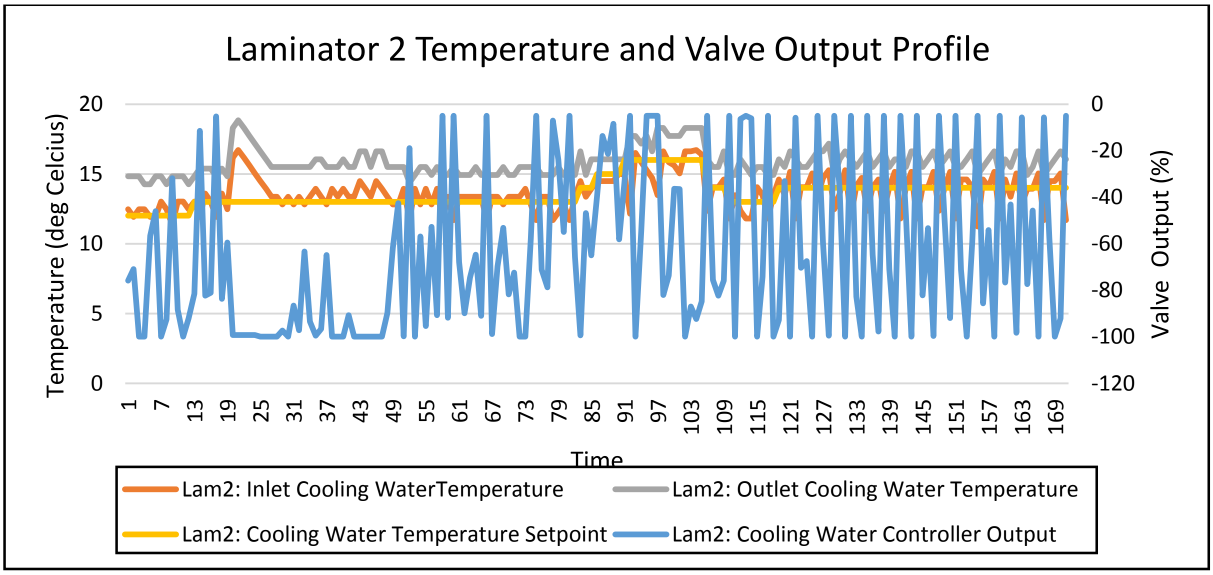



**Figure 4.22: Laminator 2 Temperature and Valve Output Profile**

However, the first set of data indicated higher savings than that of pump 1. The difference was brought about by difference in pre-set temperature where in the first set of data it was an average of 14.08 °C while in the second set it was 13.60 °C furthermore the modulation was less noisy as shown on Figure 4.23.

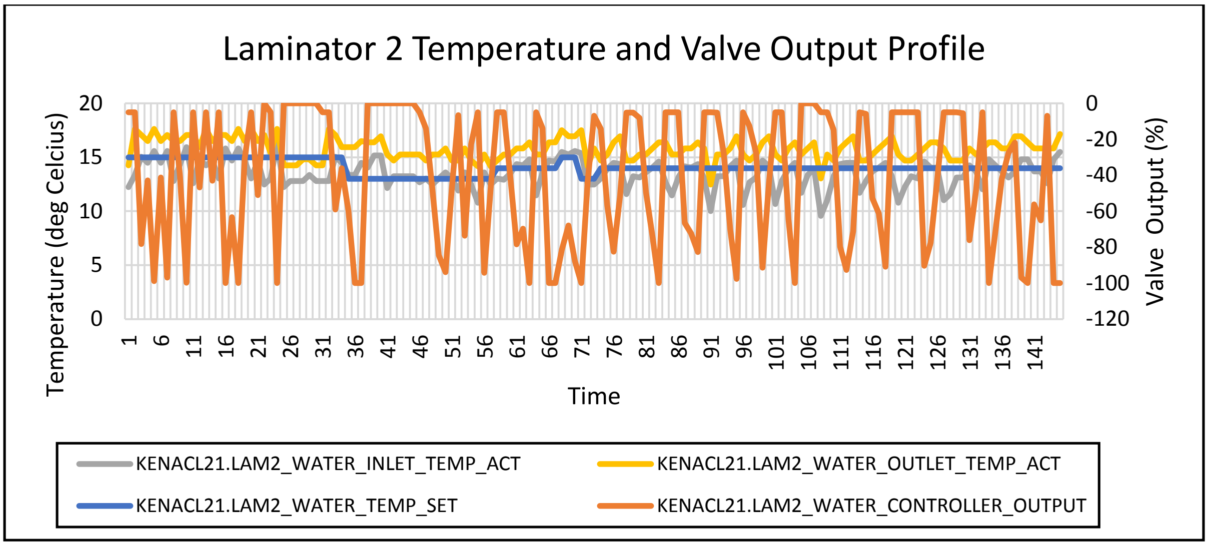



**Figure 4.23: Laminator 2 Temperature and Valve Output Profile**

# CHAPTER 5

# Economic Analysis

## 5.1 Determination of energy cost and saving

The energy saving was determined by equations 5.1 and 5.2. Table 5.2 summarises.

$$Energy\ saving\ =\ Power\ \times\ Operating\ time\text{……………. 5.1}$$

$$Cost\ saving =\ Energy\ saving\ \times\ Unit\ Cost\text{……… ……..5.1}$$

Estimation of unit cost of electricity was based on average unit cost of the past 3 months; August-October 2018 as shown on Table 5.1 gotten from electricity bills from KPLC.

**Table 5.1: August - October 2018 power bills**

| Month | Peak | Off peak | Total (Kwh) | Total Bill (Ksh) | VAT (Ksh) | Bill Less VAT | Unit Cost (Ksh) |
|---|---|---|---|---|---|---|---|
| August | 209760 | 161844 | 371604 | 6,390,562.00 | 853,627.86 | 5,536,934.14 | 14.90 |
| September | 224204 | 167576 | 391780 | 6,677,631.00 | 891,804.55 | 5,785,826.45 | 14.77 |
| October | 224324 | 167433 | 391757 | 6,713,035.00 | 896,706.03 | 5,816,328.97 | 14.85 |
| | | | | | | **AVG COST** | **14.84** |

Operating time per year: 2 shifts per day, 8 hrs per shift, 300 operating days per year.

$$Operating\ time = 2 \times 8 \times 300 = 4{,}800\ hrs/yr$$

$$VSD\ control: 11.17726kW\ \times\ KShs\frac{14.84}{kWhr} \times 4{,}800 hours = KShs\ 796{,}178.6$$

**Table 5.2: Laminator 1 savings**

| Control Type | Power | Annual Operating Time | Annual Operating Energy kWh | Unit Cost (KShs/kWh) | Annual Operating Cost (KShs) | Annual Savings (KShs) |
|---|---|---|---|---|---|---|
| None | 23.9 | 4800 | 114,720 | 14.84 | 1,702,444 | 0 |
| VSD control | 11.17726 | 4800 | 53,650 | 14.84 | 796,178.5 | 906,268.3 |

Determination of Payback period;

$$\textbf{Payback period} = \frac{\textbf{Cost of Investment}}{\textbf{Annual savings}} \times 12(Months\ in\ a\ year)$$

The cost of investment was determined by:

1. Cost of Retrofit frequency drive (Type Siemens 30hp VFD  6SL3710)=Ksh,460,000
2. Cost of Cabling and mounting devises-Lot=Ksh 200,000
3. Cost of Installation and Commissioning -Lot=Ksh 140,000

$$\textbf{Payback period} = \frac{\textbf{Cost of Investment}}{\textbf{Annual savings}} = \frac{800{,}000}{906{,}268.3}\text{x}12(\text{Months}) = \textbf{10.5 Months}$$

## 5.2 Summary of energy and cost savings for laminator 2.

The energy saving was determined by equations 5.1 and 5.2. With pump power of 23.66kW. Table 5.3 summarises.

**Table 5.3: Laminator 2 savings**

| Control Type | Power | Annual Operating Time | Annual Operating Energy | Unit Cost (KShs/kWh) | Annual Operating Cost (KShs) | Annual Savings (KShs) |
|---|---|---|---|---|---|---|
| None | 23.66 | 4800 | 113,548.3 | 14.84 | 1,685,058 | 0 |
| VFD control | 5.18456 | 4800 | 24,885.8 | 14.84 | 369,306.6 | 1,315,751 |

Determination of Payback period;

$$\textbf{Payback period} = \frac{\textbf{Cost of Investment}}{\textbf{Annual savings}} = \frac{800{,}000}{1{,}315{,}751}\text{x}12 = \textbf{7.3 Months}$$

## 5.3 Summary of energy and cost savings for laminator 3.

The energy saving was determined by equations 5.1 and 5.2. Pump power was determined to be 23.66kW.  Table 5.4 summarises.

**Table 5.4: Laminator 3 savings**

| Control Type | Power | Annual Operating Time | Annual Operating Energy | Unit Cost (KShs/kWh) | Annual Operating Cost (KShs) | Annual Savings (KShs) |
|---|---|---|---|---|---|---|
| None | 23.66 | 4800 | 113,548.3 | 14.84 | 1,685,058 | 0 |
| VFD control | 4.3173 | 4800 | 20,723 | 14.84 | 307,529.9 | 1,377,528 |

Determination of Payback period;

$$\textbf{Payback period} = \frac{\textbf{Cost of Investment}}{\textbf{Annual savings}} = \frac{800{,}000}{1{,}377{,}528}\text{x}12 = \textbf{7 Months}$$

# CHAPTER 6

## Conclusion and Recommendations

1. The total energy consumed by the pumping system in its current state was determined by the electrical energy drawn by each pump and was found to be 114,720kWh, 113,548.3kWh and 113,548.3kWh for Pump 1,2 and 3 respectively. The total energy consumed by the system annually was 341,816.6kWh.

2. The energy savings to be achieved after implementing the project was found to be 61,070kWh on pump 1 and 88,662.5kWh on pump 2 and 92,825.3kWh on pump3. This is equivalent of 242,557.8kWh annually.

3. The total cost of investment in retrofitting the feed pumps with VSDs is approximately Ksh 800,000 each totalling ksh 2,400,000 while the energy savings as a result of the upgrade was determined to be Ksh 906,268.3 for pump 1 and ksh 1,315,751 for pump 2 ksh 1,377,528 for pump 3 annually this will translate to 10.5 months for pump 1,7 months for pump 2 and7 months for pump 3 payback period respectively for the investment for individual.
4. Pump 4 circulating water to the cooling tower did not present energy saving opportunity. A 45 minutes trend of inlet and outlet temperature, indicated a constant profile between an average of 21.5 °C and 24.6 °C respectively. On the other hand, it was noted that the flow rate was constant too therefore the required results were achieved adequately. However, trending the temperatures during the cold seasons could present some saving opportunities.
5. The performance of the chiller was partially achieved by determining the cooling load as $786.5\ kW$ through the operation between 12.9 °C and 8.7 °C, however, the input power (electrical) could not be determined due to technical challenges encountered in the wiring adopted. Considering the sequencing of the chiller through its four compressors, metering had to be achieved for the entire chiller by a single meter, however, the separation of power supply prohibited this, otherwise the same could be achieved through totalising current transformers which were faulty and required replacement.

## 6.1 Future work recommendations

Recommendations for further research and improvement of this work include;

1. Deploying VSDs on pumps in other sections of utilities will greatly reduce energy consumption in the plant.
2. The set points on laminator 3 were found to be higher than the return lines from laminator 1 and Laminator 2. Therefore, feeding Lam 3 with return lines from lam 1 and 2 will negate the need for the pump 3 nor VSD lowering the cost even further, this should be investigated and matched with production requirements.
3. Automation of the chiller unit and Colling tower fans
4. During the course of the study it was observed that the chiller is in operation regardless of whether production has started, there is need to investigate energy wasted as a result of this anomaly against the time required to cool the water in the reservoir. The argument of the personnel in the ground that it took a lot of time to attain required temperatures in the reservoir before start of production resulting in lower production time utilisation (PTU).

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# Appendices

## Appendix 1: Laminator 1 valve output, inlet, outlet, pre-set temperatures Data Set 1 Recorded on 18-10-2018

| Time | Sno | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-18 09:21:00.000** | 1 | -100 | 14.04 | 17.62 | 12 |
| **2018-10-18 09:31:00.000** | 2 | -87.86 | 12.36 | 16.5 | 12 |
| **2018-10-18 09:41:00.000** | 3 | -99.66 | 12.36 | 15.94 | 12 |
| **2018-10-18 09:51:00.000** | 4 | -99.74 | 12.36 | 15.94 | 12 |
| **2018-10-18 10:01:00.000** | 5 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 10:11:00.000** | 6 | -94.41 | 12.36 | 15.94 | 12 |
| **2018-10-18 10:21:00.000** | 7 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 10:31:00.000** | 8 | -74.38 | 11.8 | 15.94 | 12 |
| **2018-10-18 10:41:00.000** | 9 | -58.98 | 11.8 | 15.94 | 12 |
| **2018-10-18 10:51:00.000** | 10 | -74.43 | 11.8 | 15.94 | 12 |
| **2018-10-18 11:01:00.000** | 11 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 11:11:00.000** | 12 | -91.94 | 12.36 | 15.94 | 12 |
| **2018-10-18 11:21:00.000** | 13 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 11:31:00.000** | 14 | -94.96 | 12.36 | 15.94 | 12 |
| **2018-10-18 11:41:00.000** | 15 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 11:51:00.000** | 16 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 12:01:00.000** | 17 | -91.7 | 12.36 | 15.94 | 12 |
| **2018-10-18 12:11:00.000** | 18 | -89.09 | 11.8 | 15.94 | 12 |
| **2018-10-18 12:21:00.000** | 19 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 12:31:00.000** | 20 | -96.49 | 12.36 | 15.94 | 12 |
| **2018-10-18 12:41:00.000** | 21 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 12:51:00.000** | 22 | -100 | 12.36 | 15.94 | 12 |
| **2018-10-18 13:01:00.000** | 23 | -44.02 | 11.8 | 13.14 | 12 |
| **2018-10-18 13:11:00.000** | 24 | -84.06 | 12.36 | 14.82 | 12 |
| **2018-10-18 13:21:00.000** | 25 | 0 | 11.8 | 15.94 | 12 |
| **2018-10-18 13:31:00.000** | 26 | 0 | 14.6 | 15.94 | 12 |
| **2018-10-18 13:41:00.000** | 27 | 0 | 14.6 | 15.94 | 12 |
| **2018-10-18 13:51:00.000** | 28 | 0 | 14.6 | 16.5 | 12 |
| **2018-10-18 14:01:00.000** | 29 | 0 | 12.36 | 13.14 | 12 |
| **2018-10-18 14:11:00.000** | 30 | -5 | 10.68 | 12.02 | 12 |
| **2018-10-18 14:21:00.000** | 31 | -90.81 | 13.48 | 17.62 | 12 |
| **2018-10-18 14:31:00.000** | 32 | -92.6 | 12.92 | 16.5 | 12 |
| **2018-10-18 14:41:00.000** | 33 | -100 | 12.36 | 15.94 | 12 |

| Time | Sno | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-18 14:51:00.000** | 34 | -99.71 | 12.36 | 16.5 | 12 |
| **2018-10-18 15:01:00.000** | 35 | -99.71 | 12.36 | 16.5 | 12 |
| **2018-10-18 15:11:00.000** | 36 | -99.71 | 13.48 | 17.62 | 12 |
| **2018-10-18 15:21:00.000** | 37 | -99.71 | 14.6 | 18.18 | 12 |
| **2018-10-18 15:31:00.000** | 38 | 0 | 14.26 | 18.18 | 12 |
| **2018-10-18 15:41:00.000** | 39 | 0 | 17.06 | 18.18 | 12 |
| **2018-10-18 15:51:00.000** | 40 | 0 | 18.18 | 18.18 | 12 |
| **2018-10-18 16:01:00.000** | 41 | -5 | 13.14 | 14.82 | 12 |
| **2018-10-18 16:11:00.000** | 42 | 0 | 11.46 | 12.58 | 12 |
| **2018-10-18 16:21:00.000** | 43 | 0 | 14.26 | 12.58 | 12 |
| **2018-10-18 16:31:00.000** | 44 | 0 | 14.26 | 13.7 | 12 |
| **2018-10-18 16:41:00.000** | 45 | 0 | 13.7 | 13.7 | 12 |
| **2018-10-18 16:51:00.000** | 46 | -5 | 9.67 | 11.46 | 12 |
| **2018-10-18 17:01:00.000** | 47 | -99.79 | 12.47 | 16.5 | 12 |
| **2018-10-18 17:11:00.000** | 48 | -87.11 | 12.47 | 16.5 | 12 |
| **2018-10-18 17:21:00.000** | 49 | -43.29 | 11.91 | 15.94 | 12 |
| **2018-10-18 17:31:00.000** | 50 | -74.36 | 11.91 | 15.38 | 12 |
| **2018-10-18 17:41:00.000** | 51 | -100 | 12.47 | 15.94 | 12 |
| **2018-10-18 17:51:00.000** | 52 | -100 | 12.47 | 15.94 | 12 |
| **2018-10-18 18:01:00.000** | 53 | -89.5 | 12.47 | 15.94 | 12 |
| **2018-10-18 18:11:00.000** | 54 | -68.66 | 12.47 | 15.94 | 12 |
| **2018-10-18 18:21:00.000** | 55 | -51.63 | 11.91 | 15.94 | 12 |
| **2018-10-18 18:31:00.000** | 56 | -34 | 11.35 | 15.94 | 12 |
| **2018-10-18 18:41:00.000** | 57 | -44.22 | 11.91 | 15.38 | 12 |
| **2018-10-18 18:51:00.000** | 58 | -95.68 | 13.59 | 17.06 | 13 |
| **2018-10-18 19:01:00.000** | 59 | -51.17 | 12.47 | 16.5 | 13 |
| **2018-10-18 19:11:00.000** | 60 | -19.93 | 12.47 | 17.06 | 13 |
| **2018-10-18 19:21:00.000** | 61 | -84.37 | 13.59 | 17.06 | 13 |
| **2018-10-18 19:31:00.000** | 62 | -98.12 | 13.59 | 17.06 | 13 |
| **2018-10-18 19:41:00.000** | 63 | -47.78 | 12.47 | 16.5 | 13 |
| **2018-10-18 19:51:00.000** | 64 | -32.26 | 12.47 | 16.5 | 13 |
| **2018-10-18 20:01:00.000** | 65 | -38.13 | 12.47 | 17.06 | 13 |
| **2018-10-18 20:11:00.000** | 66 | -26.3 | 12.47 | 17.06 | 13 |
| **2018-10-18 20:21:00.000** | 67 | -84.87 | 13.59 | 17.06 | 13 |
| **2018-10-18 20:31:00.000** | 68 | -25.1 | 13.59 | 17.62 | 14 |
| **2018-10-18 20:41:00.000** | 69 | -78.2 | 14.71 | 18.18 | 14 |
| **2018-10-18 20:51:00.000** | 70 | -33.24 | 13.59 | 17.06 | 14 |
| **2018-10-18 21:01:00.000** | 71 | -100 | 14.71 | 18.18 | 12 |

| Time | Sno | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-18 21:11:00.000** | 72 | -67.44 | 11.91 | 15.94 | 12 |
| **2018-10-18 21:21:00.000** | 73 | -96.38 | 12.47 | 15.94 | 12 |
| **2018-10-18 21:31:00.000** | 74 | -5.59 | 12.47 | 15.94 | 14 |
| **2018-10-18 21:41:00.000** | 75 | -86.92 | 14.15 | 17.62 | 14 |
| **2018-10-18 21:51:00.000** | 76 | -95.09 | 12.47 | 16.5 | 12 |
| **2018-10-18 22:01:00.000** | 77 | -64.59 | 11.91 | 16.5 | 12 |
| **2018-10-18 22:11:00.000** | 78 | -46.99 | 11.91 | 15.94 | 12 |
| **2018-10-18 22:21:00.000** | 79 | -73.37 | 11.91 | 15.38 | 12 |
| **2018-10-18 22:31:00.000** | 80 | -100 | 12.47 | 15.94 | 12 |
| **2018-10-18 22:41:00.000** | 81 | -87.06 | 12.47 | 16.5 | 12 |
| **2018-10-18 22:51:00.000** | 82 | -46.71 | 11.91 | 15.94 | 12 |
| **2018-10-18 23:01:00.000** | 83 | -47.86 | 11.91 | 15.94 | 12 |
| **2018-10-18 23:11:00.000** | 84 | -54.43 | 11.35 | 15.38 | 12 |
| **2018-10-18 23:21:00.000** | 85 | -84.5 | 11.91 | 15.38 | 12 |
| **2018-10-18 23:31:00.000** | 86 | -100 | 12.47 | 15.94 | 12 |
| **2018-10-18 23:41:00.000** | 87 | -87.19 | 12.47 | 16.5 | 12 |
| **2018-10-18 23:51:00.000** | 88 | -81.24 | 12.47 | 16.5 | 12 |
| **2018-10-19 00:01:00.000** | 89 | -38.05 | 11.91 | 15.94 | 12 |
| **2018-10-19 00:11:00.000** | 90 | -5 | 11.35 | 12.58 | 12 |
| **2018-10-19 00:21:00.000** | 91 | -57.66 | 12.47 | 15.38 | 12 |
| **2018-10-19 00:31:00.000** | 92 | -45.69 | 11.91 | 14.82 | 12 |
| **2018-10-19 00:41:00.000** | 93 | -82.2 | 12.47 | 15.38 | 12 |
| **2018-10-19 00:51:00.000** | 94 | -87.62 | 11.91 | 14.82 | 12 |
| **2018-10-19 01:01:00.000** | 95 | -48.45 | 11.91 | 14.82 | 12 |
| **2018-10-19 01:11:00.000** | 96 | -82.96 | 12.47 | 15.38 | 12 |
| **2018-10-19 01:21:00.000** | 97 | -86.19 | 11.91 | 14.82 | 12 |
| **2018-10-19 01:31:00.000** | 98 | -50.08 | 11.91 | 14.82 | 12 |
| **2018-10-19 01:41:00.000** | 99 | -69.17 | 11.91 | 15.38 | 12 |
| **2018-10-19 01:51:00.000** | 100 | -95.87 | 12.47 | 15.38 | 12 |
| **2018-10-19 02:01:00.000** | 101 | -69.41 | 11.91 | 14.82 | 12 |
| **2018-10-19 02:11:00.000** | 102 | -48.82 | 11.91 | 15.38 | 12 |
| **2018-10-19 02:21:00.000** | 103 | -84.87 | 12.47 | 15.38 | 12 |
| **2018-10-19 02:31:00.000** | 104 | -82.22 | 11.91 | 14.82 | 12 |
| **2018-10-19 02:41:00.000** | 105 | -5 | 11.35 | 13.14 | 12 |
| **2018-10-19 02:51:00.000** | 106 | 0 | 13.59 | 13.14 | 12 |
| **2018-10-19 03:01:00.000** | 107 | 0 | 9.11 | 10.9 | 12 |
| **2018-10-19 03:11:00.000** | 108 | -5 | 9.67 | 12.02 | 12 |
| **2018-10-19 03:21:00.000** | 109 | -84.78 | 12.47 | 15.38 | 12 |

| Time | Sno | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-19 03:31:00.000** | 110 | -83.92 | 11.91 | 14.82 | 12 |
| **2018-10-19 03:41:00.000** | 111 | -78.65 | 11.91 | 14.82 | 12 |
| **2018-10-19 03:51:00.000** | 112 | -87.63 | 11.91 | 14.82 | 12 |
| **2018-10-19 04:01:00.000** | 113 | -80.45 | 11.91 | 14.82 | 12 |
| **2018-10-19 04:11:00.000** | 114 | -82.14 | 11.91 | 14.82 | 12 |
| **2018-10-19 04:21:00.000** | 115 | -73.34 | 11.91 | 14.82 | 12 |
| **2018-10-19 04:31:00.000** | 116 | -49.27 | 11.91 | 14.82 | 12 |
| **2018-10-19 04:41:00.000** | 117 | -38.64 | 11.91 | 14.82 | 12 |
| **2018-10-19 04:51:00.000** | 118 | -62.64 | 11.91 | 14.82 | 12 |
| **2018-10-19 05:01:00.000** | 119 | -73.23 | 12.47 | 14.82 | 12 |
| **2018-10-19 05:11:00.000** | 120 | -81.73 | 11.91 | 14.82 | 12 |
| **2018-10-19 05:21:00.000** | 121 | -89.56 | 12.47 | 14.82 | 12 |
| **2018-10-19 05:31:00.000** | 122 | -72.05 | 11.91 | 14.82 | 12 |
| **2018-10-19 05:41:00.000** | 123 | -56.89 | 11.91 | 14.82 | 12 |
| **2018-10-19 05:51:00.000** | 124 | -43.85 | 11.91 | 14.82 | 12 |
| **2018-10-19 06:01:00.000** | 125 | -46.2 | 11.91 | 14.82 | 12 |
| **2018-10-19 06:11:00.000** | 126 | -50.13 | 11.91 | 14.82 | 12 |
| **2018-10-19 06:21:00.000** | 127 | -54.7 | 11.91 | 14.82 | 12 |
| **2018-10-19 06:31:00.000** | 128 | -73.8 | 12.47 | 14.82 | 12 |
| **2018-10-19 06:41:00.000** | 129 | -84.03 | 12.47 | 14.82 | 12 |
| **2018-10-19 06:51:00.000** | 130 | -84.97 | 12.47 | 14.82 | 12 |
| **2018-10-19 07:01:00.000** | 131 | -69.11 | 11.91 | 14.82 | 12 |
| **2018-10-19 07:11:00.000** | 132 | -78.62 | 11.91 | 14.82 | 12 |
| **2018-10-19 07:21:00.000** | 133 | -75.46 | 11.91 | 14.82 | 12 |
| **2018-10-19 07:31:00.000** | 134 | -83.16 | 11.91 | 14.82 | 12 |
| **2018-10-19 07:41:00.000** | 135 | -89.67 | 11.91 | 14.82 | 12 |
| **2018-10-19 07:51:00.000** | 136 | -92.94 | 11.91 | 14.82 | 12 |
| **2018-10-19 08:01:00.000** | 137 | -99.11 | 11.91 | 14.82 | 12 |
| **2018-10-19 08:11:00.000** | 138 | -93.83 | 11.91 | 14.82 | 12 |
| **2018-10-19 08:21:00.000** | 139 | -100 | 11.91 | 14.82 | 12 |
| **2018-10-19 08:31:00.000** | 140 | -100 | 11.91 | 14.82 | 12 |
| **2018-10-19 08:41:00.000** | 141 | -100 | 11.91 | 14.82 | 12 |
| **2018-10-19 08:51:00.000** | 142 | -100 | 11.91 | 14.82 | 12 |
| **2018-10-19 09:01:00.000** | 143 | -100 | 11.91 | 14.82 | 12 |
| **2018-10-19 09:11:00.000** | 144 | -100 | 11.91 | 13.7 | 12 |
| **2018-10-19 09:21:00.000** | 145 | -71.59 | 11.8 | 14.82 | 12 |
| | | | | | |

**Appendix 2: Laminator 2 valve output, inlet, outlet, pre-set temperatures Data Set 1 Recorded on 18-10-2018**

| Time | Sno | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-18 09:21:00.000** | 1 | -5 | 12.25 | 14.26 | 15 |
| **2018-10-18 09:31:00.000** | 2 | -5 | 13.37 | 17.62 | 15 |
| **2018-10-18 09:41:00.000** | 3 | -78.3 | 15.04 | 17.06 | 15 |
| **2018-10-18 09:51:00.000** | 4 | -42.82 | 14.49 | 16.5 | 15 |
| **2018-10-18 10:01:00.000** | 5 | -98.92 | 15.6 | 17.62 | 15 |
| **2018-10-18 10:11:00.000** | 6 | -41.17 | 14.49 | 16.5 | 15 |
| **2018-10-18 10:21:00.000** | 7 | -96.86 | 15.6 | 17.06 | 15 |
| **2018-10-18 10:31:00.000** | 8 | -5 | 12.81 | 16.5 | 15 |
| **2018-10-18 10:41:00.000** | 9 | -40.9 | 14.37 | 16.5 | 15 |
| **2018-10-18 10:51:00.000** | 10 | -99.79 | 15.94 | 17.06 | 15 |
| **2018-10-18 11:01:00.000** | 11 | -5 | 12.58 | 17.06 | 15 |
| **2018-10-18 11:11:00.000** | 12 | -46.83 | 14.82 | 15.94 | 15 |
| **2018-10-18 11:21:00.000** | 13 | -5 | 14.26 | 17.62 | 15 |
| **2018-10-18 11:31:00.000** | 14 | -42.99 | 14.71 | 16.5 | 15 |
| **2018-10-18 11:41:00.000** | 15 | -5 | 13.03 | 17.06 | 15 |
| **2018-10-18 11:51:00.000** | 16 | -100 | 15.83 | 17.06 | 15 |
| **2018-10-18 12:01:00.000** | 17 | -63.24 | 14.71 | 16.5 | 15 |
| **2018-10-18 12:11:00.000** | 18 | -100 | 15.83 | 17.62 | 15 |
| **2018-10-18 12:21:00.000** | 19 | -30.49 | 14.71 | 16.5 | 15 |
| **2018-10-18 12:31:00.000** | 20 | -5 | 13.03 | 17.62 | 15 |
| **2018-10-18 12:41:00.000** | 21 | -51.08 | 14.71 | 16.5 | 15 |
| **2018-10-18 12:51:00.000** | 22 | 0 | 12.47 | 17.06 | 15 |
| **2018-10-18 13:01:00.000** | 23 | -5 | 13.03 | 15.38 | 15 |
| **2018-10-18 13:11:00.000** | 24 | -100 | 16.28 | 17.62 | 15 |
| **2018-10-18 13:21:00.000** | 25 | 0 | 12.25 | 14.26 | 15 |
| **2018-10-18 13:31:00.000** | 26 | 0 | 12.81 | 14.26 | 15 |
| **2018-10-18 13:41:00.000** | 27 | 0 | 12.81 | 14.26 | 15 |
| **2018-10-18 13:51:00.000** | 28 | 0 | 12.81 | 14.82 | 15 |
| **2018-10-18 14:01:00.000** | 29 | 0 | 13.37 | 14.82 | 15 |
| **2018-10-18 14:11:00.000** | 30 | 0 | 12.81 | 14.26 | 15 |
| **2018-10-18 14:21:00.000** | 31 | -5 | 12.81 | 14.26 | 15 |
| **2018-10-18 14:31:00.000** | 32 | -5 | 12.81 | 17.62 | 15 |

| Time | Sno | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| 2018-10-18 14:41:00.000 | 33 | -58.96 | 15.04 | 17.06 | 15 |
| 2018-10-18 14:51:00.000 | 34 | -36.03 | 14.49 | 15.94 | 15 |
| 2018-10-18 15:01:00.000 | 35 | -59.91 | 13.37 | 15.94 | 13 |
| 2018-10-18 15:11:00.000 | 36 | -100 | 13.37 | 15.94 | 13 |
| 2018-10-18 15:21:00.000 | 37 | -100 | 14.49 | 16.5 | 13 |
| 2018-10-18 15:31:00.000 | 38 | 0 | 14.04 | 16.39 | 13 |
| 2018-10-18 15:41:00.000 | 39 | 0 | 15.16 | 16.39 | 13 |
| 2018-10-18 15:51:00.000 | 40 | 0 | 15.16 | 16.95 | 13 |
| 2018-10-18 16:01:00.000 | 41 | 0 | 12.14 | 15.27 | 13 |
| 2018-10-18 16:11:00.000 | 42 | 0 | 13.25 | 14.71 | 13 |
| 2018-10-18 16:21:00.000 | 43 | 0 | 13.25 | 15.27 | 13 |
| 2018-10-18 16:31:00.000 | 44 | 0 | 13.25 | 15.27 | 13 |
| 2018-10-18 16:41:00.000 | 45 | 0 | 13.25 | 15.27 | 13 |
| 2018-10-18 16:51:00.000 | 46 | -5 | 12.69 | 15.27 | 13 |
| 2018-10-18 17:01:00.000 | 47 | -14.08 | 13.03 | 14.71 | 13 |
| 2018-10-18 17:11:00.000 | 48 | -47.77 | 12.47 | 15.27 | 13 |
| 2018-10-18 17:21:00.000 | 49 | -84.44 | 13.03 | 15.27 | 13 |
| 2018-10-18 17:31:00.000 | 50 | -93.89 | 13.59 | 15.83 | 13 |
| 2018-10-18 17:41:00.000 | 51 | -46.66 | 13.03 | 14.71 | 13 |
| 2018-10-18 17:51:00.000 | 52 | -6.49 | 11.91 | 14.71 | 13 |
| 2018-10-18 18:01:00.000 | 53 | -73.52 | 13.59 | 15.83 | 13 |
| 2018-10-18 18:11:00.000 | 54 | -22.66 | 12.47 | 14.71 | 13 |
| 2018-10-18 18:21:00.000 | 55 | -5 | 10.79 | 14.15 | 13 |
| 2018-10-18 18:31:00.000 | 56 | -94.29 | 13.59 | 15.27 | 13 |
| 2018-10-18 18:41:00.000 | 57 | -47.37 | 12.47 | 14.15 | 13 |
| 2018-10-18 18:51:00.000 | 58 | -5 | 13.03 | 14.71 | 14 |
| 2018-10-18 19:01:00.000 | 59 | -5 | 12.92 | 15.27 | 14 |
| 2018-10-18 19:11:00.000 | 60 | -40.11 | 13.48 | 15.27 | 14 |
| 2018-10-18 19:21:00.000 | 61 | -78.45 | 14.37 | 15.83 | 14 |
| 2018-10-18 19:31:00.000 | 62 | -69.75 | 14.26 | 15.83 | 14 |
| 2018-10-18 19:41:00.000 | 63 | -100 | 14.82 | 16.39 | 14 |
| 2018-10-18 19:51:00.000 | 64 | -5 | 11.46 | 15.27 | 14 |
| 2018-10-18 20:01:00.000 | 65 | -13.87 | 13.59 | 15.27 | 14 |
| 2018-10-18 20:11:00.000 | 66 | -100 | 14.71 | 16.39 | 14 |
| 2018-10-18 20:21:00.000 | 67 | -100 | 14.6 | 16.39 | 14 |
| 2018-10-18 20:31:00.000 | 68 | -81.52 | 15.49 | 17.51 | 15 |
| 2018-10-18 20:41:00.000 | 69 | -67.92 | 15.27 | 16.95 | 15 |
| 2018-10-18 20:51:00.000 | 70 | -87.64 | 15.6 | 16.95 | 15 |

| Time | Sno | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-18 21:01:00.000** | 71 | -100 | 15.38 | 17.51 | 13 |
| **2018-10-18 21:11:00.000** | 72 | -43.23 | 12.47 | 14.15 | 13 |
| **2018-10-18 21:21:00.000** | 73 | -6.98 | 12.47 | 15.83 | 13 |
| **2018-10-18 21:31:00.000** | 74 | -14.29 | 13.03 | 14.71 | 14 |
| **2018-10-18 21:41:00.000** | 75 | -56.77 | 13.93 | 15.27 | 14 |
| **2018-10-18 21:51:00.000** | 76 | -82.51 | 14.49 | 16.39 | 14 |
| **2018-10-18 22:01:00.000** | 77 | -51.64 | 14.37 | 16.95 | 14 |
| **2018-10-18 22:11:00.000** | 78 | -5.19 | 11.58 | 14.71 | 14 |
| **2018-10-18 22:21:00.000** | 79 | -5.14 | 13.25 | 14.71 | 14 |
| **2018-10-18 22:31:00.000** | 80 | -8.24 | 13.14 | 15.27 | 14 |
| **2018-10-18 22:41:00.000** | 81 | -49.49 | 13.59 | 15.27 | 14 |
| **2018-10-18 22:51:00.000** | 82 | -73.52 | 14.04 | 15.83 | 14 |
| **2018-10-18 23:01:00.000** | 83 | -100 | 14.6 | 16.39 | 14 |
| **2018-10-18 23:11:00.000** | 84 | -5 | 12.69 | 16.39 | 14 |
| **2018-10-18 23:21:00.000** | 85 | -5 | 11.46 | 15.27 | 14 |
| **2018-10-18 23:31:00.000** | 86 | -5 | 13.14 | 15.27 | 14 |
| **2018-10-18 23:41:00.000** | 87 | -66.52 | 14.15 | 15.83 | 14 |
| **2018-10-18 23:51:00.000** | 88 | -72.31 | 14.04 | 15.83 | 14 |
| **2018-10-19 00:01:00.000** | 89 | -82.6 | 14.37 | 16.39 | 14 |
| **2018-10-19 00:11:00.000** | 90 | -5 | 13.03 | 15.83 | 14 |
| **2018-10-19 00:21:00.000** | 91 | -5 | 10.01 | 12.47 | 14 |
| **2018-10-19 00:31:00.000** | 92 | -5.16 | 13.25 | 15.27 | 14 |
| **2018-10-19 00:41:00.000** | 93 | -27.9 | 13.25 | 15.27 | 14 |
| **2018-10-19 00:51:00.000** | 94 | -70.11 | 14.15 | 15.83 | 14 |
| **2018-10-19 01:01:00.000** | 95 | -97.59 | 14.71 | 16.95 | 14 |
| **2018-10-19 01:11:00.000** | 96 | -5 | 10.57 | 15.27 | 14 |
| **2018-10-19 01:21:00.000** | 97 | -12.66 | 12.69 | 14.71 | 14 |
| **2018-10-19 01:31:00.000** | 98 | -27.58 | 13.14 | 15.27 | 14 |
| **2018-10-19 01:41:00.000** | 99 | -91.32 | 14.71 | 16.39 | 14 |
| **2018-10-19 01:51:00.000** | 100 | -44.21 | 14.15 | 16.95 | 14 |
| **2018-10-19 02:01:00.000** | 101 | -5 | 10.68 | 15.27 | 14 |
| **2018-10-19 02:11:00.000** | 102 | -5 | 12.81 | 14.71 | 14 |
| **2018-10-19 02:21:00.000** | 103 | -64.51 | 13.93 | 15.83 | 14 |
| **2018-10-19 02:31:00.000** | 104 | -100 | 14.49 | 16.39 | 14 |
| **2018-10-19 02:41:00.000** | 105 | 0 | 11.69 | 15.27 | 14 |
| **2018-10-19 02:51:00.000** | 106 | 0 | 13.37 | 15.83 | 14 |
| **2018-10-19 03:01:00.000** | 107 | 0 | 13.93 | 16.39 | 14 |
| **2018-10-19 03:11:00.000** | 108 | -5 | 9.56 | 13.03 | 14 |

| Time | Sno | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-19 03:21:00.000** | 109 | -5 | 11.02 | 15.27 | 14 |
| **2018-10-19 03:31:00.000** | 110 | -14.76 | 13.25 | 14.71 | 14 |
| **2018-10-19 03:41:00.000** | 111 | -79.63 | 14.37 | 15.83 | 14 |
| **2018-10-19 03:51:00.000** | 112 | -92.58 | 14.49 | 16.39 | 14 |
| **2018-10-19 04:01:00.000** | 113 | -71.08 | 14.49 | 16.95 | 14 |
| **2018-10-19 04:11:00.000** | 114 | -5 | 11.69 | 14.71 | 14 |
| **2018-10-19 04:21:00.000** | 115 | -5.83 | 12.81 | 14.71 | 14 |
| **2018-10-19 04:31:00.000** | 116 | -52.74 | 13.7 | 15.27 | 14 |
| **2018-10-19 04:41:00.000** | 117 | -61.14 | 14.04 | 15.83 | 14 |
| **2018-10-19 04:51:00.000** | 118 | -90.83 | 14.49 | 16.39 | 14 |
| **2018-10-19 05:01:00.000** | 119 | -5 | 13.25 | 16.95 | 14 |
| **2018-10-19 05:11:00.000** | 120 | -5 | 10.79 | 15.27 | 14 |
| **2018-10-19 05:21:00.000** | 121 | -5 | 12.25 | 14.71 | 14 |
| **2018-10-19 05:31:00.000** | 122 | -5 | 13.25 | 14.71 | 14 |
| **2018-10-19 05:41:00.000** | 123 | -5 | 13.03 | 15.27 | 14 |
| **2018-10-19 05:51:00.000** | 124 | -90.41 | 14.6 | 15.83 | 14 |
| **2018-10-19 06:01:00.000** | 125 | -77.6 | 14.04 | 16.39 | 14 |
| **2018-10-19 06:11:00.000** | 126 | -43.34 | 14.04 | 16.39 | 14 |
| **2018-10-19 06:21:00.000** | 127 | -5 | 11.02 | 15.83 | 14 |
| **2018-10-19 06:31:00.000** | 128 | -5 | 11.58 | 14.71 | 14 |
| **2018-10-19 06:41:00.000** | 129 | -5 | 13.14 | 14.71 | 14 |
| **2018-10-19 06:51:00.000** | 130 | -5.58 | 13.14 | 14.71 | 14 |
| **2018-10-19 07:01:00.000** | 131 | -76.14 | 14.26 | 15.83 | 14 |
| **2018-10-19 07:11:00.000** | 132 | -47.96 | 13.7 | 15.27 | 14 |
| **2018-10-19 07:21:00.000** | 133 | -5 | 12.02 | 15.83 | 14 |
| **2018-10-19 07:31:00.000** | 134 | -100 | 14.82 | 16.39 | 14 |
| **2018-10-19 07:41:00.000** | 135 | -71.41 | 14.26 | 16.39 | 14 |
| **2018-10-19 07:51:00.000** | 136 | -42.13 | 13.7 | 15.83 | 14 |
| **2018-10-19 08:01:00.000** | 137 | -27.61 | 13.14 | 15.83 | 14 |
| **2018-10-19 08:11:00.000** | 138 | -21.87 | 13.7 | 16.95 | 14 |
| **2018-10-19 08:21:00.000** | 139 | -96.88 | 14.82 | 16.95 | 14 |
| **2018-10-19 08:31:00.000** | 140 | -100 | 14.82 | 16.39 | 14 |
| **2018-10-19 08:41:00.000** | 141 | -56.1 | 13.7 | 15.83 | 14 |
| **2018-10-19 08:51:00.000** | 142 | -65.04 | 13.7 | 15.83 | 14 |
| **2018-10-19 09:01:00.000** | 143 | -6.95 | 12.58 | 15.83 | 14 |
| **2018-10-19 09:11:00.000** | 144 | -100 | 14.82 | 15.83 | 14 |
| **2018-10-19 09:21:00.000** | 145 | -100 | 15.49 | 17.17 | 14 |

## Appendix 3: Laminator 3 valve output, inlet, outlet, pre-set temperatures Data Set 1 Recorded on 18-10-2018

| Time | Sno | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-18 09:21:00.000** | 1 | 0 | 12.81 | 16.05 | 17 |
| **2018-10-18 09:31:00.000** | 2 | 0 | 14.37 | 18.29 | 17 |
| **2018-10-18 09:41:00.000** | 3 | -49.9 | 17.17 | 19.97 | 17 |
| **2018-10-18 09:51:00.000** | 4 | 0 | 16.05 | 21.09 | 17 |
| **2018-10-18 10:01:00.000** | 5 | -21.46 | 16.61 | 19.97 | 17 |
| **2018-10-18 10:11:00.000** | 6 | -100 | 18.29 | 21.65 | 17 |
| **2018-10-18 10:21:00.000** | 7 | -1.54 | 16.61 | 21.09 | 17 |
| **2018-10-18 10:31:00.000** | 8 | 0 | 15.49 | 18.29 | 17 |
| **2018-10-18 10:41:00.000** | 9 | 0 | 16.61 | 19.41 | 17 |
| **2018-10-18 10:51:00.000** | 10 | -21.49 | 16.61 | 19.41 | 17 |
| **2018-10-18 11:01:00.000** | 11 | -100 | 18.29 | 21.09 | 17 |
| **2018-10-18 11:11:00.000** | 12 | -100 | 18.85 | 21.65 | 17 |
| **2018-10-18 11:21:00.000** | 13 | 0 | 14.37 | 18.29 | 17 |
| **2018-10-18 11:31:00.000** | 14 | -38.9 | 16.61 | 19.97 | 17 |
| **2018-10-18 11:41:00.000** | 15 | -1.11 | 16.61 | 21.09 | 17 |
| **2018-10-18 11:51:00.000** | 16 | -52.73 | 17.17 | 19.97 | 17 |
| **2018-10-18 12:01:00.000** | 17 | -100 | 18.29 | 21.09 | 17 |
| **2018-10-18 12:11:00.000** | 18 | 0 | 15.49 | 20.53 | 17 |
| **2018-10-18 12:21:00.000** | 19 | -28.39 | 16.61 | 19.97 | 17 |
| **2018-10-18 12:31:00.000** | 20 | -2.21 | 16.61 | 21.09 | 17 |
| **2018-10-18 12:41:00.000** | 21 | 0 | 15.49 | 18.29 | 17 |
| **2018-10-18 12:51:00.000** | 22 | -17.57 | 16.61 | 19.97 | 17 |
| **2018-10-18 13:01:00.000** | 23 | 0 | 15.94 | 18.85 | 17 |
| **2018-10-18 13:11:00.000** | 24 | -57.02 | 17.62 | 20.53 | 17 |
| **2018-10-18 13:21:00.000** | 25 | 0 | 13.14 | 16.05 | 17 |
| **2018-10-18 13:31:00.000** | 26 | 0 | 14.26 | 16.05 | 17 |
| **2018-10-18 13:41:00.000** | 27 | 0 | 14.26 | 16.61 | 17 |
| **2018-10-18 13:51:00.000** | 28 | 0 | 14.26 | 16.61 | 17 |
| **2018-10-18 14:01:00.000** | 29 | 0 | 14.26 | 16.61 | 17 |
| **2018-10-18 14:11:00.000** | 30 | 0 | 14.26 | 16.61 | 17 |
| **2018-10-18 14:21:00.000** | 31 | 0 | 13.14 | 16.05 | 17 |
| **2018-10-18 14:31:00.000** | 32 | -0.75 | 15.94 | 18.85 | 17 |
| **2018-10-18 14:41:00.000** | 33 | -80.26 | 17.62 | 20.53 | 17 |
| **2018-10-18 14:51:00.000** | 34 | -17.96 | 16.5 | 21.09 | 17 |
| **2018-10-18 15:01:00.000** | 35 | -40.58 | 17.06 | 19.97 | 17 |

| Time | Sno | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| 2018-10-18 15:11:00.000 | 36 | -27.16 | 16.5 | 21.09 | 17 |
| 2018-10-18 15:21:00.000 | 37 | 0 | 15.38 | 19.41 | 17 |
| 2018-10-18 15:31:00.000 | 38 | 0 | 17.73 | 20.64 | 17 |
| 2018-10-18 15:41:00.000 | 39 | 0 | 19.41 | 20.64 | 17 |
| 2018-10-18 15:51:00.000 | 40 | 0 | 19.41 | 21.2 | 17 |
| 2018-10-18 16:01:00.000 | 41 | 0 | 15.16 | 18.4 | 16 |
| 2018-10-18 16:11:00.000 | 42 | 0 | 14.6 | 15.6 | 16 |
| 2018-10-18 16:21:00.000 | 43 | 0 | 14.6 | 15.6 | 16 |
| 2018-10-18 16:31:00.000 | 44 | 0 | 14.6 | 16.16 | 16 |
| 2018-10-18 16:41:00.000 | 45 | 0 | 14.6 | 16.16 | 16 |
| 2018-10-18 16:51:00.000 | 46 | 0 | 14.6 | 16.72 | 16 |
| 2018-10-18 17:01:00.000 | 47 | -12.4 | 15.72 | 20.08 | 16 |
| 2018-10-18 17:11:00.000 | 48 | -100 | 17.28 | 20.64 | 16 |
| 2018-10-18 17:21:00.000 | 49 | -100 | 17.73 | 20.64 | 16 |
| 2018-10-18 17:31:00.000 | 50 | -62.85 | 16.5 | 20.64 | 16 |
| 2018-10-18 17:41:00.000 | 51 | -72.78 | 17.06 | 20.64 | 16 |
| 2018-10-18 17:51:00.000 | 52 | -100 | 17.39 | 20.64 | 16 |
| 2018-10-18 18:01:00.000 | 53 | -99.11 | 17.39 | 20.64 | 16 |
| 2018-10-18 18:11:00.000 | 54 | -100 | 16.83 | 20.64 | 16 |
| 2018-10-18 18:21:00.000 | 55 | -100 | 17.39 | 20.64 | 16 |
| 2018-10-18 18:31:00.000 | 56 | -100 | 17.39 | 20.64 | 16 |
| 2018-10-18 18:41:00.000 | 57 | -99.46 | 16.83 | 20.08 | 16 |
| 2018-10-18 18:51:00.000 | 58 | -52.56 | 17.39 | 21.76 | 17 |
| 2018-10-18 19:01:00.000 | 59 | -100 | 17.17 | 20.08 | 16 |
| 2018-10-18 19:11:00.000 | 60 | -79.05 | 16.61 | 20.64 | 16 |
| 2018-10-18 19:21:00.000 | 61 | -43.51 | 15.94 | 20.64 | 16 |
| 2018-10-18 19:31:00.000 | 62 | -0.49 | 14.82 | 19.52 | 16 |
| 2018-10-18 19:41:00.000 | 63 | 0 | 12.92 | 18.4 | 16 |
| 2018-10-18 19:51:00.000 | 64 | 0 | 12.92 | 17.28 | 16 |
| 2018-10-18 20:01:00.000 | 65 | 0 | 14.6 | 17.84 | 16 |
| 2018-10-18 20:11:00.000 | 66 | -16 | 15.49 | 18.4 | 16 |
| 2018-10-18 20:21:00.000 | 67 | -2.22 | 15.49 | 18.4 | 16 |
| 2018-10-18 20:31:00.000 | 68 | -0.84 | 16.05 | 19.52 | 17 |
| 2018-10-18 20:41:00.000 | 69 | 0 | 16.05 | 19.52 | 17 |
| 2018-10-18 20:51:00.000 | 70 | 0 | 15.49 | 18.96 | 17 |
| 2018-10-18 21:01:00.000 | 71 | 0 | 15.49 | 18.96 | 17 |
| 2018-10-18 21:11:00.000 | 72 | -13.67 | 16.05 | 19.52 | 17 |
| 2018-10-18 21:21:00.000 | 73 | -26.55 | 16.5 | 18.96 | 17 |

| Time | Sno | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-18 21:31:00.000** | 74 | -100 | 16.95 | 19.52 | 16 |
| **2018-10-18 21:41:00.000** | 75 | -73.41 | 16.95 | 20.64 | 16 |
| **2018-10-18 21:51:00.000** | 76 | -47.49 | 14.71 | 17.84 | 15 |
| **2018-10-18 22:01:00.000** | 77 | -100 | 16.39 | 19.52 | 15 |
| **2018-10-18 22:11:00.000** | 78 | -12.18 | 14.15 | 16.72 | 15 |
| **2018-10-18 22:21:00.000** | 79 | -100 | 16.39 | 18.96 | 15 |
| **2018-10-18 22:31:00.000** | 80 | 0 | 12.47 | 17.28 | 15 |
| **2018-10-18 22:41:00.000** | 81 | -19.68 | 14.71 | 17.84 | 15 |
| **2018-10-18 22:51:00.000** | 82 | -10.13 | 14.71 | 18.96 | 15 |
| **2018-10-18 23:01:00.000** | 83 | -38.25 | 14.71 | 17.28 | 15 |
| **2018-10-18 23:11:00.000** | 84 | -100 | 15.83 | 18.96 | 15 |
| **2018-10-18 23:21:00.000** | 85 | 0 | 12.47 | 17.28 | 15 |
| **2018-10-18 23:31:00.000** | 86 | -20.58 | 14.71 | 17.84 | 15 |
| **2018-10-18 23:41:00.000** | 87 | -100 | 16.39 | 20.08 | 15 |
| **2018-10-18 23:51:00.000** | 88 | -22.14 | 14.15 | 17.28 | 15 |
| **2018-10-19 00:01:00.000** | 89 | -100 | 15.83 | 18.96 | 15 |
| **2018-10-19 00:11:00.000** | 90 | 0 | 15.83 | 17.84 | 15 |
| **2018-10-19 00:21:00.000** | 91 | 0 | 9.67 | 12.81 | 15 |
| **2018-10-19 00:31:00.000** | 92 | 0 | 14.71 | 17.84 | 15 |
| **2018-10-19 00:41:00.000** | 93 | -35.8 | 14.71 | 16.72 | 15 |
| **2018-10-19 00:51:00.000** | 94 | -86.83 | 15.83 | 18.4 | 15 |
| **2018-10-19 01:01:00.000** | 95 | 0 | 13.03 | 16.16 | 15 |
| **2018-10-19 01:11:00.000** | 96 | -38.48 | 14.71 | 17.28 | 15 |
| **2018-10-19 01:21:00.000** | 97 | -11.48 | 14.15 | 17.84 | 15 |
| **2018-10-19 01:31:00.000** | 98 | -27.37 | 14.71 | 17.28 | 15 |
| **2018-10-19 01:41:00.000** | 99 | -62.89 | 15.27 | 18.4 | 15 |
| **2018-10-19 01:51:00.000** | 100 | -12.1 | 14.71 | 17.28 | 15 |
| **2018-10-19 02:01:00.000** | 101 | -83.76 | 15.83 | 18.4 | 15 |
| **2018-10-19 02:11:00.000** | 102 | -27.32 | 14.15 | 16.72 | 15 |
| **2018-10-19 02:21:00.000** | 103 | -91.11 | 15.83 | 17.84 | 15 |
| **2018-10-19 02:31:00.000** | 104 | 0 | 13.03 | 16.16 | 15 |
| **2018-10-19 02:41:00.000** | 105 | 0 | 15.27 | 16.72 | 15 |
| **2018-10-19 02:51:00.000** | 106 | 0 | 15.27 | 16.72 | 15 |
| **2018-10-19 03:01:00.000** | 107 | 0 | 15.27 | 16.72 | 15 |
| **2018-10-19 03:11:00.000** | 108 | 0 | 12.92 | 17.28 | 15 |
| **2018-10-19 03:21:00.000** | 109 | 0 | 13.93 | 18.29 | 15 |
| **2018-10-19 03:31:00.000** | 110 | 0 | 14.49 | 17.73 | 15 |
| **2018-10-19 03:41:00.000** | 111 | -32.49 | 15.04 | 18.29 | 15 |

| Time | Sno | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|---|
| **2018-10-19 03:51:00.000** | 112 | -32.39 | 14.49 | 17.17 | 15 |
| **2018-10-19 04:01:00.000** | 113 | -64.02 | 15.6 | 18.85 | 15 |
| **2018-10-19 04:11:00.000** | 114 | -26.72 | 14.49 | 17.17 | 15 |
| **2018-10-19 04:21:00.000** | 115 | -98.75 | 16.16 | 18.85 | 15 |
| **2018-10-19 04:31:00.000** | 116 | -27.59 | 14.49 | 16.61 | 15 |
| **2018-10-19 04:41:00.000** | 117 | -100 | 16.16 | 18.29 | 15 |
| **2018-10-19 04:51:00.000** | 118 | 0 | 13.37 | 16.05 | 15 |
| **2018-10-19 05:01:00.000** | 119 | -44.18 | 15.04 | 17.73 | 15 |
| **2018-10-19 05:11:00.000** | 120 | -96.22 | 15.6 | 18.85 | 15 |
| **2018-10-19 05:21:00.000** | 121 | 0 | 13.37 | 17.73 | 15 |
| **2018-10-19 05:31:00.000** | 122 | 0 | 13.37 | 16.05 | 15 |
| **2018-10-19 05:41:00.000** | 123 | -16.64 | 14.49 | 17.17 | 15 |
| **2018-10-19 05:51:00.000** | 124 | -45.79 | 15.04 | 18.85 | 15 |
| **2018-10-19 06:01:00.000** | 125 | -18.98 | 14.49 | 17.17 | 15 |
| **2018-10-19 06:11:00.000** | 126 | -84.2 | 16.16 | 18.85 | 15 |
| **2018-10-19 06:21:00.000** | 127 | 0 | 12.25 | 16.05 | 15 |
| **2018-10-19 06:31:00.000** | 128 | -36.38 | 14.49 | 17.17 | 15 |
| **2018-10-19 06:41:00.000** | 129 | -11.52 | 14.49 | 18.29 | 15 |
| **2018-10-19 06:51:00.000** | 130 | -1.09 | 13.81 | 16.05 | 15 |
| **2018-10-19 07:01:00.000** | 131 | -100 | 16.05 | 18.29 | 15 |
| **2018-10-19 07:11:00.000** | 132 | -31.8 | 14.37 | 16.61 | 15 |
| **2018-10-19 07:21:00.000** | 133 | -96.04 | 15.49 | 18.29 | 15 |
| **2018-10-19 07:31:00.000** | 134 | -59.43 | 14.93 | 17.73 | 15 |
| **2018-10-19 07:41:00.000** | 135 | -70.56 | 14.93 | 17.73 | 15 |
| **2018-10-19 07:51:00.000** | 136 | -3.71 | 14.37 | 17.73 | 15 |
| **2018-10-19 08:01:00.000** | 137 | -79.53 | 15.49 | 18.29 | 15 |
| **2018-10-19 08:11:00.000** | 138 | -26.72 | 14.37 | 17.17 | 15 |
| **2018-10-19 08:21:00.000** | 139 | 0 | 13.81 | 17.73 | 15 |
| **2018-10-19 08:31:00.000** | 140 | -62.07 | 14.93 | 17.73 | 15 |
| **2018-10-19 08:41:00.000** | 141 | 0 | 13.81 | 17.17 | 15 |
| **2018-10-19 08:51:00.000** | 142 | 0 | 13.81 | 17.73 | 15 |
| **2018-10-19 09:01:00.000** | 143 | -69.73 | 15.49 | 18.29 | 15 |
| **2018-10-19 09:11:00.000** | 144 | 0 | 15.49 | 17.73 | 15 |
| **2018-10-19 09:21:00.000** | 145 | -39.15 | 15.16 | 18.07 | 15 |

## Appendix 4: Laminator 1 valve output, inlet, outlet, pre-set temperatures Data Set 2 Recorded on 7-11-2018

| Time | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-07 13:28:00.000** | -100 | 11.24 | 15.49 | 10 |
| **2018-11-07 13:38:00.000** | -100 | 11.8 | 16.05 | 10 |
| **2018-11-07 13:48:00.000** | -100 | 11.8 | 16.05 | 10 |
| **2018-11-07 13:58:00.000** | -100 | 11.8 | 16.05 | 10 |
| **2018-11-07 14:08:00.000** | -100 | 11.8 | 16.05 | 10 |
| **2018-11-07 14:18:00.000** | -100 | 11.8 | 16.05 | 10 |
| **2018-11-07 14:28:00.000** | -100 | 11.8 | 16.05 | 10 |
| **2018-11-07 14:38:00.000** | -100 | 11.24 | 16.05 | 10 |
| **2018-11-07 14:48:00.000** | -100 | 11.24 | 16.05 | 10 |
| **2018-11-07 14:58:00.000** | -100 | 11.24 | 15.49 | 10 |
| **2018-11-07 15:08:00.000** | -100 | 11.24 | 15.49 | 10 |
| **2018-11-07 15:18:00.000** | -100 | 11.24 | 16.05 | 10 |
| **2018-11-07 15:28:00.000** | -84.46 | 12.36 | 17.17 | 12 |
| **2018-11-07 15:38:00.000** | -98.54 | 12.92 | 17.17 | 12 |
| **2018-11-07 15:48:00.000** | -100 | 12.92 | 17.17 | 12 |
| **2018-11-07 15:58:00.000** | -100 | 12.92 | 17.17 | 12 |
| **2018-11-07 16:08:00.000** | -100 | 12.92 | 16.61 | 12 |
| **2018-11-07 16:18:00.000** | -74.04 | 11.8 | 16.05 | 12 |
| **2018-11-07 16:28:00.000** | -100 | 11.24 | 16.05 | 10 |
| **2018-11-07 20:08:00.000** | -100 | 16.5 | 20.41 | 10 |
| **2018-11-07 20:18:00.000** | -100 | 17.06 | 20.97 | 10 |
| **2018-11-07 20:28:00.000** | -100 | 16.5 | 20.41 | 10 |
| **2018-11-07 20:38:00.000** | -100 | 15.94 | 19.86 | 10 |
| **2018-11-07 20:48:00.000** | -100 | 15.38 | 19.3 | 10 |
| **2018-11-07 20:58:00.000** | -100 | 14.82 | 18.74 | 10 |
| **2018-11-07 21:08:00.000** | -100 | 14.26 | 18.18 | 10 |
| **2018-11-07 21:18:00.000** | -100 | 13.7 | 17.62 | 10 |
| **2018-11-07 21:28:00.000** | -100 | 13.14 | 17.62 | 10 |
| **2018-11-07 21:38:00.000** | -100 | 13.14 | 17.62 | 10 |
| **2018-11-07 21:48:00.000** | -100 | 13.14 | 17.62 | 10 |
| **2018-11-07 21:58:00.000** | -100 | 13.14 | 17.62 | 10 |
| **2018-11-07 22:08:00.000** | -100 | 13.14 | 17.62 | 10 |
| **2018-11-07 22:18:00.000** | -100 | 12.58 | 17.06 | 10 |
| **2018-11-07 22:28:00.000** | -100 | 13.14 | 17.06 | 10 |
| **2018-11-07 22:38:00.000** | -100 | 13.7 | 18.18 | 10 |
| **2018-11-07 22:48:00.000** | -100 | 13.7 | 18.18 | 10 |
| **2018-11-07 22:58:00.000** | -100 | 13.14 | 17.06 | 10 |
| **2018-11-07 23:08:00.000** | -100 | 12.58 | 16.5 | 10 |
| **2018-11-07 23:18:00.000** | -100 | 13.14 | 17.62 | 10 |

| Time | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-07 23:28:00.000** | -100 | 13.7 | 18.18 | 10 |
| **2018-11-07 23:38:00.000** | -100 | 13.7 | 17.62 | 10 |
| **2018-11-07 23:48:00.000** | -100 | 13.7 | 17.62 | 10 |
| **2018-11-07 23:58:00.000** | -100 | 14.26 | 18.74 | 10 |
| **2018-11-08 00:08:00.000** | -100 | 14.26 | 18.74 | 10 |
| **2018-11-08 00:18:00.000** | -100 | 13.7 | 18.18 | 10 |
| **2018-11-08 00:28:00.000** | -100 | 14.26 | 18.74 | 10 |
| **2018-11-08 00:38:00.000** | -100 | 14.26 | 18.74 | 10 |
| **2018-11-08 00:48:00.000** | -100 | 13.7 | 17.62 | 10 |
| **2018-11-08 00:58:00.000** | -100 | 13.14 | 17.06 | 10 |
| **2018-11-08 01:08:00.000** | -100 | 12.58 | 16.5 | 10 |
| **2018-11-08 01:18:00.000** | -100 | 12.02 | 16.5 | 10 |
| **2018-11-08 01:28:00.000** | -99.63 | 11.46 | 15.38 | 10 |
| **2018-11-08 01:38:00.000** | -100 | 10.9 | 15.38 | 10 |
| **2018-11-08 01:48:00.000** | -100 | 12.02 | 15.94 | 10 |
| **2018-11-08 01:58:00.000** | -100 | 12.02 | 15.94 | 10 |
| **2018-11-08 02:08:00.000** | -100 | 11.46 | 15.94 | 10 |
| **2018-11-08 02:18:00.000** | -100 | 11.46 | 15.94 | 10 |
| **2018-11-08 02:28:00.000** | -100 | 10.9 | 15.38 | 10 |
| **2018-11-08 02:38:00.000** | -100 | 10.9 | 15.38 | 10 |
| **2018-11-08 03:18:00.000** | -100 | 10.9 | 14.82 | 10 |
| **2018-11-08 03:28:00.000** | -100 | 10.9 | 15.38 | 10 |
| **2018-11-08 03:38:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 03:48:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 03:58:00.000** | -100 | 11.46 | 15.94 | 10 |
| **2018-11-08 04:08:00.000** | -100 | 11.46 | 15.94 | 10 |
| **2018-11-08 04:18:00.000** | -100 | 11.46 | 15.94 | 10 |
| **2018-11-08 04:28:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 04:38:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 04:48:00.000** | -100 | 10.9 | 15.38 | 10 |
| **2018-11-08 04:58:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 05:08:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 05:18:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 05:28:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 05:38:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 05:48:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 05:58:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 06:08:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 06:18:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 06:28:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 06:38:00.000** | -100 | 11.46 | 15.38 | 10 |
| **2018-11-08 06:48:00.000** | -100 | 11.46 | 15.38 | 10 |

| Time | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-08 07:08:00.000** | -73.62 | 12.02 | 15.94 | 12 |
| **2018-11-08 07:18:00.000** | -75.6 | 12.02 | 15.94 | 12 |
| **2018-11-08 07:28:00.000** | -21.37 | 12.58 | 17.06 | 13 |
| **2018-11-08 07:38:00.000** | -28.87 | 13.7 | 18.74 | 14 |
| **2018-11-08 07:48:00.000** | -39.79 | 13.7 | 18.74 | 14 |
| **2018-11-08 07:58:00.000** | -10.68 | 13.14 | 18.74 | 14 |
| **2018-11-08 08:08:00.000** | -40.75 | 13.7 | 18.74 | 14 |
| **2018-11-08 08:18:00.000** | -52.65 | 14.26 | 18.74 | 14 |
| **2018-11-08 08:28:00.000** | -74.83 | 14.82 | 19.3 | 14 |
| **2018-11-08 08:38:00.000** | -74.15 | 14.82 | 19.3 | 14 |
| **2018-11-08 08:48:00.000** | -69.16 | 14.26 | 18.74 | 14 |
| **2018-11-08 08:58:00.000** | -51.13 | 14.26 | 18.74 | 14 |
| **2018-11-08 09:08:00.000** | -51.81 | 12.02 | 16.5 | 12 |
| **2018-11-08 09:18:00.000** | -38.05 | 11.46 | 15.94 | 12 |
| **2018-11-08 09:28:00.000** | -30.96 | 11.46 | 15.94 | 12 |
| **2018-11-08 09:38:00.000** | -31.06 | 11.46 | 16.5 | 12 |
| **2018-11-08 09:48:00.000** | -51.63 | 12.02 | 17.06 | 12 |
| **2018-11-08 09:58:00.000** | -77.05 | 12.58 | 17.06 | 12 |
| **2018-11-08 10:08:00.000** | -100 | 13.14 | 17.06 | 12 |
| **2018-11-08 10:18:00.000** | -100 | 13.14 | 17.06 | 12 |
| **2018-11-08 10:28:00.000** | -100 | 13.14 | 16.5 | 12 |
| **2018-11-08 10:38:00.000** | -100 | 12.58 | 16.5 | 12 |
| **2018-11-08 10:48:00.000** | -88.17 | 13.7 | 17.06 | 13 |
| **2018-11-08 10:58:00.000** | -100 | 13.14 | 17.06 | 12 |
| **2018-11-08 11:08:00.000** | -100 | 12.02 | 15.94 | 11 |
| **2018-11-08 11:18:00.000** | -99.06 | 11.46 | 15.94 | 11 |
| **2018-11-08 11:28:00.000** | -98.4 | 11.46 | 15.38 | 11 |
| **2018-11-08 11:38:00.000** | -99.94 | 11.46 | 15.38 | 10 |
| **2018-11-08 11:48:00.000** | -59.17 | 11.46 | 15.38 | 12 |
| **2018-11-08 11:58:00.000** | -56.89 | 11.46 | 15.94 | 12 |
| **2018-11-08 12:08:00.000** | -33.22 | 11.46 | 15.94 | 12 |
| **2018-11-08 12:18:00.000** | -45.76 | 12.02 | 16.5 | 12 |
| **2018-11-08 12:28:00.000** | -49.61 | 12.02 | 16.5 | 12 |
| **2018-11-08 12:38:00.000** | -52.24 | 12.02 | 17.06 | 12 |
| **2018-11-08 12:48:00.000** | -79.03 | 12.58 | 17.06 | 12 |
| **2018-11-08 12:58:00.000** | -97.7 | 13.14 | 17.06 | 12 |
| **2018-11-08 13:08:00.000** | -100 | 14.26 | 17.62 | 13 |
| **2018-11-08 13:18:00.000** | -100 | 14.26 | 17.62 | 13 |
| **2018-11-08 13:28:00.000** | -100 | 14.26 | 17.62 | 13 |
| **2018-11-08 13:38:00.000** | -100 | 14.26 | 17.62 | 13 |
| **2018-11-08 13:48:00.000** | -100 | 14.26 | 17.62 | 13 |
| **2018-11-08 13:58:00.000** | -100 | 14.26 | 18.18 | 13 |

| Time | Lam1: Cooling Water Controller Output | Lam1: Inlet Cooling Water Temperature | Lam1: Outlet Cooling Water Temperature | Lam1: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-08 14:08:00.000** | -88.39 | 13.7 | 17.62 | 13 |
| **2018-11-08 14:18:00.000** | -86.74 | 13.7 | 18.18 | 13 |
| **2018-11-08 15:48:00.000** | -26.81 | 12.58 | 17.06 | 13 |
| **2018-11-08 15:58:00.000** | -26.89 | 12.58 | 17.06 | 13 |
| **2018-11-08 16:08:00.000** | -22.29 | 12.58 | 17.06 | 13 |
| **2018-11-08 16:18:00.000** | -15.16 | 12.58 | 17.06 | 13 |
| **2018-11-08 16:28:00.000** | -15.45 | 12.58 | 17.06 | 13 |
| **2018-11-08 16:38:00.000** | -27.05 | 12.58 | 17.06 | 13 |
| **2018-11-08 16:48:00.000** | -27.64 | 12.58 | 17.06 | 13 |
| **2018-11-08 16:58:00.000** | -22.35 | 12.02 | 16.5 | 13 |
| **2018-11-08 17:08:00.000** | -58.94 | 13.14 | 17.06 | 13 |
| **2018-11-08 17:18:00.000** | -72.05 | 13.14 | 17.06 | 13 |
| **2018-11-08 17:28:00.000** | -70.24 | 13.14 | 17.06 | 13 |
| **2018-11-08 17:38:00.000** | -76.33 | 13.14 | 17.06 | 13 |
| **2018-11-08 17:48:00.000** | -90.61 | 13.7 | 17.06 | 13 |
| **2018-11-08 17:58:00.000** | -88.05 | 13.7 | 17.06 | 13 |
| **2018-11-08 18:08:00.000** | -75.57 | 13.14 | 17.06 | 13 |
| **2018-11-08 18:18:00.000** | -75.32 | 13.14 | 17.06 | 13 |
| **2018-11-08 18:28:00.000** | -100 | 13.7 | 17.62 | 13 |
| **2018-11-08 18:38:00.000** | -100 | 13.7 | 17.62 | 13 |
| **2018-11-08 18:48:00.000** | -100 | 13.7 | 17.06 | 13 |
| **2018-11-08 18:58:00.000** | -100 | 14.26 | 17.62 | 13 |
| **2018-11-08 19:08:00.000** | -100 | 14.26 | 18.18 | 13 |
| **2018-11-08 19:18:00.000** | -100 | 14.26 | 17.62 | 13 |
| **2018-11-08 19:28:00.000** | -100 | 13.7 | 17.62 | 13 |
| **2018-11-08 19:38:00.000** | -99.88 | 14.26 | 18.18 | 13 |
| **2018-11-08 19:48:00.000** | -100 | 14.26 | 18.18 | 13 |
| **2018-11-08 19:58:00.000** | -100 | 14.26 | 18.18 | 13 |
| **2018-11-08 20:08:00.000** | -93.27 | 14.26 | 18.18 | 13 |
| **2018-11-08 20:18:00.000** | -86.84 | 13.7 | 18.18 | 13 |
| **2018-11-08 20:28:00.000** | -80.77 | 13.7 | 18.18 | 13 |
| **2018-11-08 20:38:00.000** | -72.27 | 13.7 | 18.18 | 13 |
| **2018-11-08 20:48:00.000** | -71.63 | 13.7 | 18.18 | 13 |
| **2018-11-08 20:58:00.000** | -66.34 | 13.7 | 18.18 | 13 |
| **2018-11-08 21:08:00.000** | -23.36 | 12.58 | 17.62 | 13 |
| **2018-11-08 21:18:00.000** | -19.36 | 12.58 | 17.06 | 13 |
| **2018-11-08 21:28:00.000** | -24.85 | 12.58 | 17.06 | 13 |
| **2018-11-08 21:38:00.000** | -33.94 | 12.58 | 17.06 | 13 |
| **2018-11-08 21:48:00.000** | -39.89 | 12.58 | 17.06 | 13 |
| **2018-11-08 21:58:00.000** | -44.75 | 12.58 | 17.06 | 13 |
| **2018-11-08 22:08:00.000** | -76.55 | 13.14 | 17.06 | 13 |
| **2018-11-08 22:18:00.000** | -95.49 | 13.7 | 17.06 | 13 |

## Appendix 5: Laminator 2 valve output, inlet, outlet, pre-set temperatures Data Set 2 Recorded on 7-11-2018

| Time | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-07 13:28:00.000** | -75.89 | 12.47 | 14.82 | 12 |
| **2018-11-07 13:38:00.000** | -70.89 | 11.91 | 14.82 | 12 |
| **2018-11-07 13:48:00.000** | -100 | 12.47 | 14.82 | 12 |
| **2018-11-07 13:58:00.000** | -100 | 12.47 | 14.26 | 12 |
| **2018-11-07 14:08:00.000** | -56.67 | 11.91 | 14.26 | 12 |
| **2018-11-07 14:18:00.000** | -45.97 | 11.91 | 14.82 | 12 |
| **2018-11-07 14:28:00.000** | -100 | 13.03 | 14.82 | 12 |
| **2018-11-07 14:38:00.000** | -92.46 | 12.47 | 14.26 | 12 |
| **2018-11-07 14:48:00.000** | -31.82 | 11.35 | 14.82 | 12 |
| **2018-11-07 14:58:00.000** | -88.41 | 13.03 | 14.82 | 12 |
| **2018-11-07 15:08:00.000** | -100 | 13.03 | 14.82 | 12 |
| **2018-11-07 15:18:00.000** | -92.14 | 12.47 | 14.26 | 12 |
| **2018-11-07 15:28:00.000** | -81.5 | 13.03 | 14.82 | 13 |
| **2018-11-07 15:38:00.000** | -11.52 | 11.91 | 15.38 | 13 |
| **2018-11-07 15:48:00.000** | -82.32 | 13.59 | 15.38 | 13 |
| **2018-11-07 15:58:00.000** | -81.09 | 13.03 | 15.38 | 13 |
| **2018-11-07 16:08:00.000** | -5.23 | 11.91 | 14.82 | 13 |
| **2018-11-07 16:18:00.000** | -83.72 | 13.59 | 15.38 | 13 |
| **2018-11-07 16:28:00.000** | -59.54 | 12.47 | 14.82 | 13 |
| **2018-11-07 20:08:00.000** | -99.31 | 16.16 | 18.29 | 13 |
| **2018-11-07 20:18:00.000** | -99.31 | 16.72 | 18.85 | 13 |
| **2018-11-07 20:28:00.000** | -99.31 | 16.16 | 18.29 | 13 |
| **2018-11-07 20:38:00.000** | -99.31 | 15.6 | 17.73 | 13 |
| **2018-11-07 20:48:00.000** | -99.31 | 15.04 | 17.17 | 13 |
| **2018-11-07 20:58:00.000** | -100 | 14.49 | 16.61 | 13 |
| **2018-11-07 21:08:00.000** | -100 | 13.93 | 16.05 | 13 |
| **2018-11-07 21:18:00.000** | -100 | 13.37 | 15.49 | 13 |
| **2018-11-07 21:28:00.000** | -100 | 13.37 | 15.49 | 13 |
| **2018-11-07 21:38:00.000** | -97.36 | 12.81 | 15.49 | 13 |
| **2018-11-07 21:48:00.000** | -100 | 13.37 | 15.49 | 13 |
| **2018-11-07 21:58:00.000** | -86.64 | 12.81 | 15.49 | 13 |
| **2018-11-07 22:08:00.000** | -97.13 | 13.37 | 15.49 | 13 |
| **2018-11-07 22:18:00.000** | -63.37 | 12.81 | 15.49 | 13 |
| **2018-11-07 22:28:00.000** | -93.42 | 13.37 | 15.49 | 13 |
| **2018-11-07 22:38:00.000** | -99.56 | 13.93 | 16.05 | 13 |
| **2018-11-07 22:48:00.000** | -96.65 | 13.37 | 16.05 | 13 |
| **2018-11-07 22:58:00.000** | -64.8 | 12.81 | 15.49 | 13 |
| **2018-11-07 23:08:00.000** | -100 | 13.93 | 15.49 | 13 |

| Time | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-07 23:18:00.000** | -99.96 | 13.37 | 15.49 | 13 |
| **2018-11-07 23:28:00.000** | -99.96 | 13.93 | 16.05 | 13 |
| **2018-11-07 23:38:00.000** | -90.67 | 13.37 | 15.49 | 13 |
| **2018-11-07 23:48:00.000** | -100 | 13.37 | 15.49 | 13 |
| **2018-11-07 23:58:00.000** | -100 | 14.49 | 16.61 | 13 |
| **2018-11-08 00:08:00.000** | -100 | 13.93 | 16.61 | 13 |
| **2018-11-08 00:18:00.000** | -100 | 13.37 | 15.49 | 13 |
| **2018-11-08 00:28:00.000** | -100 | 14.49 | 16.61 | 13 |
| **2018-11-08 00:38:00.000** | -100 | 13.93 | 16.61 | 13 |
| **2018-11-08 00:48:00.000** | -89.76 | 13.37 | 15.49 | 13 |
| **2018-11-08 00:58:00.000** | -61.89 | 12.81 | 15.49 | 13 |
| **2018-11-08 01:08:00.000** | -42.62 | 12.81 | 15.49 | 13 |
| **2018-11-08 01:18:00.000** | -99.78 | 13.93 | 15.49 | 13 |
| **2018-11-08 01:28:00.000** | -18.88 | 11.69 | 14.37 | 13 |
| **2018-11-08 01:38:00.000** | -100 | 13.93 | 14.93 | 13 |
| **2018-11-08 01:48:00.000** | -56.86 | 12.81 | 15.49 | 13 |
| **2018-11-08 01:58:00.000** | -95.39 | 13.93 | 15.49 | 13 |
| **2018-11-08 02:08:00.000** | -52.77 | 12.81 | 14.93 | 13 |
| **2018-11-08 02:18:00.000** | -90.69 | 13.93 | 15.49 | 13 |
| **2018-11-08 02:28:00.000** | -5 | 11.69 | 14.93 | 13 |
| **2018-11-08 02:38:00.000** | -91.81 | 13.37 | 14.93 | 13 |
| **2018-11-08 03:18:00.000** | -5 | 11.69 | 15.49 | 13 |
| **2018-11-08 03:28:00.000** | -67.93 | 13.37 | 14.93 | 13 |
| **2018-11-08 03:38:00.000** | -89.93 | 13.37 | 14.93 | 13 |
| **2018-11-08 03:48:00.000** | -74.68 | 13.37 | 14.93 | 13 |
| **2018-11-08 03:58:00.000** | -64.7 | 13.37 | 15.49 | 13 |
| **2018-11-08 04:08:00.000** | -90.97 | 13.37 | 14.93 | 13 |
| **2018-11-08 04:18:00.000** | -5 | 11.69 | 14.93 | 13 |
| **2018-11-08 04:28:00.000** | -98.87 | 13.37 | 14.93 | 13 |
| **2018-11-08 04:38:00.000** | -69.8 | 13.37 | 14.93 | 13 |
| **2018-11-08 04:48:00.000** | -53.2 | 12.81 | 15.49 | 13 |
| **2018-11-08 04:58:00.000** | -81.73 | 13.37 | 14.93 | 13 |
| **2018-11-08 05:08:00.000** | -72.43 | 13.37 | 14.93 | 13 |
| **2018-11-08 05:18:00.000** | -100 | 13.37 | 15.49 | 13 |
| **2018-11-08 05:28:00.000** | -100 | 13.93 | 15.49 | 13 |
| **2018-11-08 05:38:00.000** | -57.94 | 12.81 | 15.49 | 13 |
| **2018-11-08 05:48:00.000** | -5 | 11.69 | 15.49 | 13 |
| **2018-11-08 05:58:00.000** | -71.18 | 13.37 | 14.93 | 13 |
| **2018-11-08 06:08:00.000** | -78.78 | 13.37 | 14.93 | 13 |
| **2018-11-08 06:18:00.000** | -7.1 | 11.69 | 14.93 | 13 |
| **2018-11-08 06:28:00.000** | -23.91 | 12.25 | 15.49 | 13 |
| **2018-11-08 06:38:00.000** | -54.9 | 12.81 | 14.93 | 13 |

| Time | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-08 06:48:00.000** | -5 | 11.69 | 15.49 | 13 |
| **2018-11-08 06:58:00.000** | -65.63 | 13.37 | 14.93 | 13 |
| **2018-11-08 07:08:00.000** | -99.4 | 14.49 | 16.61 | 14 |
| **2018-11-08 07:18:00.000** | -46.82 | 13.37 | 14.93 | 14 |
| **2018-11-08 07:28:00.000** | -64.96 | 13.93 | 16.05 | 14 |
| **2018-11-08 07:38:00.000** | -39.59 | 14.49 | 16.05 | 15 |
| **2018-11-08 07:48:00.000** | -13.74 | 14.49 | 16.05 | 15 |
| **2018-11-08 07:58:00.000** | -21.34 | 14.49 | 16.05 | 15 |
| **2018-11-08 08:08:00.000** | -8.42 | 14.49 | 16.05 | 15 |
| **2018-11-08 08:18:00.000** | -58.07 | 15.04 | 16.05 | 15 |
| **2018-11-08 08:28:00.000** | -32.92 | 14.93 | 16.05 | 16 |
| **2018-11-08 08:38:00.000** | -5 | 12.14 | 17.73 | 16 |
| **2018-11-08 08:48:00.000** | -100 | 16.5 | 17.73 | 16 |
| **2018-11-08 08:58:00.000** | -54.63 | 15.83 | 17.17 | 16 |
| **2018-11-08 09:08:00.000** | -5 | 15.27 | 17.73 | 16 |
| **2018-11-08 09:18:00.000** | -5 | 14.71 | 16.61 | 16 |
| **2018-11-08 09:28:00.000** | -5 | 13.48 | 18.29 | 16 |
| **2018-11-08 09:38:00.000** | -82.02 | 16.61 | 18.29 | 16 |
| **2018-11-08 09:48:00.000** | -73.71 | 15.83 | 17.73 | 16 |
| **2018-11-08 09:58:00.000** | -36.32 | 15.6 | 17.73 | 16 |
| **2018-11-08 10:08:00.000** | -36.59 | 15.04 | 17.73 | 16 |
| **2018-11-08 10:18:00.000** | -100 | 16.61 | 18.29 | 16 |
| **2018-11-08 10:28:00.000** | -87.05 | 16.61 | 18.29 | 16 |
| **2018-11-08 10:38:00.000** | -92.42 | 16.72 | 18.29 | 16 |
| **2018-11-08 10:48:00.000** | -84.76 | 16.39 | 18.29 | 16 |
| **2018-11-08 10:58:00.000** | -5 | 12.36 | 16.05 | 14 |
| **2018-11-08 11:08:00.000** | -75.55 | 14.04 | 15.49 | 14 |
| **2018-11-08 11:18:00.000** | -82.32 | 14.04 | 15.49 | 14 |
| **2018-11-08 11:28:00.000** | -75.9 | 14.6 | 16.61 | 14 |
| **2018-11-08 11:38:00.000** | -5 | 11.8 | 14.93 | 13 |
| **2018-11-08 11:48:00.000** | -100 | 13.48 | 14.93 | 13 |
| **2018-11-08 11:58:00.000** | -6.4 | 12.36 | 16.05 | 13 |
| **2018-11-08 12:08:00.000** | -5 | 11.8 | 15.49 | 13 |
| **2018-11-08 12:18:00.000** | -6.11 | 11.8 | 14.93 | 13 |
| **2018-11-08 12:28:00.000** | -100 | 14.04 | 15.49 | 13 |
| **2018-11-08 12:38:00.000** | -74.17 | 13.48 | 15.49 | 13 |
| **2018-11-08 12:48:00.000** | -5 | 11.8 | 14.93 | 13 |
| **2018-11-08 12:58:00.000** | -100 | 13.48 | 14.93 | 13 |
| **2018-11-08 13:08:00.000** | -92.83 | 14.6 | 16.05 | 14 |
| **2018-11-08 13:18:00.000** | -33.05 | 13.48 | 15.49 | 14 |
| **2018-11-08 13:28:00.000** | -100 | 15.16 | 16.61 | 14 |
| **2018-11-08 13:38:00.000** | -5.79 | 11.8 | 16.05 | 14 |

| Time | Lam2: Cooling Water Controller Output | Lam2: Inlet Cooling Water Temperature | Lam2: Outlet Cooling Water Temperature | Lam2: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-08 13:48:00.000** | -70.42 | 14.04 | 15.49 | 14 |
| **2018-11-08 13:58:00.000** | -67.48 | 14.04 | 15.49 | 14 |
| **2018-11-08 14:08:00.000** | -100 | 15.04 | 16.05 | 14 |
| **2018-11-08 14:18:00.000** | -5 | 13.37 | 16.61 | 14 |
| **2018-11-08 15:48:00.000** | -60.02 | 14.71 | 16.61 | 14 |
| **2018-11-08 15:58:00.000** | -99.58 | 15.27 | 17.17 | 14 |
| **2018-11-08 16:08:00.000** | -5 | 12.47 | 14.93 | 14 |
| **2018-11-08 16:18:00.000** | -36.94 | 13.59 | 16.05 | 14 |
| **2018-11-08 16:28:00.000** | -100 | 15.27 | 16.61 | 14 |
| **2018-11-08 16:38:00.000** | -5 | 11.91 | 16.05 | 14 |
| **2018-11-08 16:48:00.000** | -82.75 | 14.15 | 15.49 | 14 |
| **2018-11-08 16:58:00.000** | -100 | 14.71 | 16.05 | 14 |
| **2018-11-08 17:08:00.000** | -5 | 12.36 | 16.61 | 14 |
| **2018-11-08 17:18:00.000** | -64.66 | 14.04 | 15.49 | 14 |
| **2018-11-08 17:28:00.000** | -97.74 | 14.6 | 16.05 | 14 |
| **2018-11-08 17:38:00.000** | -5 | 12.36 | 16.61 | 14 |
| **2018-11-08 17:48:00.000** | -70.85 | 14.04 | 15.49 | 14 |
| **2018-11-08 17:58:00.000** | -100 | 15.16 | 16.05 | 14 |
| **2018-11-08 18:08:00.000** | -5 | 11.8 | 16.05 | 14 |
| **2018-11-08 18:18:00.000** | -47.89 | 14.04 | 15.49 | 14 |
| **2018-11-08 18:28:00.000** | -100 | 15.16 | 16.61 | 14 |
| **2018-11-08 18:38:00.000** | -5 | 11.8 | 16.61 | 14 |
| **2018-11-08 18:48:00.000** | -82.14 | 14.04 | 15.49 | 14 |
| **2018-11-08 18:58:00.000** | -53.28 | 14.04 | 16.05 | 14 |
| **2018-11-08 19:08:00.000** | -99.61 | 15.16 | 16.61 | 14 |
| **2018-11-08 19:18:00.000** | -5 | 12.36 | 15.49 | 14 |
| **2018-11-08 19:28:00.000** | -50.28 | 14.04 | 16.05 | 14 |
| **2018-11-08 19:38:00.000** | -91.95 | 15.16 | 16.61 | 14 |
| **2018-11-08 19:48:00.000** | -5 | 11.8 | 15.49 | 14 |
| **2018-11-08 19:58:00.000** | -71.13 | 14.6 | 15.49 | 14 |
| **2018-11-08 20:08:00.000** | -100 | 14.6 | 16.05 | 14 |
| **2018-11-08 20:18:00.000** | -59.68 | 14.04 | 16.61 | 14 |
| **2018-11-08 20:28:00.000** | -5 | 11.24 | 14.93 | 14 |
| **2018-11-08 20:38:00.000** | -85.69 | 14.6 | 15.49 | 14 |
| **2018-11-08 20:48:00.000** | -54.15 | 14.04 | 16.05 | 14 |
| **2018-11-08 20:58:00.000** | -100 | 15.16 | 16.61 | 14 |
| **2018-11-08 21:08:00.000** | -5 | 11.8 | 14.93 | 14 |
| **2018-11-08 21:18:00.000** | -76.65 | 14.6 | 16.05 | 14 |
| **2018-11-08 21:28:00.000** | -43.18 | 13.37 | 15.49 | 14 |
| **2018-11-08 21:38:00.000** | -98.29 | 15.04 | 16.61 | 14 |
| **2018-11-08 21:48:00.000** | -5.64 | 12.81 | 16.61 | 14 |
| **2018-11-08 21:58:00.000** | -77.34 | 13.93 | 14.93 | 14 |

## Appendix 6: Laminator 3 valve output, inlet, outlet, pre-set temperatures Data Set 2

| Time | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-07 13:28:00.000** | -78.83 | 17.73 | 21.2 | 17 |
| **2018-11-07 13:38:00.000** | -67.66 | 17.17 | 19.52 | 17 |
| **2018-11-07 13:48:00.000** | 0 | 14.26 | 17.84 | 17 |
| **2018-11-07 13:58:00.000** | 0 | 13.14 | 18.4 | 17 |
| **2018-11-07 14:08:00.000** | 0 | 15.38 | 21.2 | 17 |
| **2018-11-07 14:18:00.000** | -100 | 18.18 | 22.32 | 17 |
| **2018-11-07 14:28:00.000** | -100 | 19.3 | 22.32 | 17 |
| **2018-11-07 14:38:00.000** | -100 | 18.18 | 20.64 | 17 |
| **2018-11-07 14:48:00.000** | -8.3 | 16.5 | 20.64 | 17 |
| **2018-11-07 14:58:00.000** | -78.32 | 17.62 | 20.08 | 17 |
| **2018-11-07 15:08:00.000** | 0 | 13.7 | 17.84 | 17 |
| **2018-11-07 15:18:00.000** | 0 | 13.7 | 19.52 | 17 |
| **2018-11-07 15:28:00.000** | -44.53 | 17.17 | 22.32 | 17 |
| **2018-11-07 15:38:00.000** | -100 | 18.85 | 22.32 | 17 |
| **2018-11-07 15:48:00.000** | -61.94 | 17.06 | 20.64 | 17 |
| **2018-11-07 15:58:00.000** | -40.8 | 17.06 | 20.64 | 17 |
| **2018-11-07 16:08:00.000** | 0 | 12.58 | 17.84 | 17 |
| **2018-11-07 16:18:00.000** | 0 | 15.94 | 21.2 | 17 |
| **2018-11-07 16:28:00.000** | -100 | 18.74 | 22.32 | 17 |
| **2018-11-07 20:08:00.000** | -100 | 18.4 | 22.76 | 17 |
| **2018-11-07 20:18:00.000** | -75.99 | 17.28 | 21.65 | 17 |
| **2018-11-07 20:28:00.000** | -83.86 | 17.28 | 20.53 | 17 |
| **2018-11-07 20:38:00.000** | -98.69 | 17.84 | 20.53 | 17 |
| **2018-11-07 20:48:00.000** | -97.66 | 17.84 | 20.53 | 17 |
| **2018-11-07 20:58:00.000** | -76.59 | 17.28 | 19.97 | 17 |
| **2018-11-07 21:08:00.000** | -42.93 | 16.72 | 19.41 | 17 |
| **2018-11-07 21:18:00.000** | 0 | 15.04 | 19.41 | 17 |
| **2018-11-07 21:28:00.000** | 0 | 15.6 | 19.97 | 17 |
| **2018-11-07 21:38:00.000** | 0 | 14.49 | 18.85 | 17 |
| **2018-11-07 21:48:00.000** | -79.77 | 17.28 | 21.09 | 17 |
| **2018-11-07 21:58:00.000** | -100 | 18.96 | 22.21 | 17 |
| **2018-11-07 22:08:00.000** | 0 | 14.49 | 18.85 | 17 |
| **2018-11-07 22:18:00.000** | -77.77 | 17.28 | 21.09 | 17 |
| **2018-11-07 22:28:00.000** | -49.3 | 16.72 | 21.65 | 17 |
| **2018-11-07 22:38:00.000** | -79.16 | 17.28 | 21.65 | 17 |
| **2018-11-07 22:48:00.000** | -76.93 | 17.84 | 21.65 | 17 |
| **2018-11-07 22:58:00.000** | -84.51 | 17.28 | 21.09 | 17 |
| **2018-11-07 23:08:00.000** | -90.37 | 17.28 | 19.97 | 17 |
| **2018-11-07 23:18:00.000** | -93.98 | 17.28 | 20.53 | 17 |
| **2018-11-07 23:28:00.000** | 0 | 15.6 | 20.53 | 17 |
| **2018-11-07 23:38:00.000** | -7.77 | 16.16 | 21.09 | 17 |

| Time | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-07 23:48:00.000** | -15.05 | 16.16 | 21.09 | 17 |
| **2018-11-07 23:58:00.000** | -56.07 | 17.28 | 21.65 | 17 |
| **2018-11-08 00:08:00.000** | -69.14 | 17.28 | 21.65 | 17 |
| **2018-11-08 00:18:00.000** | -78.13 | 17.84 | 21.65 | 17 |
| **2018-11-08 00:28:00.000** | -93.56 | 17.84 | 21.65 | 17 |
| **2018-11-08 00:38:00.000** | -99.34 | 18.4 | 21.65 | 17 |
| **2018-11-08 00:48:00.000** | -98.92 | 17.84 | 21.65 | 17 |
| **2018-11-08 00:58:00.000** | -100 | 18.4 | 22.21 | 17 |
| **2018-11-08 01:08:00.000** | -81.98 | 17.28 | 19.41 | 17 |
| **2018-11-08 01:18:00.000** | -71.37 | 17.28 | 20.53 | 17 |
| **2018-11-08 01:28:00.000** | -73.31 | 17.28 | 20.53 | 17 |
| **2018-11-08 01:38:00.000** | 0 | 13.37 | 17.73 | 17 |
| **2018-11-08 01:48:00.000** | 0 | 13.93 | 19.41 | 17 |
| **2018-11-08 01:58:00.000** | 0 | 15.6 | 21.09 | 17 |
| **2018-11-08 02:08:00.000** | -63.44 | 17.28 | 22.21 | 17 |
| **2018-11-08 02:18:00.000** | -100 | 18.96 | 22.21 | 17 |
| **2018-11-08 02:28:00.000** | -100 | 18.4 | 21.09 | 17 |
| **2018-11-08 02:38:00.000** | -8.74 | 16.72 | 20.53 | 17 |
| **2018-11-08 03:18:00.000** | 0 | 16.61 | 22.21 | 17 |
| **2018-11-08 03:28:00.000** | -100 | 17.73 | 20.53 | 17 |
| **2018-11-08 03:38:00.000** | -99.88 | 18.85 | 22.21 | 17 |
| **2018-11-08 03:48:00.000** | -100 | 19.41 | 22.21 | 17 |
| **2018-11-08 03:58:00.000** | -70.46 | 17.28 | 20.41 | 17 |
| **2018-11-08 04:08:00.000** | -20.64 | 16.72 | 20.41 | 17 |
| **2018-11-08 04:18:00.000** | -69.33 | 17.28 | 20.41 | 17 |
| **2018-11-08 04:28:00.000** | 0 | 15.04 | 17.62 | 17 |
| **2018-11-08 04:38:00.000** | 0 | 13.93 | 19.86 | 17 |
| **2018-11-08 04:48:00.000** | -100 | 18.96 | 22.09 | 17 |
| **2018-11-08 04:58:00.000** | -100 | 18.29 | 20.97 | 17 |
| **2018-11-08 05:08:00.000** | -25.4 | 16.28 | 20.3 | 17 |
| **2018-11-08 05:18:00.000** | -56.73 | 17.39 | 20.86 | 17 |
| **2018-11-08 05:28:00.000** | 0 | 15.16 | 18.07 | 17 |
| **2018-11-08 05:38:00.000** | 0 | 12.92 | 18.62 | 17 |
| **2018-11-08 05:48:00.000** | -57.96 | 17.39 | 21.98 | 17 |
| **2018-11-08 05:58:00.000** | -100 | 19.07 | 22.54 | 17 |
| **2018-11-08 06:08:00.000** | -100 | 17.95 | 20.86 | 17 |
| **2018-11-08 06:18:00.000** | -18.45 | 16.72 | 20.3 | 17 |
| **2018-11-08 06:28:00.000** | -39.36 | 17.28 | 20.3 | 17 |
| **2018-11-08 06:38:00.000** | 0 | 14.93 | 17.51 | 17 |
| **2018-11-08 06:48:00.000** | -0.59 | 13.7 | 19.18 | 17 |
| **2018-11-08 06:58:00.000** | -100 | 18.18 | 22.54 | 17 |
| **2018-11-08 07:08:00.000** | -100 | 18.85 | 22.09 | 17 |

| Time | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-08 07:18:00.000** | -77.15 | 17.62 | 20.41 | 17 |
| **2018-11-08 07:28:00.000** | 0 | 15.94 | 19.86 | 17 |
| **2018-11-08 07:38:00.000** | -16.63 | 16.05 | 18.18 | 17 |
| **2018-11-08 07:48:00.000** | 0 | 14.26 | 20.41 | 17 |
| **2018-11-08 07:58:00.000** | -99.05 | 18.74 | 22.65 | 17 |
| **2018-11-08 08:08:00.000** | -99.29 | 18.07 | 20.97 | 17 |
| **2018-11-08 08:18:00.000** | -7.15 | 16.72 | 20.41 | 17 |
| **2018-11-08 08:28:00.000** | 0 | 14.93 | 17.62 | 17 |
| **2018-11-08 08:38:00.000** | 0 | 14.82 | 20.97 | 17 |
| **2018-11-08 08:48:00.000** | -100 | 19.3 | 22.65 | 17 |
| **2018-11-08 08:58:00.000** | -100 | 18.07 | 20.97 | 17 |
| **2018-11-08 09:08:00.000** | -25.48 | 16.95 | 20.97 | 17 |
| **2018-11-08 09:18:00.000** | -13.62 | 16.28 | 18.18 | 17 |
| **2018-11-08 09:28:00.000** | 0 | 13.37 | 19.3 | 17 |
| **2018-11-08 09:38:00.000** | -86.84 | 17.84 | 22.09 | 17 |
| **2018-11-08 09:48:00.000** | -100 | 18.96 | 22.09 | 17 |
| **2018-11-08 09:58:00.000** | -28.11 | 16.72 | 20.41 | 17 |
| **2018-11-08 10:08:00.000** | -71.31 | 17.73 | 20.41 | 17 |
| **2018-11-08 10:18:00.000** | 0 | 13.59 | 17.62 | 17 |
| **2018-11-08 10:28:00.000** | -9.59 | 16.83 | 22.09 | 17 |
| **2018-11-08 10:38:00.000** | -100 | 19.18 | 22.65 | 17 |
| **2018-11-08 10:48:00.000** | -80.8 | 17.39 | 20.41 | 17 |
| **2018-11-08 10:58:00.000** | -41.1 | 17.39 | 20.41 | 17 |
| **2018-11-08 11:08:00.000** | 0 | 13.93 | 17.62 | 17 |
| **2018-11-08 11:18:00.000** | 0 | 14.49 | 20.41 | 17 |
| **2018-11-08 11:28:00.000** | -100 | 19.07 | 22.65 | 17 |
| **2018-11-08 11:38:00.000** | -100 | 18.51 | 21.53 | 17 |
| **2018-11-08 11:48:00.000** | 0 | 16.28 | 20.41 | 18 |
| **2018-11-08 11:58:00.000** | -62.08 | 17.95 | 20.41 | 18 |
| **2018-11-08 12:08:00.000** | 0 | 13.81 | 19.3 | 18 |
| **2018-11-08 12:18:00.000** | -100 | 19.86 | 23.21 | 18 |
| **2018-11-08 12:28:00.000** | -56.11 | 18.18 | 20.97 | 18 |
| **2018-11-08 12:38:00.000** | -30.86 | 18.18 | 21.53 | 18 |
| **2018-11-08 12:48:00.000** | -0.07 | 13.48 | 19.3 | 18 |
| **2018-11-08 12:58:00.000** | -100 | 19.63 | 23.21 | 18 |
| **2018-11-08 13:08:00.000** | -37.68 | 17.39 | 20.97 | 18 |
| **2018-11-08 13:18:00.000** | -70.52 | 18.29 | 20.41 | 18 |
| **2018-11-08 13:28:00.000** | 0 | 15.6 | 21.53 | 18 |
| **2018-11-08 13:38:00.000** | -100 | 19.97 | 23.21 | 18 |
| **2018-11-08 13:48:00.000** | -0.53 | 17.06 | 20.97 | 18 |
| **2018-11-08 13:58:00.000** | -0.17 | 15.04 | 18.18 | 18 |
| **2018-11-08 14:08:00.000** | 0 | 16.72 | 22.09 | 18 |

| Time | Lam3: Cooling Water Controller Output | Lam3: Inlet Cooling Water Temperature | Lam3: Outlet Cooling Water Temperature | Lam3: Cooling Water Temperature Set point |
|---|---|---|---|---|
| **2018-11-08 14:18:00.000** | -100 | 19.74 | 23.21 | 18 |
| **2018-11-08 15:48:00.000** | 0 | 16.5 | 20.97 | 18 |
| **2018-11-08 15:58:00.000** | 0 | 14.82 | 19.86 | 18 |
| **2018-11-08 16:08:00.000** | -14.84 | 17.62 | 22.65 | 18 |
| **2018-11-08 16:18:00.000** | -100 | 19.52 | 22.65 | 18 |
| **2018-11-08 16:28:00.000** | -11.31 | 17.51 | 21.53 | 18 |
| **2018-11-08 16:38:00.000** | 0 | 13.03 | 18.18 | 18 |
| **2018-11-08 16:48:00.000** | -100 | 19.63 | 23.21 | 18 |
| **2018-11-08 16:58:00.000** | -49.98 | 17.84 | 20.97 | 18 |
| **2018-11-08 17:08:00.000** | -52.03 | 17.73 | 19.86 | 18 |
| **2018-11-08 17:18:00.000** | 0 | 15.38 | 21.53 | 18 |
| **2018-11-08 17:28:00.000** | -100 | 19.86 | 23.21 | 18 |
| **2018-11-08 17:38:00.000** | 0 | 16.95 | 20.97 | 18 |
| **2018-11-08 17:48:00.000** | 0 | 15.27 | 18.18 | 18 |
| **2018-11-08 17:58:00.000** | -19.85 | 17.51 | 22.65 | 18 |
| **2018-11-08 18:08:00.000** | -100 | 20.19 | 23.21 | 18 |
| **2018-11-08 18:18:00.000** | -1.09 | 17.28 | 20.97 | 18 |
| **2018-11-08 18:28:00.000** | 0 | 16.39 | 18.74 | 18 |
| **2018-11-08 18:38:00.000** | -48.68 | 18.07 | 23.21 | 18 |
| **2018-11-08 18:48:00.000** | -100 | 19.97 | 22.65 | 18 |
| **2018-11-08 18:58:00.000** | 0 | 17.17 | 20.97 | 18 |
| **2018-11-08 19:08:00.000** | -0.58 | 13.14 | 18.74 | 18 |
| **2018-11-08 19:18:00.000** | -100 | 19.3 | 23.21 | 18 |
| **2018-11-08 19:28:00.000** | -68.44 | 18.29 | 20.97 | 18 |
| **2018-11-08 19:38:00.000** | -56.17 | 18.18 | 21.53 | 18 |
| **2018-11-08 19:48:00.000** | 0 | 13.81 | 19.86 | 18 |
| **2018-11-08 19:58:00.000** | -100 | 19.41 | 23.21 | 18 |
| **2018-11-08 20:08:00.000** | -29.56 | 17.39 | 20.97 | 18 |
| **2018-11-08 20:18:00.000** | -44.06 | 17.73 | 19.86 | 18 |
| **2018-11-08 20:28:00.000** | 0 | 14.71 | 20.97 | 18 |
| **2018-11-08 20:38:00.000** | -100 | 19.52 | 23.21 | 18 |
| **2018-11-08 20:48:00.000** | 0 | 17.06 | 20.97 | 18 |
| **2018-11-08 20:58:00.000** | -53.93 | 18.07 | 20.41 | 18 |
| **2018-11-08 21:08:00.000** | 0 | 14.6 | 20.97 | 18 |
| **2018-11-08 21:18:00.000** | -100 | 19.52 | 22.65 | 18 |
| **2018-11-08 21:28:00.000** | -10.56 | 17.17 | 20.41 | 18 |
| **2018-11-08 21:38:00.000** | -59.46 | 17.73 | 20.97 | 18 |
| **2018-11-08 21:48:00.000** | 0 | 13.14 | 18.74 | 18 |
| **2018-11-08 21:58:00.000** | -100 | 19.18 | 23.21 | 18 |
| **2018-11-08 22:08:00.000** | -33.15 | 17.28 | 20.97 | 18 |
| **2018-11-08 22:18:00.000** | -33 | 17.17 | 19.3 | 18 |
| **2018-11-08 22:28:00.000** | 0 | 16.95 | 22.65 | 18 |

## Appendix 7: Pump 4 flow rate data taken on 14-11-2018

| S No | Time | Volume flow m3/h |
|---|---|---|
| 1 | 11/14/2018 3:10:38 PM | 159.9480438 |
| 2 | 11/14/2018 3:10:40 PM | 159.7518768 |
| 3 | 11/14/2018 3:10:42 PM | 159.8665314 |
| 4 | 11/14/2018 3:10:43 PM | 159.8594208 |
| 5 | 11/14/2018 3:10:45 PM | 159.8250885 |
| 6 | 11/14/2018 3:10:46 PM | 160.0129852 |
| 7 | 11/14/2018 3:10:48 PM | 159.7520294 |
| 8 | 11/14/2018 3:10:50 PM | 159.8523407 |
| 9 | 11/14/2018 3:10:51 PM | 159.6895905 |
| 10 | 11/14/2018 3:10:53 PM | 159.4240723 |
| 11 | 11/14/2018 3:10:55 PM | 159.2795715 |
| 12 | 11/14/2018 3:10:56 PM | 159.4796143 |
| 13 | 11/14/2018 3:10:58 PM | 159.5439911 |
| 14 | 11/14/2018 3:11:00 PM | 159.5990753 |
| 15 | 11/14/2018 3:11:01 PM | 159.3211823 |
| 16 | 11/14/2018 3:11:03 PM | 159.2720184 |
| 17 | 11/14/2018 3:11:04 PM | 159.464035 |
| 18 | 11/14/2018 3:11:06 PM | 159.3304596 |
| 19 | 11/14/2018 3:11:08 PM | 159.3892212 |
| 20 | 11/14/2018 3:11:09 PM | 159.3721313 |
| 21 | 11/14/2018 3:11:11 PM | 159.33284 |
| 22 | 11/14/2018 3:11:13 PM | 159.5538788 |
| 23 | 11/14/2018 3:11:14 PM | 159.6352081 |
| 24 | 11/14/2018 3:11:16 PM | 159.5706024 |
| 25 | 11/14/2018 3:11:17 PM | 159.3668976 |
| 26 | 11/14/2018 3:11:19 PM | 159.5474701 |
| 27 | 11/14/2018 3:11:21 PM | 159.5579071 |
| 28 | 11/14/2018 3:11:22 PM | 159.5413666 |
| 29 | 11/14/2018 3:11:24 PM | 159.4491425 |
| 30 | 11/14/2018 3:11:26 PM | 159.4727631 |
| 31 | 11/14/2018 3:11:27 PM | 159.5398712 |
| 32 | 11/14/2018 3:11:29 PM | 159.5361938 |
| 33 | 11/14/2018 3:11:30 PM | 159.4443665 |
| 34 | 11/14/2018 3:11:32 PM | 159.5974884 |
| 35 | 11/14/2018 3:11:34 PM | 159.7953644 |
| 36 | 11/14/2018 3:11:35 PM | 159.8037262 |
| 37 | 11/14/2018 3:11:37 PM | 159.8432007 |
| 38 | 11/14/2018 3:11:39 PM | 159.953476 |
| 39 | 11/14/2018 3:11:40 PM | 160.8151703 |
| 40 | 11/14/2018 3:11:42 PM | 160.8936768 |
| 41 | 11/14/2018 3:11:43 PM | 160.9131622 |
| 42 | 11/14/2018 3:11:45 PM | 160.9676971 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 43 | 11/14/2018 3:11:47 PM | 160.8438873 |
| 44 | 11/14/2018 3:11:48 PM | 161.3727875 |
| 45 | 11/14/2018 3:11:50 PM | 161.3727875 |
| 46 | 11/14/2018 3:11:52 PM | 161.3749847 |
| 47 | 11/14/2018 3:11:53 PM | 161.2486115 |
| 48 | 11/14/2018 3:11:55 PM | 161.110733 |
| 49 | 11/14/2018 3:11:56 PM | 160.9226837 |
| 50 | 11/14/2018 3:11:58 PM | 160.8187103 |
| 51 | 11/14/2018 3:12:00 PM | 160.9132233 |
| 52 | 11/14/2018 3:12:01 PM | 160.9448395 |
| 53 | 11/14/2018 3:12:03 PM | 160.9141998 |
| 54 | 11/14/2018 3:12:05 PM | 160.847229 |
| 55 | 11/14/2018 3:12:06 PM | 160.6682281 |
| 56 | 11/14/2018 3:12:08 PM | 160.8144989 |
| 57 | 11/14/2018 3:12:10 PM | 160.8635254 |
| 58 | 11/14/2018 3:12:11 PM | 160.7857513 |
| 59 | 11/14/2018 3:12:13 PM | 160.5624237 |
| 60 | 11/14/2018 3:12:14 PM | 160.3961029 |
| 61 | 11/14/2018 3:12:16 PM | 160.3446198 |
| 62 | 11/14/2018 3:12:18 PM | 160.2212372 |
| 63 | 11/14/2018 3:12:19 PM | 160.1044769 |
| 64 | 11/14/2018 3:12:21 PM | 160.0050507 |
| 65 | 11/14/2018 3:12:23 PM | 160.0135956 |
| 66 | 11/14/2018 3:12:24 PM | 159.8414612 |
| 67 | 11/14/2018 3:12:26 PM | 159.2415314 |
| 68 | 11/14/2018 3:12:27 PM | 159.1287231 |
| 69 | 11/14/2018 3:12:29 PM | 159.1443787 |
| 70 | 11/14/2018 3:12:31 PM | 159.4218445 |
| 71 | 11/14/2018 3:12:32 PM | 159.5717773 |
| 72 | 11/14/2018 3:12:34 PM | 159.5997772 |
| 73 | 11/14/2018 3:12:36 PM | 159.7444305 |
| 74 | 11/14/2018 3:12:37 PM | 159.9403534 |
| 75 | 11/14/2018 3:12:39 PM | 160.013443 |
| 76 | 11/14/2018 3:12:40 PM | 160.1772308 |
| 77 | 11/14/2018 3:12:42 PM | 160.2146606 |
| 78 | 11/14/2018 3:12:44 PM | 160.0968933 |
| 79 | 11/14/2018 3:12:45 PM | 159.9303131 |
| 80 | 11/14/2018 3:12:47 PM | 159.7606812 |
| 81 | 11/14/2018 3:12:49 PM | 159.7299042 |
| 82 | 11/14/2018 3:12:50 PM | 159.7021484 |
| 83 | 11/14/2018 3:12:52 PM | 159.5656281 |
| 84 | 11/14/2018 3:12:54 PM | 159.7483368 |
| 85 | 11/14/2018 3:12:55 PM | 159.69841 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 86 | 11/14/2018 3:12:57 PM | 159.8412628 |
| 87 | 11/14/2018 3:12:58 PM | 159.7827606 |
| 88 | 11/14/2018 3:13:00 PM | 159.581955 |
| 89 | 11/14/2018 3:13:02 PM | 159.8931732 |
| 90 | 11/14/2018 3:13:03 PM | 159.9123993 |
| 91 | 11/14/2018 3:13:05 PM | 159.9222565 |
| 92 | 11/14/2018 3:13:07 PM | 160.0277557 |
| 93 | 11/14/2018 3:13:08 PM | 159.9507599 |
| 94 | 11/14/2018 3:13:10 PM | 159.7963715 |
| 95 | 11/14/2018 3:13:11 PM | 159.6338959 |
| 96 | 11/14/2018 3:13:13 PM | 159.6053009 |
| 97 | 11/14/2018 3:13:15 PM | 159.5838318 |
| 98 | 11/14/2018 3:13:16 PM | 159.6222992 |
| 99 | 11/14/2018 3:13:18 PM | 159.6663513 |
| 100 | 11/14/2018 3:13:19 PM | 159.7516022 |
| 101 | 11/14/2018 3:13:21 PM | 159.8030548 |
| 102 | 11/14/2018 3:13:23 PM | 159.7557526 |
| 103 | 11/14/2018 3:13:24 PM | 159.8672333 |
| 104 | 11/14/2018 3:13:26 PM | 160.0573273 |
| 105 | 11/14/2018 3:13:28 PM | 160.3100433 |
| 106 | 11/14/2018 3:13:29 PM | 160.5848694 |
| 107 | 11/14/2018 3:13:31 PM | 160.7770844 |
| 108 | 11/14/2018 3:13:32 PM | 160.7437897 |
| 109 | 11/14/2018 3:13:34 PM | 160.7580719 |
| 110 | 11/14/2018 3:13:36 PM | 160.5423431 |
| 111 | 11/14/2018 3:13:37 PM | 160.2782288 |
| 112 | 11/14/2018 3:13:39 PM | 160.1961823 |
| 113 | 11/14/2018 3:13:41 PM | 160.0915222 |
| 114 | 11/14/2018 3:13:42 PM | 160.1232758 |
| 115 | 11/14/2018 3:13:44 PM | 160.212204 |
| 116 | 11/14/2018 3:13:45 PM | 160.252594 |
| 117 | 11/14/2018 3:13:47 PM | 160.3486328 |
| 118 | 11/14/2018 3:13:49 PM | 160.4141083 |
| 119 | 11/14/2018 3:13:50 PM | 160.8625946 |
| 120 | 11/14/2018 3:13:52 PM | 160.8780212 |
| 121 | 11/14/2018 3:13:54 PM | 160.9911957 |
| 122 | 11/14/2018 3:13:55 PM | 161.1439362 |
| 123 | 11/14/2018 3:13:57 PM | 161.5228119 |
| 124 | 11/14/2018 3:13:59 PM | 161.5554047 |
| 125 | 11/14/2018 3:14:00 PM | 161.5039215 |
| 126 | 11/14/2018 3:14:02 PM | 161.4338989 |
| 127 | 11/14/2018 3:14:03 PM | 161.2250519 |
| 128 | 11/14/2018 3:14:05 PM | 161.0010529 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 129 | 11/14/2018 3:14:07 PM | 160.8955231 |
| 130 | 11/14/2018 3:14:08 PM | 161.0260468 |
| 131 | 11/14/2018 3:14:10 PM | 161.1299896 |
| 132 | 11/14/2018 3:14:11 PM | 161.2177887 |
| 133 | 11/14/2018 3:14:13 PM | 161.2875671 |
| 134 | 11/14/2018 3:14:15 PM | 161.3925476 |
| 135 | 11/14/2018 3:14:16 PM | 161.4824371 |
| 136 | 11/14/2018 3:14:18 PM | 161.4332123 |
| 137 | 11/14/2018 3:14:20 PM | 161.3067169 |
| 138 | 11/14/2018 3:14:21 PM | 161.2012177 |
| 139 | 11/14/2018 3:14:23 PM | 161.1327515 |
| 140 | 11/14/2018 3:14:25 PM | 161.1394806 |
| 141 | 11/14/2018 3:14:26 PM | 161.1425934 |
| 142 | 11/14/2018 3:14:28 PM | 160.9776154 |
| 143 | 11/14/2018 3:14:29 PM | 161.0018463 |
| 144 | 11/14/2018 3:14:31 PM | 161.0542755 |
| 145 | 11/14/2018 3:14:33 PM | 161.1611481 |
| 146 | 11/14/2018 3:14:34 PM | 161.3961029 |
| 147 | 11/14/2018 3:14:36 PM | 161.2939911 |
| 148 | 11/14/2018 3:14:37 PM | 161.2380524 |
| 149 | 11/14/2018 3:14:39 PM | 161.1893463 |
| 150 | 11/14/2018 3:14:41 PM | 161.0185089 |
| 151 | 11/14/2018 3:14:42 PM | 161.2795563 |
| 152 | 11/14/2018 3:14:44 PM | 161.319046 |
| 153 | 11/14/2018 3:14:46 PM | 160.9371948 |
| 154 | 11/14/2018 3:14:47 PM | 160.9832764 |
| 155 | 11/14/2018 3:14:49 PM | 161.092392 |
| 156 | 11/14/2018 3:14:51 PM | 161.6880951 |
| 157 | 11/14/2018 3:14:52 PM | 161.6880951 |
| 158 | 11/14/2018 3:14:54 PM | 161.7994843 |
| 159 | 11/14/2018 3:14:55 PM | 161.8440857 |
| 160 | 11/14/2018 3:14:57 PM | 161.7542114 |
| 161 | 11/14/2018 3:14:59 PM | 161.6064301 |
| 162 | 11/14/2018 3:15:00 PM | 161.8369293 |
| 163 | 11/14/2018 3:15:02 PM | 161.9825897 |
| 164 | 11/14/2018 3:15:04 PM | 162.0489655 |
| 165 | 11/14/2018 3:15:05 PM | 161.7849579 |
| 166 | 11/14/2018 3:15:07 PM | 161.4163818 |
| 167 | 11/14/2018 3:15:08 PM | 161.2628937 |
| 168 | 11/14/2018 3:15:10 PM | 160.9917908 |
| 169 | 11/14/2018 3:15:12 PM | 160.8557281 |
| 170 | 11/14/2018 3:15:13 PM | 160.8260956 |
| 171 | 11/14/2018 3:15:15 PM | 160.8508759 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 172 | 11/14/2018 3:15:17 PM | 160.7300262 |
| 173 | 11/14/2018 3:15:18 PM | 160.5685425 |
| 174 | 11/14/2018 3:15:20 PM | 160.5828857 |
| 175 | 11/14/2018 3:15:22 PM | 160.6507111 |
| 176 | 11/14/2018 3:15:23 PM | 160.6191101 |
| 177 | 11/14/2018 3:15:25 PM | 160.7206268 |
| 178 | 11/14/2018 3:15:26 PM | 160.8874512 |
| 179 | 11/14/2018 3:15:28 PM | 161.1824493 |
| 180 | 11/14/2018 3:15:30 PM | 161.2202911 |
| 181 | 11/14/2018 3:15:31 PM | 161.2683258 |
| 182 | 11/14/2018 3:15:33 PM | 161.3135529 |
| 183 | 11/14/2018 3:15:35 PM | 161.2315216 |
| 184 | 11/14/2018 3:15:36 PM | 161.1026764 |
| 185 | 11/14/2018 3:15:38 PM | 161.0433807 |
| 186 | 11/14/2018 3:15:39 PM | 160.8686371 |
| 187 | 11/14/2018 3:15:41 PM | 160.5873871 |
| 188 | 11/14/2018 3:15:43 PM | 160.5429382 |
| 189 | 11/14/2018 3:15:44 PM | 160.6608429 |
| 190 | 11/14/2018 3:15:46 PM | 160.7342377 |
| 191 | 11/14/2018 3:15:48 PM | 160.6250458 |
| 192 | 11/14/2018 3:15:49 PM | 160.7570038 |
| 193 | 11/14/2018 3:15:51 PM | 160.8829498 |
| 194 | 11/14/2018 3:15:53 PM | 161.1006927 |
| 195 | 11/14/2018 3:15:54 PM | 161.1551666 |
| 196 | 11/14/2018 3:15:56 PM | 161.1155396 |
| 197 | 11/14/2018 3:15:58 PM | 160.9492645 |
| 198 | 11/14/2018 3:15:59 PM | 160.4958038 |
| 199 | 11/14/2018 3:16:01 PM | 160.5526123 |
| 200 | 11/14/2018 3:16:02 PM | 160.2547455 |
| 201 | 11/14/2018 3:16:04 PM | 160.2046814 |
| 202 | 11/14/2018 3:16:06 PM | 160.3673248 |
| 203 | 11/14/2018 3:16:07 PM | 160.4645233 |
| 204 | 11/14/2018 3:16:09 PM | 160.5465546 |
| 205 | 11/14/2018 3:16:11 PM | 160.7608185 |
| 206 | 11/14/2018 3:16:12 PM | 160.8519135 |
| 207 | 11/14/2018 3:16:14 PM | 161.0140228 |
| 208 | 11/14/2018 3:16:16 PM | 161.272171 |
| 209 | 11/14/2018 3:16:17 PM | 161.1561127 |
| 210 | 11/14/2018 3:16:19 PM | 161.0668182 |
| 211 | 11/14/2018 3:16:20 PM | 160.9520721 |
| 212 | 11/14/2018 3:16:22 PM | 160.7420349 |
| 213 | 11/14/2018 3:16:24 PM | 160.7885284 |
| 214 | 11/14/2018 3:16:25 PM | 160.8290863 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 215 | 11/14/2018 3:16:27 PM | 160.8347473 |
| 216 | 11/14/2018 3:16:29 PM | 160.8614197 |
| 217 | 11/14/2018 3:16:30 PM | 160.9388428 |
| 218 | 11/14/2018 3:16:32 PM | 160.8677063 |
| 219 | 11/14/2018 3:16:34 PM | 160.9645386 |
| 220 | 11/14/2018 3:16:35 PM | 160.8408051 |
| 221 | 11/14/2018 3:16:37 PM | 160.8413849 |
| 222 | 11/14/2018 3:16:38 PM | 160.9437103 |
| 223 | 11/14/2018 3:16:40 PM | 161.0124359 |
| 224 | 11/14/2018 3:16:42 PM | 160.8939514 |
| 225 | 11/14/2018 3:16:43 PM | 160.7381744 |
| 226 | 11/14/2018 3:16:45 PM | 160.7105713 |
| 227 | 11/14/2018 3:16:47 PM | 160.6898041 |
| 228 | 11/14/2018 3:16:48 PM | 160.7353668 |
| 229 | 11/14/2018 3:16:50 PM | 160.7585297 |
| 230 | 11/14/2018 3:16:51 PM | 160.5999603 |
| 231 | 11/14/2018 3:16:53 PM | 160.9408875 |
| 232 | 11/14/2018 3:16:55 PM | 161.1693115 |
| 233 | 11/14/2018 3:16:56 PM | 161.27388 |
| 234 | 11/14/2018 3:16:58 PM | 161.3684845 |
| 235 | 11/14/2018 3:17:00 PM | 161.5361786 |
| 236 | 11/14/2018 3:17:01 PM | 161.9486389 |
| 237 | 11/14/2018 3:17:03 PM | 162.0671234 |
| 238 | 11/14/2018 3:17:05 PM | 161.7944794 |
| 239 | 11/14/2018 3:17:06 PM | 161.6904755 |
| 240 | 11/14/2018 3:17:08 PM | 161.562027 |
| 241 | 11/14/2018 3:17:09 PM | 161.4852905 |
| 242 | 11/14/2018 3:17:11 PM | 161.384201 |
| 243 | 11/14/2018 3:17:13 PM | 161.4789886 |
| 244 | 11/14/2018 3:17:14 PM | 161.4548492 |
| 245 | 11/14/2018 3:17:16 PM | 161.4877777 |
| 246 | 11/14/2018 3:17:17 PM | 161.5700226 |
| 247 | 11/14/2018 3:17:19 PM | 161.5789032 |
| 248 | 11/14/2018 3:17:21 PM | 161.7910309 |
| 249 | 11/14/2018 3:17:22 PM | 162.0345306 |
| 250 | 11/14/2018 3:17:24 PM | 162.0745087 |
| 251 | 11/14/2018 3:17:26 PM | 161.9590912 |
| 252 | 11/14/2018 3:17:27 PM | 161.8265533 |
| 253 | 11/14/2018 3:17:29 PM | 161.752182 |
| 254 | 11/14/2018 3:17:31 PM | 161.4974823 |
| 255 | 11/14/2018 3:17:32 PM | 161.4271393 |
| 256 | 11/14/2018 3:17:34 PM | 161.4645233 |
| 257 | 11/14/2018 3:17:35 PM | 161.6488647 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 258 | 11/14/2018 3:17:37 PM | 161.6331635 |
| 259 | 11/14/2018 3:17:39 PM | 161.4273224 |
| 260 | 11/14/2018 3:17:40 PM | 161.3465729 |
| 261 | 11/14/2018 3:17:42 PM | 161.5186462 |
| 262 | 11/14/2018 3:17:43 PM | 161.4232025 |
| 263 | 11/14/2018 3:17:45 PM | 161.3846436 |
| 264 | 11/14/2018 3:17:47 PM | 161.3392944 |
| 265 | 11/14/2018 3:17:48 PM | 161.2683563 |
| 266 | 11/14/2018 3:17:50 PM | 161.1246948 |
| 267 | 11/14/2018 3:17:52 PM | 160.9647369 |
| 268 | 11/14/2018 3:17:53 PM | 160.979538 |
| 269 | 11/14/2018 3:17:55 PM | 160.979538 |
| 270 | 11/14/2018 3:17:56 PM | 160.5730133 |
| 271 | 11/14/2018 3:17:58 PM | 160.476181 |
| 272 | 11/14/2018 3:18:00 PM | 160.4593811 |
| 273 | 11/14/2018 3:18:01 PM | 160.5206451 |
| 274 | 11/14/2018 3:18:03 PM | 160.5346832 |
| 275 | 11/14/2018 3:18:05 PM | 160.461731 |
| 276 | 11/14/2018 3:18:06 PM | 160.3827057 |
| 277 | 11/14/2018 3:18:08 PM | 159.8777313 |
| 278 | 11/14/2018 3:18:09 PM | 159.8796539 |
| 279 | 11/14/2018 3:18:11 PM | 160.0063324 |
| 280 | 11/14/2018 3:18:13 PM | 159.961853 |
| 281 | 11/14/2018 3:18:14 PM | 159.8906708 |
| 282 | 11/14/2018 3:18:16 PM | 159.829483 |
| 283 | 11/14/2018 3:18:18 PM | 159.7808075 |
| 284 | 11/14/2018 3:18:19 PM | 159.7900848 |
| 285 | 11/14/2018 3:18:21 PM | 159.9146881 |
| 286 | 11/14/2018 3:18:23 PM | 160.2246857 |
| 287 | 11/14/2018 3:18:24 PM | 160.2215729 |
| 288 | 11/14/2018 3:18:26 PM | 160.1494598 |
| 289 | 11/14/2018 3:18:27 PM | 160.1000214 |
| 290 | 11/14/2018 3:18:29 PM | 160.336319 |
| 291 | 11/14/2018 3:18:31 PM | 160.7033386 |
| 292 | 11/14/2018 3:18:32 PM | 160.758316 |
| 293 | 11/14/2018 3:18:34 PM | 160.8620453 |
| 294 | 11/14/2018 3:18:36 PM | 160.8086395 |
| 295 | 11/14/2018 3:18:37 PM | 160.6983795 |
| 296 | 11/14/2018 3:18:39 PM | 160.5410767 |
| 297 | 11/14/2018 3:18:40 PM | 160.4572754 |
| 298 | 11/14/2018 3:18:42 PM | 160.1394196 |
| 299 | 11/14/2018 3:18:44 PM | 160.1753998 |
| 300 | 11/14/2018 3:18:45 PM | 160.1714478 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 301 | 11/14/2018 3:18:47 PM | 160.2785187 |
| 302 | 11/14/2018 3:18:49 PM | 160.5121155 |
| 303 | 11/14/2018 3:18:50 PM | 160.5840302 |
| 304 | 11/14/2018 3:18:52 PM | 160.3938141 |
| 305 | 11/14/2018 3:18:54 PM | 160.5466156 |
| 306 | 11/14/2018 3:18:55 PM | 160.3214569 |
| 307 | 11/14/2018 3:18:57 PM | 160.2488861 |
| 308 | 11/14/2018 3:18:58 PM | 160.2537994 |
| 309 | 11/14/2018 3:19:00 PM | 160.2016144 |
| 310 | 11/14/2018 3:19:02 PM | 160.2640533 |
| 311 | 11/14/2018 3:19:03 PM | 160.3438568 |
| 312 | 11/14/2018 3:19:05 PM | 160.5785675 |
| 313 | 11/14/2018 3:19:07 PM | 160.3712311 |
| 314 | 11/14/2018 3:19:08 PM | 160.2094574 |
| 315 | 11/14/2018 3:19:10 PM | 160.5774689 |
| 316 | 11/14/2018 3:19:12 PM | 160.5400238 |
| 317 | 11/14/2018 3:19:13 PM | 160.5218506 |
| 318 | 11/14/2018 3:19:15 PM | 160.639801 |
| 319 | 11/14/2018 3:19:16 PM | 160.4907684 |
| 320 | 11/14/2018 3:19:18 PM | 160.3618622 |
| 321 | 11/14/2018 3:19:20 PM | 160.2583466 |
| 322 | 11/14/2018 3:19:21 PM | 160.0849457 |
| 323 | 11/14/2018 3:19:23 PM | 160.0332489 |
| 324 | 11/14/2018 3:19:25 PM | 160.1342926 |
| 325 | 11/14/2018 3:19:26 PM | 159.8836823 |
| 326 | 11/14/2018 3:19:28 PM | 159.4816437 |
| 327 | 11/14/2018 3:19:29 PM | 159.41716 |
| 328 | 11/14/2018 3:19:31 PM | 159.4261932 |
| 329 | 11/14/2018 3:19:33 PM | 159.413681 |
| 330 | 11/14/2018 3:19:34 PM | 159.1291962 |
| 331 | 11/14/2018 3:19:36 PM | 158.8286133 |
| 332 | 11/14/2018 3:19:37 PM | 158.5430145 |
| 333 | 11/14/2018 3:19:39 PM | 158.5153656 |
| 334 | 11/14/2018 3:19:41 PM | 158.6263123 |
| 335 | 11/14/2018 3:19:42 PM | 158.6212311 |
| 336 | 11/14/2018 3:19:44 PM | 158.7697601 |
| 337 | 11/14/2018 3:19:46 PM | 158.989975 |
| 338 | 11/14/2018 3:19:47 PM | 159.1691589 |
| 339 | 11/14/2018 3:19:49 PM | 159.2982483 |
| 340 | 11/14/2018 3:19:51 PM | 159.5365143 |
| 341 | 11/14/2018 3:19:52 PM | 159.6066132 |
| 342 | 11/14/2018 3:19:54 PM | 159.6201935 |
| 343 | 11/14/2018 3:19:55 PM | 159.5409851 |

| S No | Time | Volume flow m3/h |
|---|---|---|
| 344 | 11/14/2018 3:19:57 PM | 159.4536285 |
| 345 | 11/14/2018 3:19:59 PM | 159.3426514 |
| 346 | 11/14/2018 3:20:00 PM | 159.3740082 |
| 347 | 11/14/2018 3:20:02 PM | 159.6342468 |
| 348 | 11/14/2018 3:20:04 PM | 159.7921448 |
| 349 | 11/14/2018 3:20:05 PM | 160.0153198 |
| 350 | 11/14/2018 3:20:07 PM | 159.8994141 |
| 351 | 11/14/2018 3:20:09 PM | 159.7676544 |
| 352 | 11/14/2018 3:20:10 PM | 159.8374481 |
| 353 | 11/14/2018 3:20:12 PM | 159.9225311 |
| 354 | 11/14/2018 3:20:13 PM | 160.1370392 |
| 355 | 11/14/2018 3:20:15 PM | 160.208725 |
| 356 | 11/14/2018 3:20:17 PM | 160.250351 |
| 357 | 11/14/2018 3:20:18 PM | 160.2899323 |
| 358 | 11/14/2018 3:20:20 PM | 160.3689423 |
| 359 | 11/14/2018 3:20:21 PM | 160.3132782 |
| 360 | 11/14/2018 3:20:23 PM | 160.2317352 |
| 361 | 11/14/2018 3:20:25 PM | 160.5816345 |
| 362 | 11/14/2018 3:20:26 PM | 160.7765045 |
| 363 | 11/14/2018 3:20:28 PM | 160.8606415 |
| 364 | 11/14/2018 3:20:29 PM | 160.9505157 |
| 365 | 11/14/2018 3:20:31 PM | 161.1244202 |
| 366 | 11/14/2018 3:20:33 PM | 161.3637238 |
| 367 | 11/14/2018 3:20:34 PM | 161.4094086 |
| 368 | 11/14/2018 3:20:36 PM | 161.4634857 |
| 369 | 11/14/2018 3:20:37 PM | 161.4410858 |

# Appendix 8: Chiller average inlet/outlet temperature

| S No | Time | Temperature Out | Temperature In |
|---|---|---|---|
| 1 | 14/11/2018 15:00 | 26.1 | 21.8 |
| 2 | 14/11/2018 15:01 | 25.1 | 21.7 |
| 3 | 14/11/2018 15:02 | 25.1 | 21.8 |
| 4 | 14/11/2018 15:03 | 24.9 | 21.7 |
| 5 | 14/11/2018 15:04 | 24.7 | 21.6 |
| 6 | 14/11/2018 15:05 | 24.3 | 21.5 |
| 7 | 14/11/2018 15:06 | 24.6 | 21.7 |
| 8 | 14/11/2018 15:07 | 24.7 | 21.6 |
| 9 | 14/11/2018 15:08 | 24.7 | 21.7 |
| 10 | 14/11/2018 15:09 | 24.7 | 21.7 |
| 11 | 14/11/2018 15:10 | 24.8 | 21.6 |
| 12 | 14/11/2018 15:11 | 24.8 | 21.6 |
| 13 | 14/11/2018 15:12 | 24.8 | 21.7 |
| 14 | 14/11/2018 15:13 | 24.8 | 21.6 |
| 15 | 14/11/2018 15:14 | 24.7 | 21.7 |
| 16 | 14/11/2018 15:15 | 24.6 | 21.4 |
| 17 | 14/11/2018 15:16 | 24.5 | 21.4 |
| 18 | 14/11/2018 15:17 | 24.4 | 21.4 |
| 19 | 14/11/2018 15:18 | 24.6 | 21.4 |
| 20 | 14/11/2018 15:19 | 24.4 | 21.3 |
| 21 | 14/11/2018 15:20 | 24.4 | 21.3 |
| 22 | 14/11/2018 15:21 | 24.5 | 21.4 |
| 23 | 14/11/2018 15:22 | 24.5 | 21.4 |
| 24 | 14/11/2018 15:23 | 24.5 | 21.3 |
| 25 | 14/11/2018 15:24 | 24.8 | 21.7 |
| 26 | 14/11/2018 15:25 | 24.6 | 21.6 |
| 27 | 14/11/2018 15:26 | 24.7 | 21.5 |
| 28 | 14/11/2018 15:27 | 24.4 | 21.6 |
| 29 | 14/11/2018 15:28 | 24.6 | 21.6 |
| 30 | 14/11/2018 15:29 | 24.8 | 21.5 |
| 31 | 14/11/2018 15:30 | 24.5 | 21.5 |
| 32 | 14/11/2018 15:31 | 24.6 | 21.6 |
| 33 | 14/11/2018 15:32 | 24.4 | 21.7 |
| 34 | 14/11/2018 15:33 | 24.5 | 21.6 |
| 35 | 14/11/2018 15:34 | 24.4 | 21.5 |
| 36 | 14/11/2018 15:35 | 24.6 | 21.4 |
| 37 | 14/11/2018 15:36 | 24.0 | 21.3 |
| 38 | 14/11/2018 15:37 | 24.2 | 21.6 |
| 39 | 14/11/2018 15:38 | 24.4 | 21.3 |
| 40 | 14/11/2018 15:39 | 24.6 | 21.3 |
| 41 | 14/11/2018 15:40 | 24.5 | 21.3 |
| 42 | 14/11/2018 15:41 | 24.4 | 21.4 |

| S No | Time | Volume flow m3/h | S No |
|---|---|---|---|
| 43 | 14/11/2018 15:42 | 24.4 | 21.3 |
| 44 | 14/11/2018 15:43 | 24.5 | 21.3 |
| 45 | 14/11/2018 15:44 | 24.3 | 21.1 |
| 46 | 14/11/2018 15:45 | 24.5 | 21.3 |