Automation of the humidifier for the BOCLE and SL-BOCLE

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Abstract

The aim of the project was to investigate whether the automation of the humidifier was a viable option for the BOCLE/SL-BOCLE machine and to convert the Simulink simulation model for the BOCLE/SL-BOCLE to LabVIEW. The humidifier had many unforeseen problems which required to be fixed and the manual humidifier was investigated to be the best option for the BOCLE machine as compared to automating the humidifier.

The laboratory manual and this report were written and a backup CD was created. The online wiki-page of the Tribology group was updated. This project helped to get a good understanding of how the BOCLE and SL-BOCLE machines operate and the test procedure for each machine was studied.

The tasks that remain are the continuation of the Simulink simulation conversion to LabVIEW and the installation of the new wet air needle valve upon its arrival.

The suggested recommendations are to cut the inner diameter of the cylinder for the bubbler to size during maintenance and the load cell wiring for both the BOCLE and SL-BOCLE should be checked for proper wiring because the external friction force indicator values are incorrect and do not change much with an increase in load.

Keywords: Friction, wear, lubricity, relative humidity

Contents

1. Introduction

The University of Pretoria received two lubricity evaluators from Sasol in 2012 which were the Ball-on-Cylinder Lubricity-Evaluator (BOCLE) and the Scuffing-Load Ball-on-Cylinder Lubricity Evaluator (SL-BOCLE). The machines were first commissioned in 2012. In the space of 5 years the machines were out of use and became redundant. Several parts and wiring of the machines either lost or longer working. In 2017 the machines were reconditioned. Figure 1 shows the picture of the BOCLE and SL-BOCLE in the tribology labs.

Figure 1: Image of the BOCLE (left) and SL-BOCLE (right) (Langenhoven, 2012).

The aim of this project is focused on the automation of the humidifier of the BOCLE/SL-BOCLE and switching the Simulink simulation model to LabVIEW.

The objectives of this project were to do the following:

- Replace missing/not working parts of the humidifier for both the BOCLE and the SL-BOCLE
- Ensure that the BOCLE and SL-BOCLE are in good working condition
- Switch the manual humidifier into an automated humidifier for the BOCLE and SL-BOCLE
- Convert the Simulink simulation model for the BOCLE and SL-BOCLE to LabVIEW because LabVIEW has a more interactive interface and Simulink is an extension of MATLAB (MATLAB interface) which the university no longer has an updated license for.
- Calibrate frictional measurement for the SL_BOCLE
- Re-establish temperature control of the BOCLE and SL_BOCLE.

2. Literature

2.1 BOCLE and SL-BOCLE

The ball-on-cylinder lubricity evaluator (BOCLE) was devised to measure the lubricity of aviation turbine fuels (Hsieh &Bruno, 2015). The BOCLE test involves a standard ball loaded on a rotating cylinder which picks up a fluid film from a reservoir. The temperature and humidity are closely controlled. Wear develops on both the ball and cylinder over time (Dukek, 1988). Figure 2 shows the schematic diagram of the BOCLE.

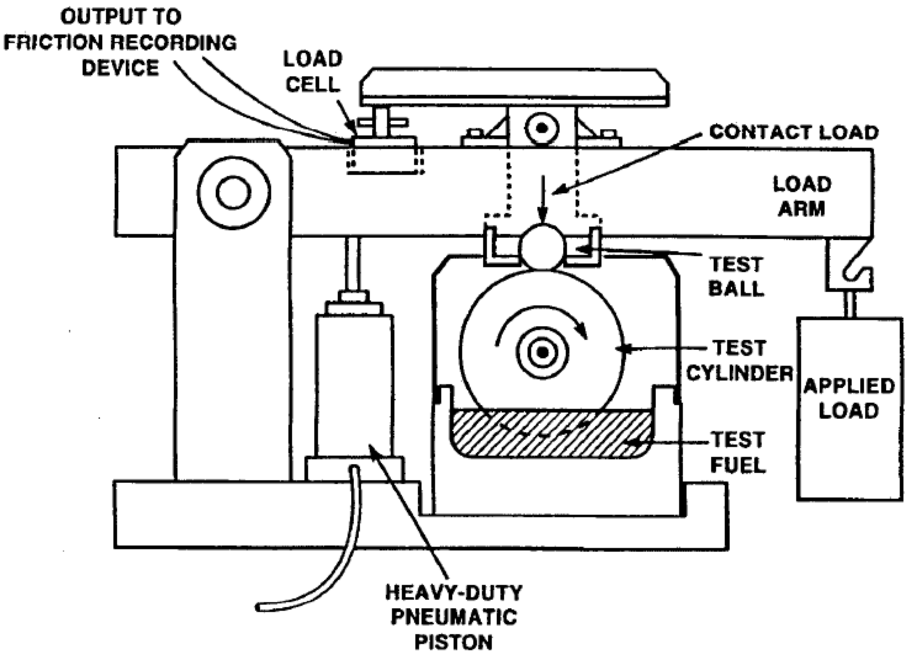

Figure 2: Schematic of ball-on-cylinder lubricity evaluator (not including instrumentation) (ASTM D6078, 1999).

The lubricity of a fuel on the BOCLE is determined by the measurement of an oval wear scar on a ball that has been in contact with the rotating cylinder which is partially immersed in a fuel sample under controlled conditions. The reported value is the average of the major and minor axes of the oval wear scar in millimetres (Black *et al, sa*). The wear scar diameter is calculated by using Equation 1.

$$WSD = \frac{d_{major} + d_{minor}}{2} \tag{1}$$

The Scuffing-Load Ball-on-Cylinder Lubricity Evaluator (SL-BOCLE) is a measure of the fuels ability to lubricate under conditions of high contact stress, which results in severe scuffing. The final result of the SL-BOCLE test is report as the average applied load in grams required to cause adhesive scuffing, as defined using two separate test specimens (Lacey & Erwin, 1999). Scuffing occurs when the friction coefficient is above 0.175 which can be seen in Figure 3.

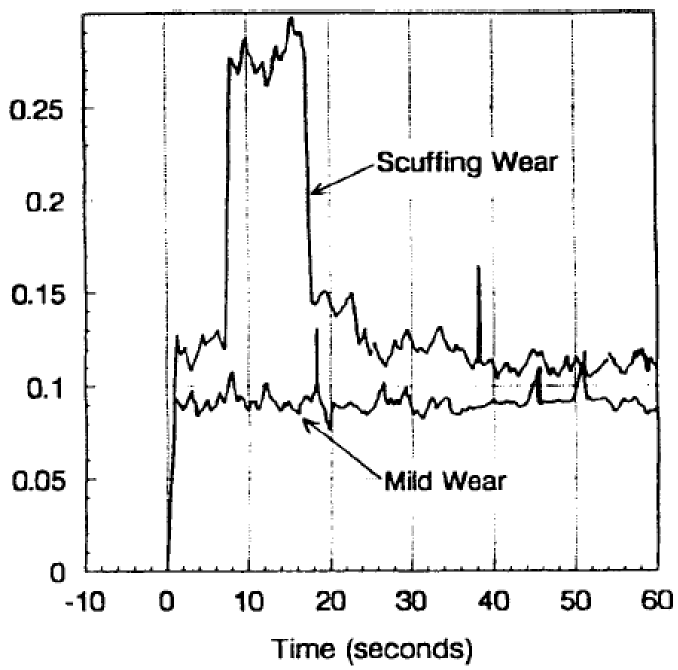

Figure 3: Scuffing wear (ASTM D6078, 1999).

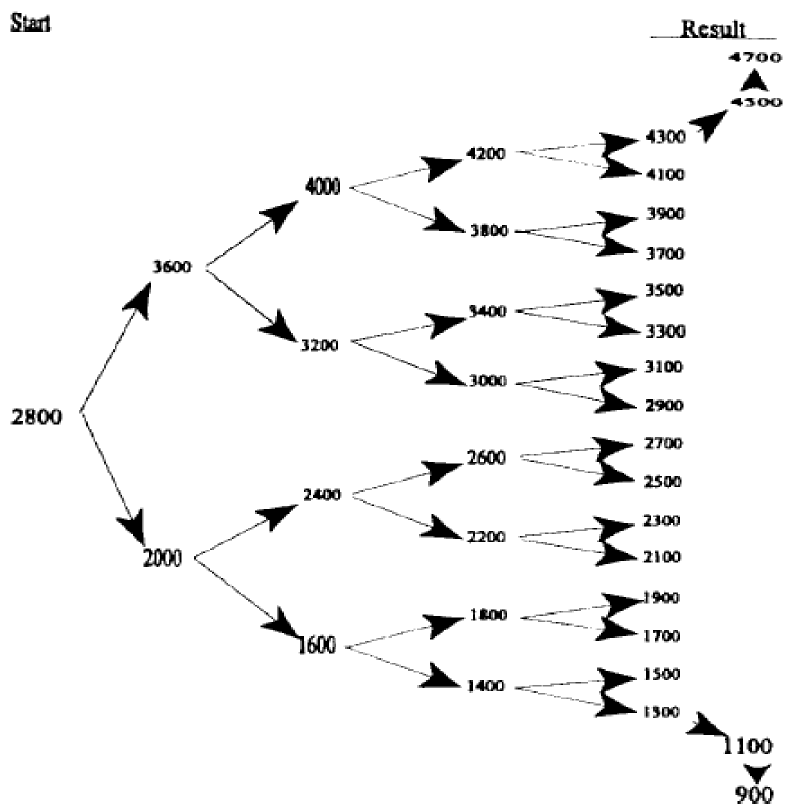

Figure 4: Recommended load sequence schematic (in grams) (ASTM D6078, 1999).

The load sequence schematic is designed in such a way that it is likely to lead to the scuffing load value in a shorter time. It is suggested to start with a load of 2800 g. If scuffing occurs, a lower load is applied. If scuffing does not occur, a higher load is applied. The procedure is continued until the applied load for a maximum coefficient exceeding and not exceeding 0.175 differs by 100 g (ASTM D6078, 1999). The calculation for the maximum friction coefficient is shown is Equation 2

$$\mu_m = \frac{F_t}{2F_a} \tag{2}$$

With F_t as the maximum tangential friction force (e.g from the friction trace recording) and F_a is the applied load. The contact load is twice the amount of the applied load.

The limitations of the BOCLE method are the BOCLE is run at 25 °C which is a temperature that is not characteristic in air craft environments and the test is limited to measurement of boundary lubrication which is a regime that is not characteristic of used aircraft fuel pumps (Black *et al, sa*).

Table 1 shows the standardised test parameters for the BOCLE and SL-BOCLE.

Table 1: Standardised test parameters for the BOCLE and SL-BOCLE (Hsieh & Bruno, 2015).

	BOCLE	SL-BOCLE
ASTM method	D5001-10	D6078-04
Test geometry	Ball-on-cylinder	Ball-on-cylinder
Test motion	Rotating cylinder	Rotating cylinder
Ball diameter	12.7mm	12.7mm
Ball material (Hardened)	AISI E-52100 steel	AISI E-52100 steel
Counterface material	Hardened SAE 8720 steel	Hardened SAE 8720 steel
Cylinder diameter	50 ± 1 mm	50 ± 1 mm
Fluid volume	50 ±1 ml	50 ± 1 ml
Frequency	240 ± 0.5 rpm	525 ± 0.5 rpm
Fluid temperature	25 ± 1 °C	25 ± 1 °C
Relative humidity	10 ± 0.2 %	50 ± 1 %
Applied load	500 g	1 to 5 kg
Test duration	30 ± 0.1 min	1 min/increment
Sliding velocity	0.63 ± 0.01 $m \cdot s^{-1}$	1.38 ± 0.03 $m \cdot s^{-1}$
Sliding distance	1130 ± 23 m	82.5 m/incr.

Number of cycles	7.2×10^3	525/incr.

2.2 Humidity

Humidification is the transfer of material from a liquid phase to a gas phase that is insoluble in the liquid phase (Vaisala, 2013). A humidifier is a device that increases the humidity (moisture) in an area. The principle of the BOCLE/SL-BOCLE humidifier is dry air from the dryer mixes with the wet air (saturated air) from the bubbler to form required humidity in the chamber

2.2.1 Relative humidity

Relative humidity measures the water vapour relative to the temperature of the air. It is expressed the ratio of the amount of water vapour in air to the total amount of water vapour that could be held at that temperature. The value is expressed as a percentage. The relative humidity equation is shown in Equation 3 (Vaisala, 2013).

$$RH = \frac{P_{H_2O}}{P^*_{H_2O}(T)} \times 100\% \qquad (3)$$

The relative humidity is sensitive to temperature because the vapour pressure of the water is a function of temperature. The vapour pressure is calculated using the Antoine equation. The Antoine's equation given by Equation 4 (Green & Perry, 2007: 2-60) calculates the vapour pressure (in Pa) at a given temperature (in K).

$$P^*_w = \exp\left(C_1 + \frac{C_2}{T} + C_3 \ln(T) + C_4 T^{C_5}\right) \qquad (4)$$

The following constants are for water:

C1 =73.647

C2 =-7258.2

C3 =-7.3037

C4 =4.1653E-06

C5 =2

The water vapour saturation pressures given by the Antoine equation are exactly valid only in a vacuum. The real vapour pressure will increase if other gases are present (Vaisala, 2013). The true vapour pressure is given Equation 5.

$$P_{H_2O}^{*} = P_w^{*} \times f \tag{5}$$

The enhancement factor is described by Equation 6 (Vaisala, 2013).

$$f = \frac{x_{H_2O} \times P}{P_w^{*}} \tag{6}$$

Equation 7 describes the mass fraction water.

$$x_{H_2O} = \frac{m_{H_2O}}{m_{H_2O} + m_{air}} = \frac{H}{H + 1} \tag{7}$$

The pressure of water is calculated using the ideal gas law given by Equation 8.

$$P_{H_2O} = \frac{n_{H_2O}RT}{V} \tag{8}$$

2.2.2 Absolute humidity

Absolute humidity expressed in Equation 9 is the measure of water vapour in air in mass per volume, regardless of the temperature (Vaisala, 2013).

$$H_{abs} = \frac{m_{H_2O}}{V} = \frac{MM_{H_2O} \times P}{RT} \tag{9}$$

The total pressure of the wet air is described by Equation 10.

$$P = P_{N_2} + P_{O_2} + P_{H_2O} + P_{others} \tag{10}$$

2.2.3 Mixing ratio

The mixing ratio also known as the humidity is given by Equation 11 (Vaisala, 2013).

$$H = \frac{m_{H_2O}}{m_{air}} = \frac{MM_{H_2O} \times P}{\rho_{air} RT} = \frac{H_{abs}}{\rho_{air}} \tag{11}$$

3. Work done on BOCLE and SL-BOCLE Hardware

The pieces of equipment which needed to be replaced were the following:

- The dryer assembly of the humidifier for the SL-BOCLE (D_o=80mm and D_i=76mm)
- The pump for the BOCLE and the pump for the SL-BOCLE (There is no temperature control due to the pumps not working)
- Ring and mandrel assembly for the SL-BOCLE

One pump and a US adapter plug were bought. The plug and US adapter will be used on the BOCLE or SL-BOCLE depending on which machine is being used at the time. The decision to only buy one pump and one US adapter instead of two plugs and two US adapter plugs for the machines was made because the ring and mandrel assembly for the SL-BOCLE could not be bought. The suppliers of the rind and mandrel assembly do not export to South Africa. It would too much money to get the exact replica of the ring and mandrel assembly made, and therefore the ring and mandrel for the BOCLE will also be used to SL-BOCLE test. The pump was installed but does not pump water because the adapter does not fit into the pump power inlet. The circular rim of the new pump connection prevents the pump from receiving power. The decision was made to connect the pump externally from the BOCLE and the pump works well with the external connection.

The transparent acrylic tube for the dryer assembly cylinder with an outside diameter of 80mm and an inside diameter of 74 mm was bought instead of the original on which had an inside diameter of 76 mm because the company did not have the tube with the specific measurement I needed and the correct tube would take months to arrive. The tube was cut to the correct size by using the cracked cylinder as the template for the measurement. Aquarium silirub was bought to bond and seal the acrylic tube to the metal base and to ensure no leakage of water would occur.

4. Condition of manual humidifier

The condition of the BOCLE and the SL-BOCLE had to be assessed first by performing the lubricity tests and by checking whether the results on the Simulink simulation model are realistic.

The process flow diagram of the BOCLE and SL-BOCLE is shown by Figure 5.

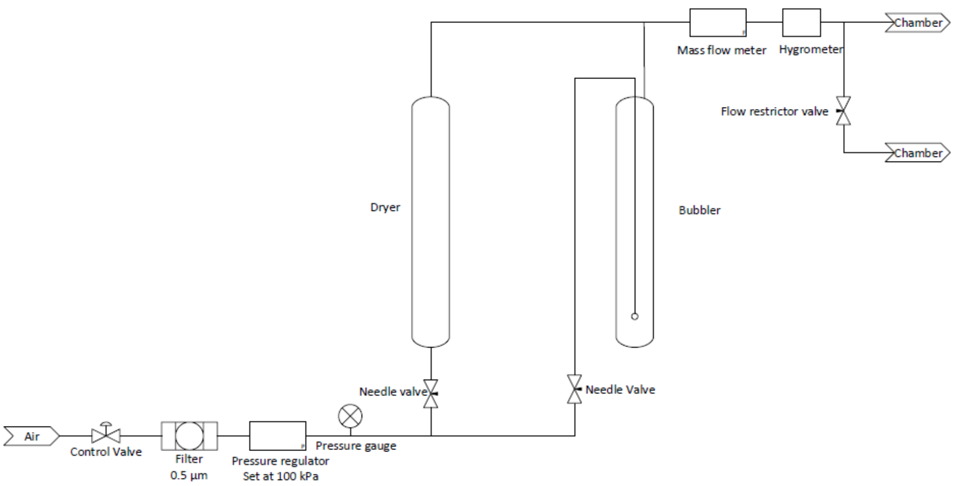

Figure 5: Process flow diagram of the BOCLE and SL-BOCLE.

The BOCLE and SL-BOCLE have a manual humidifier which mixes the dry air and the wet air together to get a required humidity. The air entering the humidifier is compressed air which is controlled by a manual flow valve. The filter lets particles less than 0.5 µm pass through. The pressure is set to 100 kPa for the BOCLE (200 kPa for the SL-BOCLE) to ensure that the water in the bubbler does not leave the bubbler and into the pipeline. The hygrometer is a capacitive hygrometer which senses the relative humidity of the conditioned air. The conditioned air is split so there is flow of conditioned into the chamber and conditioned air aerated into test oil.

The dryer contains silica gel beads which acts as a desiccant and removes moisture from the compressed air. The silica gel used is in bead form and dry. Silica gel is amorphous and an extremely porous form of silica. Its absorption and desorption of moisture is purely physical and there is no change in size or shape of the particle as it absorbs moisture. The beaded silica gel offers superior performance for 0-30 % relative humidity. The beaded form of the silica gel offers low abrasion which greatly reduces breakage of the gel, thus producing far less dust and extends the service life of the gel (Conservation Support Systems, 2013).

The orange indicating silica gel is what is used for the BOCLE/SL-BOCLE. This silica gel is a high capacity beaded silica gel which is heavy metal free, chemically inert, non-flammable, non-toxic and environmentally friendly humidity indicator. This type of silica gel is used whenever visual control of moisture is desirable. The degree of moisture uptake is indicated by a colour change from the orange to a dark greenish/blue at 6% weight water loading (Conservation Support Systems, 2013).The orange green silica gel can absorb up to 40 % of its weight, of water (Conservation by Design, 2003).

To regenerate the exhausted orange-green silica gel, it should be heated to between 105 °C and 110 °C. This will result in a colour change from a dark deep green to a deep orange (Conservation by Design, 2003).

The bubbler of the humidifier has a sparger which is a metal porous sphere. A sparger is widely used in gas-liquid contacting applications. Sparging refers to the process of injecting a gas through a diffuser into a liquid phase. The compressed air enters at the bottom of the water level in the bubbler by use of the sparger. The water bubbles and wet air leaves the bubbler. The wet air and the dry air mix to form conditioned air with a specific relative humidity.

4.1 Condition of the BOCLE

In attempt to perform the lubricity test on the BOCLE, the conditioned air flow meter was not working and the humidity on the Simulink program did not change when a change in the mixing ratio was implemented. This was an indication that the moist air did not reach the hygrometer. This resulted in the conditioned air not reaching the chamber. There was a realisation that there is a blockage in the lines after the mixing point of the dry air and the wet air flow because the bubbler worked fine. The decision was made to check each line after the mixing point for blockages by cleaning the lines with a pipe cleaner and flushing compressed air through each line to unclog any line that was blocked. This method did not work and it was realised that the lines were not clogged up. The next solution was to flush compressed air into the inlet of the conditioned air flowmeter to check whether the flowmeter worked fine. The outlet of the flowmeter did not have compressed air flowing out which meant that the conditioned air flowmeter was clogged. Continuation of flushing the inlet to the flowmeter with compressed air for a few minutes resulted in dust coming out from the outlet of the flowmeter. The conditioned air flowmeter was no longer blocked.

The motor of the BOCLE was not working (spinning) and it was realised that the wiring of the BOCLE motor was not connected. The wiring was fixed by taping the two wires together (the electrical schematic is on page 16 of the BOCLE operating manual). The readings of the motor on the Simulink simulation were incorrect even after fixing the wiring on the BOCLE motor. The wiring of the motor from the BOCLE, junction box and the OPTO 22 were removed and reconnected. After reconnecting the wiring and starting the simulation the BOCLE motor speed was still unrealistic. It was realised that the motor is always on when the BOCLE machine is on, even when the motor is in the off position. The motor switch does not work properly but it is not a problem, it would be a problem it did not switch on. The speed of the motor can be seen on the BOCLE motor speed indicator.

The friction indicator of the BOCLE was not giving the correct values and it was realised that the wiring is fine because the friction indicator values were exactly the same as the Simulink simulation model. It is suspected that the wiring of the load cell is not properly connected and therefore cannot detect the load.

4.2 Condition of the SL-BOCLE

In attempt to perform a lubricity test of the SL-BOCLE, the humidifier bubbler was not working properly. The sparger did not have compressed air coming out of it. The pressure gauge reading increased with an increase in the compressed air flowrate and therefore created a build-up of pressure in the bubbler. When the flowrate of dry air is decreased the pressure reading also decreased. It was suspected that there was a block in the line or the sparger was blocked. The lines before the sparger were cleaned using pipe cleaners and reinstalled but the bubbler was still not working.

The next solution was to pass compressed air straight to the connection line going to the compressed air entering the bubbler to check whether the sparger worked. The sparger does work as bubbles were forming in the bubbler. The next solution was to check whether needle valve works by flushing compressed air into the inlet position of the wet air needle valve and see whether the outlet to the needle valve will have flow coming out. The needle valve did not have air coming out of the outlet even the needle valve position was adjusted throughout the process. I removed the needle valve and dismantled it to see whether it can be salvaged. The needle valve appears to be over turned and once a needle valve has been overturned it cannot be fixed and has to be replaced. A new needle has been ordered and still awaiting its arrival.

The SL-BOCLE test was then run with the humidifier off. The Simulink simulation shows that the humidifier values are not realistic which is expected and the motor speed and friction values are not realistic. The SL-BOCLE speed can be seen on motor speed indicator.

The external friction force indicator of the SL-BOCLE does not show realistic values and it was realised that the wiring is fine because the friction indicator values were exactly the same as the Simulink simulation model. The SL-BOCLE was then zerod so when there is no load put on the load arm the reading is zero. I suspect the wiring of the load cell is not properly connected and therefore cannot detect the load.

5. Humidifier automation designs

The aim of designing the automation of the humidifier is to make the control of the relative humidity of the chamber much easier. Several designs are proposed in order to find the ideal design for the automation of the humidifier of the BOCLE/SL-BOCLE.

5.1 Design 1

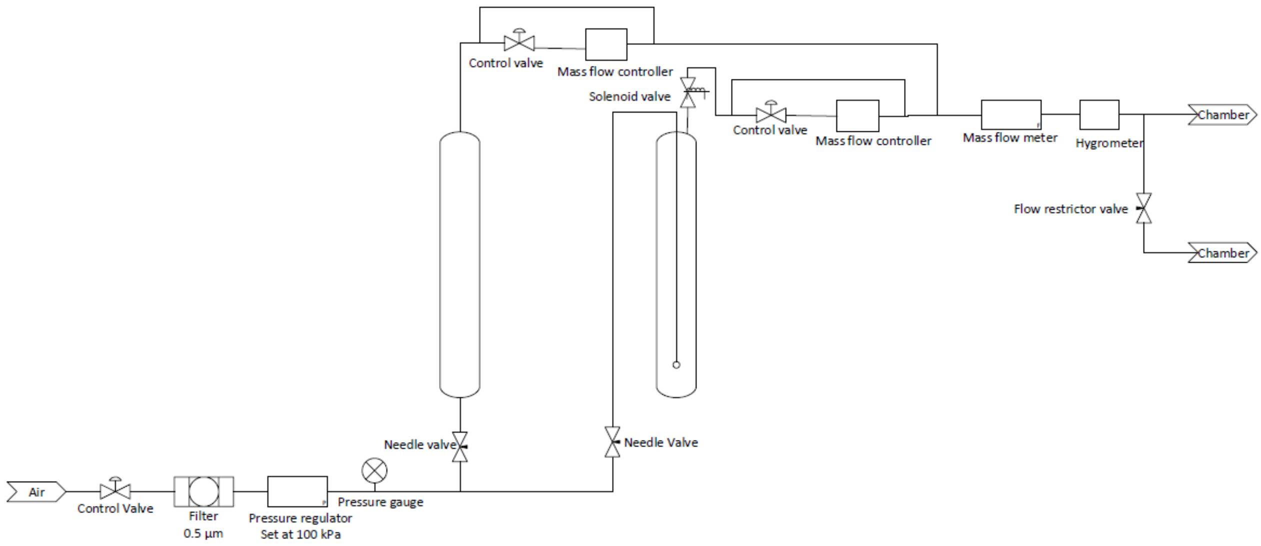

Figure 6: Process flow diagram of Design 1 for the automation of humidifier.

Figure 6 shows the humidity automation design which includes two mass flow controllers for the dry air and wet air. The system can be operated manually and automatically by use of the bypass lines. The manual operation uses the needle valves to adjust the flow of the compressed air into the dryer and bubbler to achieve the required relative humidity. The control valves which are in the same line as the mass flow controllers have to be closed when using the manual system operation. The automatic operation requires the needle valves to be open and the mass flow controllers adjust the flow of the wet air and the dry air to the achieve the required relative humidity. The shut close valve which is indicated by the solenoid valve is there as a safety mechanism to ensure that the water does not bubble past a certain limit and enter the pipes. The solenoid valve is connected to a level sensor. If the water goes past a certain level the solenoid valve shuts close ensuring the water does not leave the bubbler and into the pipes.

Turbulence and agitation caused in tanks can cause the decrease of the accuracy of the float switches and other devices. This decrease in the accuracy can cause damage to the sensitive switches. The problems which are susceptible to float switches are the rapid switch activation and deactivation also known as on-off cycling or chatter and premature wear. The problems can be prevented by a slosh guard. The slosh guard covers the switch while still allowing in an amount of liquid adequate to monitor the tank levels. The use of the slosh guard weakens or even completely eliminates the effects of the liquid agitation and allows for accurate tank level measurements (SMD Fluid Controls, 2018).

The disadvantages of this design is that the shut close valve can cause a pressure build up in the bubbler. The use of manual control valves to switch from the manual and automatic system operation is not practical since the manual control valves will be situated at the back of the machine where it is out of reach. The bypass line is also not fully isolated from the main line especially when the automatic system is in operation because some dry air and wet air flow will split into the bypass line. The model requires lots of equipment which is very costly. The equipment required and the prices of the equipment are listed in Table 2.

Table 2: Prices of equipment required for design 1.

Equipment	Price incl VAT
2 x mass flow controllers	2 xR22 310
2 x manual control valves	2 x R342.76
Solenoid valve	R1 454.75
Level sensor	R118.62
Slosh guard	R3343.15
	R50 222.04

5.2 Design 2

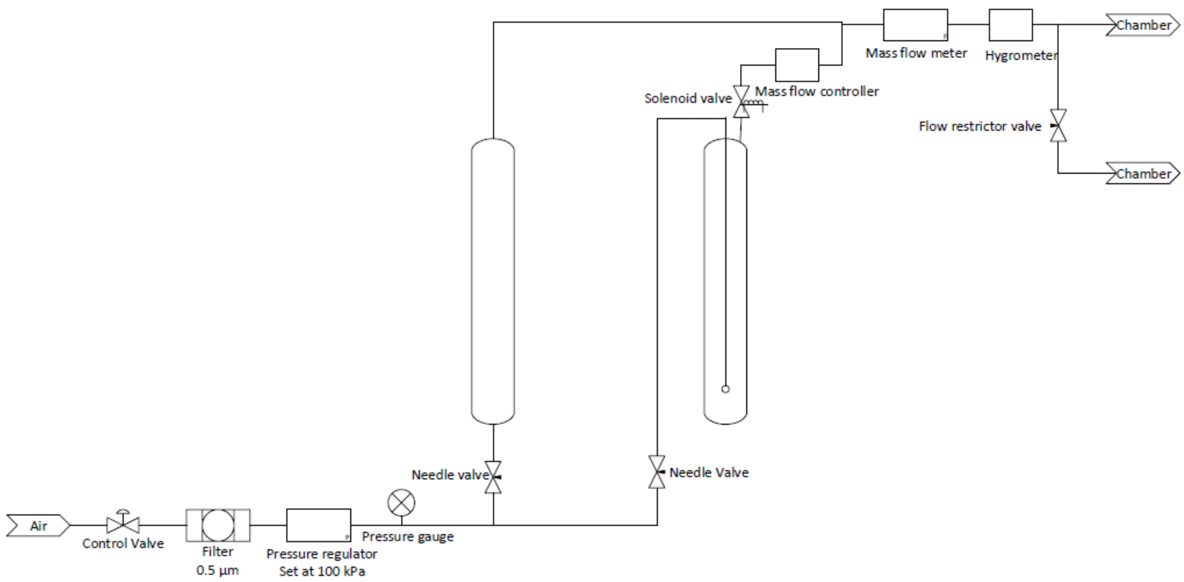

Figure 7: Process flow diagram for Design 2 for the automation of humidifier.

Figure 7 shows the humidifier automation design where the dry air is manually controlled by adjusting the needle valve and the wet air is automatically controlled by a mass flow controller. The needle valve of the bubbler is opened and the mass flow controller controls the wet air flowrate so it can achieve the relative humidity setpoint.

The solenoid valve acts as a shut close valve which shuts close when the bubbled water reaches a certain height. The height of the water is detected by the level sensor which is connected to the solenoid valve. The shut close valve is there as a safety mechanism so the water does not enter the pipelines.

The disadvantages of this design is that there can be a pressure build up in the bubbler due to the shut close valve.The equipment required to implement the design and their prices is listed in Table 3.

Table 3: Prices of equipment required for design 2.

Equipment	Price incl VAT
Mass flow controller	R22 310
Solenoid valve	R1 454.75
Slosh guard	R3343.15
Level sensor	R118.62
	R27 226.52

5.3 Design 3

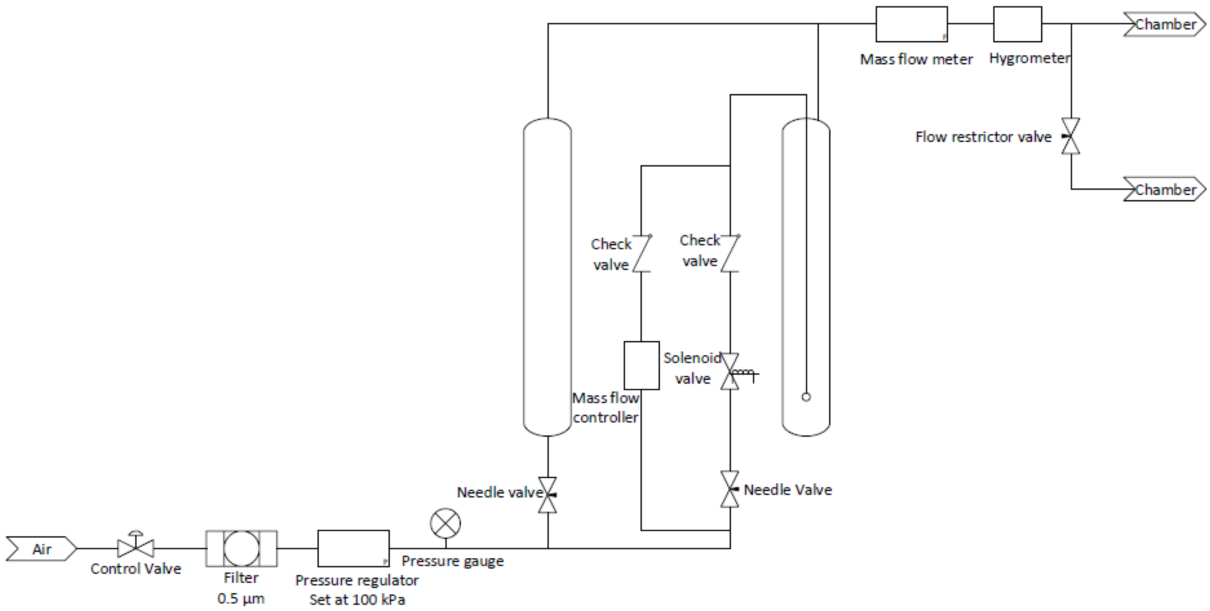

Figure 8: Process flow diagram for Design 3 for the automation of humidifier

Figure 8 shows the humidifier automation design where the compressed air to the dryer is manually controlled using the needle valve while the compressed air entering the bubbler can be automatically controlled or manually controlled. The solenoid valve ensures that the water in the bubbler does not enter the pipelines. The level sensor senses the water in the bubbler and if the water passes a certain level the solenoid valve shuts close. The check valves are connected to the manual and automatic side of the bubbler to ensure only one flow direction and to ensure that if the solenoid valve opens due to back pressure the manual side does not disturb the automatic side. The check valves makes sure that the automatic and manual sides are isolated independent systems.

The problem with this design is that there is not a way to measure the wet air flowrate because we only controlling the compressed air into the bubbler and we cannot assume that the wet air flowrate is equal to the flowrate of the compressed air into the bubbler because it passes through water. The dry air of the bubbler does not help us in finding the relative humidity of the conditioned air. Figure 8 show the equipment and prices of equipement required in implement the design.

Table 4: Prices of equipment required for Design 3.

Equipment	Prices incl VAT
Mass flow controller	R22 310
2 x check valves	2 x R782
Solenoid valve	R1 454.75
Slosh guard	R3 343.15
Level sensor	R118.62
	R28 790.52

5.4 Design 4

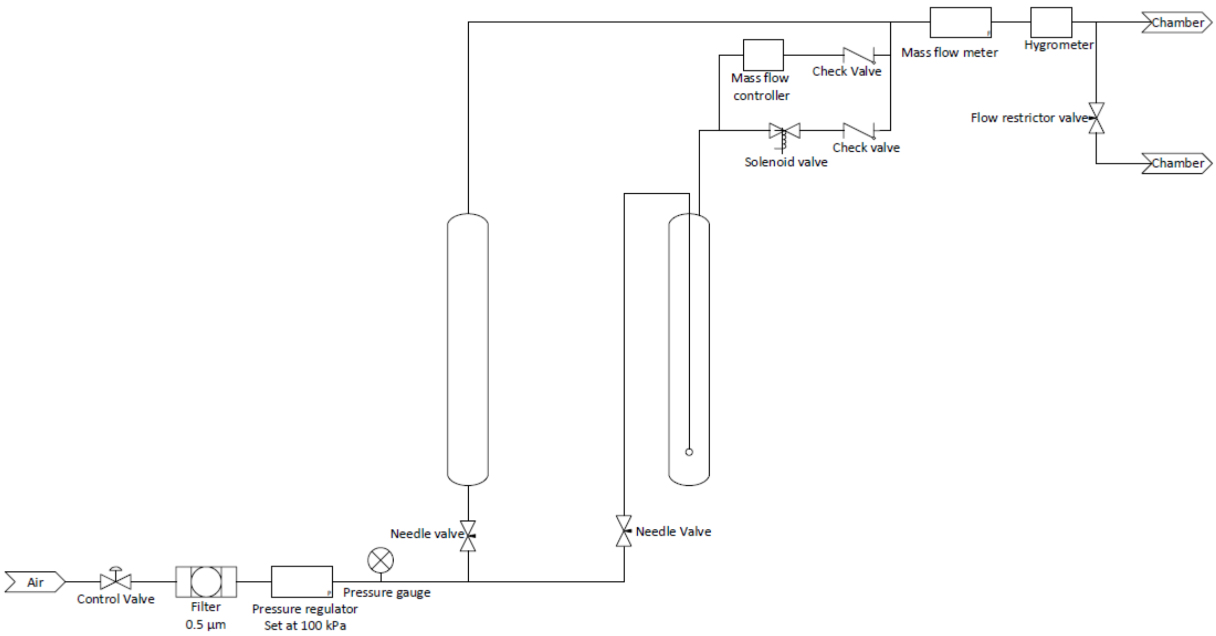

Figure 9: Process flow diagram for Design 4 for the automation of the humidifier.

Figure 9 shows the humidity automation design which is similar to Design 3 shown in Figure 8 but instead of controlling the compressed air to the bubbler, the wet air is controlled. This is a better design as it focuses on controlling the wet air flowrate which is required to achieve the required relative humidity. The price of equipment is the same as for the design 3 in Figure 8 and show in Table 4.

5.5 Design 5

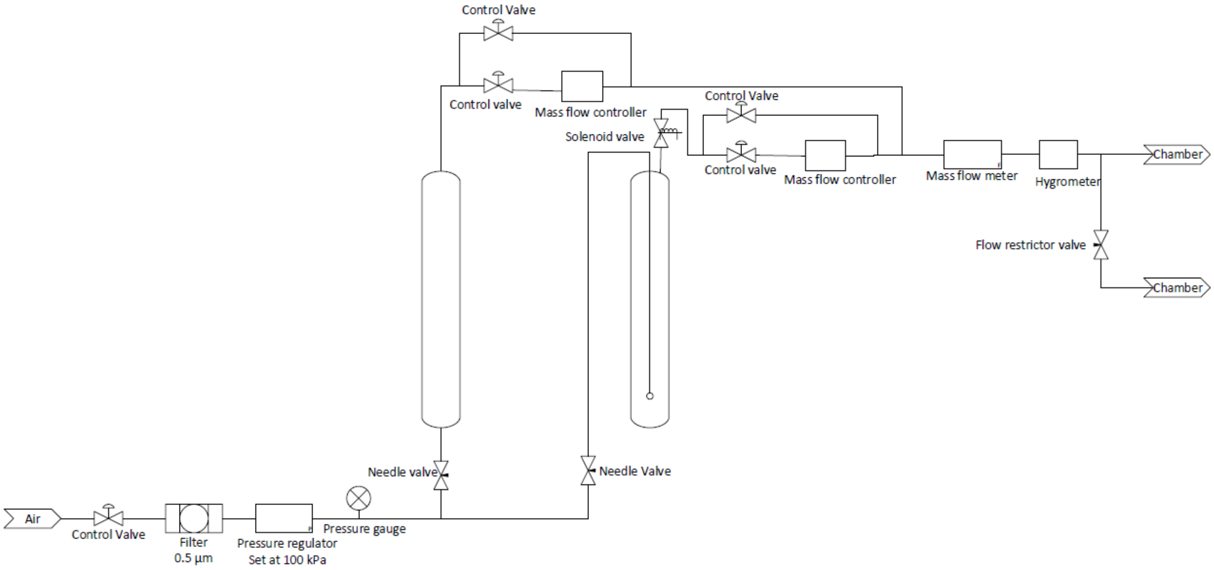

Figure 10: Process flow diagram for Design 5 for the automation of humidifier.

Design 5 is very similar to design 1 with an added manual control valve by the bypass line to make sure that the bypass line is completely isolated for independent manual and automatic system operations. The operating procedure is just like design 1. This design has lots of equipment which needs to be installed which is very costly.

The disadvantages of this design are that a pressure build up can occur due to the closing of the shut close valve during operation which can cause a safety hazard. The use of the manual control valves to isolate the manual and automatic system operatiom is not practical since the manual control valves will be situated at the back of the machine where it is out of reach. Table 5 shows the equipement required to implement the design and the prices of the equipment.

Table 5: Prices of equipment required for design 5.

Equipment	Price incl VAT
2 x mass flow controllers	2 xR22 310
4 x manual control valves	4 x R342.76
Solenoid valve	R1 454.75
Slosh guard	R3343.15
Level sensor	R118.62
	R50 907.56

5.6 Design 6

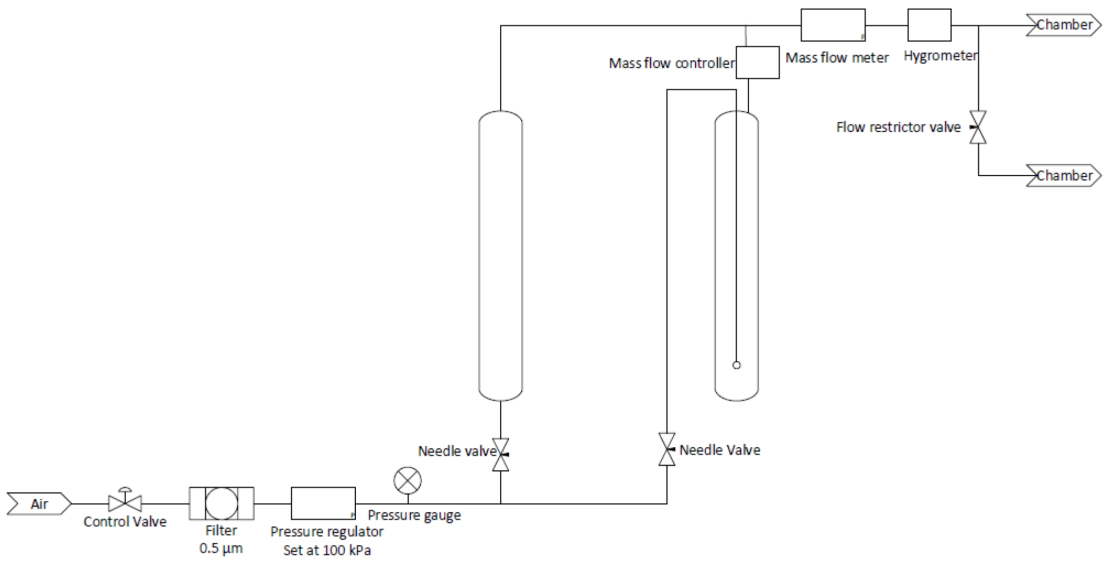

Figure 11: Process flow diagram for Design 6 for the automation of humidifier.

This design consists of adding a mass flow controller to control the wet air flowrate of the bubbler. This design is very simple and the level of the water in the bubbler can be visually inspected to make sure that it does not exceed a specific limit. The price of the mass flow meter is R22 310 including VAT.

The designs which are the best in terms of cost, simplicity and practicality are Design 2, Design 4 and Design 6. Due to the shut close valves which are installed in design 2 and 4 which serve as a safety hazard because they could lead to the build-up of pressure in the bubbler. Design 2 and Design 4 are therefore are not user friendly. The best automatic humidifier design is Design 6.

6. Manual humidifier designs

The manual designs of the BOCLE/SL-BOCLE are discussed below. The best design of the manual humidifier will be compared to the best automated humidifier to see which design is best and whether the automation of the humidifier is a viable option.

6.1 Design 1

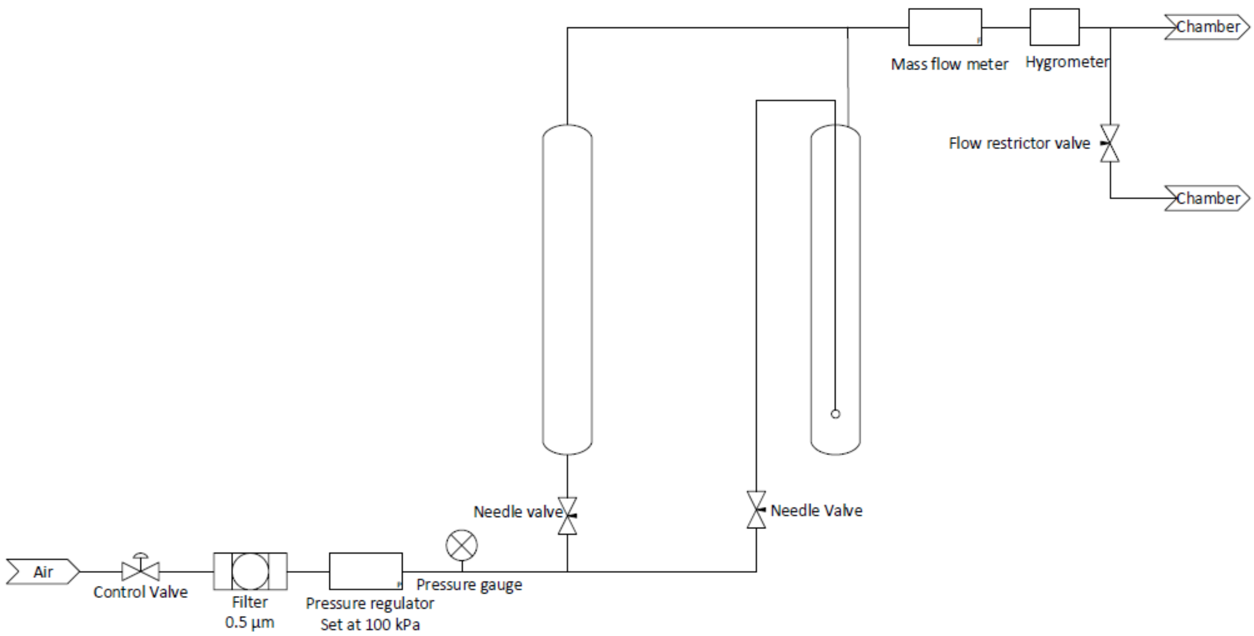

Figure 12: Process flow diagram for manual humidifier.

Figure 12 shows the manual humidifier which is the design that came with the original BOCLE/SL-BOCLE machine. The manual humidifier has two needle valves for the compressed air into the dryer and the bubbler which can be adjusted to the required relative humidity. The water level of the bubbler can be detected by visual inspection.

6.2 Design 2

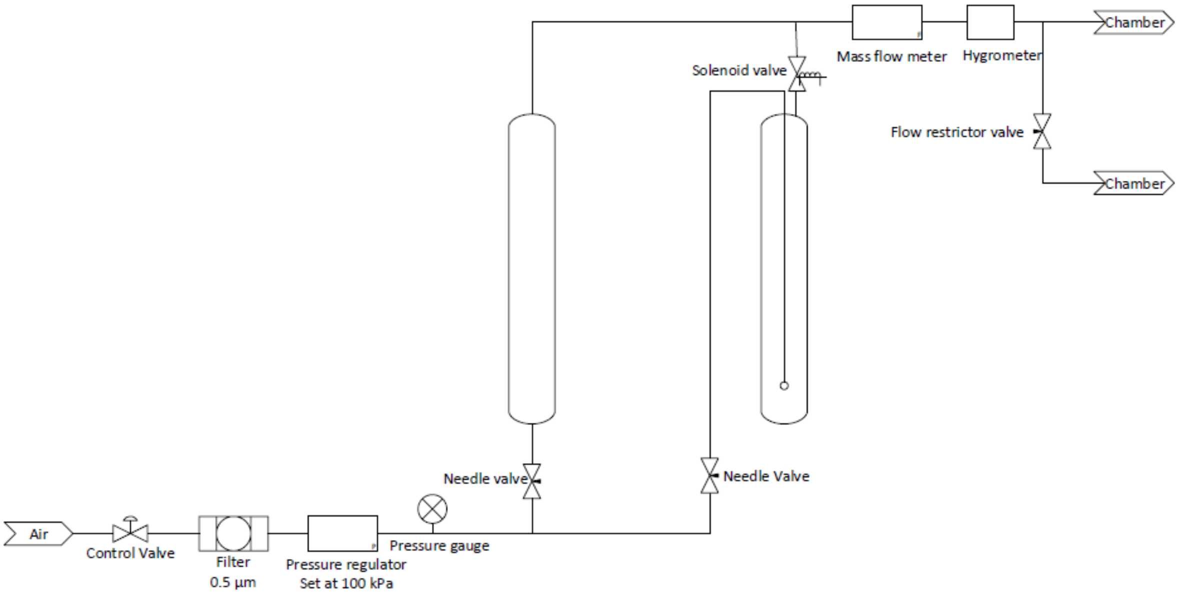

Figure 13: Process flow diagram of a manual humidifier with a level sensor.

Design 2 shown in Figure 13 shows the manual humidifier which has a level sensor and a solenoid valve which acts as a shut close valve. The level sensor detects the level of the water in the bubbler and when it reaches a certain level the solenoid valve shuts close. This safety mechanism is installed to improve the safety of the machine and ensure that the water does not go inside the pipes.

The disadvantages of the shut close valve is that a pressure build-up can occur when the shut close valve is closed which can cause a safety hazard. Table 6 shows the equipment required to implement Design 2 and the prices of the equipment.

Table 6: Prices of equipment for manual humidifier Design no 2.

Equipment	Prices
Solenoid valve	R1 454.75
Slosh guard	R3343.15
Level sensor	R118.62
	R4 916.52

The best manual humidifier design is the original design which came with the BOCLE/SL-BOCLE in Design 1 because it is safe to use. Design 2 can cause a pressure build up in the bubbler which can cause a safety hazard.

The two designs, the manual humidifier Design 1 and the automatic humidifier Design 6, will be compared further to see the performance of both designs by coding a dynamic simulation of the manual humidifier and coding a PID controller simulation for the humidifier with a mass flow controller of the wet air stream.

7. Modelling

Modelling of the humidifier system involved using equations and laws. The wet air coming out of the bubbler is dependent on the following:

- The gas flow rate into the column which is dependant of the flowrate of compressed air fed into the column
- The bubble size which is dependent on the gas flow rate and the sparger
- The pressure
- The inlet temperature of the compressed air
- The temperature of the water which is dependent on the atmospheric temperature, the inlet compressed air temperature and the compressed air flowrate.
- The compressed air humidity
- The composition of the compressed air
- The water level of the bubbler.

The dry air coming out of the dryer is dependent on the following:

- The temperature, flowrate and humidity of compressed air.
- The temperature of the atmosphere.
- The conditions of the silica gel beads.

The factors which affect the dry air stream and wet air stream which cannot be controlled by the user are the compressed air temperature and humidity, and the atmospheric temperature.

The factors which determine the chamber humidity are the following:

- The atmospheric temperature and the atmospheric humidity
- The wet air flow rate and the wet air humidity
- The dry air flowrate and the dry air humidity

The temperature stays relatively constant for short. Large changes can be seen during change of seasons. The humidifier model was done around the mixing point of the humidifier where the dry air coming for the dryer mixes with the wet air coming from the bubbler. These two flowrates mix to form the conditioned air with a specific relative humidity. This was done to simplify the model for the dynamic simulation.

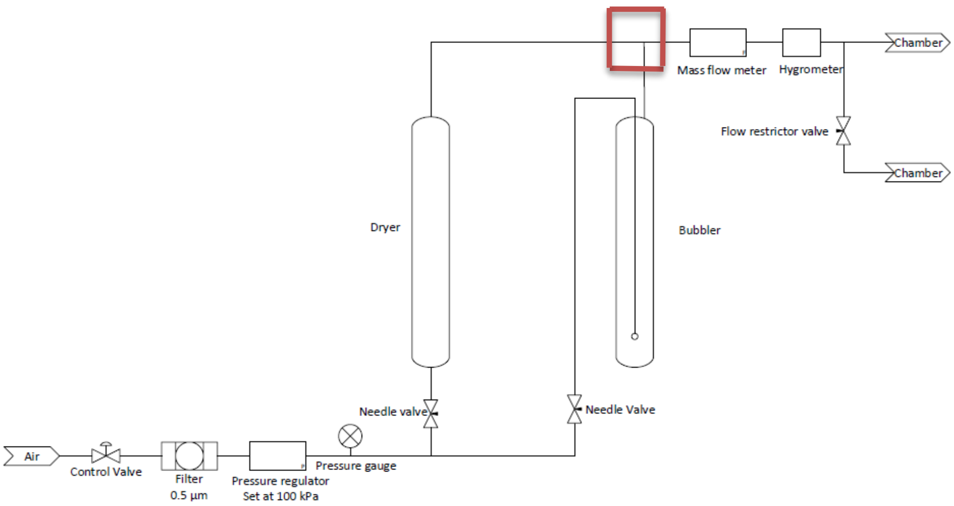

Figure 14: Modelling of humidifier done around the mixing point.

The dry air has a percentage saturation humidity of close to 0% since it has been passed through the dryer. The wet air has a percentage saturation humidity which is close to 100% since the wet air out of the bubbler is saturated. The psychrometric chart shown in Figure 15 was used to find the humidity and enthalpy of the wet air and dry air for the python dynamic simulation model.

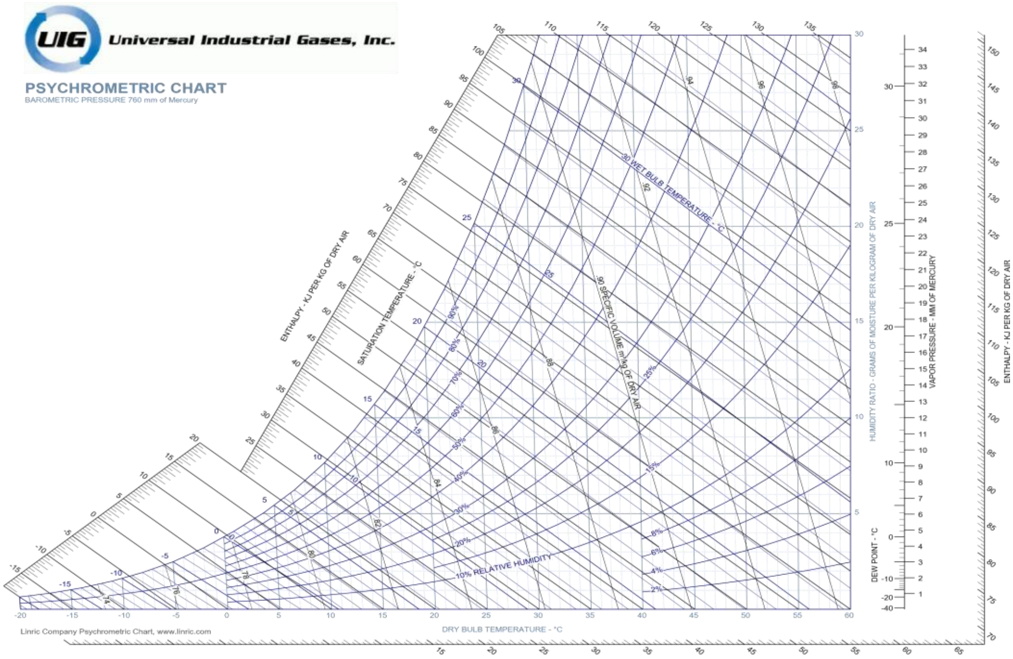

Figure 15: Psychrometric Chart for a water and air system (SampleTemplates, 2018).

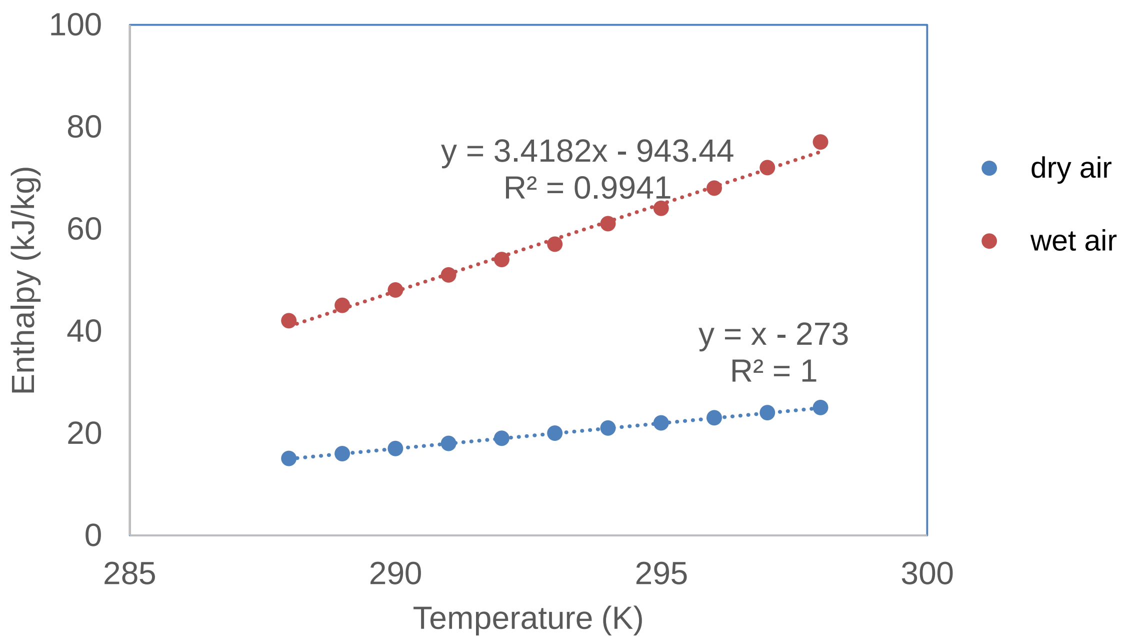

Figure 16: Correlation for the enthalpy versus temperature of wet air and dry air.

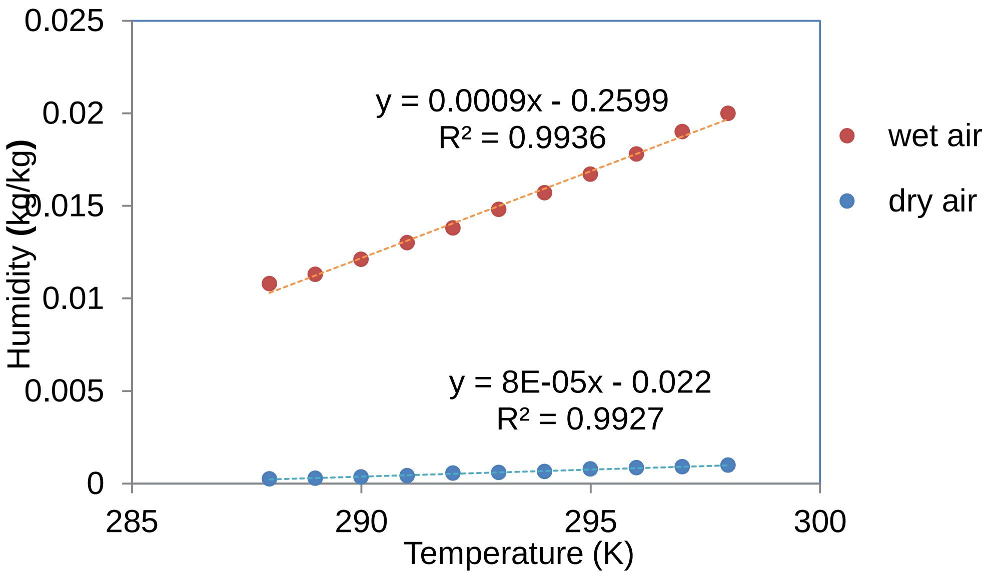

Figure 17: Correlation for the humidity versus temperature for the dry air and wet air.

The results of the dynamic simulation for a constant dry air and wet air flowrates ($1.9\ l{\cdot}min^{-1}$ dry air and $1.9\ l{\cdot}min^{-1}$ wet air) and assuming a pressure drop of 17 kPa.

Figure **18**, Figure 19 and Figure 20 show the results from the dynamic simulation.

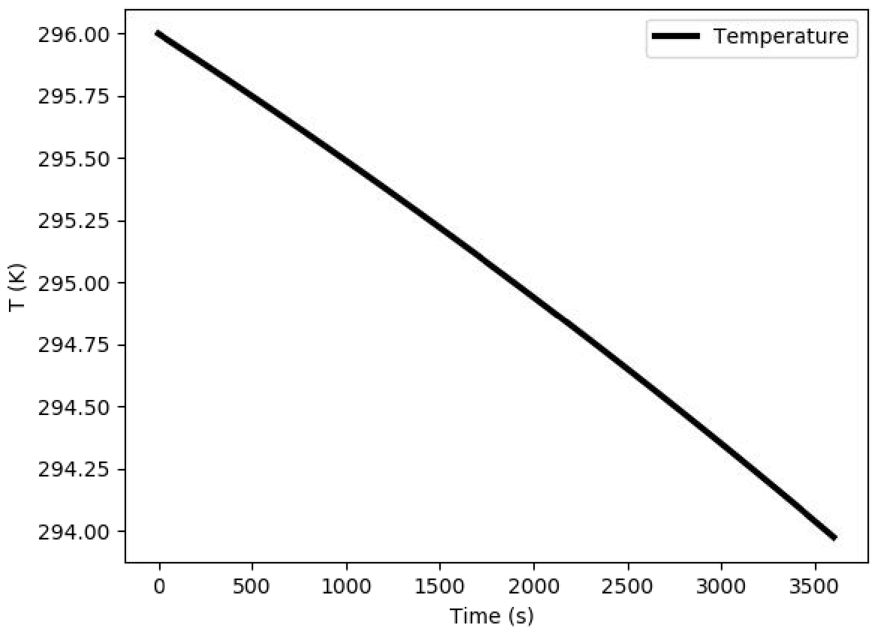

Figure 18: Temperature versus time graph for the humidifier simulation.

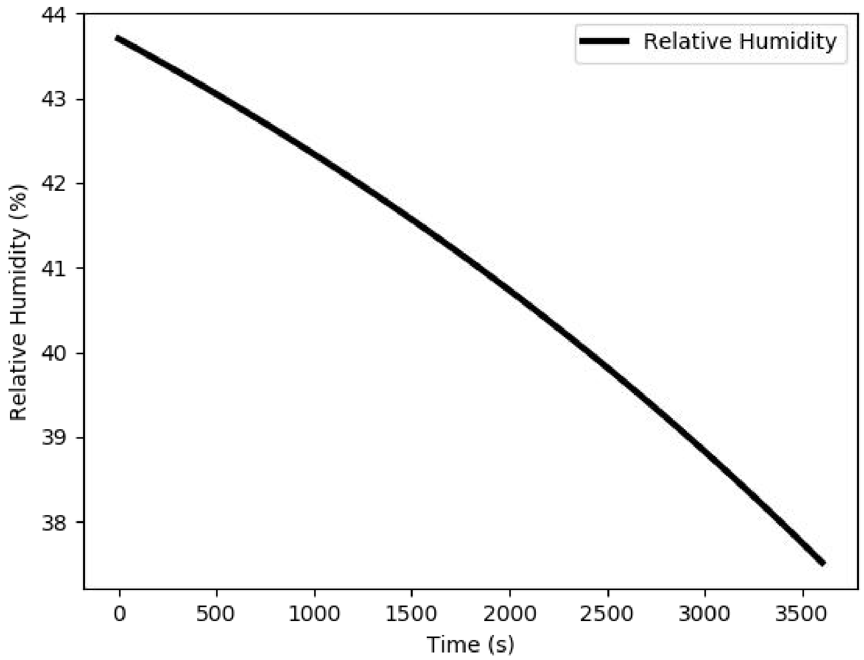

Figure 19: The Relative humidity versus time graph for humidifier simulation.

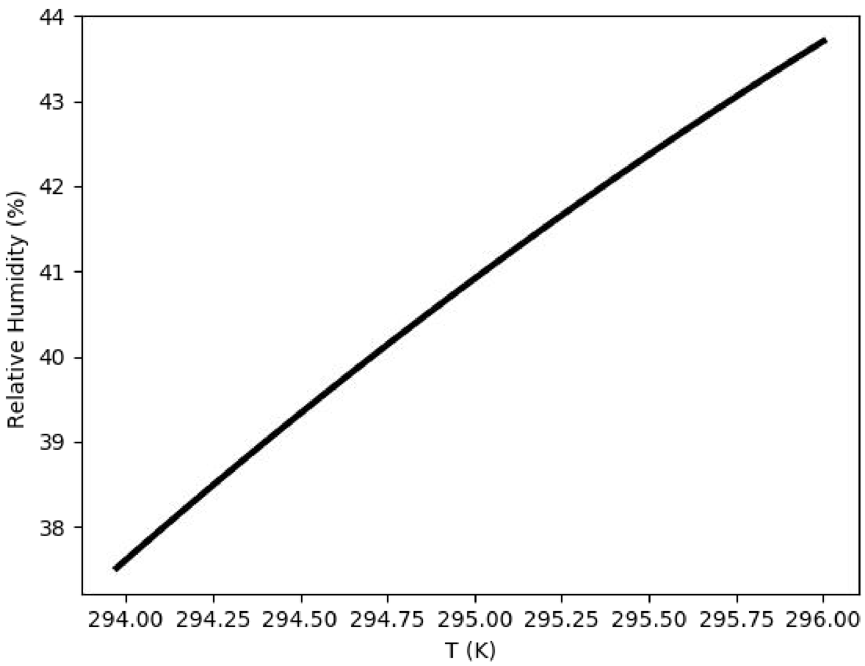

Figure 20: The relative humidity versus temperature graph for humidifier simulation.

To test whether the hygrometer and humidifier equipment work properly the dynamic simulation of the humidifier was modelled in python to see the percentage error between the model and the rig using the Equation 12.

$$\% \, error = \frac{RH_m - RH_e}{RH_m} \times 100 \tag{12}$$

The BOCLE relative humidity percentage error at a temperature of 22.6564 ºC is

$$\%error = \frac{42.84 - 40.87}{42.84} \times 100 = 4.6 \, \%.$$

The percentage error is lower than 5% so the performance of the humidifier is acceptable.

8. Control

The PID controller of design 6 was implemented in python to see the results of controlling the humidifier. The mass flow controller controls the wet air flowrate in order to achieve a desired relative humidity. The set point of the relative humidity is 10%. Tuning of the controller was done using the the empirical gain tuning method. The response of the controller with k = -0.8, tau_i = 100000, tau_d = 1 is shown in Figure 21 and Figure 22. Figure 21 shows you the controller output with the upper saturation limit and the lower saturation limit.

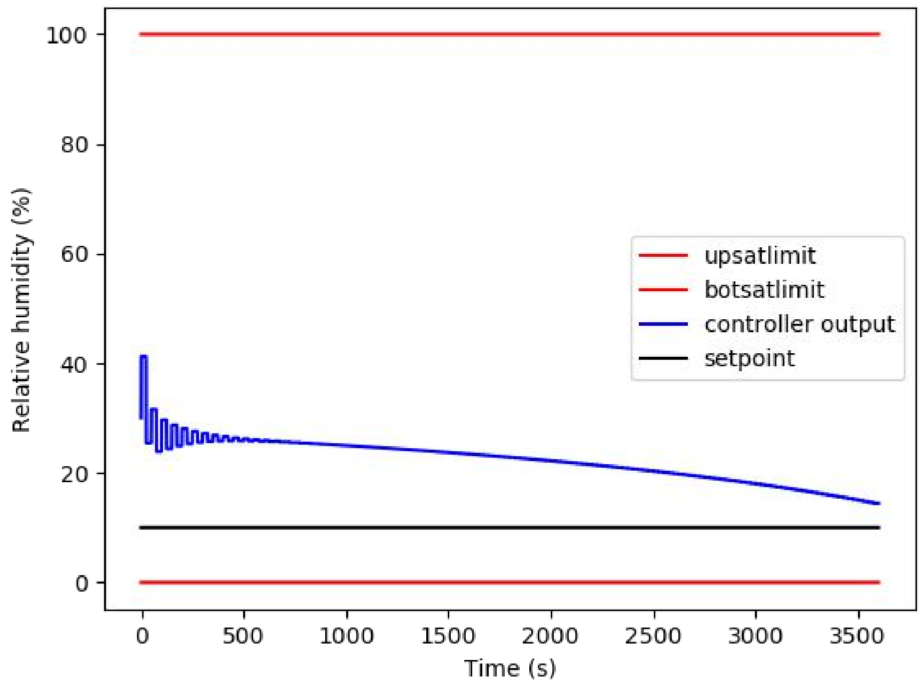

Figure 21: Controller output with the upper and lower limits.

Figure 22 shows the controller output with the setpoint plotted only so the results can be seen on a smaller scale.

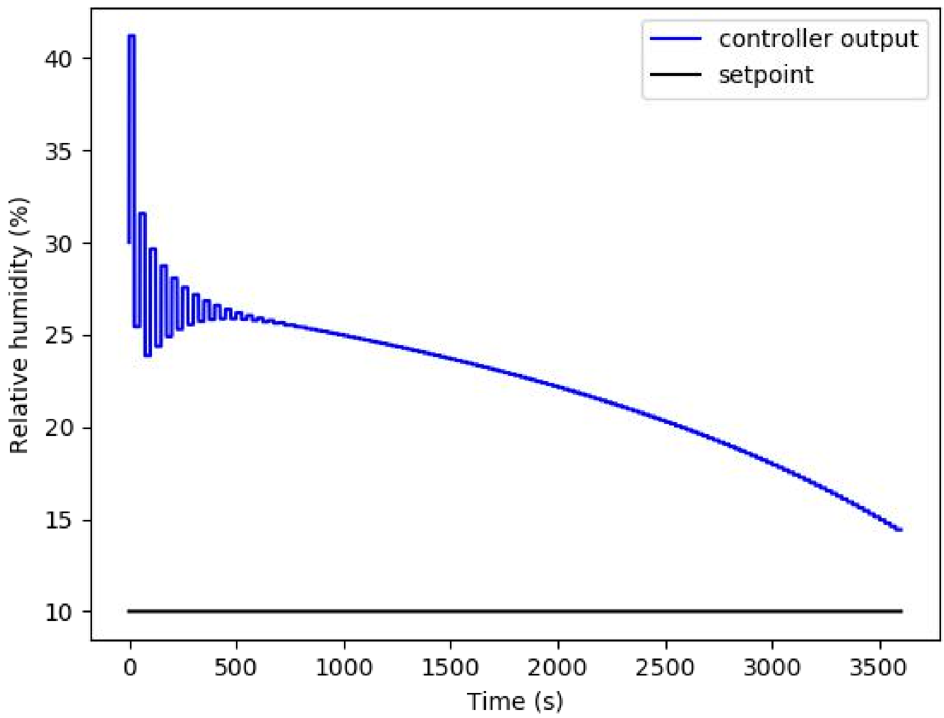

Figure 22: Output of the wet air controller with set point.

The controller is limited in range because the conditioned flow to the chamber is set to 3.8 l·min^{-1}. The controller controls the wet air flowrate. A change in the the wet air flowrate will lead to a change in a dry air flowrate in order to still achieve the conditioned air flowrate of 3.8 l·min^{-1} but the controller is only on the wet air. The controller output is plotted over a range of one hour; the controller needs more time to converge to the set point as shown in Figure 21 and Figure 22. The controller would work much better if the conditioned air did not have to be 3.8 l·min^{-1} or if the dry air flowrate was also controlled. The best decision between the automated humidifier design 6 and the manual humidifier Design 1 is the manual humidifier Design 1. The performance of the humidifier is acceptable. The percentage error is below 5%.

9. Friction measurement for the SL-BOCLE

The following method is used to calibrate the friction signal of the SL-BOCLE. On the BOCLE/SL-BOCLE PC computer, press start and then go to OPTO EIEIO (the OPTO machine should be on).Open the OPTO EIEIO and press connect as shown in Figure 23. Make sure that the correct IP address is inserted. The IP address for the BOCLE/SL-BOCLE is 137.215.117.226. Make sure that the SL-BOCLE Simulink simulation model is running.

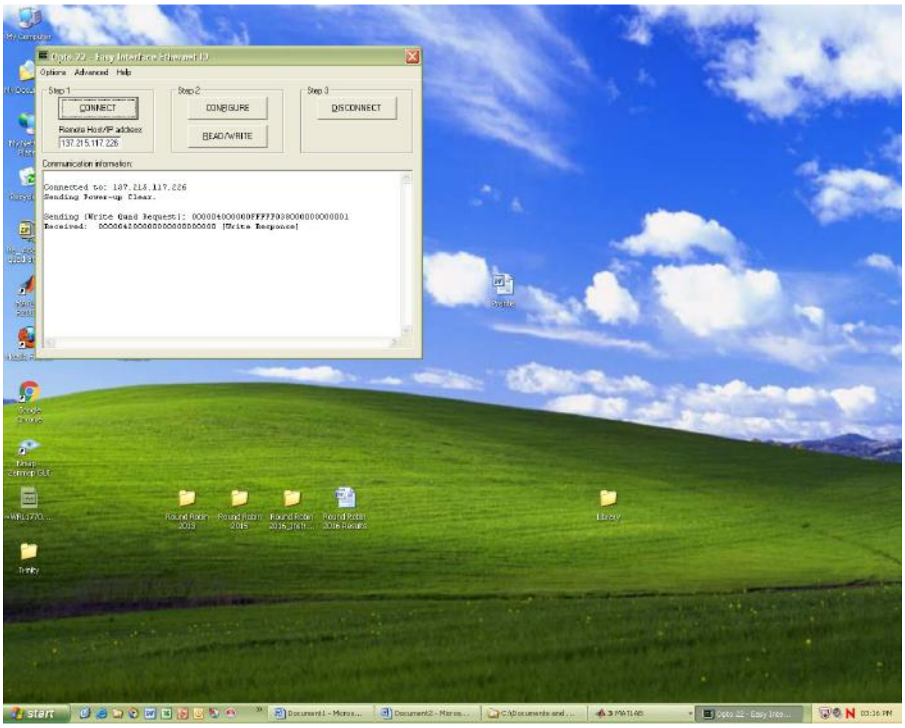

Figure 23: Connect to OPTO EIEIO.

After connecting to the OPTO EIEIO, Press read/write.

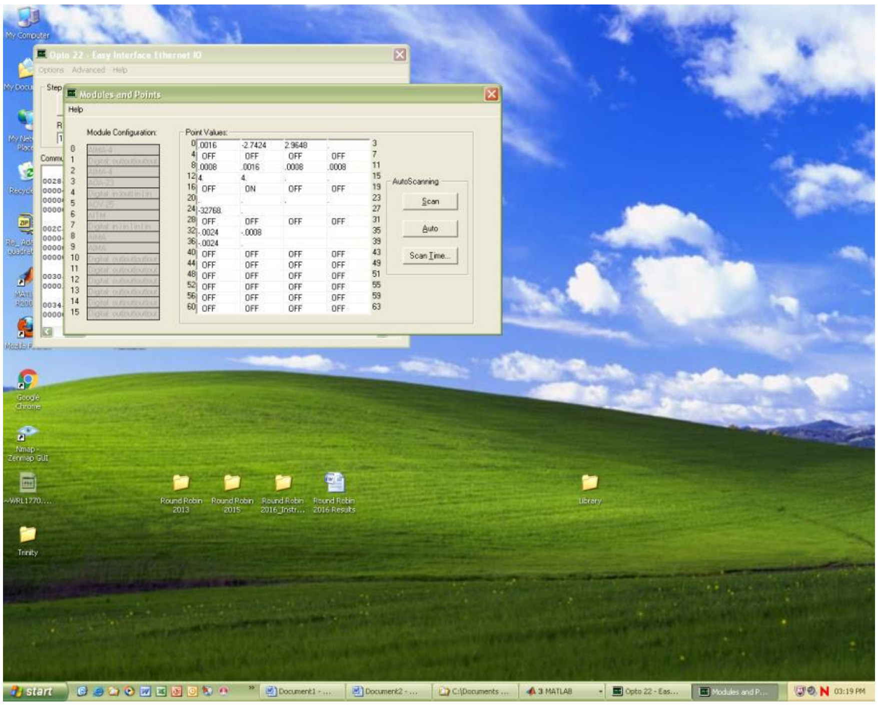

Figure 24: The voltage and current readings of the OPTO 22.

Table 7: Friction measurement signal transformation

Unit	Line	Output (V)	Minimum required resistance (Ω)	Input to OPTO module (mA)
BOCLE	331/441	0-1	± 50	0-20
SL-BOCLE	551/661	0-4	± 200	0-20

The friction measurement of the SL-BOCLE is connected on the module 0 on the first position. The load was change and signal reading on the OPTO 22 was noted. The calibration signal to Simulink is shown in Figure 25.

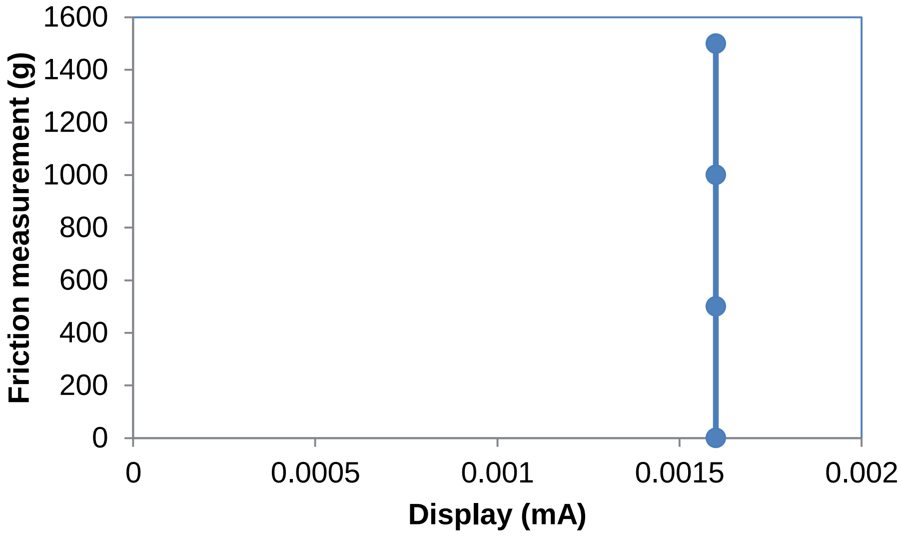

Figure 25: Friction force Simulink signal calibration for SL-BOCLE.

The calibration does not show a linear response like the BOCLE Simulink signal calibration. This could be due to a loose connection of the new load cell which was installed in 2012 because the wiring network for friction measurement has been checked and can be confirmed that it is connected well because the Simulink and external friction force indicator values are the same.

10. Test fuel temperature Control

The temperature control of the BOCLE /SL-BOCLE has been re-established due to the new pump installation. The BOCLE/SL-BOCLE uses an external water circulating system to maintain the test fuel tank assembly at a required temperature of 25 ºC. The submersible pump circulates water through the built-in heat exchanger of the fuel test tank.

Depending on the ambient temperature of the laboratory the water reservoir container should be 5 ºC above the set point temperature or 5 ºC below the set point temperature. The set point temperature for the BOCLE/SL_BOCLE is 25 ºC. The two scenarios are the following:

- Laboratory temperature below 25 ºC

  If the laboratory ambient temperature is below the set point, add hot water into the reservoir container to bring the temperature up to approximately 30 ºC. Set the machine to "HEAT'' as well as on the BOCLE/SL-BOCLE Simulink model.
- Laboratory temperature above 25 ºC

  If the laboratory ambient temperature is above the set point, add a few ice cubes or ice water into the reservoir container to bring the temperature down to approximately 20 ºC. Set the machine to ''COOL'' as well as on the BOCLE/ SL-BOCLE Simulink model.

11. Simulink to LabVIEW conversion

Installation of LabVIEW on the BOCLE/SL-BOCLE PC was not a success because there was not enough space to install it. The other problem that was encountered is that the BOCLE/SL-BOCLE PC is also used as the SRV machine PC. The SRV program works with an old operating system (Windows xp) and LabVIEW cannot operate on that operating system. Updating the operating system to the one which works with LabVIEW could cause the SRV to not function. The alternative options were to get a new PC or use an existing PC which is in the tribology that already has LabVIEW installed. The PC for the FZG machine was used as the BOCLE/SL-BOCLE LabVIEW PC because it already has LabVIEW installed on it and the PC was already in the LAB and therefore there was no need to get a new PC. The BOCLE Simulink model was the focus for this section and is shown in Figure 26.

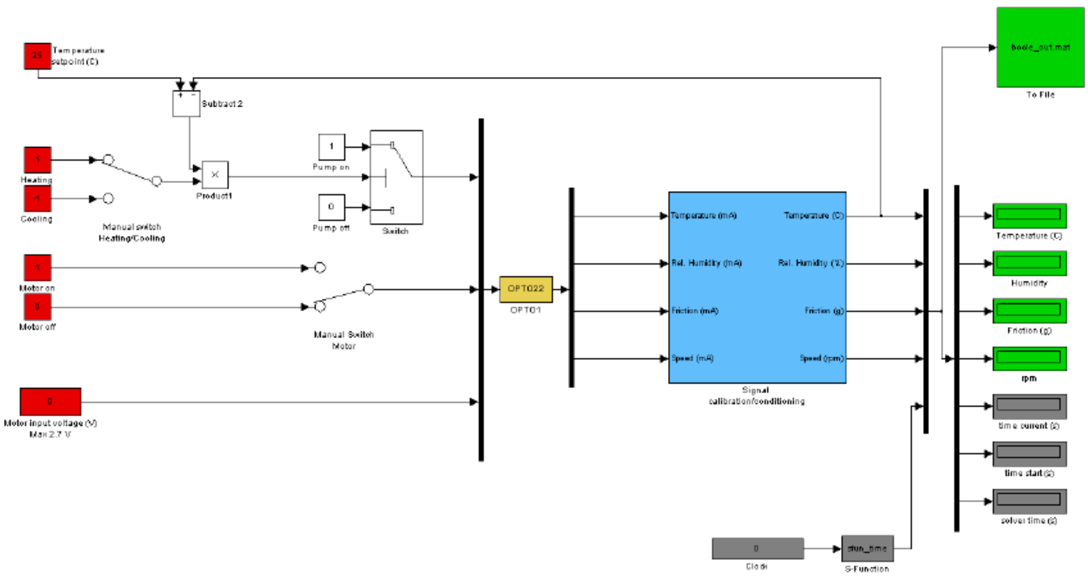

Figure 26: Simulink simulation model for the BOCLE**.**

The strategy for converting the Simulink simulation model to LabVIEW was to first find a way to take the existing code and convert it to LabVIEW and then try decoding the converted file. If this strategy does not work out then the next step would be to start the conversion of the Simulink simulation model from scratch.

The first attempt was using the function matlab script node in LabVIEW to import Simulink simulation model into LabVIEW. This did not work as the matlab script node is used for adding MATLAB coding into LABVIEW. The file which needed to be converted was a Simulink simulation model.

The second attempt was interfacing MATLAB with LABVIEW by creating a virtual port between the two softwares (MATLAB and LabVIEW) so we can create data communication between the two softwares. This method requires MATLAB to be installed on the same PC as the LabVIEW PC. The other softwares that needed to be installed for the interfacing to be successful were VSPE (Virtual Serial Port Emulator), flash magic, NI-VISA and MATLAB. The Virtual Serial Port emulator is a software which provides the utility to access multiple COM ports on the same PC. The flash magic software is a terminal software where you can check whether your virtual port is connected properly it receives information from the COM connector and displays the input information which has been received from the COM connector. The NI-VISA add on to LabVIEW is a runtime engine which provides runtime support for NI-VISA applications. Without the NI-VISA software you would not be able to see the virtual COM Connector in LabVIEW due to the runtime being too slow. The softwares were successfully installed onto the LabVIEW PC except for MATLAB. The MATLAB coding needs to be implemented for the interfacing to be complete. The block diagram and the front panel for the interfacing are shown in Figure 27 and Figure 28 respectively.

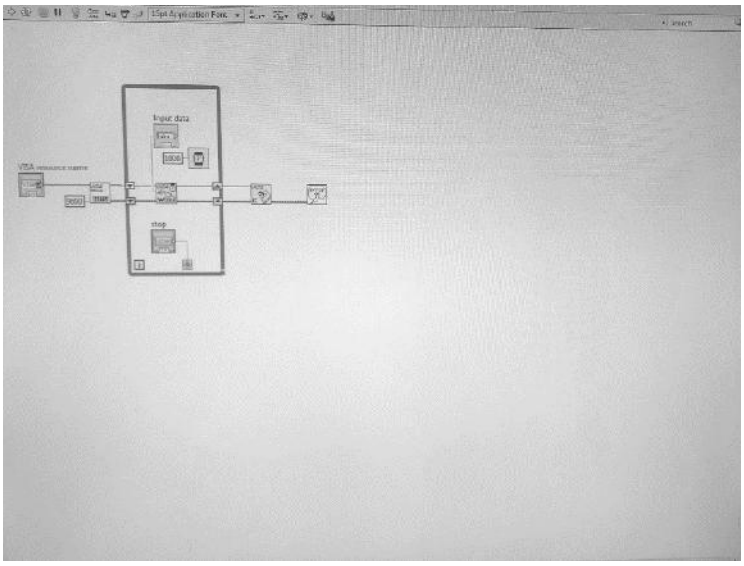

Figure 27: Block diagram of the code for interfacing MATLAB and LabVIEW.

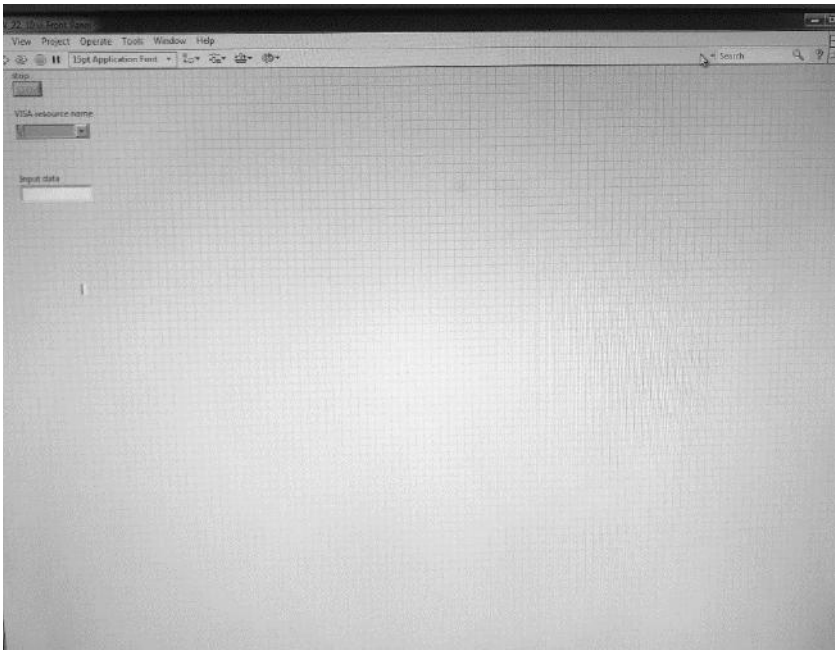

Figure 28: Front panel of the interfacing MATLAB and LabVIEW.

Some knowledge of how to code and use SIMULINK and LabVIEW was learnt through the previous attempt of trying to convert the existing code in Simulink to LABVIEW. The final attempt was to start the conversion from scratch. The BOCLE calibration model was attempted first for the conversion into LabVIEW because it is a simpler model than the Simulink BOCLE simulation model. It was realised that the control design and simulation module had to be added to LabVIEW in order to implement transfer functions. Figure 29 and Figure 30 shows the block diagram and from panel of the calibration model respectively in LabVIEW. Difficulties were encountered in connecting the transfer functions to the rest of the model.

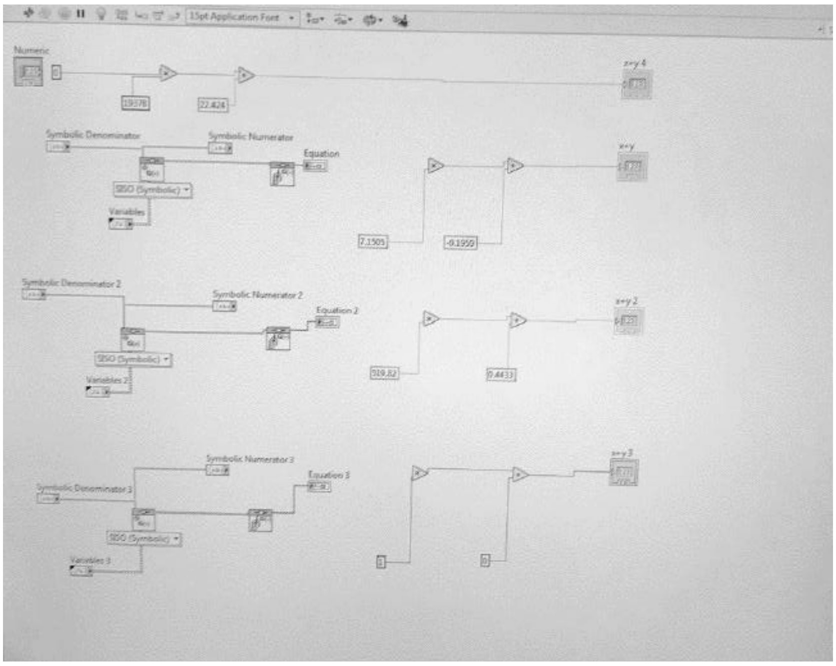

Figure 29: Block diagram of the calibration model of BOCLE on LabVIEW.

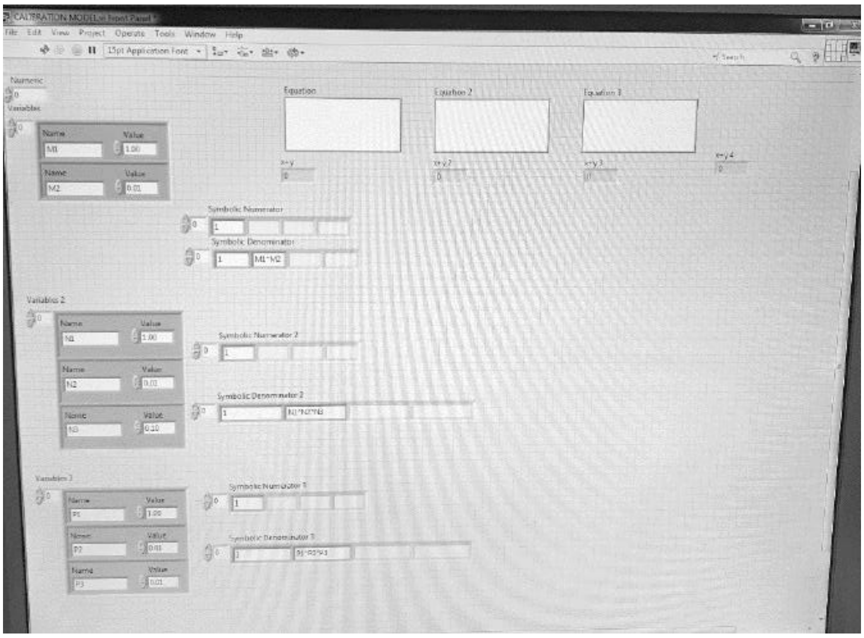

Figure 30: Front panel of the calibration model of the BOCLE in LabVIEW.

12. Conclusion and Recommendations

The missing components have been replaced for the BOCLE and the SL-BOCLE. The BOCLE humidifier works well and the automation of the humidifier is not necessary.The humidifier performance of the SL-BOCLE can be examined after the new wet air needle valve is installed. The temperature control of the fuel oil was re-established: the new pump recirculates water from the water reservoir into the heat exchanger. The friction force calibration was completed on the SL-BOCLE and the results showed that there is something wrong with the connection of the load cell. It is recommended that the wiring of the load cell for the BOCLE and SL-BOCLE be checked out to see whether all the wires are connected properly because the external friction indicator does not give the correct readings of the load and does not change much with a change in load.

The Simulink to LabVIEW conversion has not been completed due to the time constrain but some progress has been made.

It is recommended that in the future when doing maintenance of the the bubbler cylinder, inner diameter of the cylinder should be cut to size so the silicone can be removed from the assembly of the bubbler and no longer be used.

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