UTS

41030 Engineering Capstone

Investigation into Rangehood Mounted Fire Detection System

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1. Abstract (Or Executive Summary)

Most household fires are started in the kitchen more specifically on the stovetop, however, this is an area in which traditional fire detection systems are not suitable. Existing kitchen fire suppression systems are expensive and often prone to false alarms. After conducting research I began the development of an Arduino-based sensor array. The final array featured the ability to record ambient temperature and humidity, a flam sensor, a PM2.5 sensor for counting airborne particulates of various sizes and a smoke detector was also included.

Various experiments were conducted with the sensor array data was collected with just burners on in different configurations, a smoking wok was used to show a situation that should be flagged as a hazard, and this data was compared to the data collected in the non-hazardous conditions of a large boiling pot of water as well as a Flambe. Analysis of the data collected reveals interesting and useful trends. Temperature and humidity were not as useful as expected as they seemed to vary steadily over time and the smoke detector was useless. The PM25 showed the most promise with particles > 10um / 0.1L air being 52 times more abundant in the hazardous test than in any other non-hazardous test. The flame sensor alos showed promise as it could not detect the gas burners of burning alcohol but could detect both a lighter and a match. If further development were to take the PM2.5 and flame detector would be at the focus.

2. Introduction

Cooking is, by far, the leading cause of home fires and home fire injuries, with fire departments in the United States Responding to an Estimated 170,000 home cooking fires. These fires caused an estimated 135 deaths, 3,000 injuries and over $494 million in property loss. [US Fire Administration, 2023]
The Following report details research into various fire detection techniques and systems. It then describes the development of a proof of concept rangehood intergraded sensor suite that can differentiate between gas burners, a Flambé and oil fire. Finally, it will delve into the experimentation with the sensor array and the results and findings of said experimentation.

Many improvements were made to both the system itself as well as the methods used to organise the data. These improvements will be explored as they happened in relation to where they coincide with the reporting of said data.

This approach has been pursued as the most common cause of house fires is pots and pans catching fire. A dedicated and specialised fire detection system in this area will likely drastically improve alarm response times, quickly alerting occupants of emergencies. A specialised system would also reduce the false alarms known to occur with existing commercial kitchen fire suppression systems. Often ruining hundreds of dollars of food and putting kitchens severely behind schedule. These existing systems are also expensive. An effort was made throughout the development of the sensor array to use relatively cheap sensors. Budget constraints also made using an Arduino Uno the best option. The open-source nature and simplicity were also factors in this choice.

3. Acknowledgement of Country

I respectfully acknowledge the Traditional Owners and Custodians of the land on which we live and work, the Aboriginal people, and pay my deepest respects to their elders, past, present, and emerging.

Australia's history is deeply intertwined with fire, and the Aboriginal people have long held a profound understanding of fire management. Their intricate knowledge and practices in fire prevention have shaped the Australian landscape for thousands of years. By utilising controlled burns, they skillfully managed the land, promoting biodiversity and preventing larger, destructive fires.

With my research, I hope to continue this country's tradition of fire prevention and detection, always inspired by the techniques used by the original custodians of the land on which we live.

4. Literature Review

“Fire and smoke kill more people every year than many other forces. While controlled fire serves us in so many instances, uncontrolled fire can be of harm.” The rapid detection of fire and its control can save lives and property damage worth millions. Conventional and addressable are two main types of fire alarm systems, but unfortunately, these fire alarm systems often generate false alarms. (Sarwar, B., Bajwa, I. S., Jamil, N., Ramzan, S., & Sarwar, N., 2019) Throughout the conducted literature research, the above statement shares many common sentiments found in most similar solutions. Most solutions point to traditional fire detection systems' tendency for false alarms as a critical reason a new solution is beneficial.
The London fire brigade alone responds to a false alarm every 10 minutes, resulting in a loss of 37 million dollars a year. (Sarwar, B., Bajwa, I. S., Jamil, N., Ramzan, S., & Sarwar, N., 2019). False alarms also have many flow-on effects that aren't obvious at a glance,”A Novel Method for Smart Fire Detection Using Acoustic Measurements and Machine Learning: Proof of Concept. Fire Technology”(Martinsson, J., Runefors, M., Frantzich, H., Glebe, D., McNamee, M., & Mogren, O. 2022) points to issues such as unnecessary interruptions to business operations forces people to evacuate and introduces a high unnecessary traffic risk.

Kalina Szafarczyk. (2022). Found that 95% of surveyed facilities had experienced a false alarm in 2021. The article also points to False alarms having the added effect of occupants becoming indifferent to alarms. This nonchalant attitude can even occur in those monitoring the fire control panels. This nonchalant attitude can lead to fatal consequences. This is just another reason why a new system with a reduced risk of false alarms is something that many are investigating.

There have been attempts to improve the accuracy and reliability of traditional smoke detector systems. The Article “Reducing the Multi-Sensor Smoke Detectors Susceptibility to False Triggering” (Kalina Szafarczyk. 2022.) details an attempt to set up smoke detectors in various configurations and determine if there was a configuration that would drastically reduce false alarms. While some configurations showed a small reduction in false alarms, these would only be suitable for use under certain conditions, with their solution only applicable in rooms where dust and aerosols are commonly present. While this is an improvement, it still shows the need for a more drastic change in the fire detection approach to improve accuracy and reliability further.

While the motive to create a smart fire detection system is incredibly similar amongst the available literature, it is in the implementation where most differ. Almost all systems found in prominent literature utilise the Internet of Things (IoT), which “is a collection of wired and internet-accessible computers.”(Hariveena, Ch, Anitha, K., & Ramesh, P.,2020) “ Over the Internet, these machines can be linked and help us manipulate or gather data from them” (Hariveena, Ch, Anitha, K., & Ramesh, P.,2020). In the case of a fire detection system, the ‘Things’ are sensors and in the case of the Hariveena system “A gas sensor senses the presence of some CO2-like flammable gas. The temperature sensor senses any unexpected changes in the temperature of the room. Using a Raspberry Pi 3, the networking and data compilation is completed ”(Hariveena, Ch, Anitha, K., & Ramesh, P. ,2020).

A similar system that too relies on IoT and contains multiple sensors is the Intelligent Fire Warning Application Using IoT and an Adaptive Neuro-Fuzzy Inference System. (Sarwar, B., Bajwa, I. S., Jamil, N., Ramzan, S., & Sarwar, N. 2019). , however, it uses a temperature sensor, humidity sensor, and smoke and flame sensor. Where this system differs is in how the data is analysed. Rather than simply comparing values to thresholds in a more traditional way, such as the first system proposed by Hariveena, Ch, Anitha, K., & Ramesh, P, this system uses an AI-based fuzzy logic algorithm is used; “ to make the decisive decision based on the severity of the given circumstances.” “This purposed system utilises the fuzzy logic-based algorithm to detect the fire and, depending on the severity, activates the alarm and sends an alert message to the authorities.”(Sarwar, B., Bajwa, I. S., Jamil, N., Ramzan, S., & Sarwar, N. (2019) Both these IoT systems have their benefits, with the first being far more straightforward than the latter can be incredibly advantageous as it leaves less room for error and failure which is vital when dealing with something as destructive as fire. The fuzzy logic allowing more varied and decisive output can be very beneficial, especially in areas such as kitchens and bathrooms where false alarms can be common. Despite most systems making use of IoT, it is not necessarily beneficial for all systems, such as those with a very small survey area or systems looking to be simple and robust.

While almost all residential systems are proposing the use of IoT, there are however other approaches, particularly for outdoor and industrial use. These systems leverage “digital camera technology and video processing techniques”. These systems are computer vision-based fire detection systems that “employ three major stages. The first stage is the flame pixel classification, the second stage is the moving object segmentation, and the last part is the analysis of candidate regions. This analysis is usually based on two figures of merit; the region's shape and the region's temporal changes.” (Çelik, T., & Demirel, H. ,2009.) The performance of these systems is critically tied to the performance and accuracy of these stages. While they require a large amount of processing power, these systems can detect fire very successfully, but when done correctly, they can survey for fire very successfully.

Many of the proposed systems have been multi-sensor based, utilising a plethora of different sensors; however, there has yet to be a system that utilises the acoustic signals put out by fire. The article A Novel Method for Smart Fire Detection Using Acoustic Measurements and Machine Learning: Proof of Concept (Martinsson, J., Runefors, M., Frantzich, H., Glebe, D., McNamee, M., & Mogren, O. 2022) determines that the acoustic spectrum is a viable area for fire detection. The team found that their acoustic-based system could detect the presence of fire with 98.4% accuracy in a laboratory setting. This system relies on machine learning and has shown different responses based on the material that is set alight. The use of microphones could be helpful as a complementary signal in a multi-signal machine learning-based system; however, the authors point to much more needed research and development in the area before it is viable.

The research has shown the viability and advantages of many different sensors in the context of fire detection. The article Recent Advances in Sensors for Fire Detection, (Khan, F., Xu, Z., Sun, J., Khan, F. M., Ahmed, A., & Zhao, Y. 2022) expresses this point and also claims that while advancements to these sensors many are more useful in a different situation. There is yet to be a perfect general-use fire detection sensor. For example, local Heat sensors are accurate but slow as the fire must come to them, while optical heat sensors can be easily tripped if not correctly configured, resulting in false alarms in rooms such as kitchens where controlled fire is common.

All the systems focused on thus far have concentrated on detecting fire in a broad area, whether that be the whole home, a warehouse or a single room. By focusing on an area that causes more house fires than any other in the residential area, the stovetop rather than the whole home. The research will focus on warning the user before the oil reaches its combustion temperature and being able to determine the difference between the controlled fire of the gas burner and another source of fire. I was able to find one paper on a similar system with a focus purely on, “a sensor module that monitors the gas stove in the kitchen.” “All the gases produce CO2 during the combustion. In the proposed system, CO2 concentration is measured by an electrochemical CO2 sensor placed in the sensor module, which is installed near the gas stove. When the gas stove is turned on, the CO2 concentration increases due to the continuous combustion. Based on the measured concentration, an algorithm determines the on/off state of the gas stove”(Kweon, S.-J., Park, J.-H., Park, C.-O., Yoo, H.-J., & Ha, S. .2022) Using this data the system can determine whether the fire is from the gas burner or a separate source. This is a clever and mostly simple system I will use something similar as a starting point but wish to investigate further functionality. This research would also be useful in reducing false alarms due to controlled fire in other systems with this issue.

5. <u>Ranghood Mounted Sensor Array Development</u>

5.1 Design Used for Initial Testing.

From the outset of development, I decided that an Arduino Uno would be chosen to bring the sensor array together and collect the data. This choice was made due to time budgetary and time constraints, mostly because I had one and was familiar with the operation of the device and software. The open-source nature of the Arduino platform was also a beneficial factor, with many libraries existing to simplify sensor operation. Initially, I had a few sensors in mind that I wanted to be a part of the array. These were a temperature sensor, a humidity sensor and some type of smoke detector. However, these sensors were absent in the initial test completed for this report. The only sensor in use was the Linker Flame Sensor Module For Arduino.

Sensor Moduel

 Linker Flame Sensor Module [Jaycar, 2023]	This sensor has a flame-sensitive phototransistor. When a flame is present, it emits infrared (IR) and visible light. The sensor detects this light. It has Digital and Analog Output as well as interfacing easily with the Arduino controller. Unfortunately, this model does not have adjustable sensitivity, not allowing fine-tuning of the threshold for flame detection.

Why this sensor was chosen

One of my original goals was to be able to spot a flame with my sensor array, and by far the simplest way to achieve it seemed was through the use of a flame sensor. Theoretically, this sensor in a finalised system could spot a flame that was not the gas burners. If this were the case, it would be flagged in the system, allowing for this information to be used in conjunction with other readings to determine if this was a fire hazard as opposed to something like a flambe. However, I was unfamiliar with this type of sensor and wished to know its effectiveness in spotting flame and what burning fuel sources it could detect; hence, this sensor was isolated in the initial testing.

Initial Test Circuit

Appendix 1.1

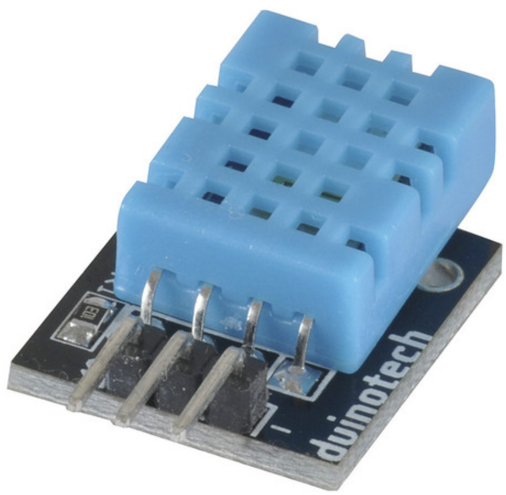
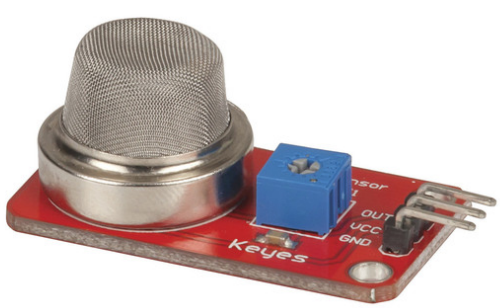
Initial Test Code

Appendix 1.2

5.2 Four Sensor Array

After the first test was completed, I finally got my hands on the two sensor modules that measured the three factors I knew I wanted to collect from the beginning of development that being temperature, humidity (handled by the same sensor model) and smoke detection. Implementation of these sensors was simple in the case of the wiring and the code having example code within their data sheets.

Sensor Modules

 Duinotech DT11 Temperature / Humidity Sensor Module	This module incorporates a temperature sensor and a humidity sensor within the same housing. The temperature sensor measures the ambient temperature, while the humidity sensor measures the relative humidity of the surrounding environment. The DT11 sensor provides digital output data. It sends both temperature and humidity data through a single pin. This sensor also has integrated signal conditioning, allowing it to easily interface with the microcontroller. [Components101, 2021]
 Duinotech MQ-2 Smoke Detector	The Duinotech MQ-2 Smoke Detector is A compact smoke detector module that can detect butane, propane, methane, alcohol, hydrogen and smoke. The sensitivity of this particular sensor can be adjusted through the use of a potentiometer on the PCB. The Duinotech MQ-2 provides digital output data and also has integrated signal conditioning, allowing it to easily interface with the microcontroller. [Jaycar, 2023]

Why these Sensors Were Chosen.
I included the Duinotech DT11 Temperature / Humidity Sensor Module to see how the measured factors would change over the operation of the stovetop. As almost all tests began from ambient conditions, this module was useful in establishing and showing baseline conditions. Changes in humidity levels can also indicate the presence of smoke or steam; hence, I was interested in the viability of this factor in the early warning fire detection system. For this to be the case, the sensor would have to give noticeably different readings for both humidity and smoke for this to be viable. The main reason I wanted to measure temperature throughout my testing was to see how the temperature varied depending on the normal operating state of the stove for example, how temperature would change with one burner on compared to two and so on.

This sensor was reliable and provided helpful data throughout my testing that was helpful at establishing baselines; however, neither temperature nor humidity was especially useful in detecting a fire hazard, especially where a key factor of this investigation was determining the difference between normal cooking flame and dangerous flame.

While I did not think a smoke detector would be of much use in this system, considering its location right near a stovetop, it is the most common sensor used in household fire alarm systems, and I wished to see how poorly it would act in this circumstance.
My assumption was correct throughout my testing; The smoke detector was of little use, and I was unable to uncover any useful information from it throughout my testing. Whether this was pulley due to the area in which it was operating, I cannot tell. It may be that the sensor was faulty.

Four Sensor Array Circuit Diagram
Appendix 2.1

Four Sensor Array Code
Appendix 2.2

5.3 Finalised Sensor Array.

In the testing completed with the four sensor array, a gap quickly formed in the information, knowing a change would need to be made for a satisfactory conclusion to be found. The investigation quickly showed a particular sensor that could be the solution. The finalised version of the array included one additional sensor, the PMS7003 Laser PM2.5 Sensor.

Sensor Module

<table>
<tr>
<td>

PMS7003 Laser PM2.5 Sensor</td>
<td>The PMS7003 is a laser-based particulate matter (PM) sensor designed to measure the concentration of airborne particles with a diameter of 2.5 micrometres (PM2.5) and other sizes.

The sensor uses laser scattering technology to detect and count particles in the air. A laser beam is directed into the air sample, and scattered light is measured to determine the concentration of particles.

This version of the PMS7003 includes a built-in fan to ensure a consistent flow of air through the sensor for accurate and reliable measurements.</td>
</tr>
</table>

Why this Sensor Was Chosen.
A stovetop produces many particles into the air, whether that be in the form of smoke, steam gasses, etc. I believed the key to the early warning system and differentiating between normal and dangerous stove top conditions was telling these emissions apart. My research suggests that these particles would be of different sizes; hence, the PM2.5 was an obvious addition to the system. This was not always going to be the last sensor; however, during initial testing with the PM2.5, it became clear that this would be the most pivotal sensor in the system.

Finalised Array Circuit Diagram
Appendix 3.1

Finalised Array Code
Appendix 3.2

6. Experimentation

6.1 Flame Detector test

The very first testing was done to test the fame sensor for its usefulness and sensitivity as well as to ensure that the code functioned correctly. My hypothesis for this test was that the flame sensor would detect all three types of fire at a range of 50mm with a narrow field of detection (FOD).

Method

- The circuitry was set as shown in Appendix 1.1 and the code used can be seen in Appendix 1.2.
- Once the system was started I received a recurring “Safe” message in the console.
- The source of the fire was brought close to the sensor if it detected the flame a “Fire” message was shown in the console.
- If this was the case I moved the lighter back to get a maximum range of accurate reading, noting down the distance.
- I then moved the lighter around to get an idea of the field of detection (FOD).
- I completed this method for a lighter the Stovetop, burning hand sanitiser and a match.
    - For the stovetop the sensor was moved rather than the source.

Results

Fire Source	Detection	Detection Distance (mm)	FOD at Max range
Lighter	Yes	55	±5°
Stove Top Burner	No	N/A	N/A
Match	Yes	55	±5°
Hand Sanatier (Alcohol)	No	N/A	N/A

Discussion

The flame detector was successful at constantly spotting both the lighter and the match at a range of 55mm with a field of detection of ±5° from the centre axis of the sensor direction at its max range. This was as I suspected and what I thought would be consistent for all sources. This was not the case the sensor was unable to ever detect the flame from the stove top burner or the burning hand sanitiser. This suggests that the flame detector is not sensitive to the IR emission spectrum of these flames. This was very interesting and a factor that could be extremely useful, especially considering the environment of the intended use.

Conclusion & Recommendations

The initial testing of the flame detector yielded promising results especially the specific tuning of the sensor allowing it to detect fire from a match and a lighter but not from the stove top gas burner or the burning alcohol. While the range and field of detection were as predicted, the values were still very small. These sensors could potentially be used in a stovetop fire detection system however a significant number of them would have to be used to account for the lack of range and small FOD. investigation into similar sensors with greater range and FOD could be highly beneficial to the fire detection system however this is not currently in the project's scope.

6.2 Stovetop States

The following section will detail the 2nd and 3rd sets of experimentation that took place that is because they are the same except for two key differences. For the first test, the extraction test was off and for the second it was on and the final version of the sensor array was used. The purpose of this experimentation was to view how significantly the measured conditions varied depending on the state of the stovetop. I hypothesised that the conditions would vary drastically from a single burner being on compared to more and that the extraction would have a large effect on all measured parameters.

Method

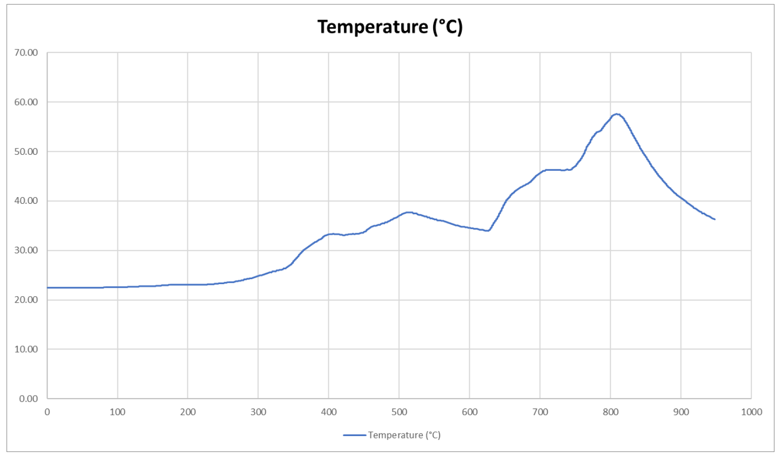
- The circuitry was set as shown in Appendix 3.1 and the code used can be seen in Appendix 3.2.
- Connected USB cable from the laptop to the sensor array
- Ensure data is being collected correctly.
- The sensor array was mounted as shown in Appendix 4.1 on the range hood.
- Put extraction into the required state in this case, on for the first test and off for the second.
- Began data collection of ambient conditions for more than 60 seconds.
- Then the stove top conditions were changed every 60 seconds proceeding through the below list of states
    - Burner 1 (B1), Burner 2 (B2), Burner 3 (B3), Burner 4 (B4), Burner 5 (B5), Burner 6 (B6), Burner 1&2(B1&2), Burner 5&6 (B5&6), Burner 3&4 (B3&4), All Burners and Finally and Egg was fried on burner 6 as the final state of the test.
    - A Labelled Diagram of the stovetop can be seen in appendix 4.2

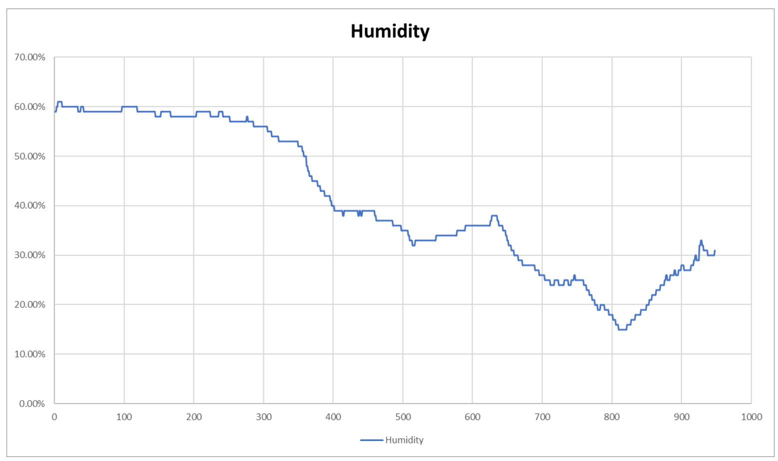
Results

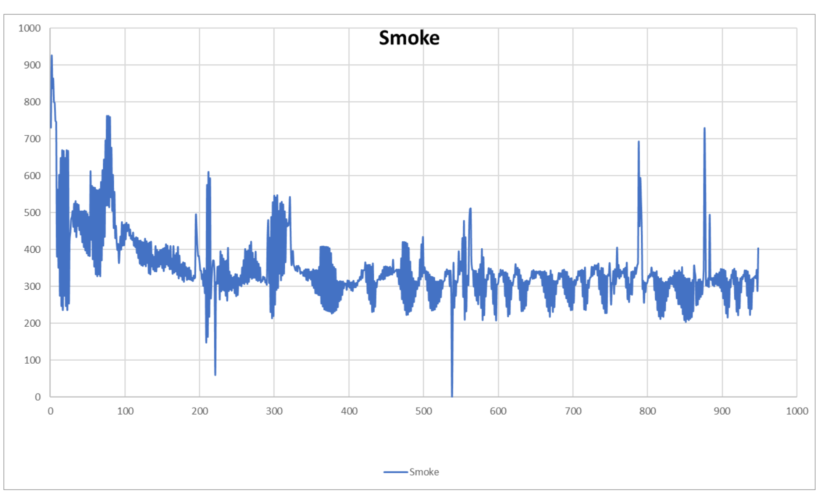
Full results for the test can be found in “Data and Graphs.xlsx” at
https://github.com/H0NKS/Investigation-into-Rangehood-Mounted-Fire-Detection-System
Larger versions of graphs can be seen in Appendix 5

Extraction Off

Time Line	
State	Time (Seconds)
Ambient	1
Burner 1	217
Burner 2	277
Burner 3	337
Burner 4	397
Burner 5	457
Burner 6	517
Burner 1 & 2	577
Burner 5 & 6	637
Burner 3 & 4	697
All Burners	757
Egg Frying	817
End	948

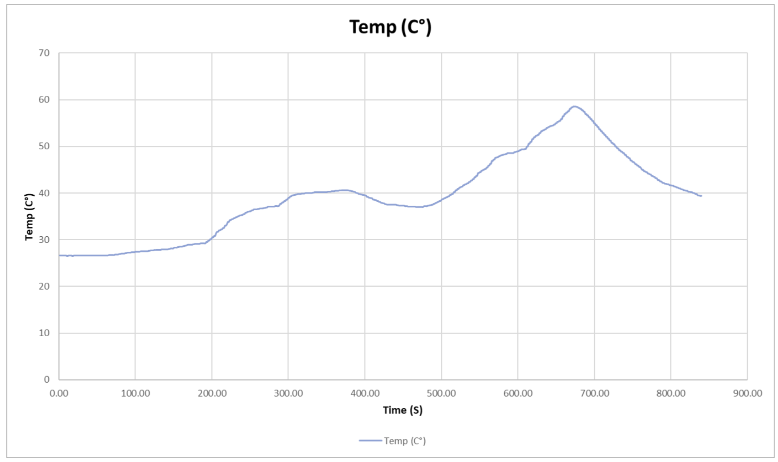


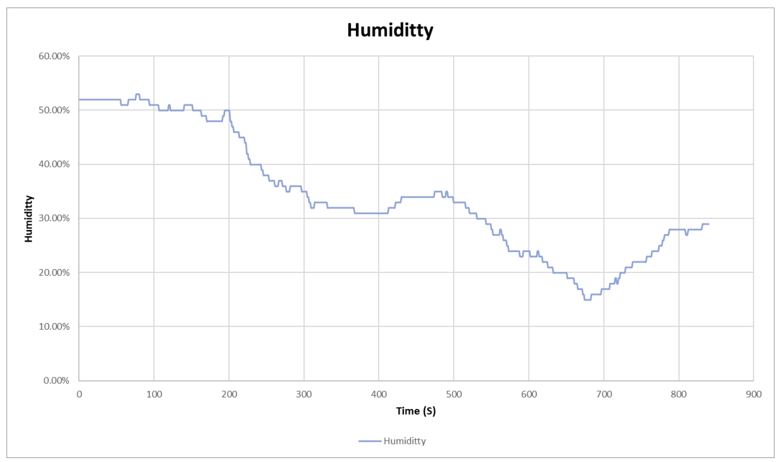


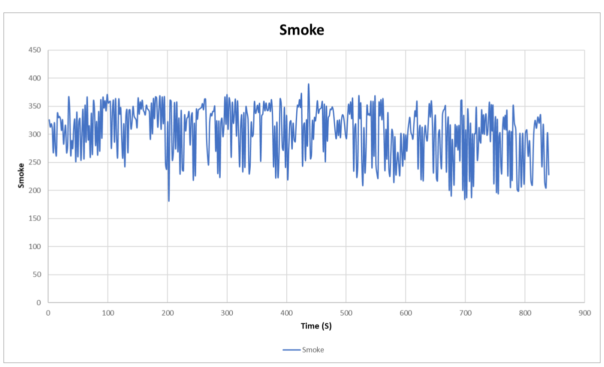


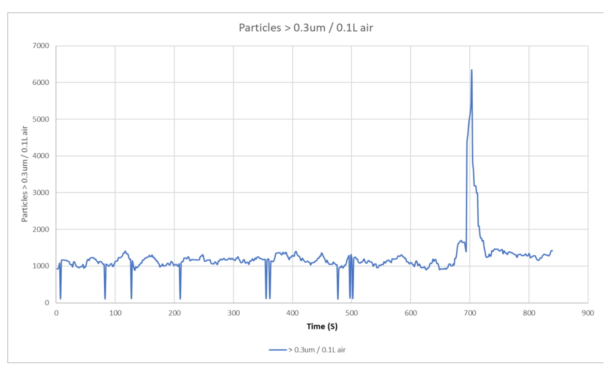
Extraction on

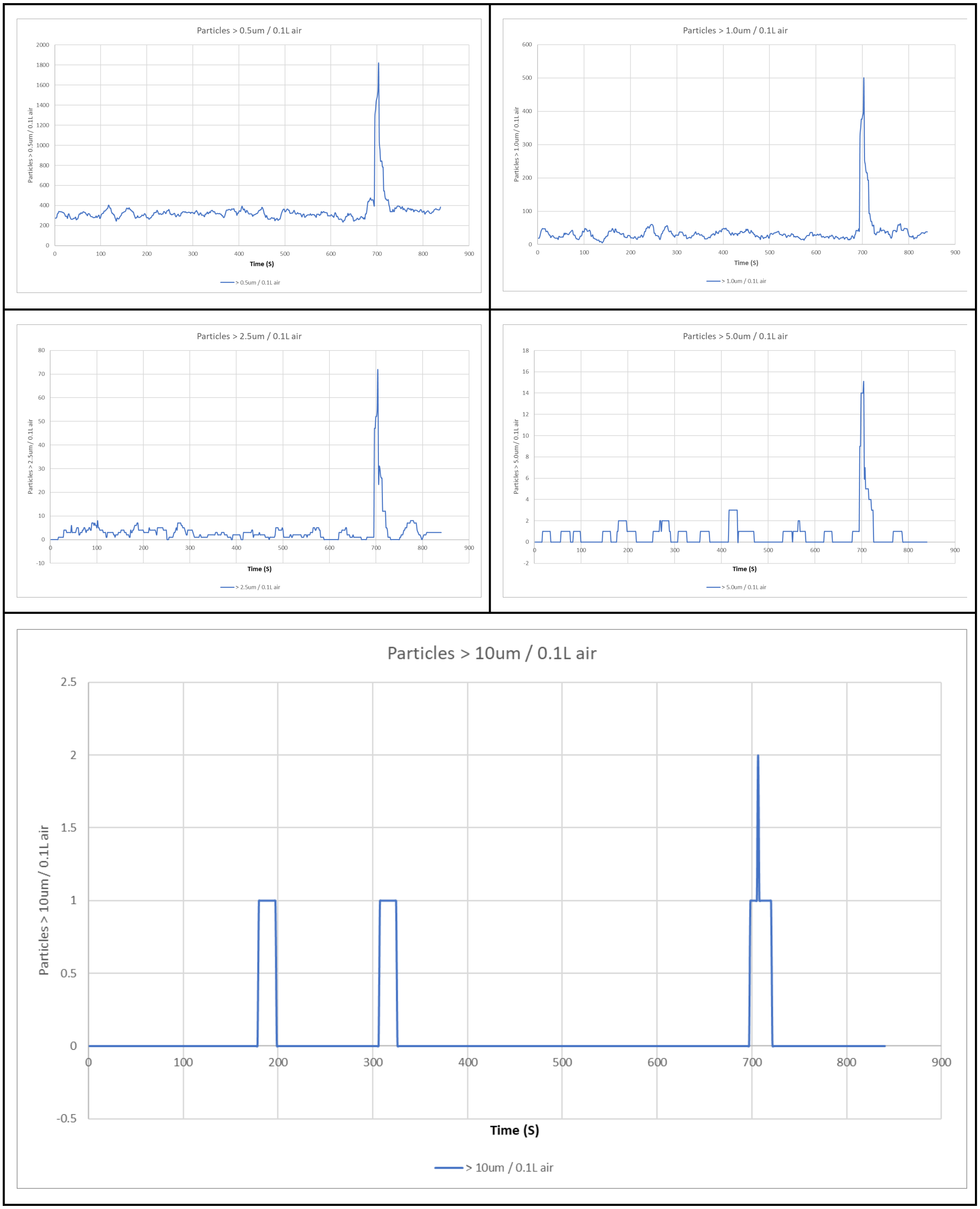
Time Line	
State	Time (Seconds)
Ambient	1
Burner 1	60
Burner 2	120
Burner 3	180
Burner 4	240
Burner 5	300
Burner 6	360
Burner 1 & 2	420
Burner 5 & 6	480
Burner 3 & 4	540
All Burners	600
Egg Frying	660
End	840










Particles > 0.5um / 0.1L air
Particles > 0.5um / 0.1L air
Time (S)
> 0.5um / 0.1L air
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Particles > 10um / 0.1L air
Particles > 10um / 0.1L air
Time (S)
> 10um / 0.1L air

Maximums		
Factor	Value	@ Time (Seconds)
Temperature	58.6	672-675
Humidity (Min)	15%	675 - 683
Smoke	388	436
Particles > 0.3um / 0.1L air	6300	703
Particles > 0.5um / 0.1L air	1803	703
Particles > 1.0um / 0.1L air	497	703
Particles > 2.5um / 0.1L air	71	703
Particles > 5.0um / 0.1L air	15	704
Particles > 10um / 0.1L air	2	706

Discussion

Both tests went well. The sensor array functioned as designed, as far as my hypothesis was concerned I was completely wrong. At the same time, there was a noticeable change between the different states, the data suggest, that time under use is more of a factor when it comes to affecting temperature and humidity. It also seems that the extraction fan had little to no effect on temperature and humidity. The only difference in these values between the tests is due to the higher ambient temperature on the day the second test was conducted.

While the smoke detector did record noticeably different values between tests I was unable to gain any useful info from this. These tests began my suspicion that the smoke detector may be useless in this circumstance or simply defective. The second experiment however showed the PM2.5 sensor to be working correctly.

Another perhaps noticeable difference in the data was how it is organised as it was with the first test that I had my first issue with data organisation. Throughout all testing, data was printed to the Arduino console and then copied to an Excel spreadsheet to be organised and used in graphs. The problem, however, arose that you can not copy all data from the base Auduino console at once this led to me having to manually copy and paste almost 5000 lines 25 lines at a time to a spreadsheet. This was a problem that had to be resolved. Luckily I found a more customisable external console that I could tailor to my needs. While Data organisation was still the most time-consuming part of this whole project this solution drastically cut down the time required per experiment.

Conclusion & Recommendations
Although the results of these tests were not What I expected this experimentation was still extremely worthwhile as these results would become my baseline that all others would be compared to. Also due to the negligible difference seen between results with extraction on compared to off in conjunction with the large amount of time each experiment required for the data to be organised, I decided all further testing would take place with the extraction fans on.

6.3 Smoking Wok Test

Obviously due to safety concerns actual grease fire was not able to be part of the experimentation however before a grease fire can begin the oil needs to be heated past its smoke point. Heating oil past its smoke point is common when seasoning a pan such as a wok. Seasoning pans is something I do often hence I was certain that I could conduct this experiment safely.

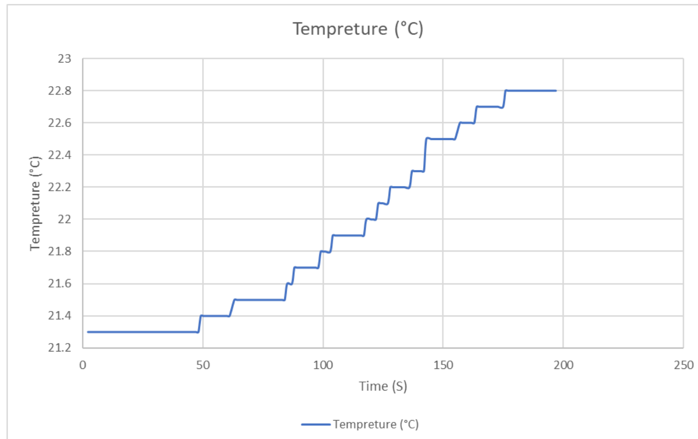
The goal of this experiment was to collect data from a similar situation to what a finally completed Rangehood Mounted Fire Detection System would have to flag as a fire risk. The data collected in this experiment will be compared to all others to find stand-out features that could be used to monitor for in a final solution as what precepts a possible grease/ pan fire.

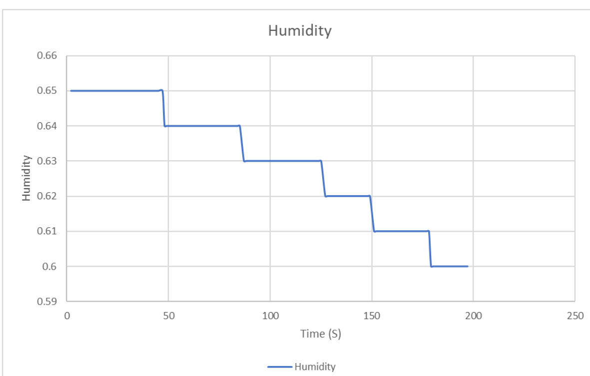
Method
- The circuitry was set as shown in Appendix 3.1 and the code used can be seen in Appendix 3.2.
- The sensor array was mounted as shown in Appendix 4.1 on the range hood.
- Connected USB cable from the laptop to the sensor array
- Ensure data is being collected correctly.
- Turn on the rangehood extraction fans.
- Collected ambient data for 16 seconds
- At 17 seconds the wok burner (B1) was turned on.
- At 77 seconds small amounts of smoke become noticeable
- The amount of smoke increases until the burner is turned off at 137 seconds.
- Data collection was stopped at 197 seconds when the wok had stopped producing significant smoke.

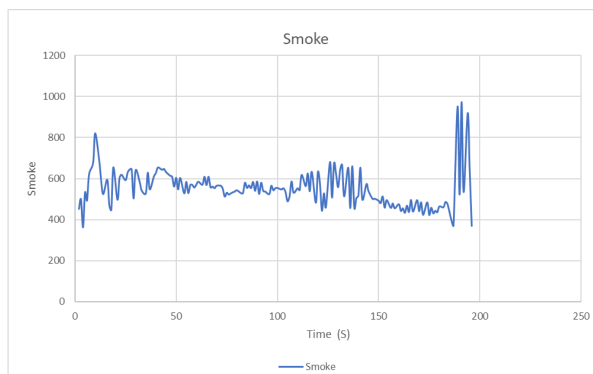
Results

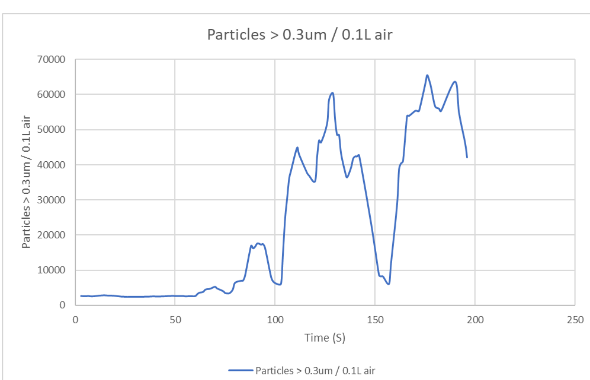
Full results for the test can be found in “Data and Graphs.xlsx” at
https://github.com/H0NKS/Investigation-into-Rangehood-Mounted-Fire-Detection-System
Larger versions of graphs can be seen in Appendix 5

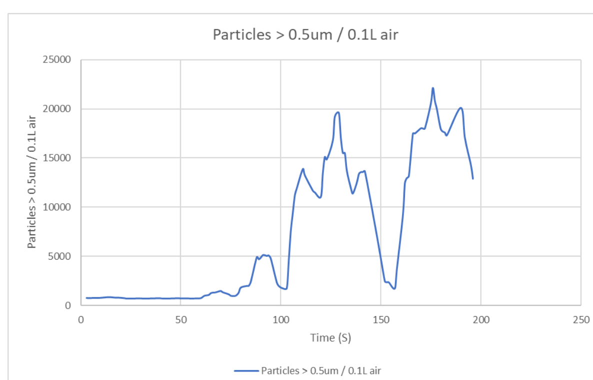
Timeline	
State	Time (Seconds)
Ambient	1
Burner 1 On	17
Burner 1 Off	137
End	197

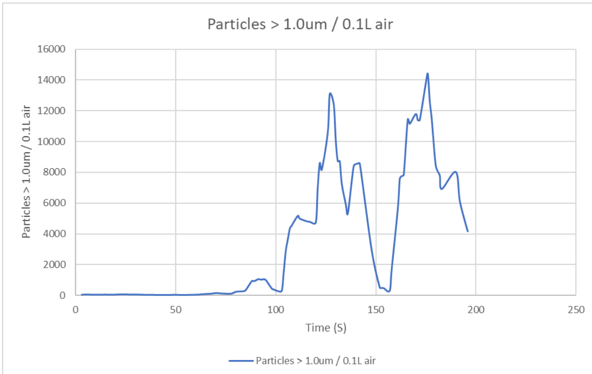


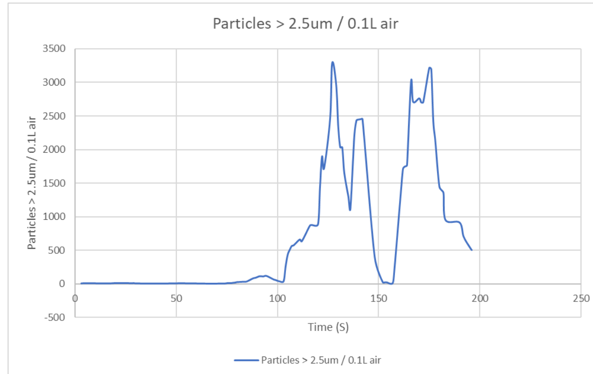


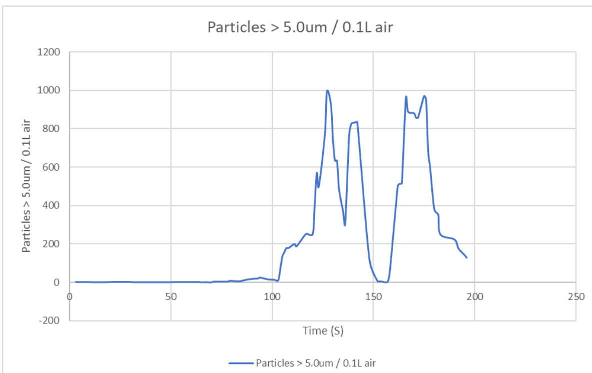


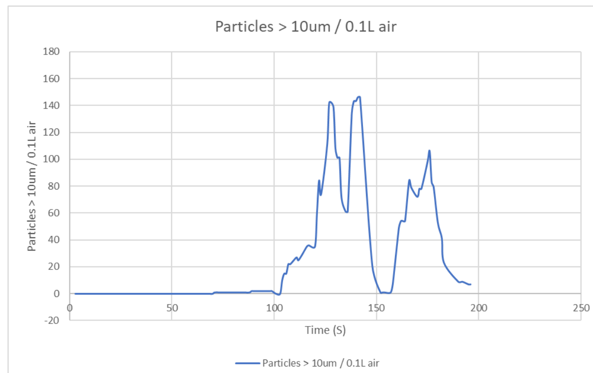












Maximums		
Factor	Value	@ Time (Seconds)
Temperature	22.8	176 - 197
Humidity (Min)	60%	179 - 197
Smoke	973	191
Particles > 0.3um / 0.1L air	65535	176
Particles > 0.5um / 0.1L air	22126	176
Particles > 1.0um / 0.1L air	14430	176
Particles > 2.5um / 0.1L air	3285	127
Particles > 5.0um / 0.1L air	996	127
Particles > 10um / 0.1L air	146	141 - 142

Discussion

This test went incredibly well with the PM2.5 reading being especially promising. As I suspected due to the relatively short duration of the test and its utilising only a single burner humidity and temperature saw only a slight change of 5% and 1.4°C respectively. As stated previously the PM2.5 readings were far different with drastic changes especially compared to previous tests. The smallest difference being with particles > 0.3um / 0.1L air with the maximum in this test having 10 times more than the maximum seen in the Stovetop State Test; Extraction On. This difference increased as the particle size increased with Particles > 10um / 0.1L air being 73 times more abundant at the maximum with a max value of 146 compared to just 2 in the previous test.

Conclusion & Recommendations

Based on the results of this test further testing would have a great focus on the PM2.5 sensor, especially the Particles > 10um / 0.1L air. If such a great difference in Particles > 10um / 0.1L air remains present in further standard cooking practice tests compared to the hazardous smoking pan it could be of great use in a final range hood fire detection system.

6.3 Steam Test

Steam is commonly present around the stovetop and produced in all cooking actions. For this test, I wished to compare the readings from the module in the presence of a large amount of steam and see if this could be distinguished easily from the smoking wok readings.   To achieve this I put a large pot of boiling water on the largest burner to produce a large amount of steam. This was also the first test I recorded on film as I thought it would be helpful when looking back at the data.

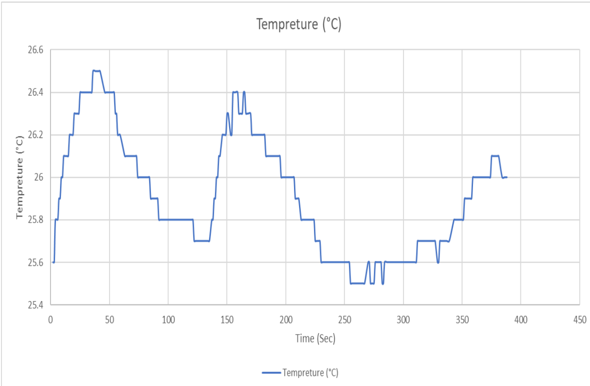
Method

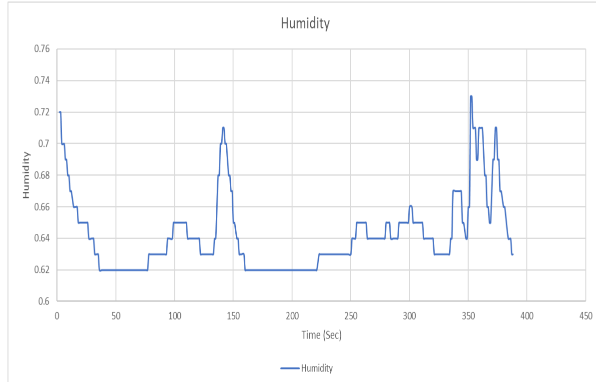
- The circuitry was set as shown in Appendix 3.1 and the code used can be seen in Appendix 3.2.
- The sensor array was mounted as shown in Appendix 4.1 on the range hood.
- Connected USB cable from the laptop to the sensor array
- Ensure data is being collected correctly.
- Turn on the rangehood extraction fans.
- Pre-boiled water on B1 to reduce experiment time.
- Camera was set up and recording began
- Data collection began when water was simmering.
- At 309 (5:09) seconds large amounts of steam are being produced
- At 604 the burner is turned off.
- Data collection is ended at 388 Seconds (6:28)

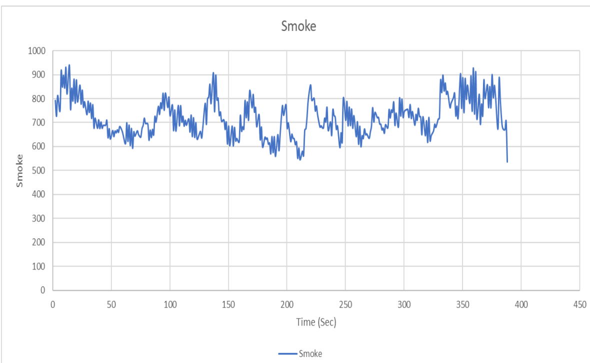
Results
Video Link: https://www.youtube.com/watch?v=QfTZIulmOIE
Full results for the test can be found in "Data and Graphs.xlsx" at
https://github.com/H0NKS/Investigation-into-Rangehood-Mounted-Fire-Detection-System
Larger versions of graphs can be seen in Appendix 5

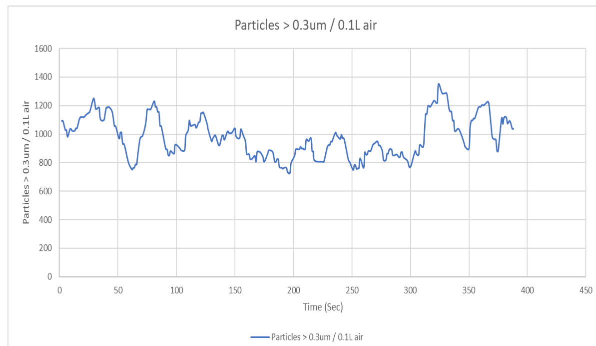
Timeline		
State	Time (Seconds)	Time (Mins: Secs)
B1 On, Water Simmering	1	0:01
Large Amounts of Steam Being Produced	309	5:09
B1 Turned Off	364	6:04
End	388	6:28

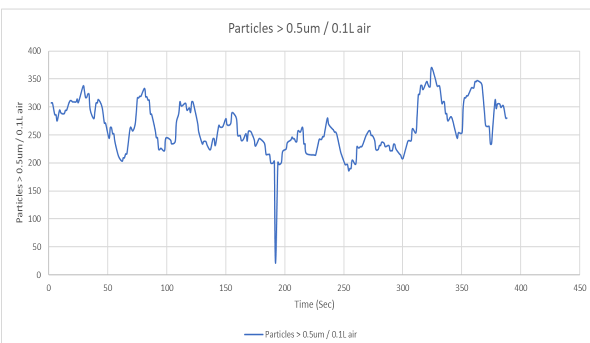
Maximums		
Factor	Value	@ Time (Seconds)
Temperature	26.5	36.42
Humidity (Min)	62%	Var
Smoke	940	14
Particles > 0.3um / 0.1L air	1350	324
Particles > 0.5um / 0.1L air	370	324
Particles > 1.0um / 0.1L air	48	75-78
Particles > 2.5um / 0.1L air	16	39-41
Particles > 5.0um / 0.1L air	9	39-41
Particles > 10um / 0.1L air	1	65-81

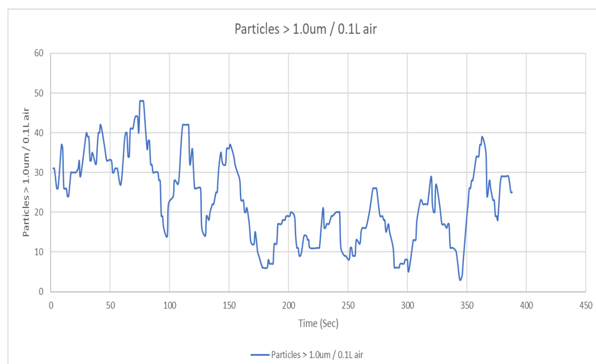

Tempreture (°C)
Tempreture (°C)
Time (Sec)
Tempreture (°C)

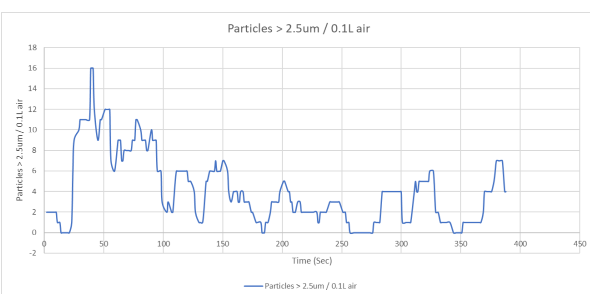

Humidity
Humidity
Time (Sec)
Humidity

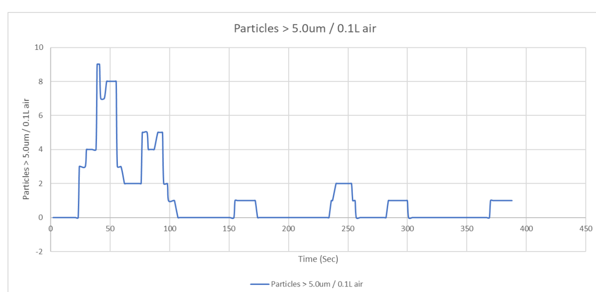

Smoke
Smoke
Time (Sec)
Smoke

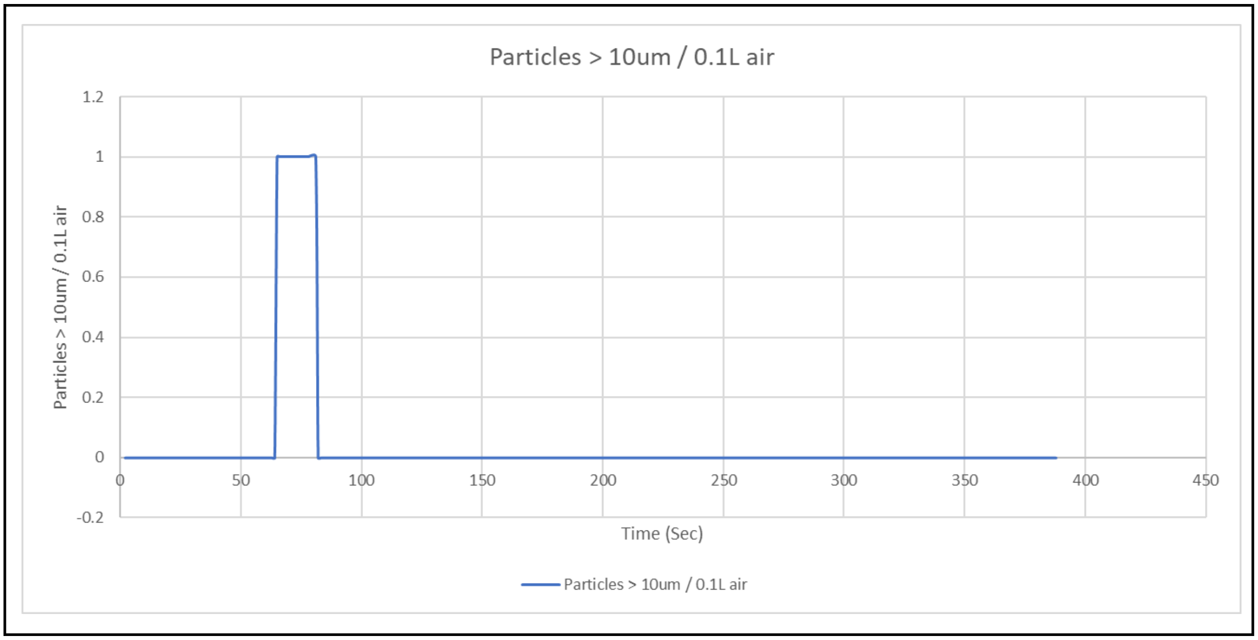

Particles > 0.3um / 0.1L air
Particles > 0.3um / 0.1L air
Time (Sec)
Particles > 0.3um / 0.1L air


Particles > 0.5um / 0.1L air
Particles > 0.5um / 0.1L air
Time (Sec)
Particles > 0.5um / 0.1L air


Particles > 1.0um / 0.1L air
Particles > 1.0um / 0.1L air
Time (Sec)
Particles > 1.0um / 0.1L air


Particles > 2.5um / 0.1L air
Particles > 2.5um / 0.1L air
Time (Sec)
Particles > 2.5um / 0.1L air


Particles > 5.0um / 0.1L air
Particles > 5.0um / 0.1L air
Time (Sec)
Particles > 5.0um / 0.1L air



Discussion

This test went for longer than the last resulting in a slightly greater temperature change but still a small change. All the steam present also impacted the humidity causing it to rise when detected. Most important however was the fact that the steam produced almost no large particles with the maximum particles > 10um / 0.1L air reading being just 1. All other particle sizes also had a significantly lower presence than the smoking wok however it is most easily seen in the large particles as they are almost non-existent in this experiment.

Conclusion & Recommendations

This test supports the ability of PM2.5 particles > 10um / 0.1L reading to be useful in a final system to base, an early warning/fire hazard alarm. Once again we can see that the smoke sensor is mostly useless in this circumstance. Overall this test went well and showed this was a path worth further investiagatyion.

6.4 Alcohol Burn Test

Since the outset of this project one of my main goals was to ensure that the final system would not cause a false alarm during a Flambe (Burning alcohol during coooking). As this is a commonly used cooking technique more so commercially but also in people's homes. This test would be the final test in this project. I was confident that the large particles detected during the smoking wok experiment would not be present during this test as alcohol burns far more cleanly than oil.

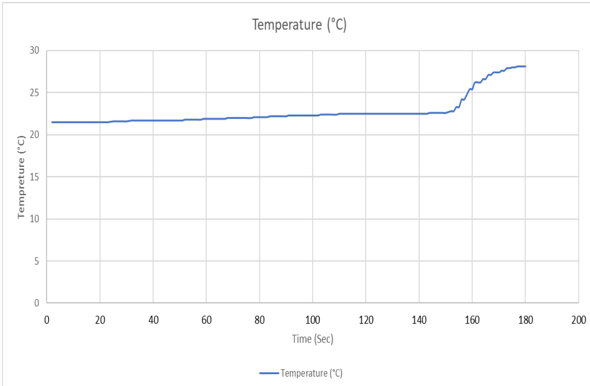
Method

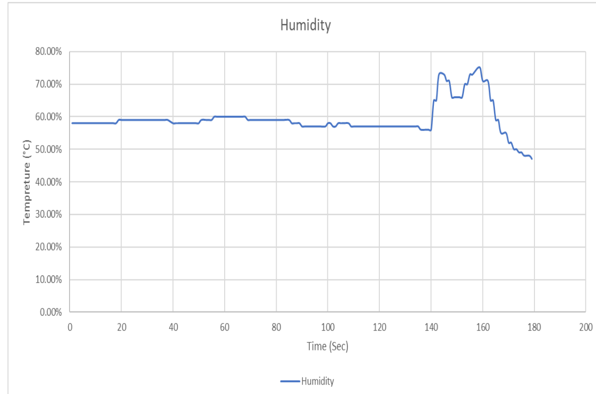
- The circuitry was set as shown in Appendix 3.1 and the code used can be seen in Appendix 3.2.
- Ingredients were prepared
    - 200ml Fresh Orange Juice
    - 1 tsp orange zest
    - 25g Butter
    - 3 tbs Brown Sugar
    - 50ml Cointreau (Alcohol)
- The sensor array was mounted as shown in Appendix 4.1 on the range hood.
- Connected USB cable from the laptop to the sensor array
- Ensure data is being collected correctly.
- Turn on the rangehood extraction fans.
- Camera Set up and recording started.
- Data Collection began as B1 was turned on and butter began to melt.
- At 55 seconds the Orange Zest was added.
- At 80 the sugar was added.
- At 83 orange juice was added.
- The pan was brought away from the flame and at 112 the alcohol was added.
- The Pan was brought back to the burner and tipped slightly towards the flame igniting the alcohol vapers hence starting the flambe at 1114 seconds.
- At 132 seconds the flambe was over meaning all alcohol has burnt off.
- At 136 more orange juice was added
- Data collection was stopped at 181 Seconds.

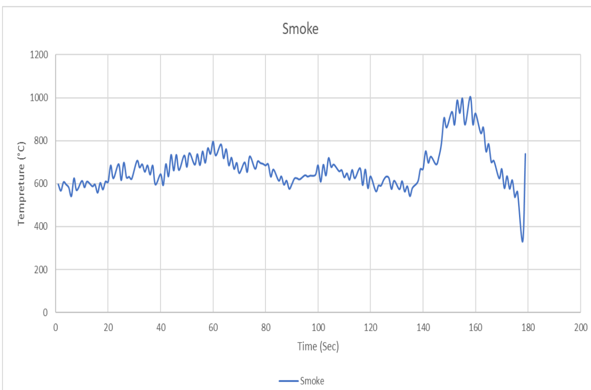
Results
Video Link: https://www.youtube.com/watch?v=4OnZBmoq35Q
Full results for the test can be found in “Data and Graphs.xlsx” at
https://github.com/H0NKS/Investigation-into-Rangehood-Mounted-Fire-Detection-System
Larger versions of graphs can be seen in Appendix 5

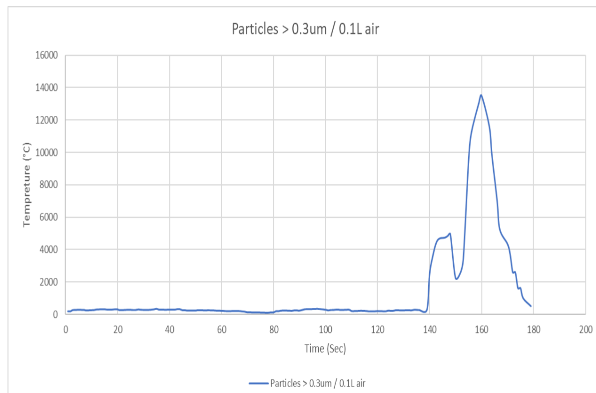
Timeline		
State	Time (Seconds)	Time (Mins: Secs)
B1 On / Butter Melting	1	0:01
Orange Zest Added	55	0:55
Sugar Added	80	1:20
Orange Juice Added	83	1:23
Alcohol Added	112	1:52
Flambe Started	114	1:54
Flambe Ended	132	2:12
More Orange Juice Added	136	2:16
End	181	3:01

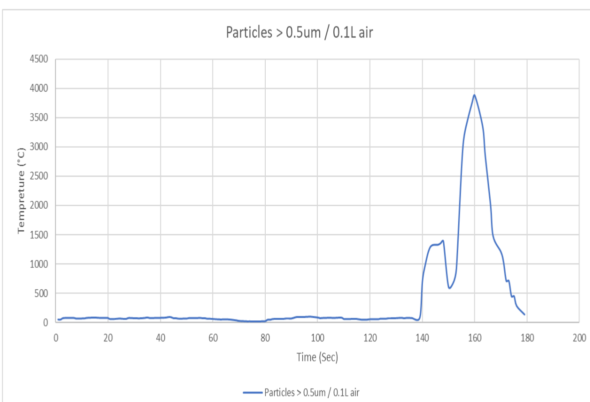
Maximums		
Factor	Value	@ Time (Seconds)
Temperature	28.1	177-180
Humidity (Min)	47%	159-160
Smoke	1004	159
Particles > 0.3um / 0.1L air	13518	162
Particles > 0.5um / 0.1L air	3874	162
Particles > 1.0um / 0.1L air	634	161
Particles > 2.5um / 0.1L air	91	162
Particles > 5.0um / 0.1L air	18	161-162
Particles > 10um / 0.1L air	3	158

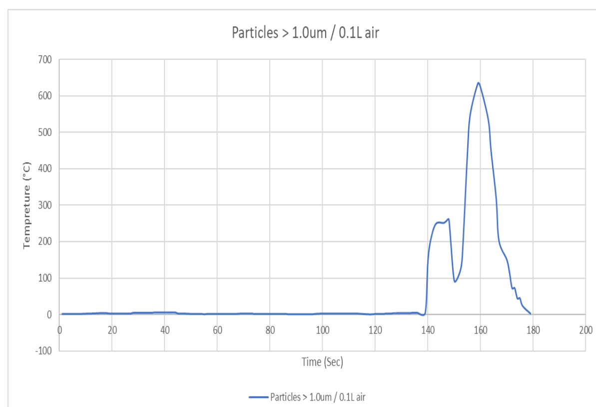

Temperature (°C)
Tempreture (°C)
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Temperature (°C)

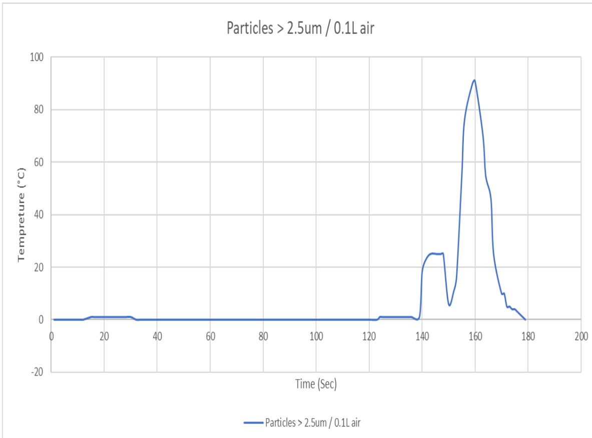

Humidity
Tempreture (°C)
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Humidity

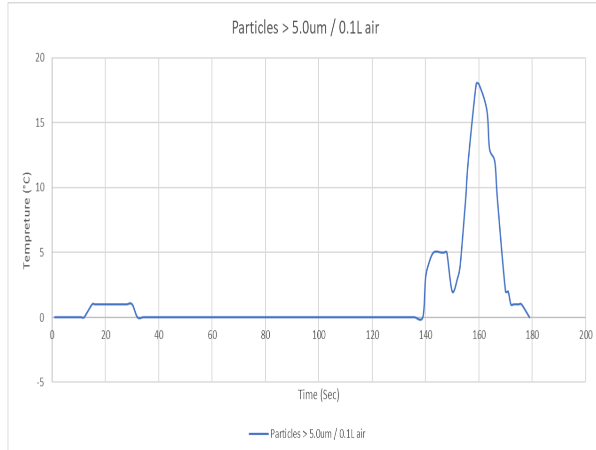

Smoke
Tempreture (°C)
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Smoke

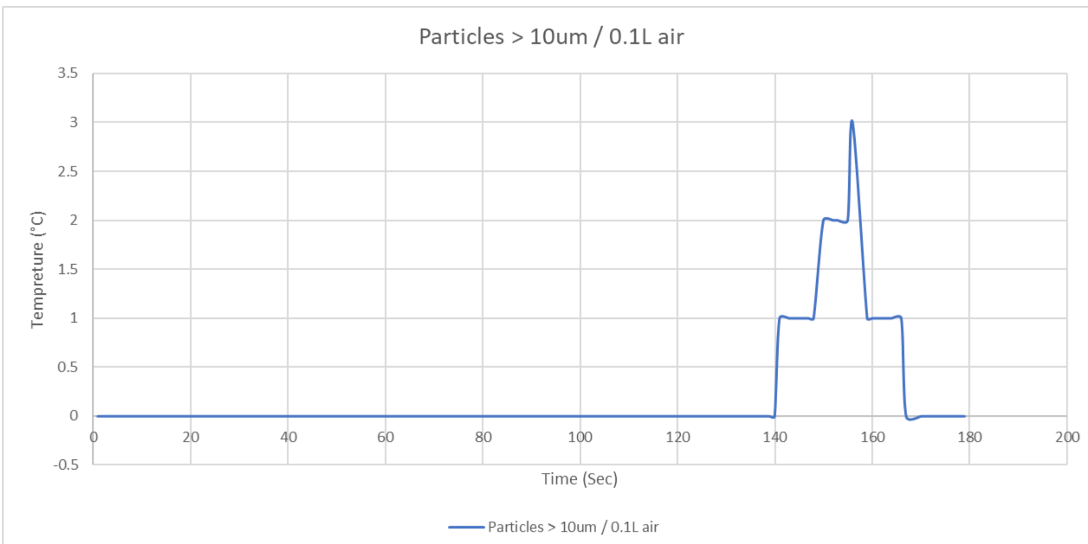

Particles > 0.3um / 0.1L air
Tempreture (°C)
16000
14000
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 0.3um / 0.1L air


Particles > 0.5um / 0.1L air
Tempreture (°C)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 0.5um / 0.1L air


Particles > 1.0um / 0.1L air
Tempreture (°C)
700
600
500
400
300
200
100
0
-100
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 1.0um / 0.1L air







Discussion

The final test was a total success and the data collected matched my expectations except for the temperature values the flame produced during the flambe was not insignificant and I assumed there would be a greater increase in ambient temperature due to this however there was not. The small temperature change that did happen was quite delayed from when the flambe started.

Surprisingly this test saw the most consistent and useful data collected by the smoke detector however due to its performance in other tests this was not analysed extensively. Most importantly were the PM2.5 readings that once again were in line with the running theory that a smoking pan and hence a fire hazard would create far more particles greater than 10um than any other stove top state. The largest value of Particles > 10um / 0.1L air was 3; 67 times less than that produced during the smoking wok experiment.

Conclusion & Recommendations

This experiment further supports the PM2.5 Particles > 10um / 0.1L air as an effective factor to notice and predict a fire hazard. This experiment also proved that I had achieved one of my major goals developing a sensor module that could detect a fire hazard and also not give a false alarm during a Flambe or other normal kitchen operations.

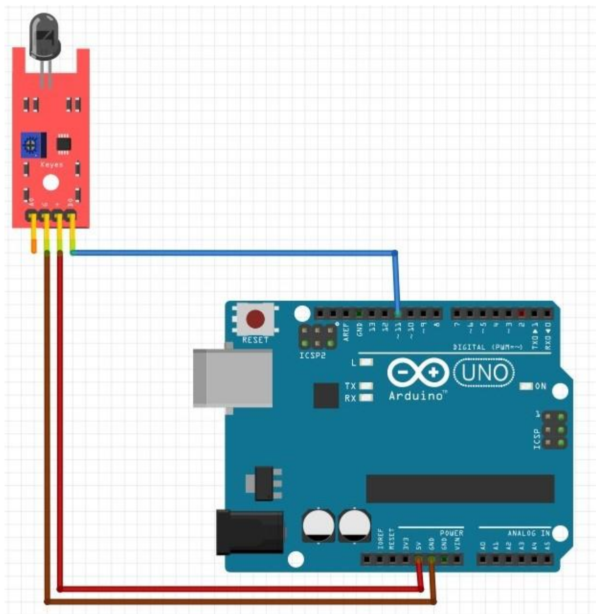
7. Overall Conclusions and Recommendations

I am pleased with what I have been able to achieve throughout this project, the sensor module I created was able to achieve all I wanted from it within the scope of the project. The major overall finding was that temperature and humidity do vary during the cooking process these changes are steady and not easily disguisable between hazardous and non-hazardous conditions at least not in a timely matter. It was also confirmed as suspected that a standard smoke detector is of almost no use in this environment. The PM 2.5 provided readings in which the hazardous readings were easily and quickly distinguishable from non-hazardous conditions including flambe conditions that many other systems would struggle to account for. Finally, the flame sensors used had the characteristic of not spotting alcohol or stovetop burner flame but were sensitive to other flame sources. This characteristic could make them viable in a final system.

Further investigation would be required before a final solution could be developed, experimentation in more common cooking conditions such as high temperature searing and the previously tested conditions happening in concert would have to be explored. My recommendation for a final solution would be that a PM2.5 sensor would be the main sensor on which the detection logic would be based. Either purely based on the particles greater than 10um reading or as a ratio of particles greater than 0.3 to particles greater than 10um. I believe this is a better option for example in normal in no no-hazardous conditions through testing the ratio was around 3000 while during the smoke test, it was ~500 this solution would perhaps be more suited as it would be less susceptible to false alarms when many of burners are in use. If this ceiling/ratio was reached or overcome this would signal the waning alarm. In conjunction Many flame detectors mounted in strategic locations would monitor for flame if a flame were to be detected and the limit/ratio established earlier was exceeded this would initiate the fire suppression system. I believe this system could be effective with a quick response time and minimal to no false alarms however significantly more development would be required before this is certain.

8. <u>Appendices</u>

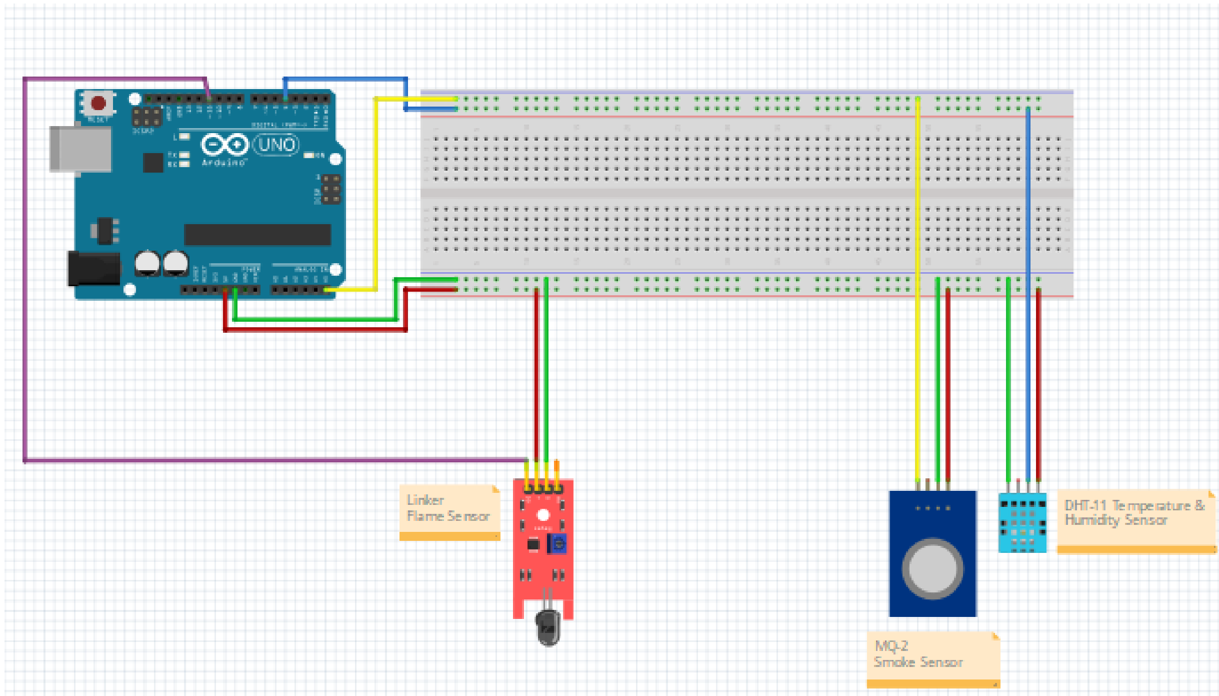
Appendix 1.1: Initial Test Circuit



Appendix 1.2 Initial Test Code

```
Flame_Detectro_Test

const int flamePin = 11;
int flame = HIGH;
unsigned long time;

void setup() {
  // put your setup code here, to run once:
  pinMode(flamePin, INPUT);
  Serial.begin(9600);

}

void loop() {
  // put your main code here, to run repeatedly:
  flame = digitalRead(flamePin);
  if (flame== LOW){

    Serial.println("Safe");
    delay(100);
  }
  else {
Serial.println("Fire");
```

Appendix 2.1 Four Sensor Array Circuit Diagram

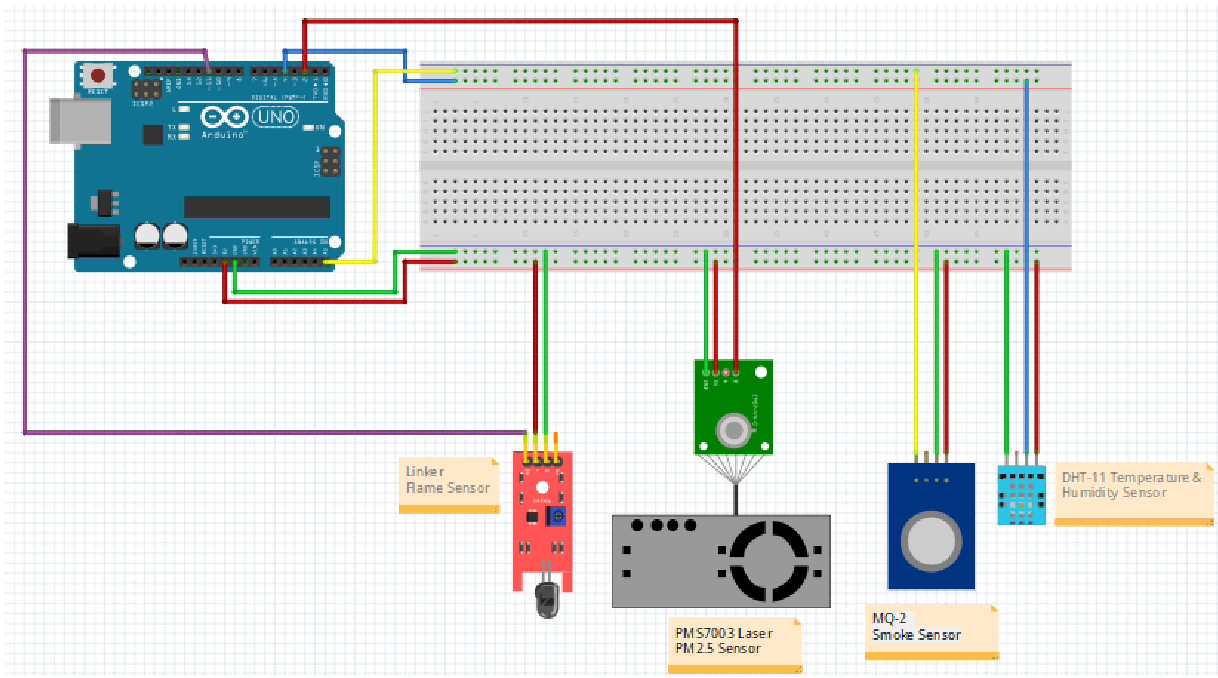


Appendix 2.2 Four Sensor Array Code

```
Detector_Test
#include <Adafruit_Sensor.h>
#include <DHT.h>
#define DHTPIN 2
#define DHTTYPE DHT11 // DHT 11
//#define DHTTYPE DHT22 // DHT 22 (AM2302)
//#define DHTTYPE DHT21 // DHT 21 (AM2301)
// Initialize DHT sensor for normal 16mhz Arduino:
DHT dht = DHT(DHTPIN, DHTTYPE);
const int flamePin = 11;
const int TH = A0;
int flame = HIGH;
double t = 0;
const int smokeA0 = A5;
int pm25;

void setup() {
  // put your setup code here, to run once:
  pinMode(flamePin, INPUT);
  pinMode(smokeA0, INPUT);
  Serial.begin(9600);
  dht.begin();


}
```

```
void loop() {
  // put your main code here, to run repeatedly:
  flame = digitalRead(flamePin);
  float h = dht.readHumidity();
  float t = dht.readTemperature();
  int s = analogRead(smokeA0);

  Serial.print("Smoke: ");
  Serial.println(s);

    float hic = dht.computeHeatIndex(t, h, false);
    Serial.print("Humidity: ");
    Serial.print(h);
    Serial.println(" % ");

    Serial.print("Temperature: ");
    Serial.print(t);
    Serial.print(" \xC2\xB0");
    Serial.println("C | ");

    Serial.print("Heat index: ");
    Serial.print(hic);
    Serial.print(" \xC2\xB0");
    Serial.println("C | ");

  if (flame== LOW){

    Serial.println("Safe");
    delay(1000);
  }
  else {
Serial.println("Fire");
 delay(1000);
  }
}
```

Appendix 3.1: Finalised Array Circuit Diagram

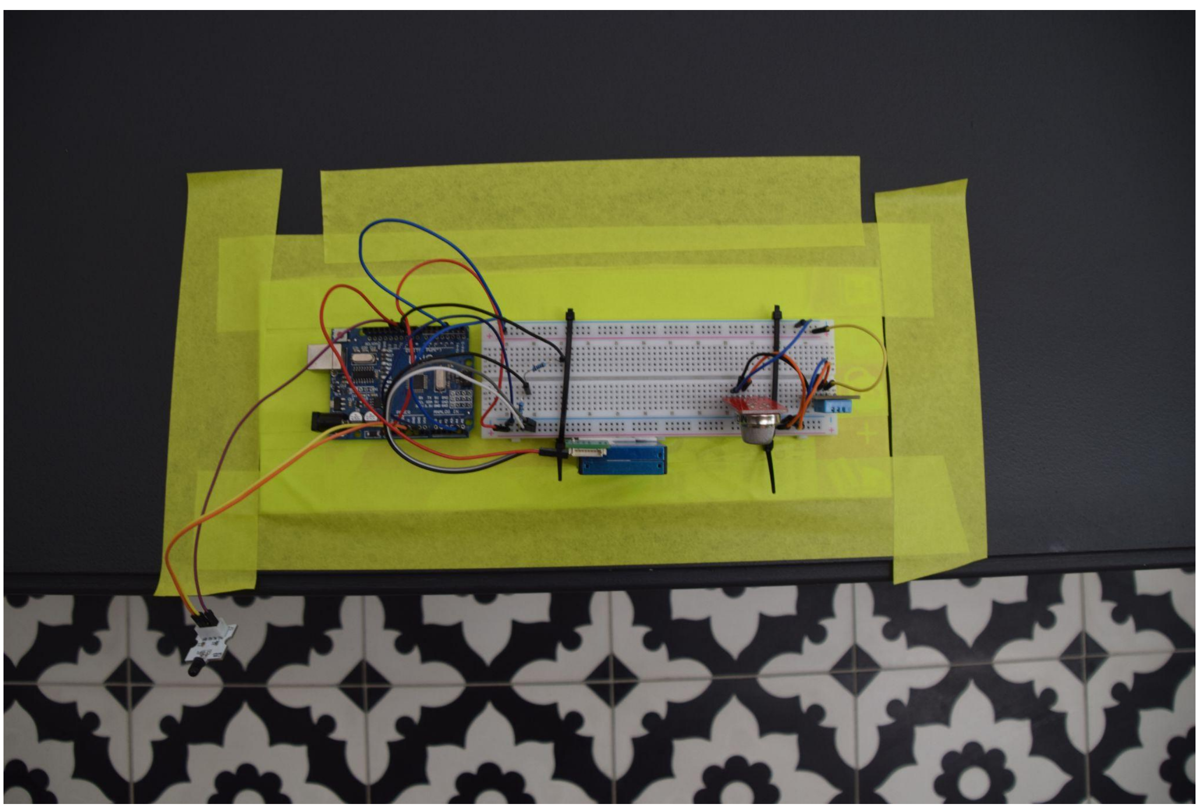


Appendix 3.2: Finalised Array Code

```
Final_Array

//PM2.5 Library
#include "Adafruit_PM25AQI.h"
// Temp/Humidity Sensor library
#include <DHT.h>
#include <SoftwareSerial.h>

// Temp/Humidity Sensor Pin Setup
#define DHTPIN 4
#define DHTTYPE DHT11 // DHT 11
// Initialize DHT sensor for normal 16mhz Arduino:
DHT dht = DHT(DHTPIN, DHTTYPE);

//Srial Setup for PM2.5
SoftwareSerial pmSerial(2, 3);
Adafruit_PM25AQI aqi = Adafruit_PM25AQI();

//Falame sensor pin
const int flamePin = 11;


//Smoke Sensor Pin
const int smokeA0 = A5;

//Variables
const int TH = A0;
int flame = HIGH;
double t = 0;


void setup() {
  // put your setup code here, to run once:

//PM2.5 Setup Code
Serial.begin(115200);
  while (!Serial) delay(10);

  Serial.println("Adafruit PMSA003I Air Quality Sensor");

  // Wait one second for sensor to boot up!
  delay(1000);

  // If using serial, initialize it and set baudrate before starting!
  // Uncomment one of the following
  //Serial1.begin(9600);
  pmSerial.begin(9600);

  // There are 3 options for connectivity!
  //if (! aqi.begin_I2C()) {      // connect to the sensor over I2C
  //if (! aqi.begin_UART(&Serial1)) { // connect to the sensor over
hardware serial
  if (! aqi.begin_UART(&pmSerial)) { // connect to the sensor over
software serial
    Serial.println("Could not find PM 2.5 sensor!");
    while (1) delay(10);
  }

  Serial.println("PM25 found!");



//Other Sensor Setup Code
  pinMode(flamePin, INPUT);
  pinMode(smokeA0, INPUT);
  dht.begin();

}
```

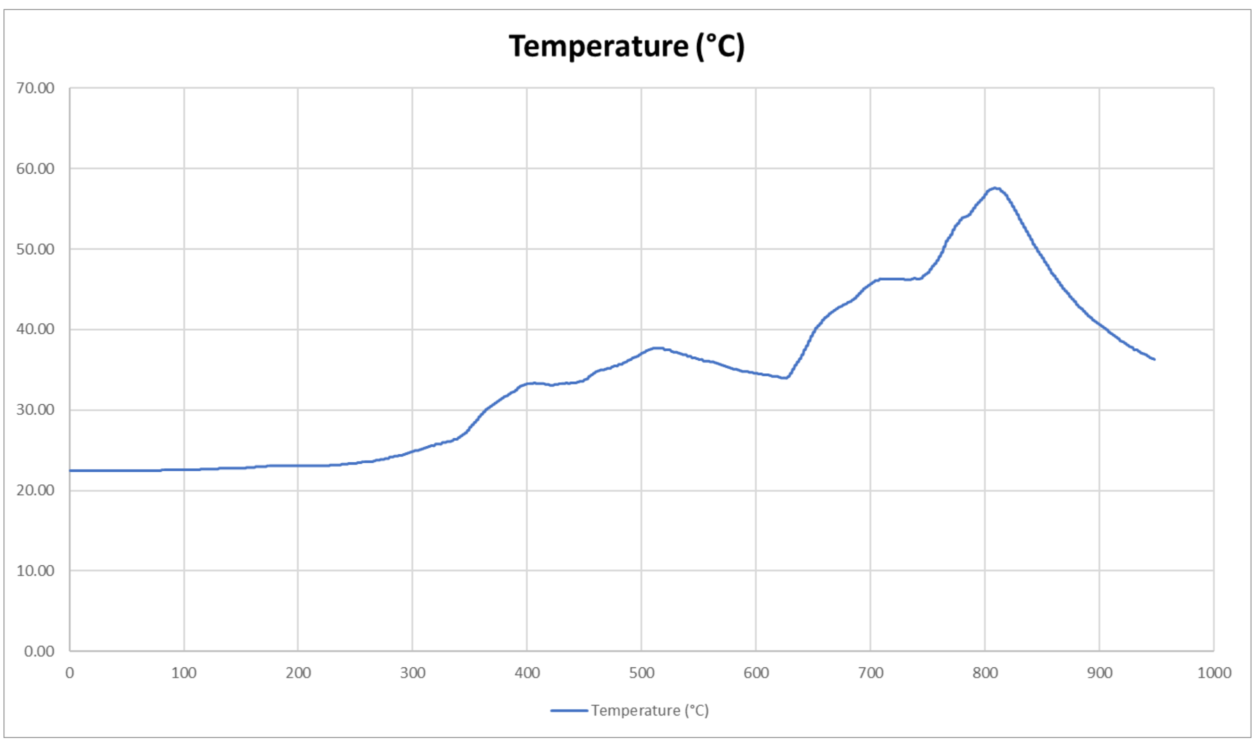
```
void loop() {
  // put your main code here, to run repeatedly:


   //Other Sensor Code
  flame = digitalRead(flamePin);
  float h = dht.readHumidity();
  float t = dht.readTemperature();
  int s = analogRead(smokeA0);


  Serial.print("Smoke: ");
  Serial.println(s);

    float hic = dht.computeHeatIndex(t, h, false);
    Serial.print("Humidity: ");
    Serial.print(h);
    Serial.println(" % ");

    Serial.print("Temperature: ");
    Serial.print(t);
    Serial.print(" \xC2\xB0");
    Serial.println("C | ");

    Serial.print("Heat index: ");
    Serial.print(hic);
    Serial.print(" \xC2\xB0");
    Serial.println("C | ");

  if (flame== LOW){

    Serial.println("Safe");
    delay(1000);
  }
  else {
Serial.println("Fire");
 delay(1000);
  }

  //PM2.5 Code
   PM25_AQI_Data data;

  if (! aqi.read(&data)) {
    Serial.println("Could not read from AQI");
    delay(500);  // try again in a bit!
    return;
  }
  Serial.println("AQI reading success");

  Serial.println();
  Serial.println(F("---------------------------------------"));
  Serial.println(F("Concentration Units (standard)"));
  Serial.println(F("---------------------------------------"));
  Serial.print(F("PM 1.0: ")); Serial.print(data.pm10_standard);
  Serial.print(F("\t\tPM 2.5: ")); Serial.print(data.pm25_standard);
  Serial.print(F("\t\tPM 10: ")); Serial.println(data.pm100_standard);
  Serial.println(F("Concentration Units (environmental)"));
  Serial.println(F("---------------------------------------"));
  Serial.print(F("PM 1.0: ")); Serial.print(data.pm10_env);
  Serial.print(F("\t\tPM 2.5: ")); Serial.print(data.pm25_env);
  Serial.print(F("\t\tPM 10: ")); Serial.println(data.pm100_env);
  Serial.println(F("---------------------------------------"));
  Serial.print(F("Particles > 0.3um / 0.1L air:"));
Serial.println(data.particles_03um);
  Serial.print(F("Particles > 0.5um / 0.1L air:"));
Serial.println(data.particles_05um);
  Serial.print(F("Particles > 1.0um / 0.1L air:"));
Serial.println(data.particles_10um);
  Serial.print(F("Particles > 2.5um / 0.1L air:"));
Serial.println(data.particles_25um);
  Serial.print(F("Particles > 5.0um / 0.1L air:"));
Serial.println(data.particles_50um);
  Serial.print(F("Particles > 10 um / 0.1L air:"));
Serial.println(data.particles_100um);
  Serial.println(F("---------------------------------------"));

}
```

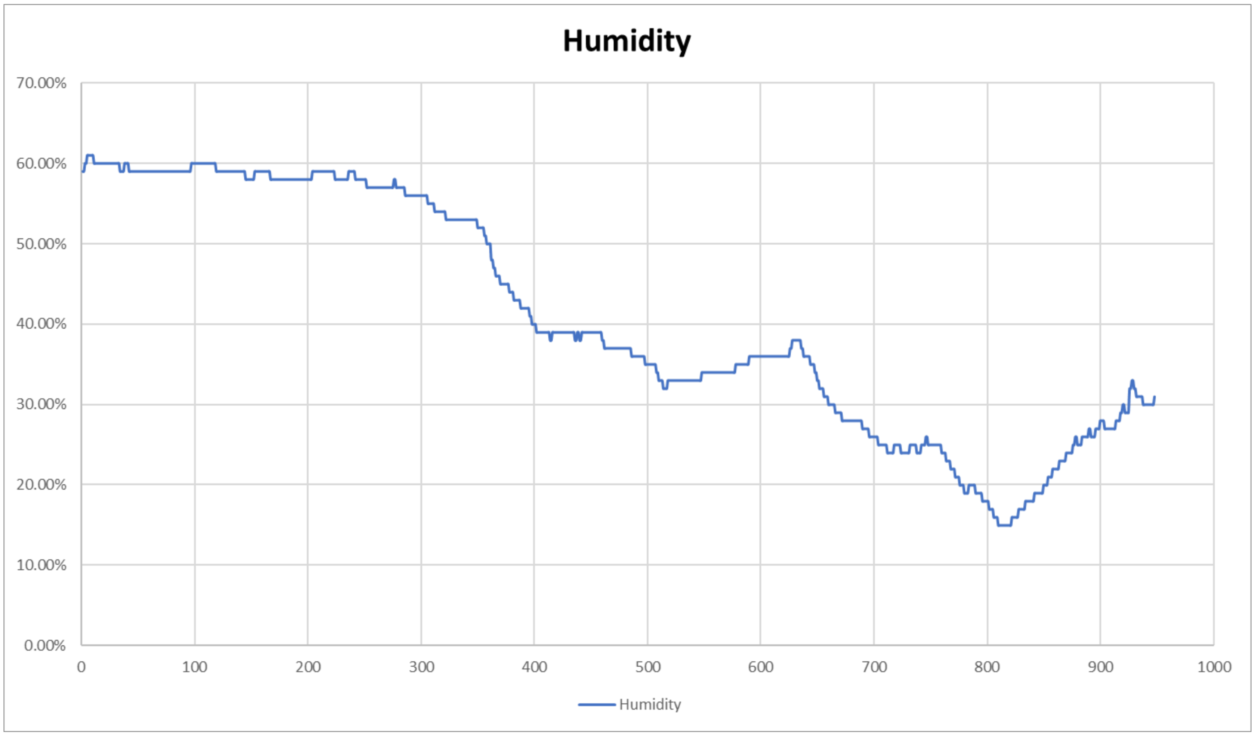
Appendix 4.1: Sensor Array Mounting

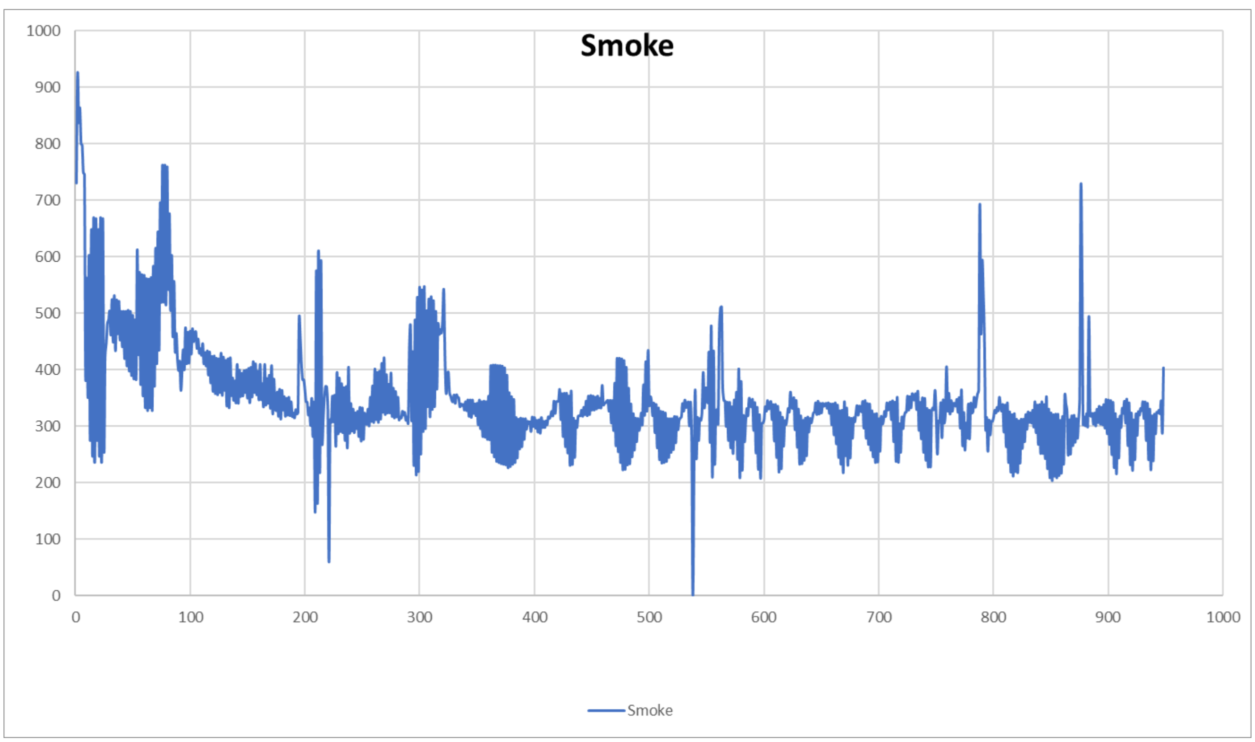


Appendix 4.2: Labeled Stovetop

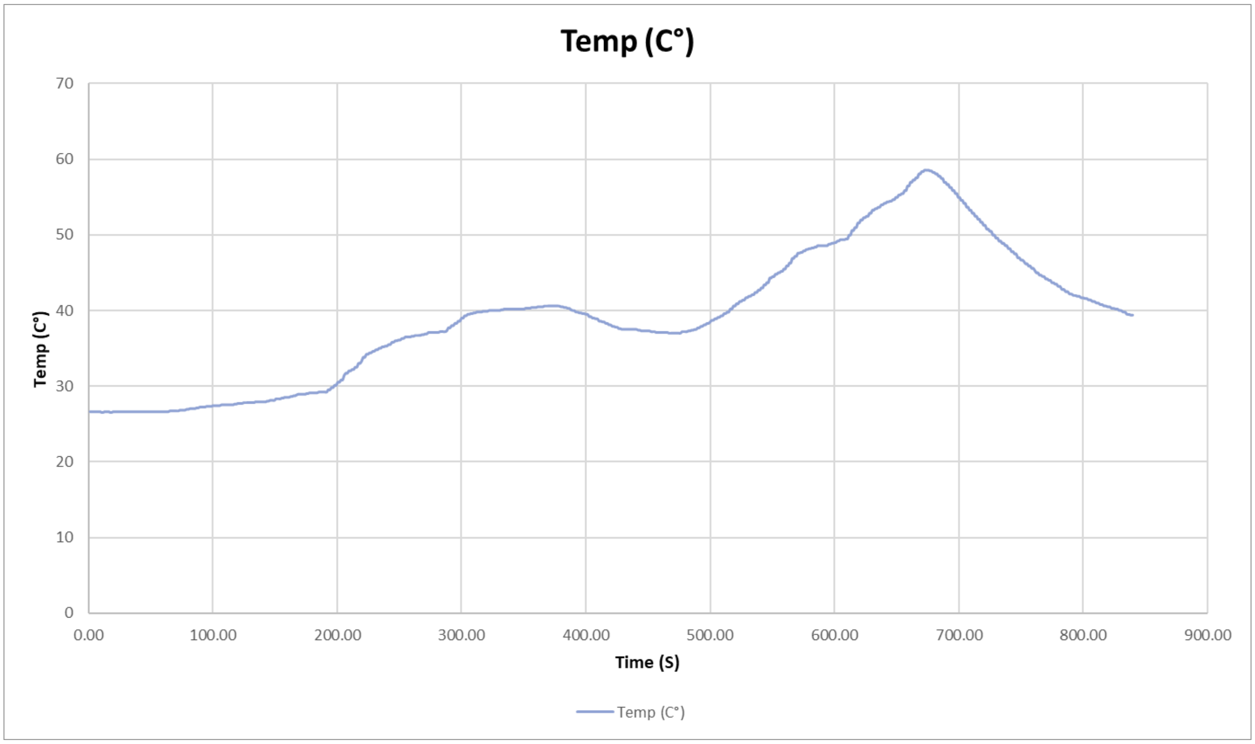
Appendix 5.1: Graphs Stovetop States Extraction Off

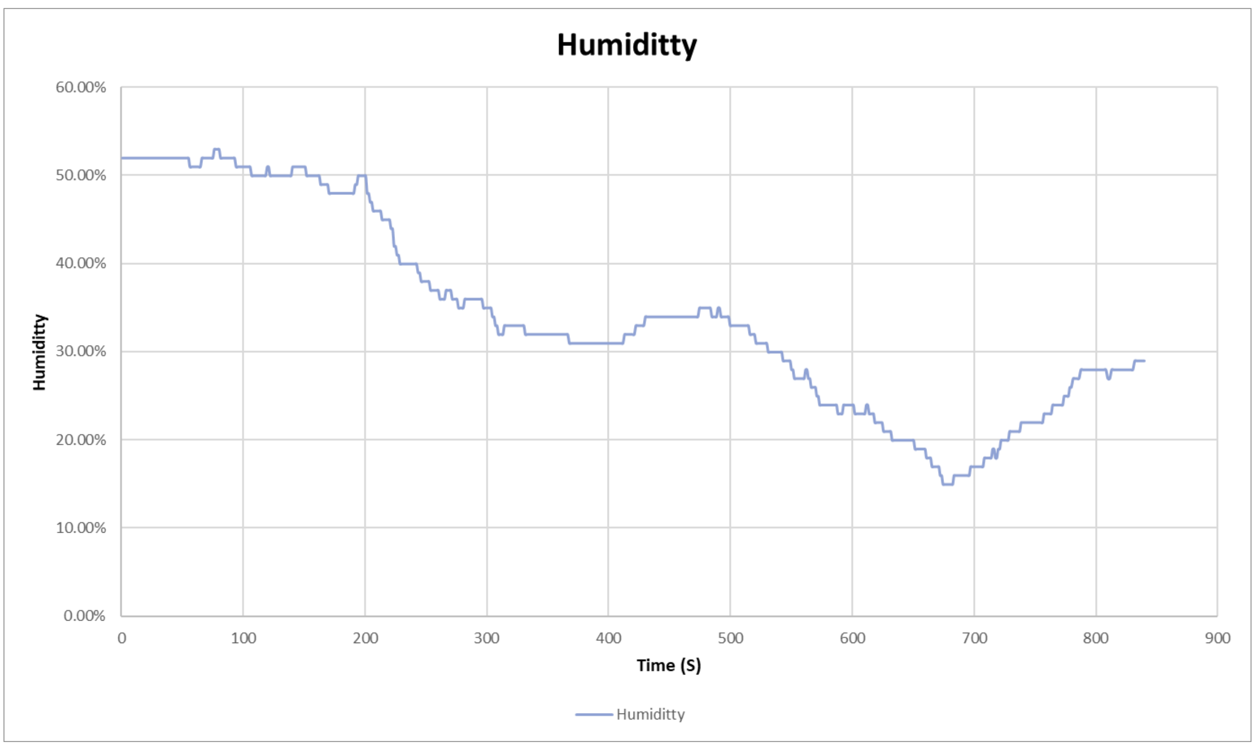


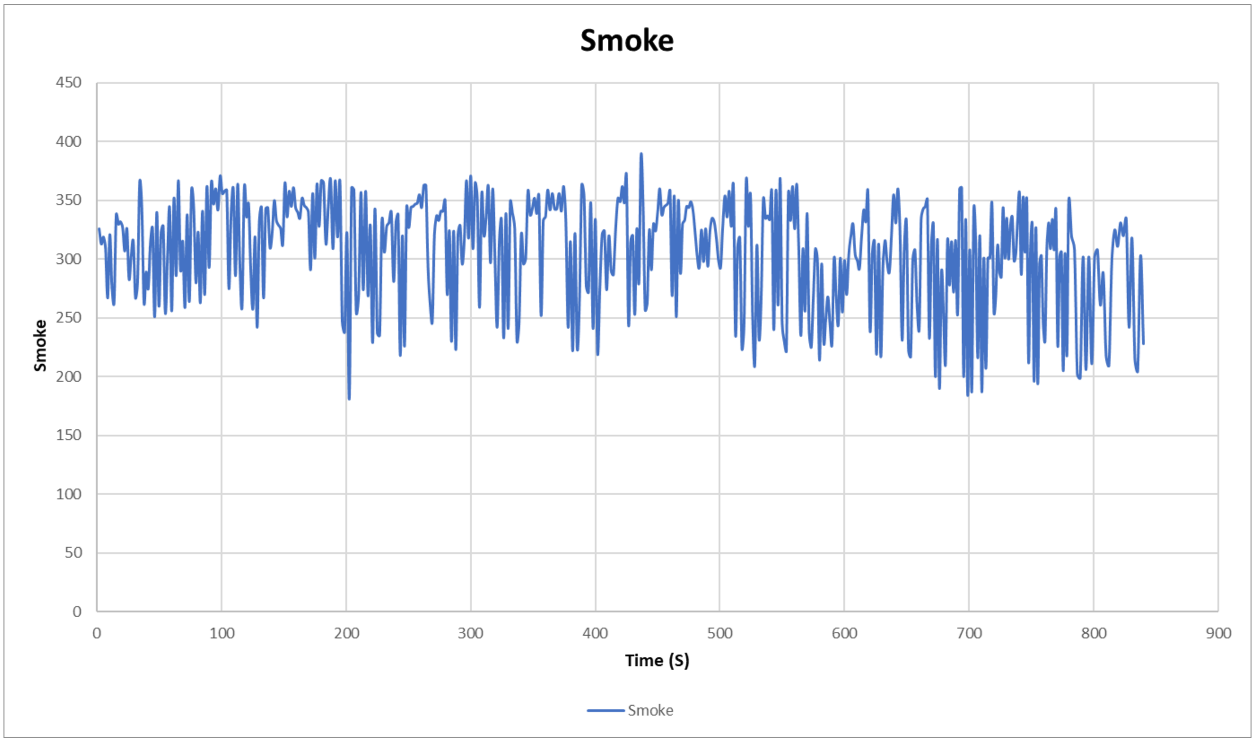

Humidity
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
0
100
200
300
400
500
600
700
800
900
1000
Humidity

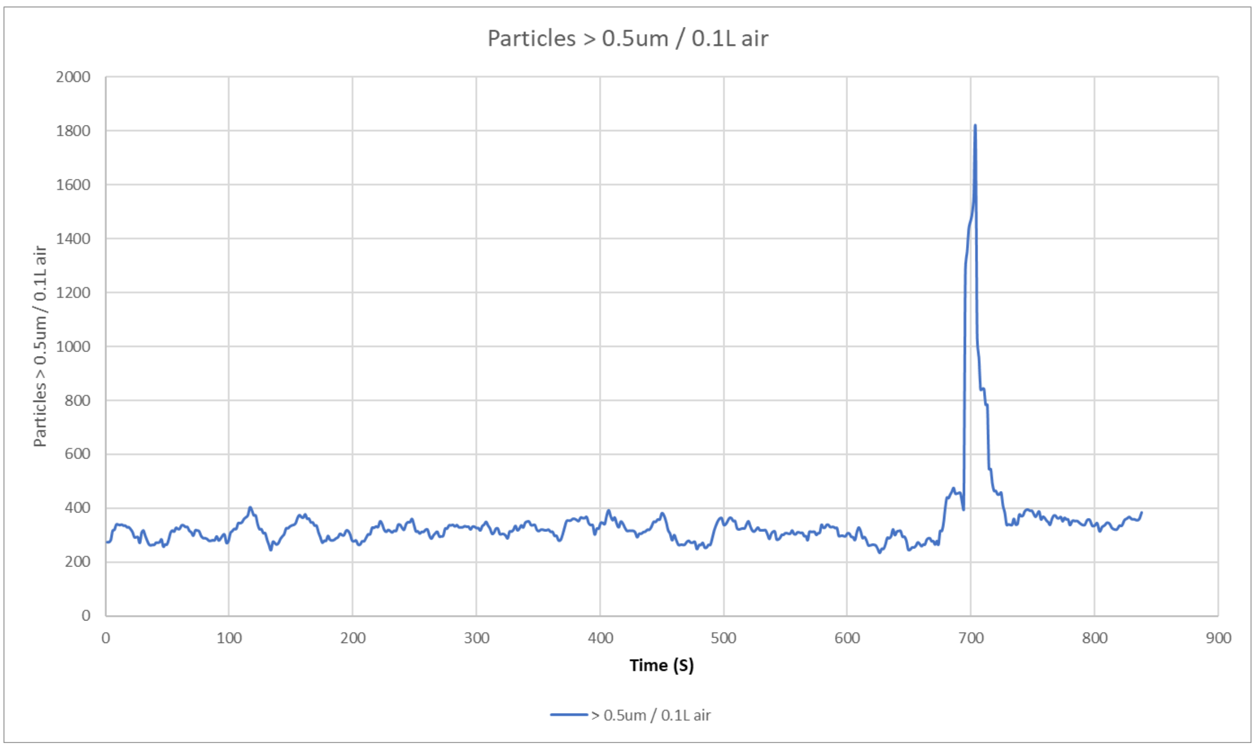

Smoke
1000
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
Smoke

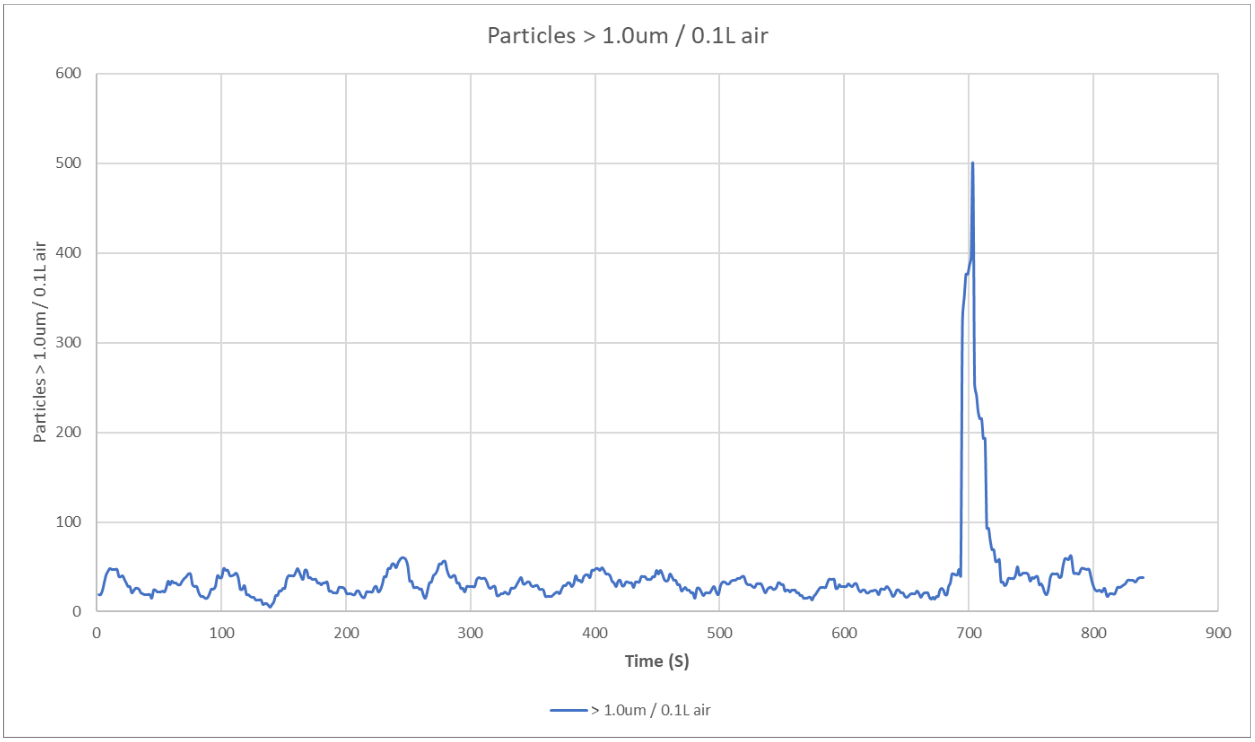
Appendix 5.2: Graphs Stovetop States Extraction On

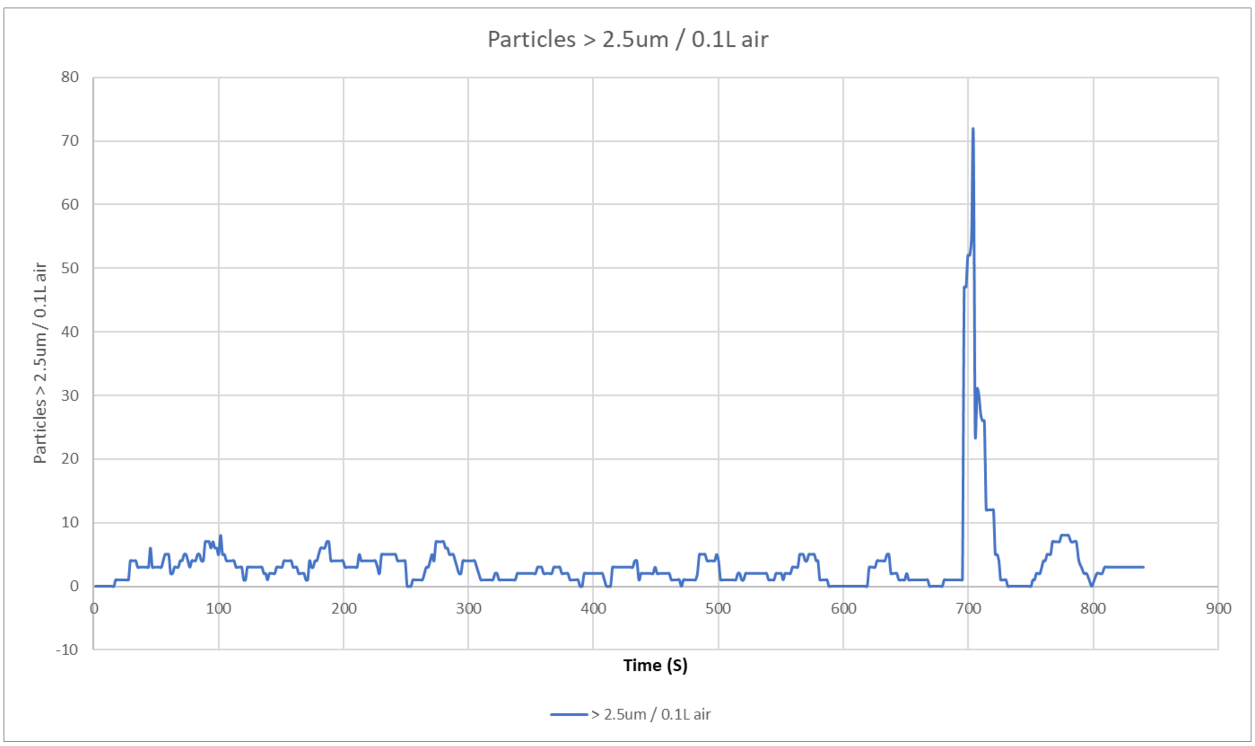


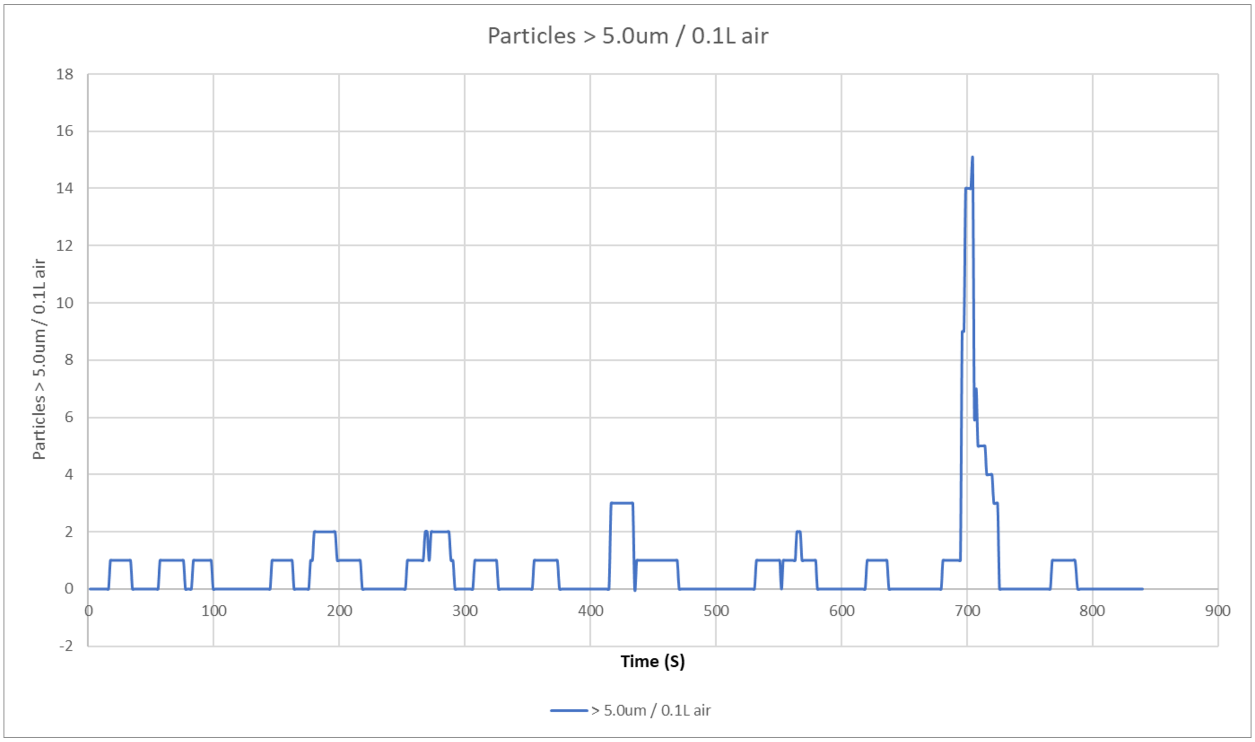



Smoke
450
400
350
300
250
200
150
100
50
0
Smoke
0
100
200
300
400
500
600
700
800
900
Time (S)
Smoke

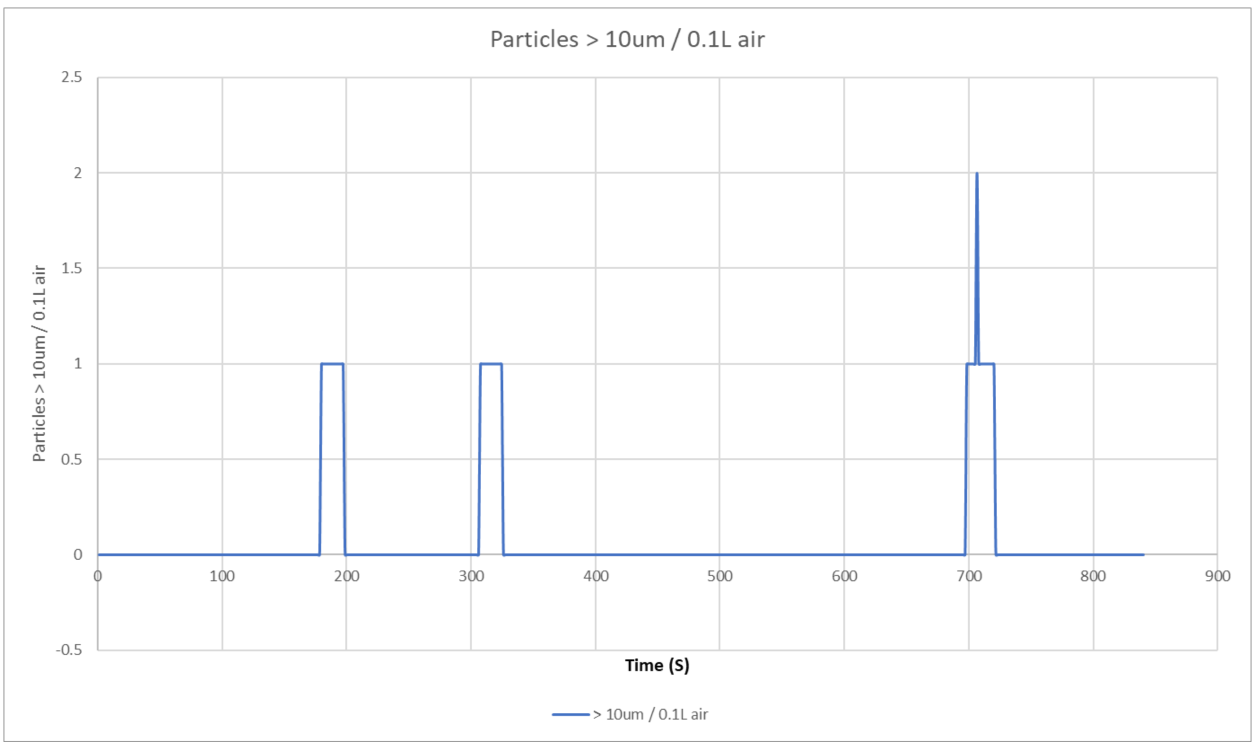

Particles > 0.5um / 0.1L air
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Particles > 0.5um / 0.1L air
0
100
200
300
400
500
600
700
800
900
Time (S)
> 0.5um / 0.1L air


Particles > 1.0um / 0.1L air
Particles > 1.0um / 0.1L air
0
100
200
300
400
500
600
0
100
200
300
400
500
600
700
800
900
Time (S)
> 1.0um / 0.1L air


Particles > 2.5um / 0.1L air
Particles > 2.5um / 0.1L air
-10
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
Time (S)
> 2.5um / 0.1L air

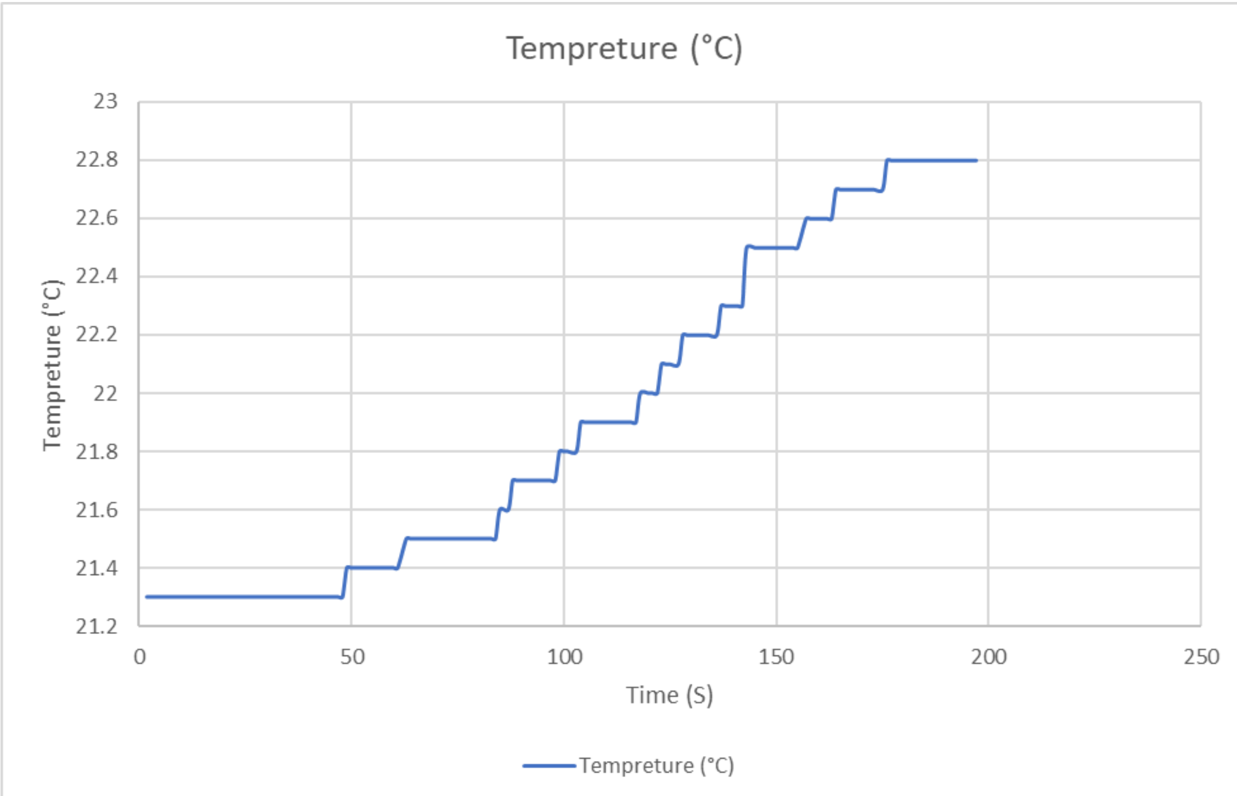


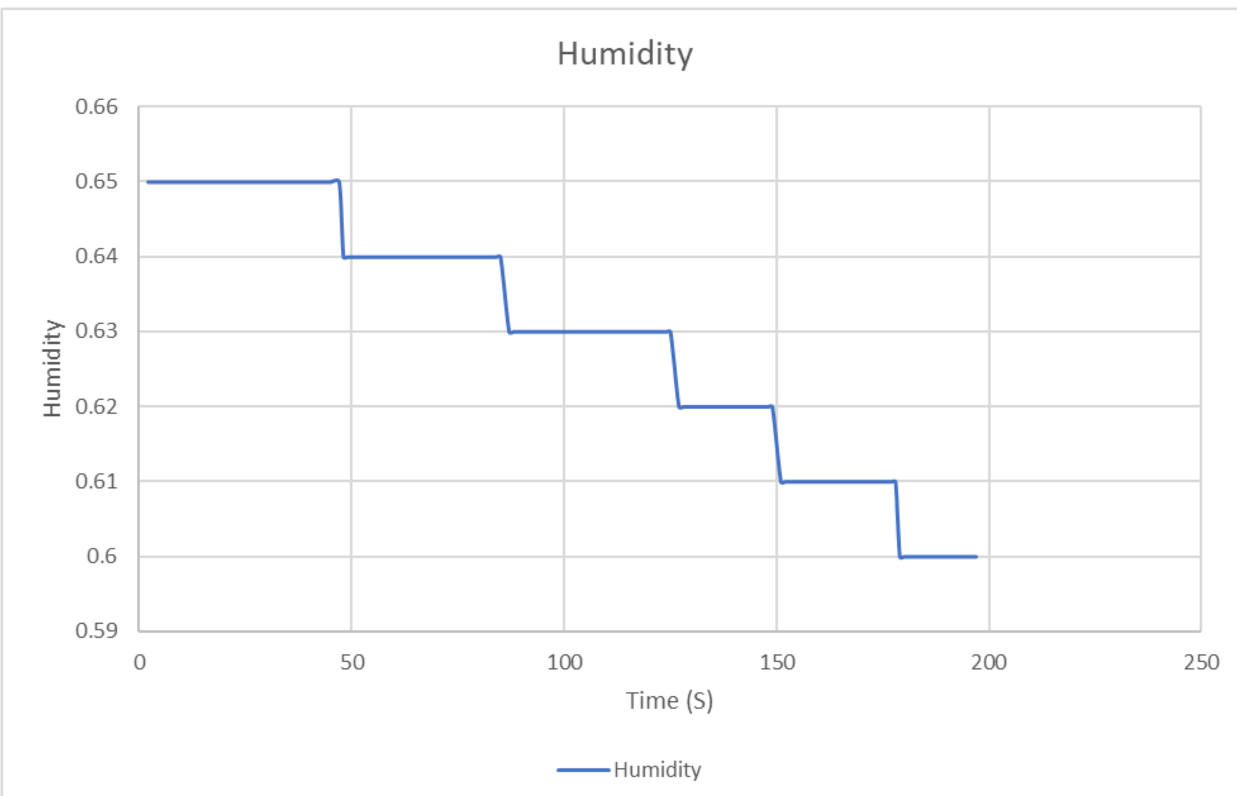
Particles > 5.0um / 0.1L air
Particles > 5.0um / 0.1L air
18
16
14
12
10
8
6
4
2
0
-2
0
100
200
300
400
500
600
700
800
900
Time (S)
> 5.0um / 0.1L air

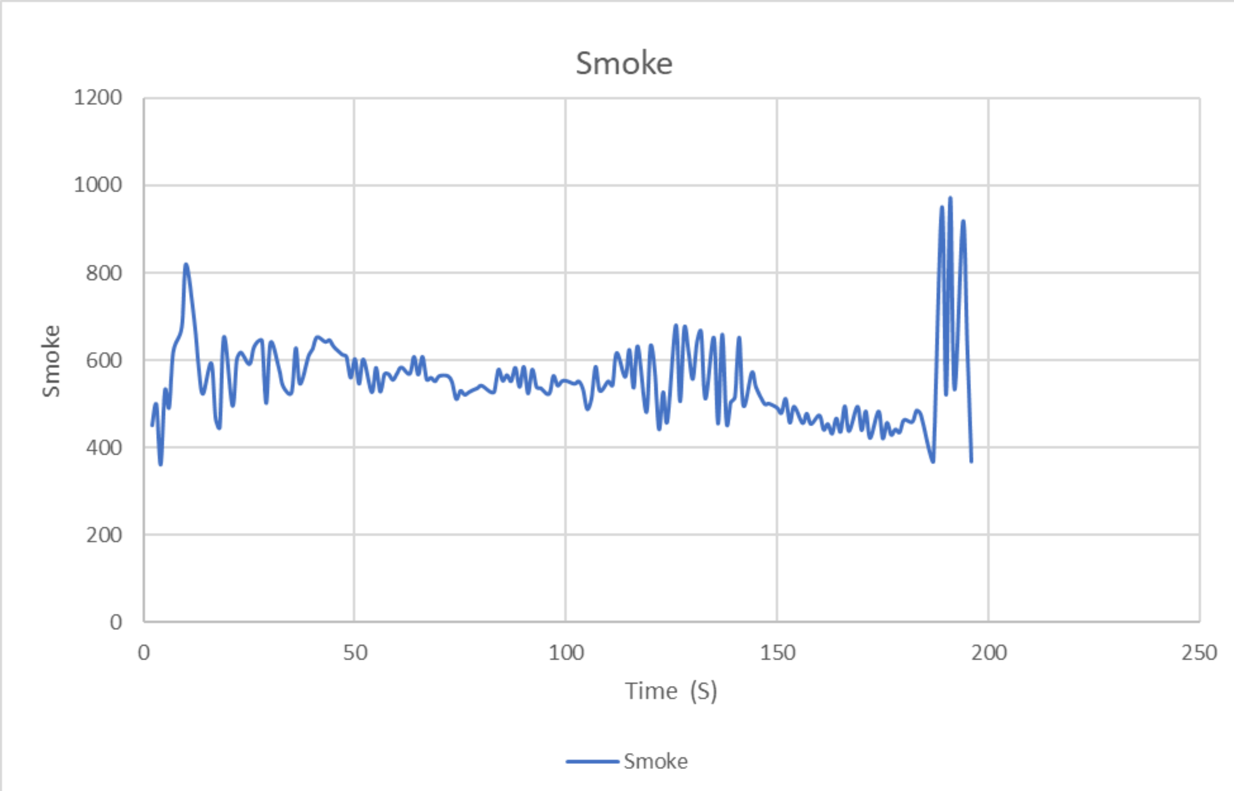


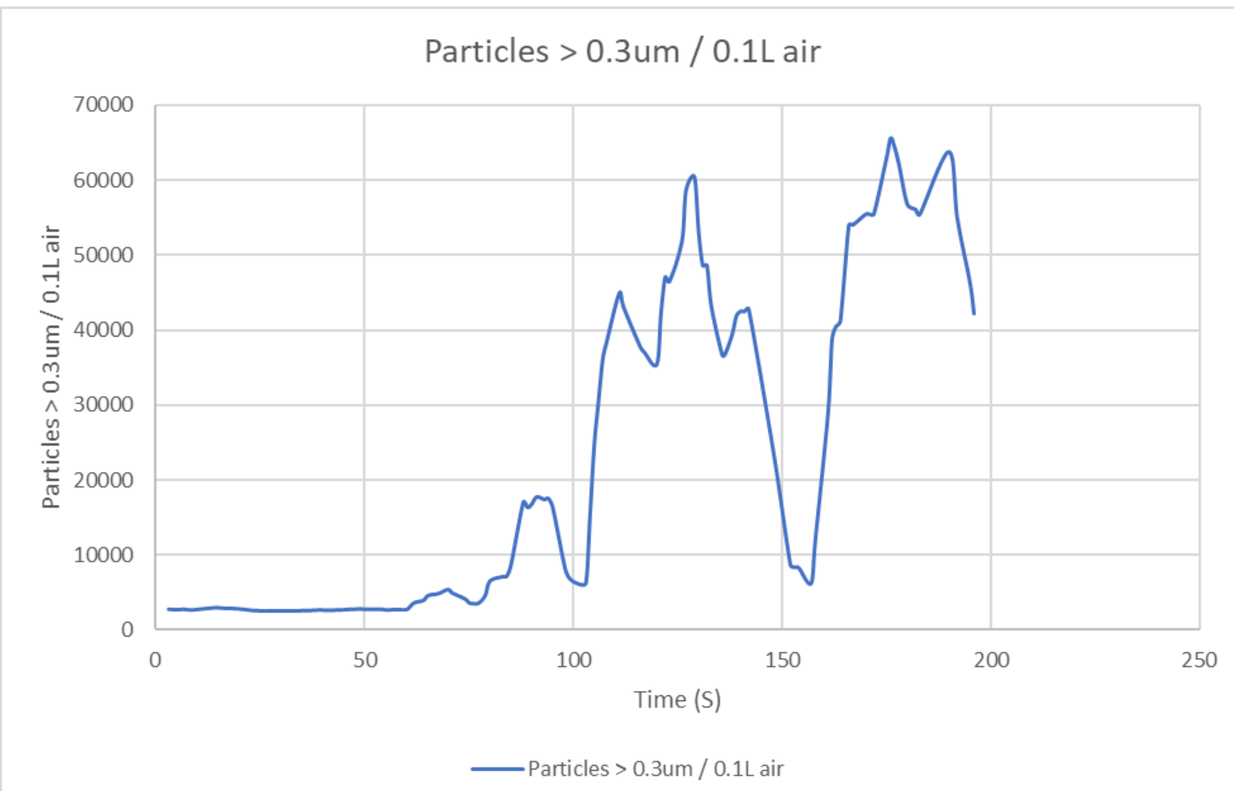
Particles > 10um / 0.1L air
Particles > 10um / 0.1L air
2.5
2
1.5
1
0.5
0
-0.5
0
100
200
300
400
500
600
700
800
900
Time (S)
> 10um / 0.1L air

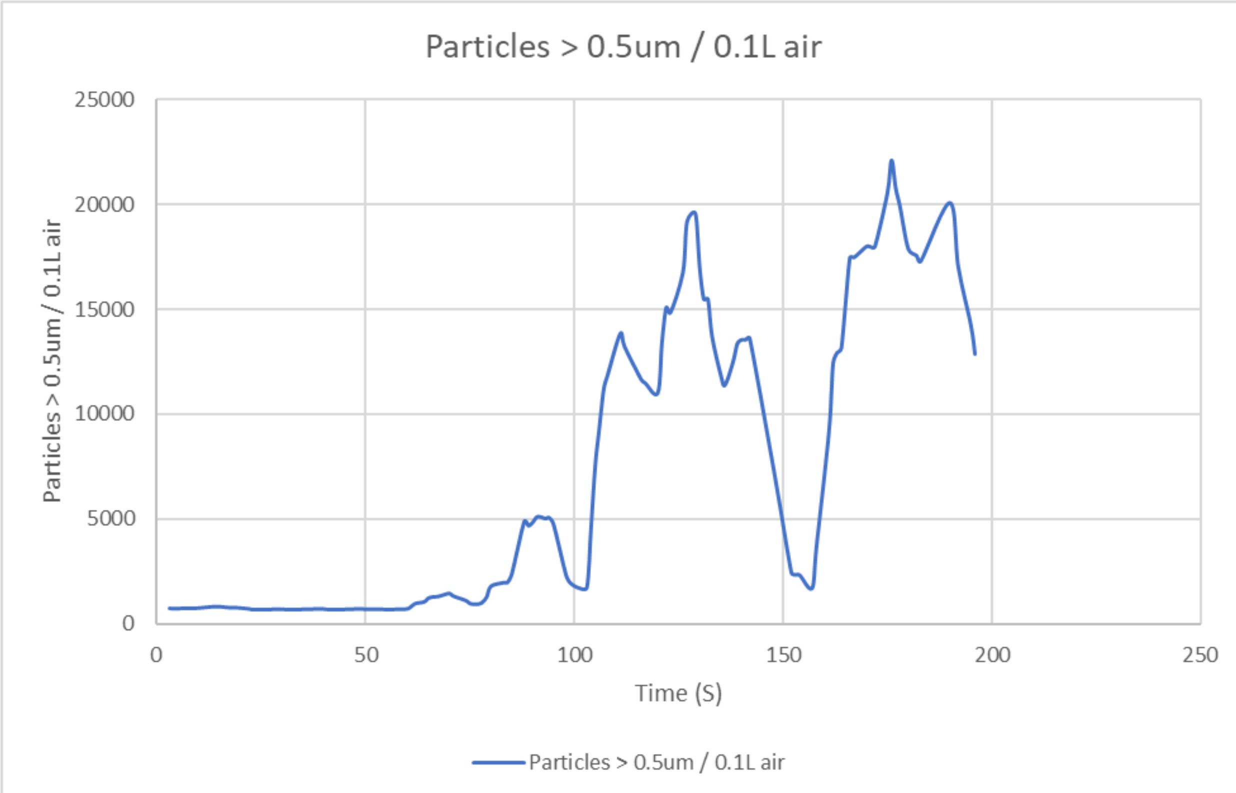
Appendix 5.3: Graphs Smoking Wok Test Extraction On

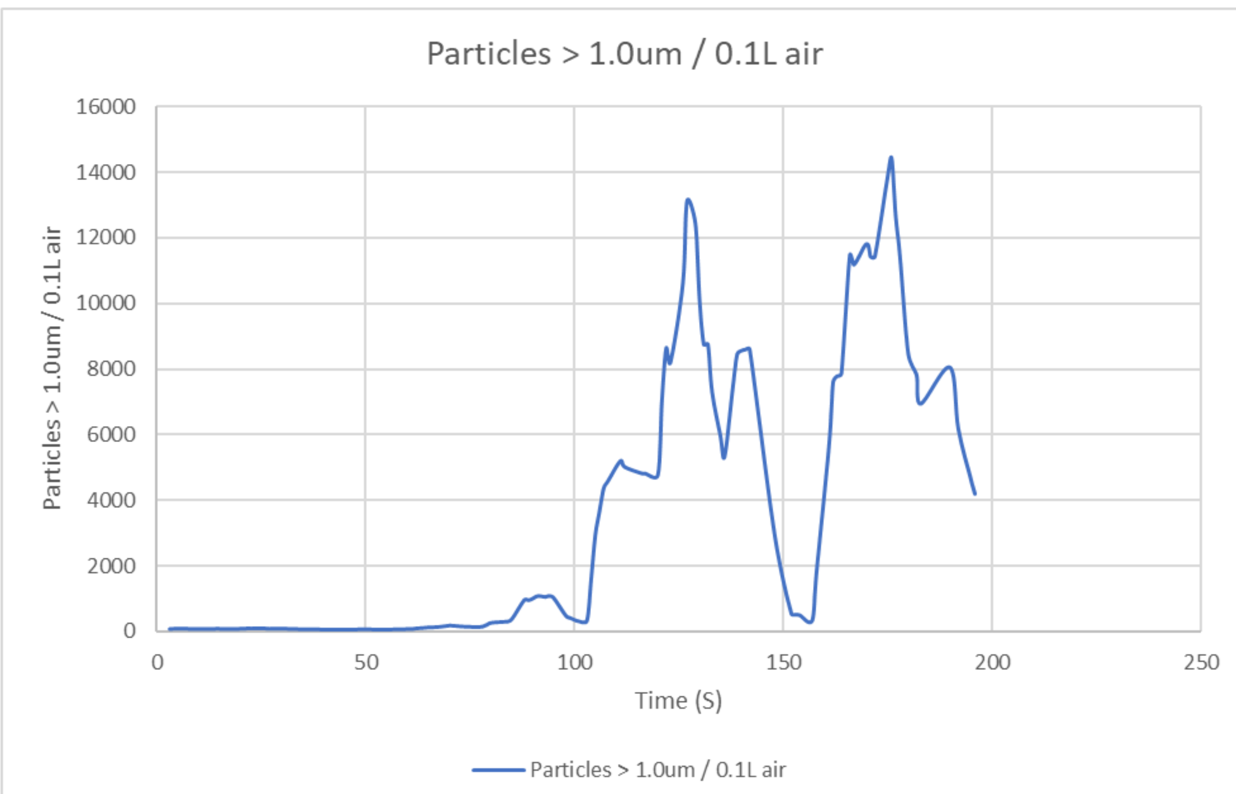


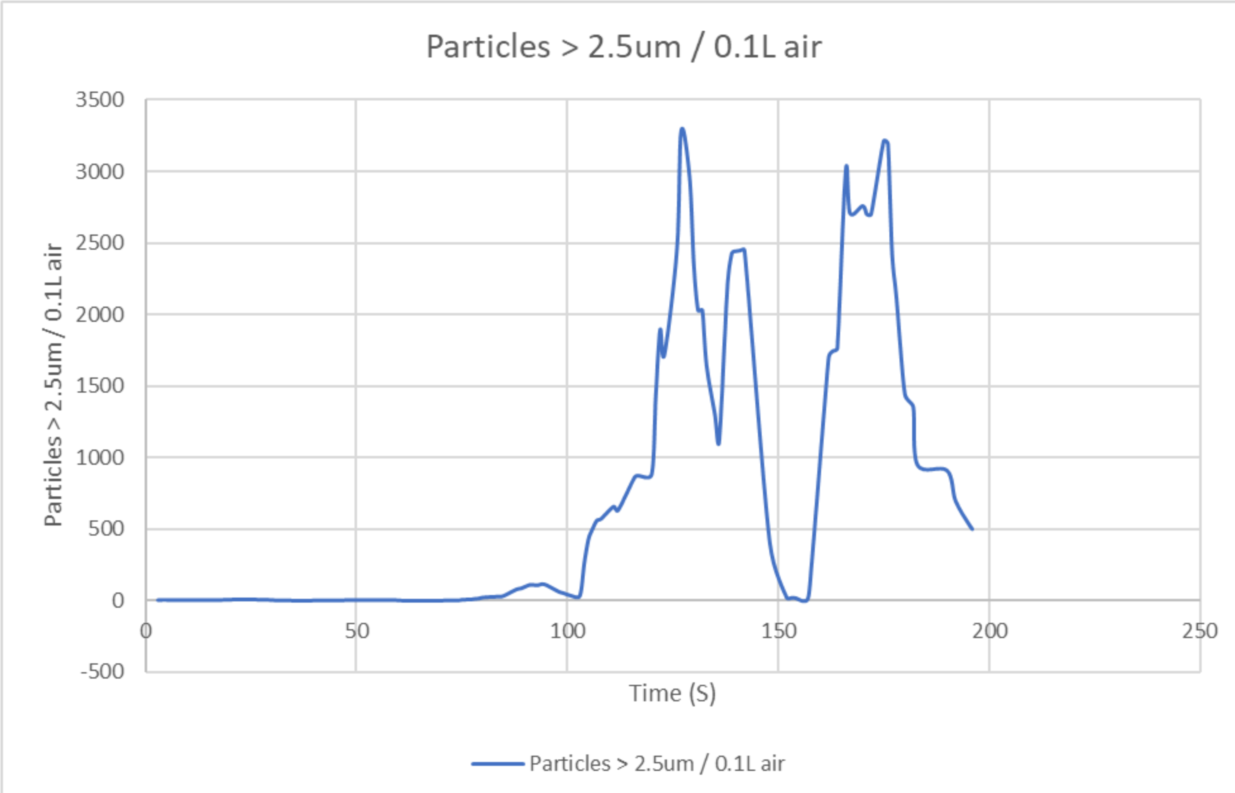


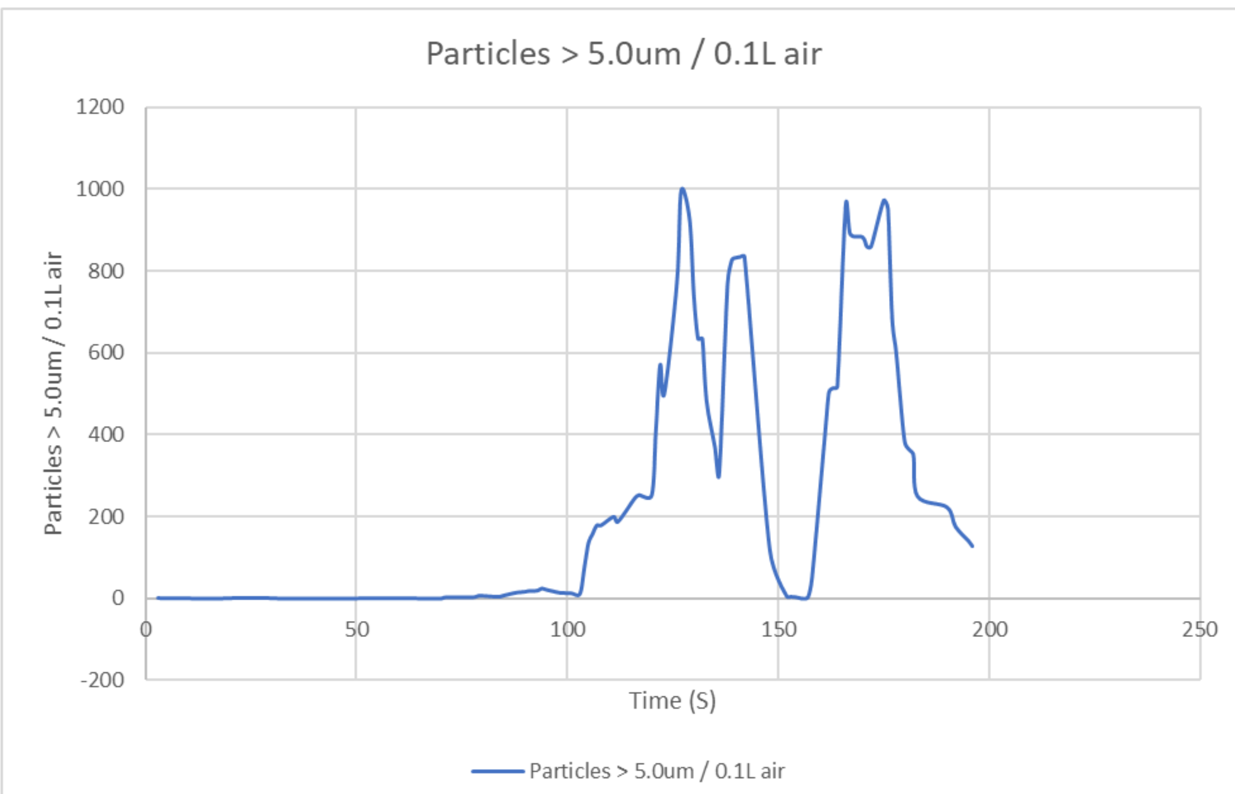

Smoke
1200
1000
800
600
400
200
0
Smoke
0
50
100
150
200
250
Time (S)
Smoke

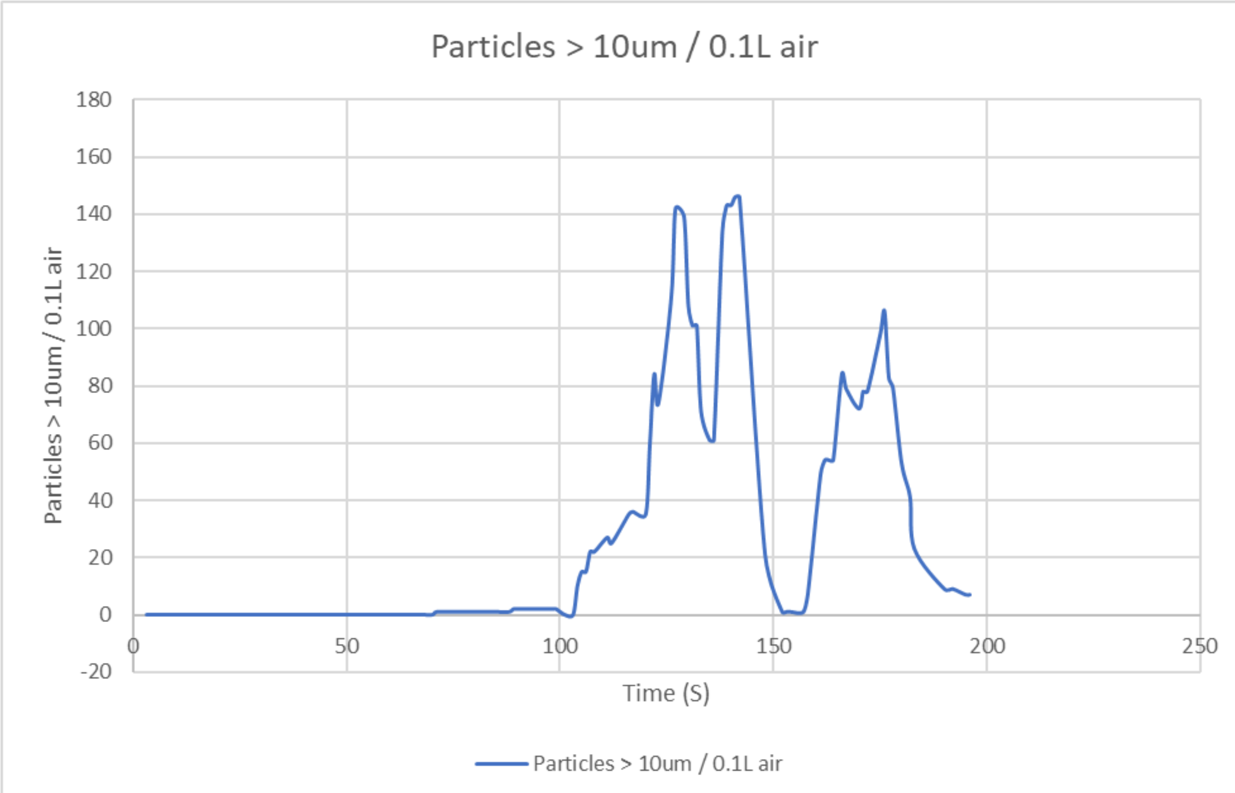

Particles > 0.3um / 0.1L air
70000
60000
50000
40000
30000
20000
10000
0
Particles > 0.3um / 0.1L air
0
50
100
150
200
250
Time (S)
Particles > 0.3um / 0.1L air


Particles > 0.5um / 0.1L air
Particles > 0.5um / 0.1L air
25000
20000
15000
10000
5000
0
0
50
100
150
200
250
Time (S)
Particles > 0.5um / 0.1L air

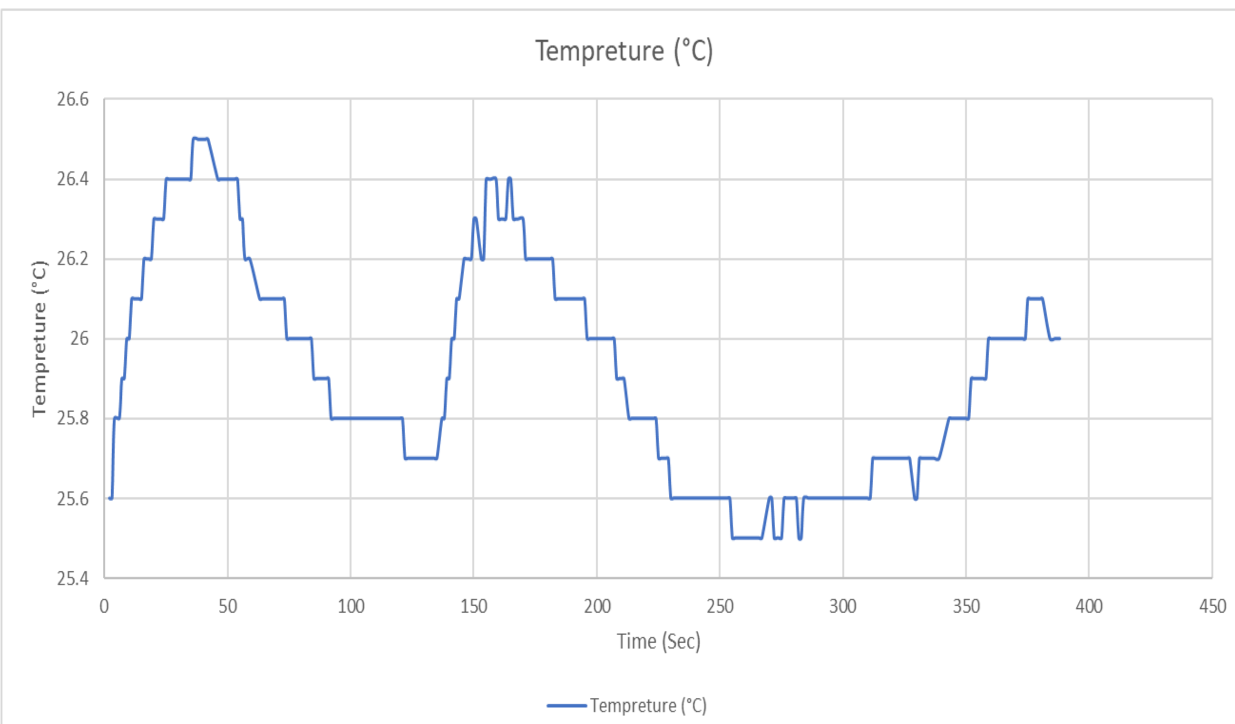

Particles > 1.0um / 0.1L air
Particles > 1.0um / 0.1L air
16000
14000
12000
10000
8000
6000
4000
2000
0
0
50
100
150
200
250
Time (S)
Particles > 1.0um / 0.1L air

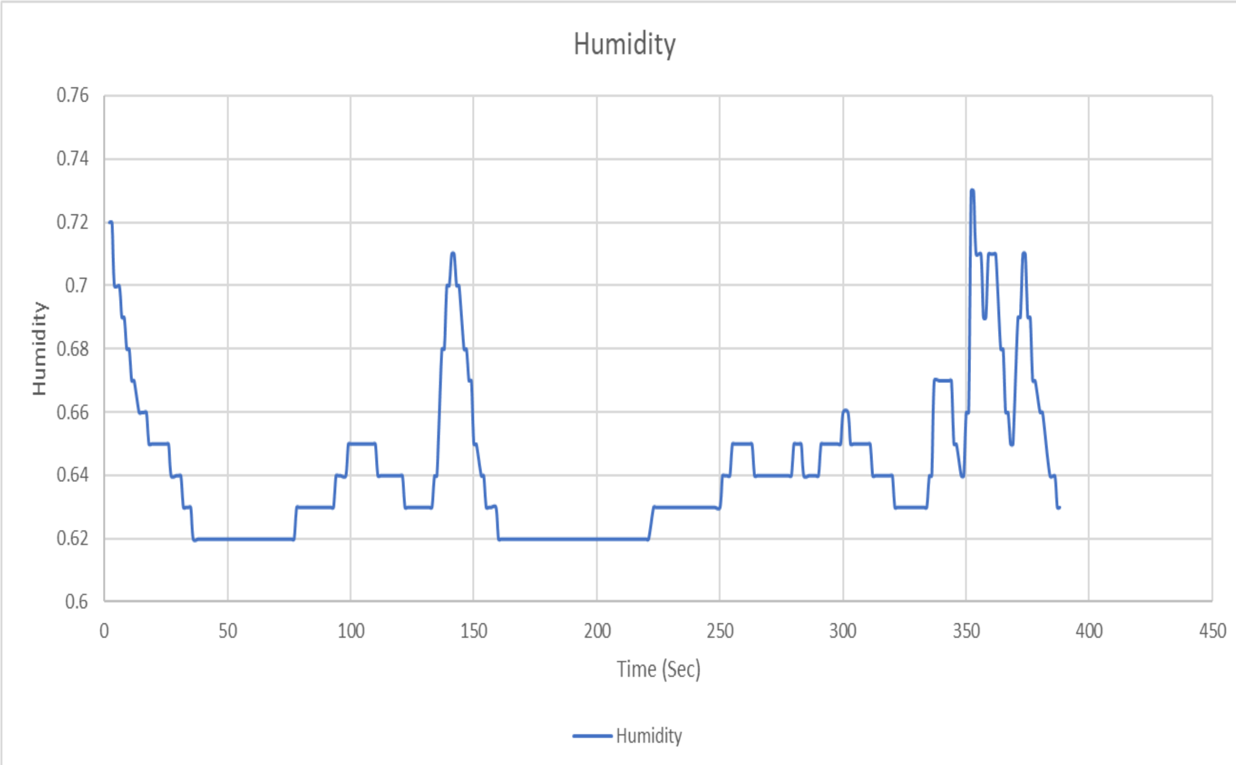

Particles > 2.5um / 0.1L air
Particles > 2.5um / 0.1L air
3500
3000
2500
2000
1500
1000
500
0
-500
0
50
100
150
200
250
Time (S)
Particles > 2.5um / 0.1L air

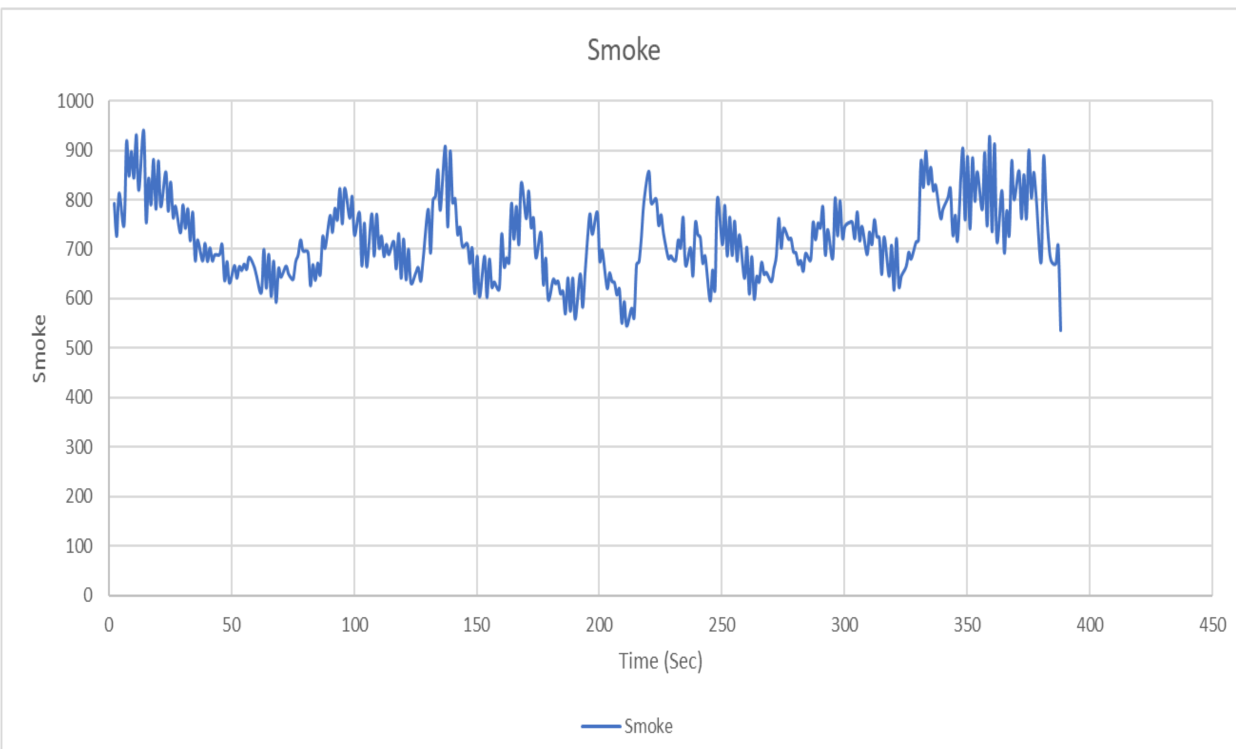

Particles > 5.0um / 0.1L air
Particles > 5.0um / 0.1L air
1200
1000
800
600
400
200
0
-200
0
50
100
150
200
250
Time (S)
Particles > 5.0um / 0.1L air

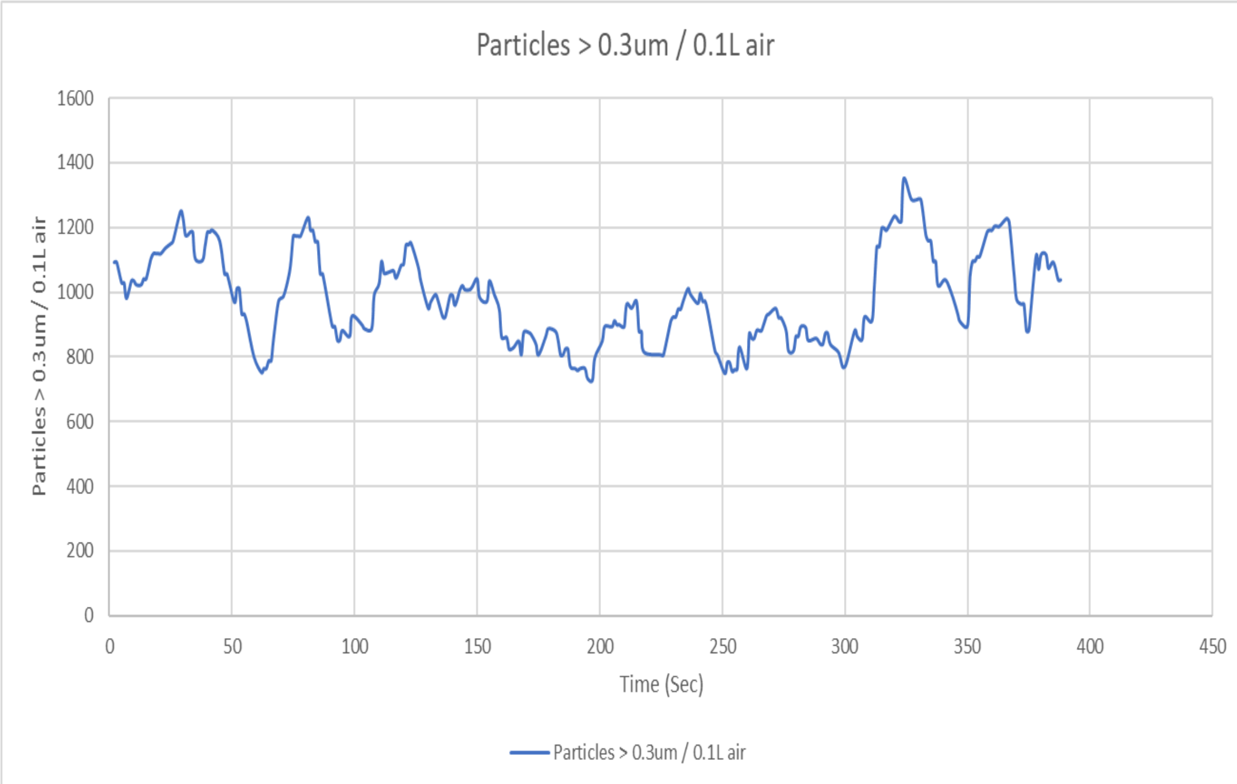


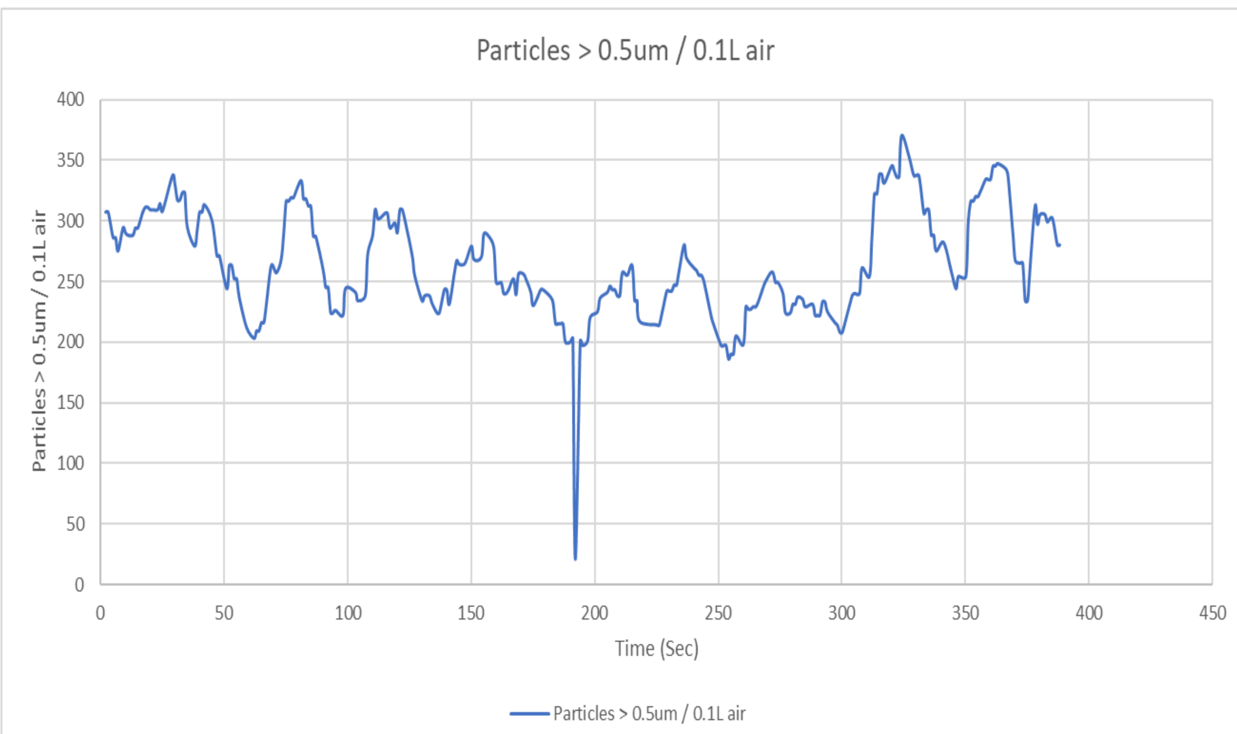
Appendix 5.4: Graphs Steam Test Extraction On

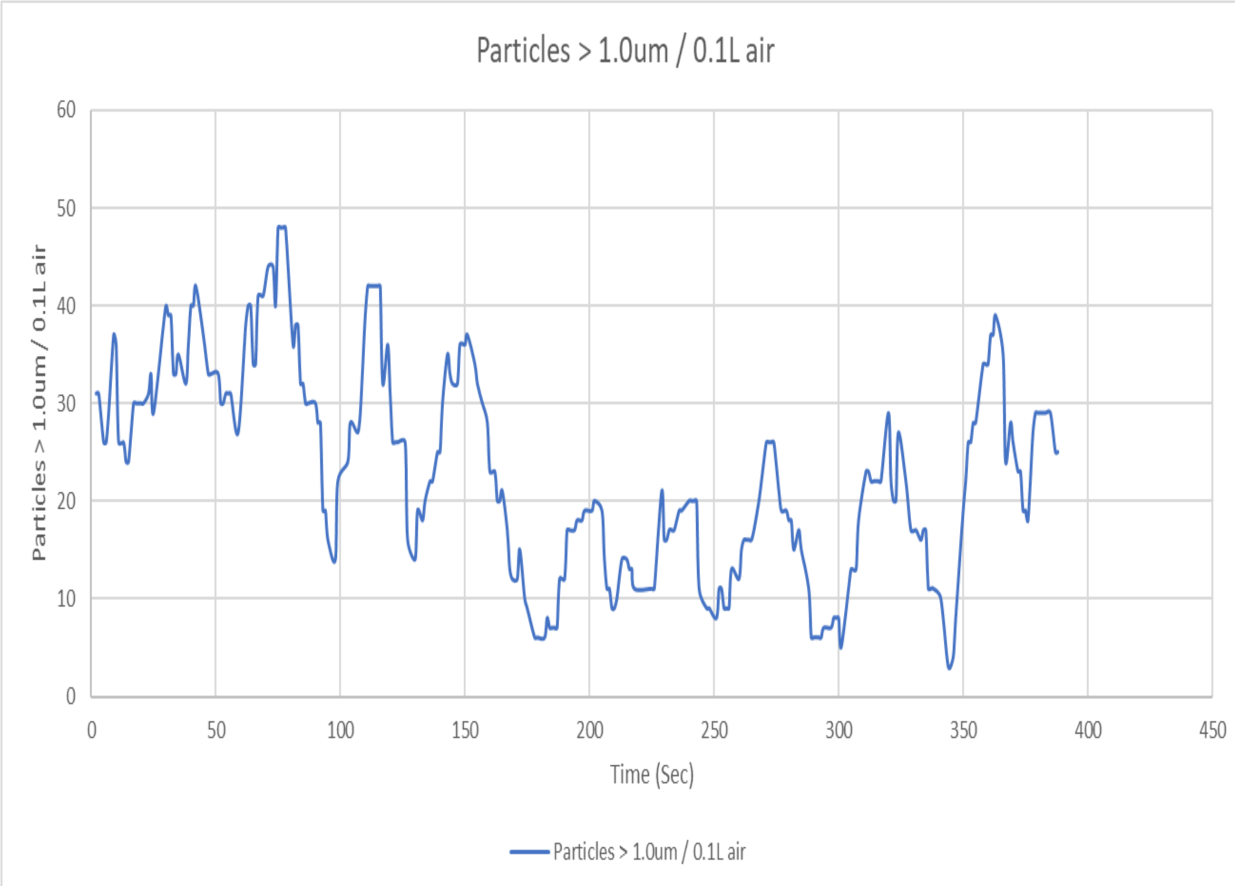


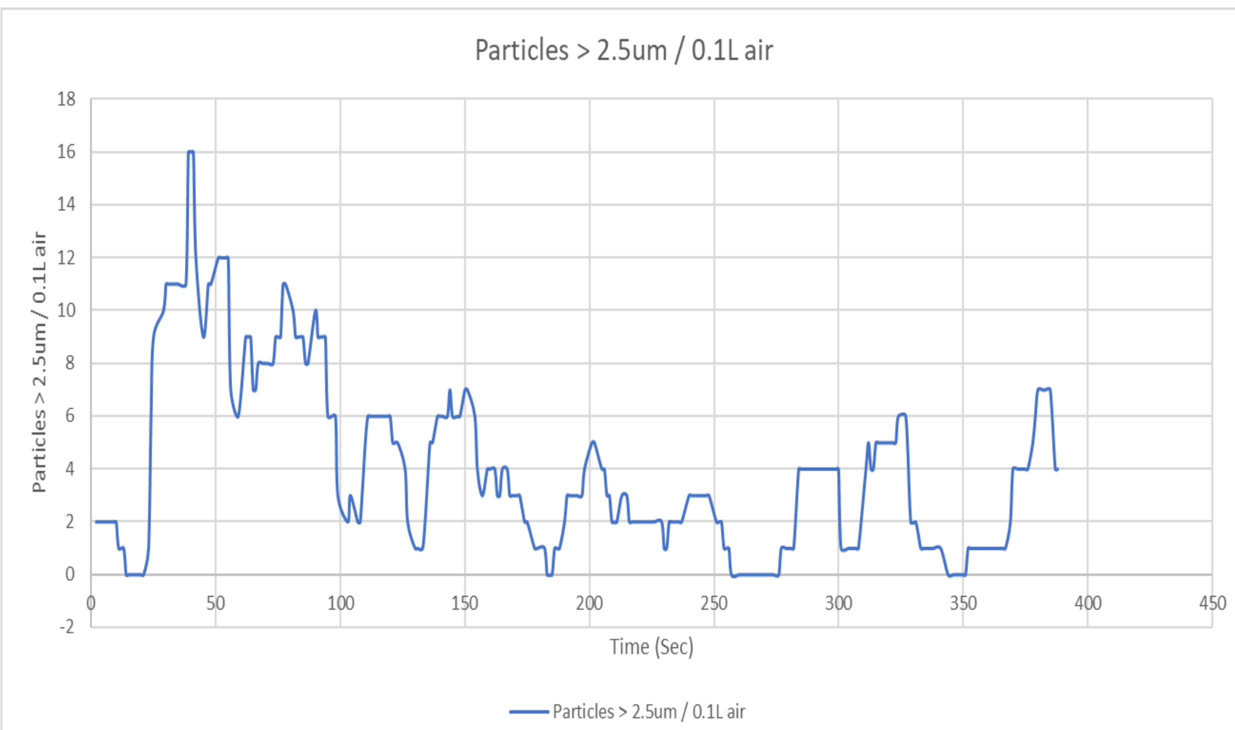

Humidity
0.76
0.74
0.72
0.7
0.68
0.66
0.64
0.62
0.6
Humidity
0
50
100
150
200
250
300
350
400
450
Time (Sec)
Humidity

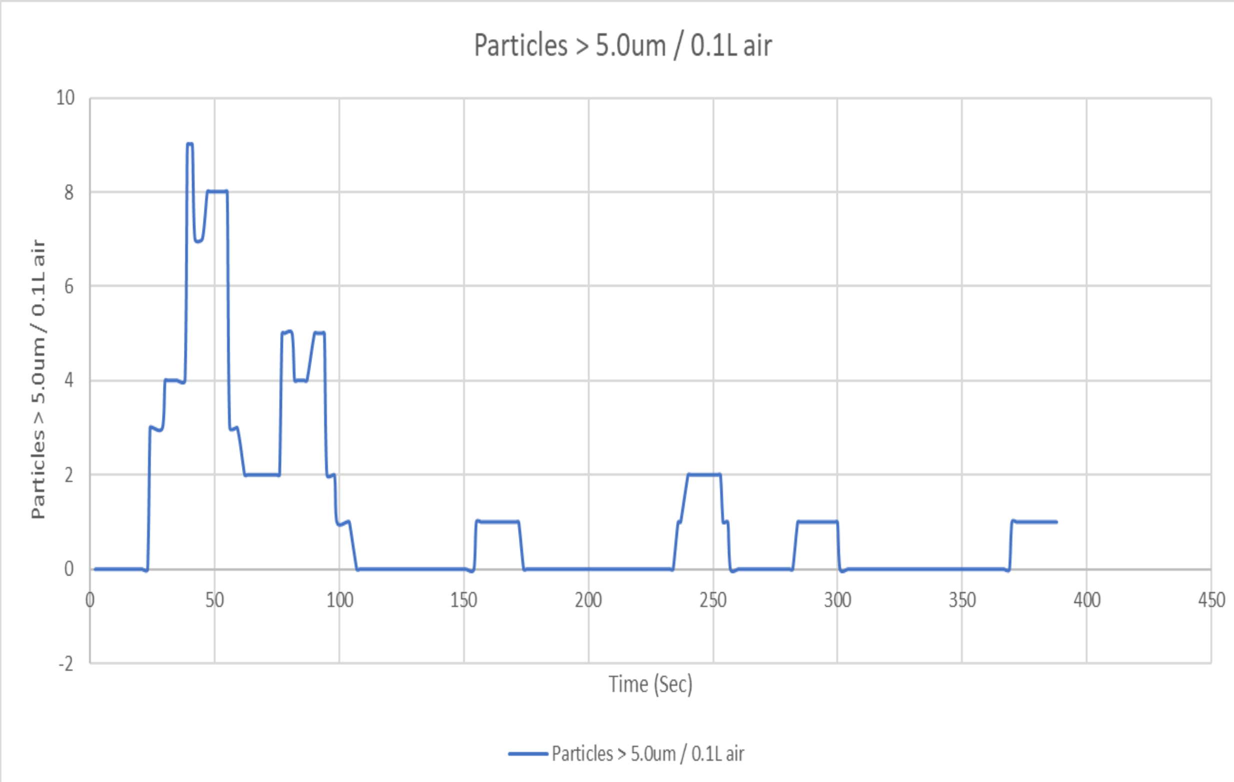

Smoke
1000
900
800
700
600
500
400
300
200
100
0
Smoke
0
50
100
150
200
250
300
350
400
450
Time (Sec)
Smoke


Particles > 0.3um / 0.1L air
Particles > 0.3um / 0.1L air
0
200
400
600
800
1000
1200
1400
1600
0
50
100
150
200
250
300
350
400
450
Time (Sec)
Particles > 0.3um / 0.1L air

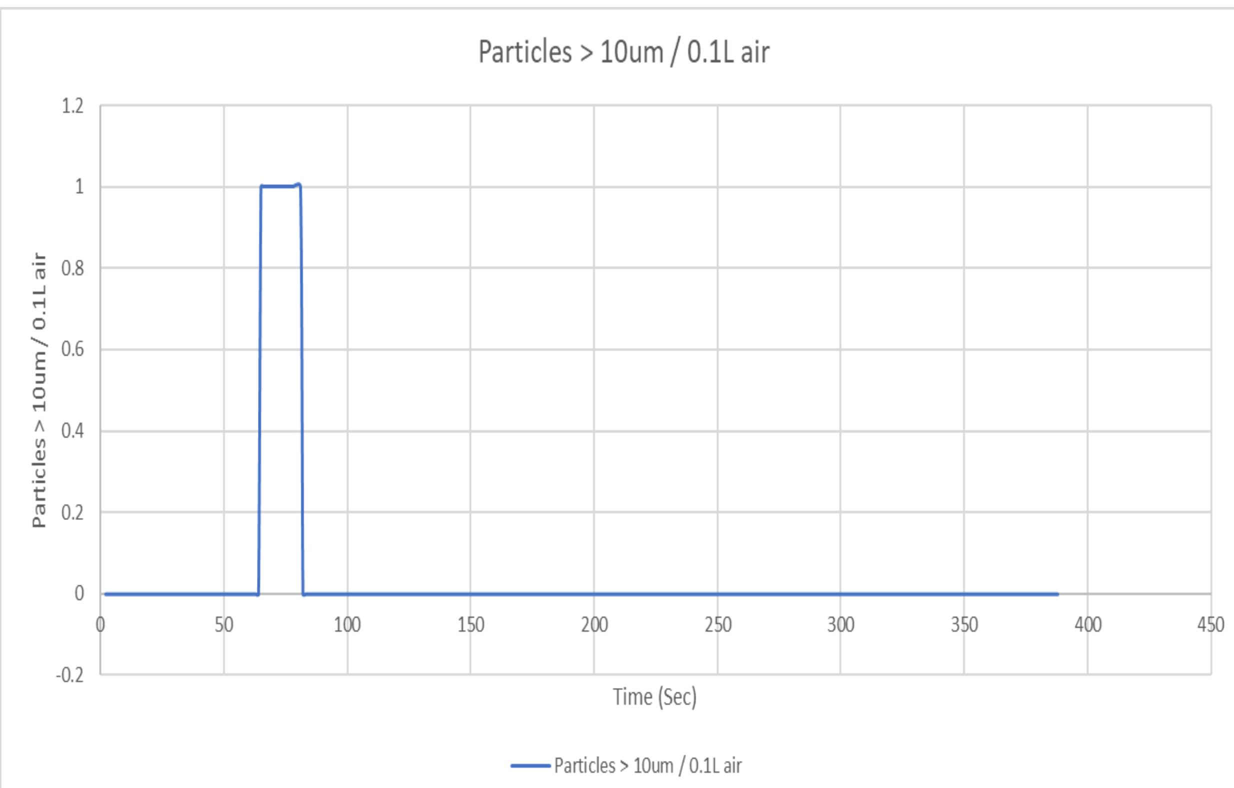

Particles > 0.5um / 0.1L air
Particles > 0.5um / 0.1L air
0
50
100
150
200
250
300
350
400
0
50
100
150
200
250
300
350
400
450
Time (Sec)
Particles > 0.5um / 0.1L air


Particles > 1.0um / 0.1L air
Particles > 1.0um / 0.1L air
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
450
Time (Sec)
Particles > 1.0um / 0.1L air


Particles > 2.5um / 0.1L air
Particles > 2.5um / 0.1L air
18
16
14
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
350
400
450
Time (Sec)
Particles > 2.5um / 0.1L air

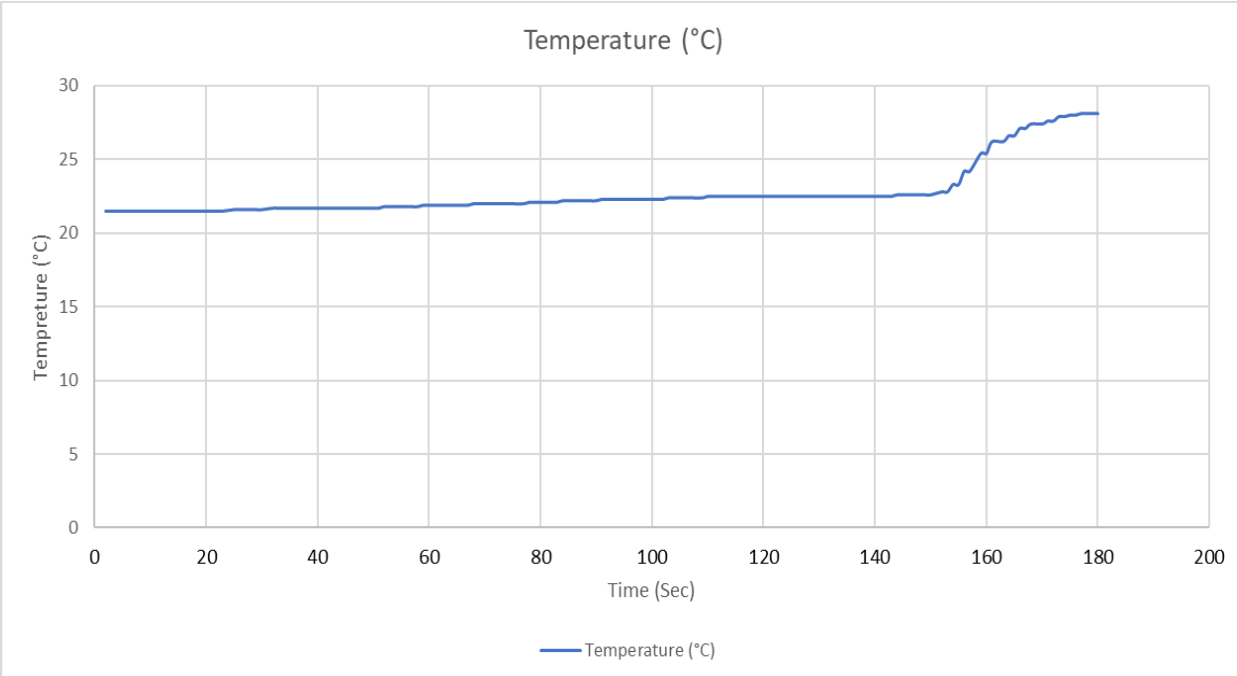


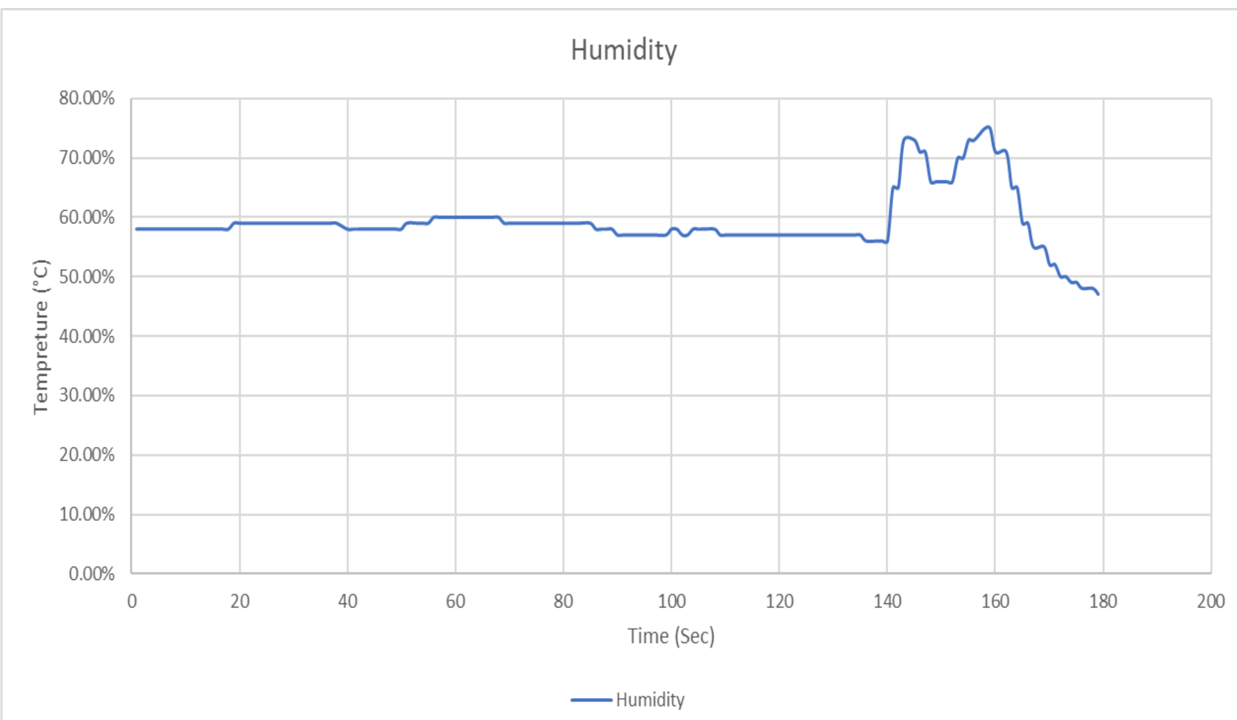
Particles > 5.0um / 0.1L air
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
350
400
450
Particles > 5.0um / 0.1L air
Time (Sec)
Particles > 5.0um / 0.1L air

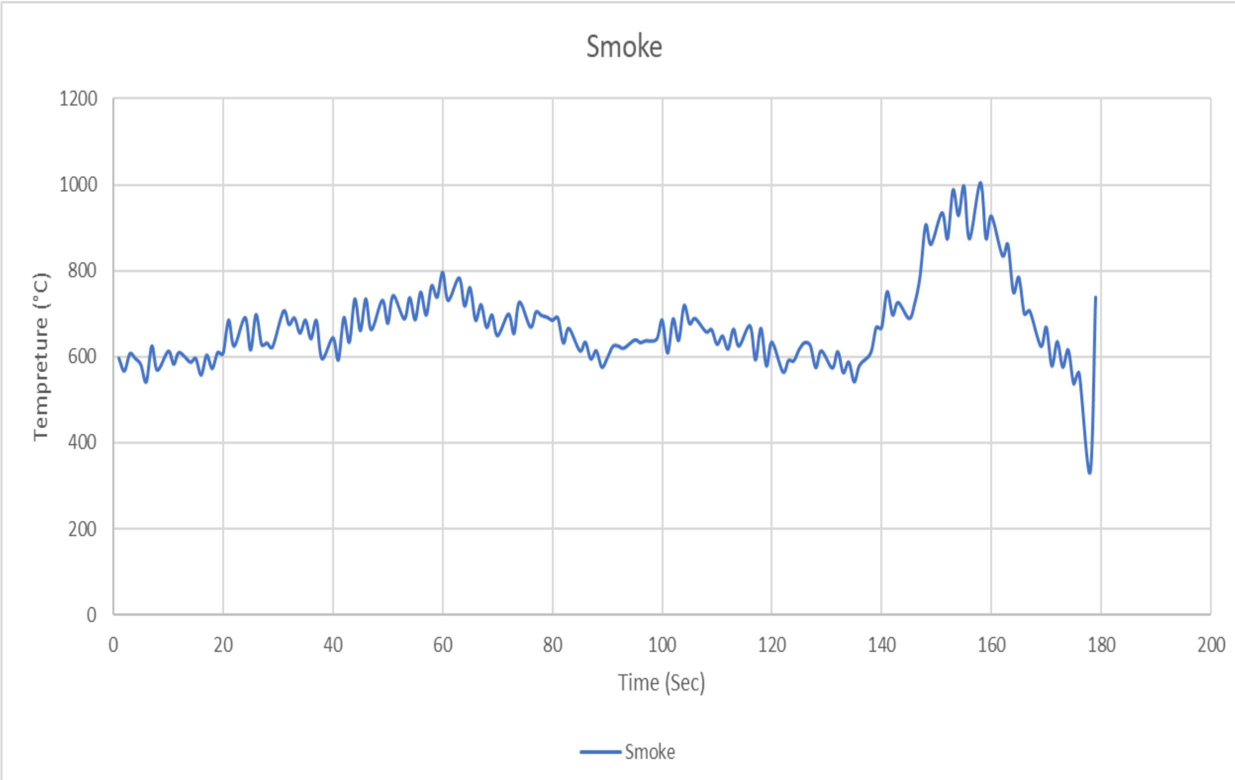


Particles > 10um / 0.1L air
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
50
100
150
200
250
300
350
400
450
Particles > 10um / 0.1L air
Time (Sec)
Particles > 10um / 0.1L air

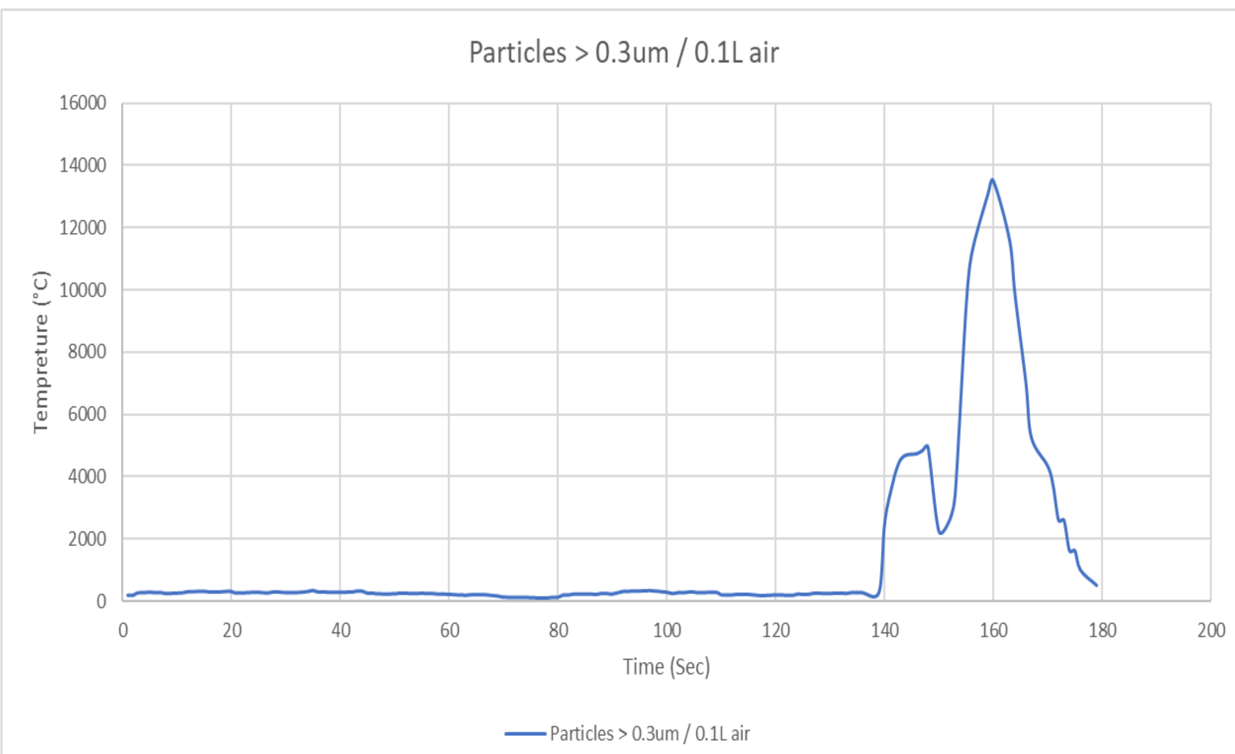
Appendix 5.5: Graphs Alcohol Burn Test



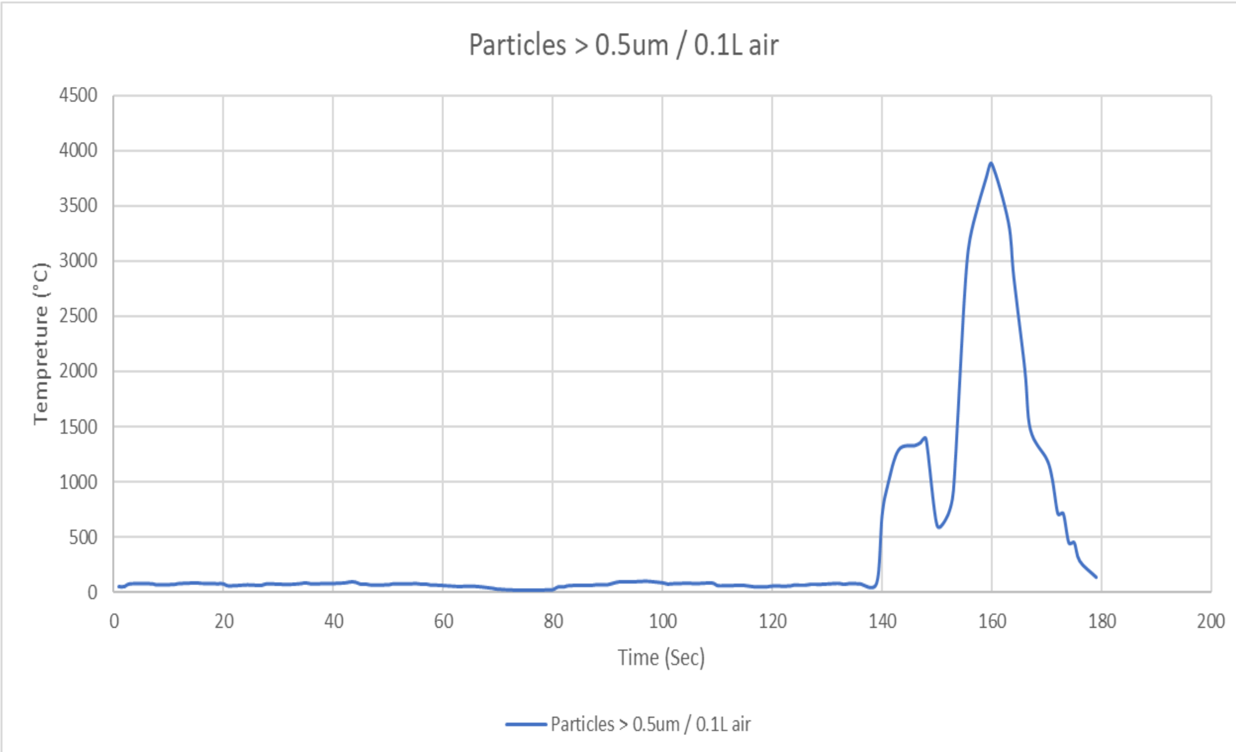




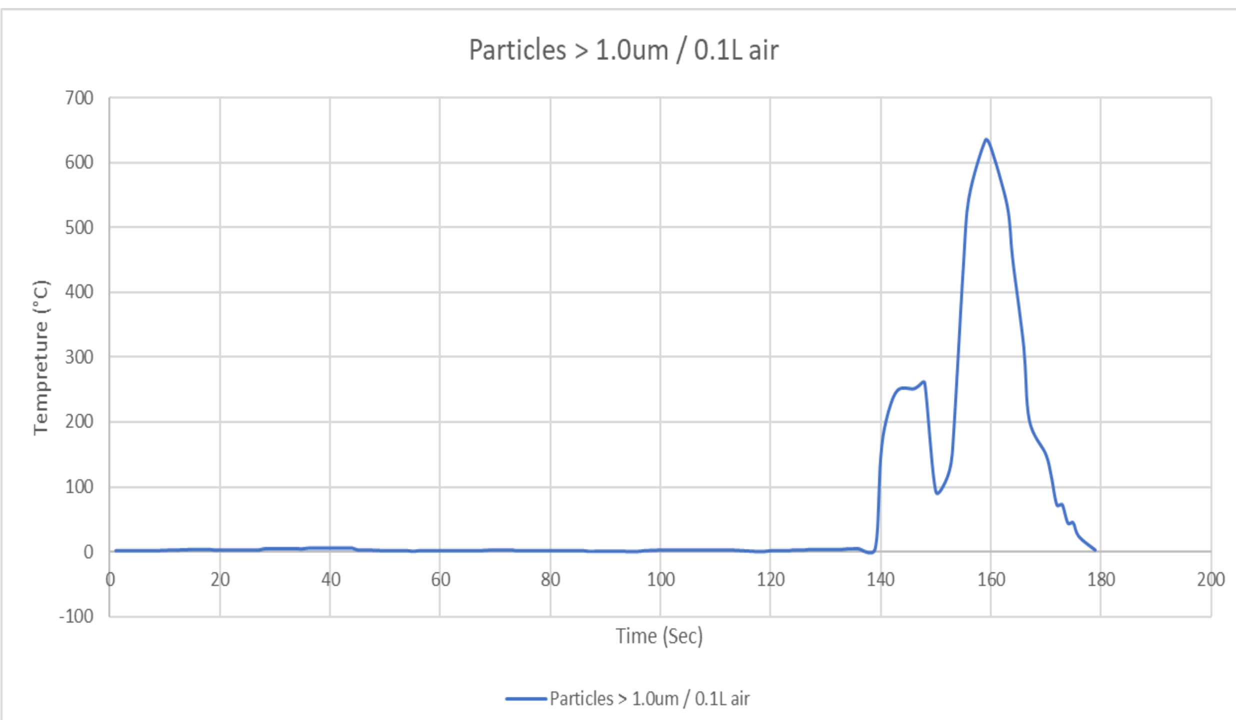
Smoke
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
200
Tempreture (°C)
Time (Sec)
Smoke



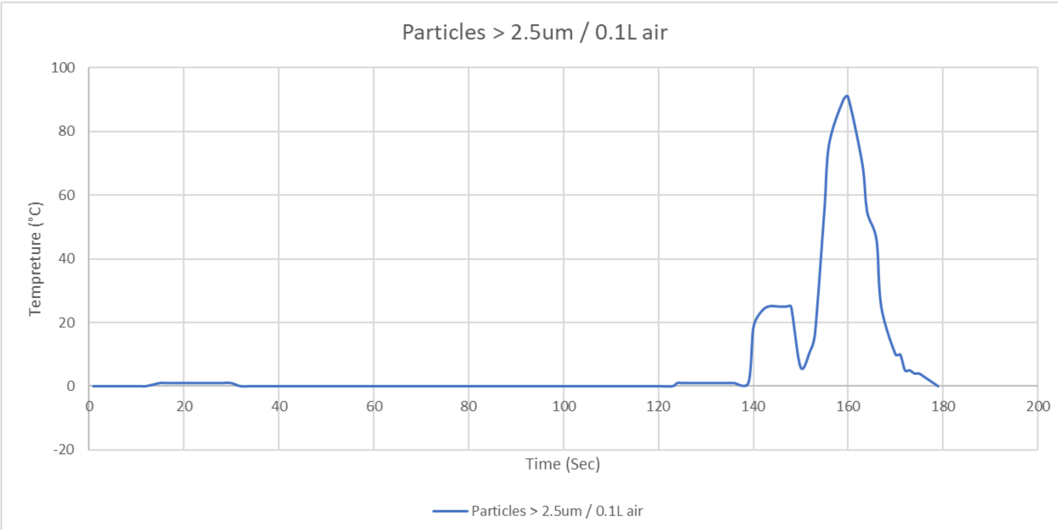
Particles > 0.3um / 0.1L air
16000
14000
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
120
140
160
180
200
Tempreture (°C)
Time (Sec)
Particles > 0.3um / 0.1L air



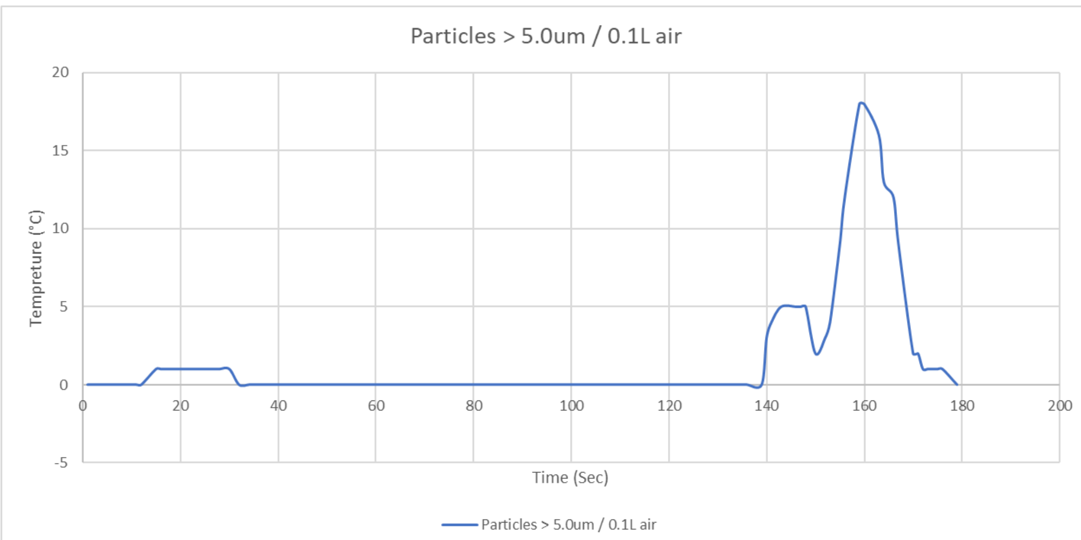
Particles > 0.5um / 0.1L air
Tempreture (°C)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 0.5um / 0.1L air



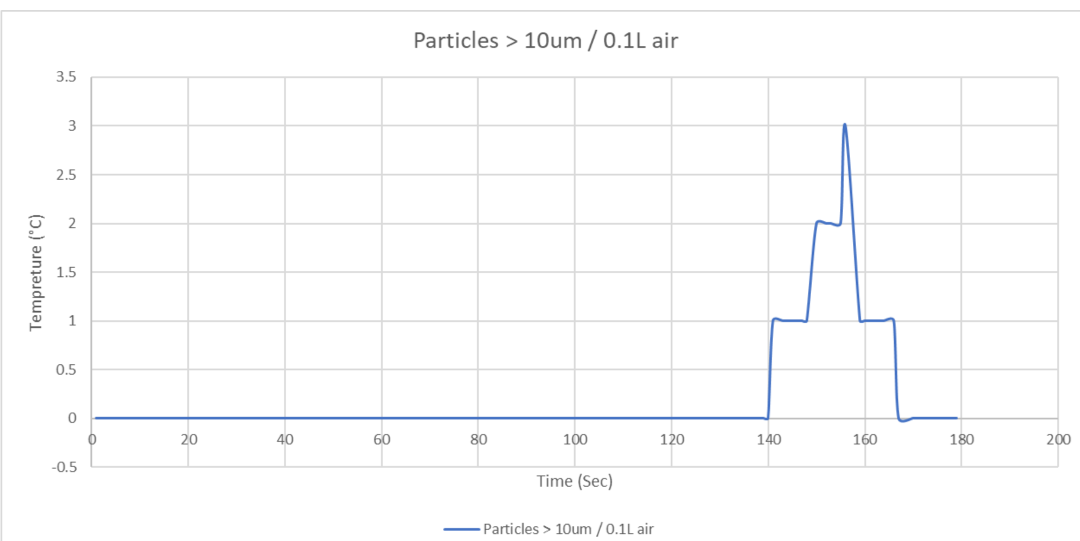
Particles > 1.0um / 0.1L air
Tempreture (°C)
700
600
500
400
300
200
100
0
-100
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 1.0um / 0.1L air



Particles > 2.5um / 0.1L air
100
80
60
40
20
0
-20
Tempreture (°C)
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 2.5um / 0.1L air



Particles > 5.0um / 0.1L air
20
15
10
5
0
-5
Tempreture (°C)
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 5.0um / 0.1L air



Particles > 10um / 0.1L air
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Tempreture (°C)
0
20
40
60
80
100
120
140
160
180
200
Time (Sec)
Particles > 10um / 0.1L air

9. **Bibliography**

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