Studies on the application of gas cooling as used by firefighters

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Abstract

Gas cooling is a technique used by firefighters to create a safer work environment inside a compartment fire. By spraying water into the smoke layer, the smoke layer temperature will decrease significantly. Next to the lower temperature, the flammability of the smoke layer will also decrease. Due to the cooling of the fire gases, the smoke layer may contract.

This work focused on different parameters that may affect the efficiency of gas cooling and was based on experiments. A series of tests were conducted inside an adjusted half-scale ISO9705 room. A rotatable nozzle was used to analyse different application methods, spraying times, spray angles and droplet size. Temperatures inside the room, velocities in the door opening and contraction of the smoke layer were measured.

Out of the experimental results, the conclusion was made that there were no large differences between using the sweep or the pulsing method. There is no such thing as the one method that is the best way to apply the water spray to cool the overhead fire gases. The time between every spray must be as small as possible. It is better to open the nozzle once until enough water is applied into the smoke layer than open the nozzle multiple times for the same amount of total used water.

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STUDIES ON THE APPLICATION OF GAS COOLING AS USED BY FIREFIGHTERS

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Out of the experimental results, the conclusion was made that there were no large differences between using the sweep or the pulsing method. There is no such thing as the one method that is the best way to apply the water spray to cool the overhead fire gases. When the fire gases must be cooled on a larger distance, pulsing will result in better cooling of the fire gases. The sweep is less influenced by the droplet size. So when the desired work pressure is not possible on the firefighter’s nozzle, and the ideal droplet sizes are not created, the cooling efficiency of the sweep method will be less influenced.

The time between every spray must be as small as possible. It is better to open the nozzle once until enough water is applied into the smoke layer than open the nozzle multiple times for the same amount of water.

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1 Introduction

Gas cooling is a technique used by firefighters when an internal fire attack is deployed. A hot smoke layer can be formed in a compartment fire. In the growth phase there is colder ambient air underneath the hot fire gases. The hot smoke layer possesses different dangers. The impaired visibility can make the orientation and search actions of the firefighters more difficult. The hot layer also has the risk of igniting, which can cause an escalation of the fire in the room where the firefighters are located.

A fire must be put out on the seat of the fire. So, an internal attack is mostly necessary. Or as Sir Eyre Massey Shaw said [1]:

> "In order to extinguish a fire properly, it is necessary for the fireman to approach it for the purpose of putting the water wherever it is most wanted. Any attempt to extinguish the fire from a distance almost invariably proves a failure."

So for approaching the fire gas cooling is used to reduce the dangers in the hot smoke layer above the firefighters. The gas cooling technique can be summarized in following key rules [2]:

- Gas cooling is most important when the fire is shielded and hot fire gases are overhead.
- Gas cooling is a control technique and does not extinguish the fire.
- Extinguishing the fires generally requires a direct attack on the seat of the fire.

Figure 1: Firefighter cooling the burning gas layer at training facility MSB Revinge – Picture by Stefan Svensson

1.1 History

During the early 1980s two Swedish fire chiefs (Mats Rosander & Krister Giselsson) were the first once noticed that putting water droplets into the smoke layer resulted in a safer work environment for firefighters [3] [4]. They introduced the gas cooling technique that was aimed at cooling and inerting hot fire gases in a fire compartment. 'Pulsations' were directed to the overhead smoke layer by making use of a fog nozzle. Using the spraying pattern of the fog nozzle had more influence on the smoke layer then the old traditional methods of directing a straight stream at the ceiling.

After Paul Grimwood wrote the book Fog Attack in 1992 [3], the London fire brigade also started training and further developing of this technique. For long a compartment fire was only considered as a two-dimensional problem, in that it excluded the volume of hot gases produced. In 2005 the book '3D Fire Fighting' came out [5]. This made the awareness worldwide that fire gases were also seen as a fuel and a danger to firefighters. A compartment fire was now being seen as a three-dimensional problem. From that point, gas cooling is sometimes also recognized as the 3D-technique.

1.2 Previous research

The research work of Van de Veire [6] provides several conclusions that delivers a better understanding of the basics in gas cooling. Of all the nozzles he used, a higher working pressure, and thus a smaller droplet size, for a same nozzle always resulted in a more efficient cooling of the gases.

He showed that a better distribution of the droplets, from a full cone nozzle, resulted in better cooling efficiency inside the smoke layer. Also that the cooling in the back of the room was better than the nozzles with the smaller droplets. The reach of a nozzle is therefore important for cooling the fire gases in the back of the room. He showed that small droplets that evaporate quickly, will cool the front fire gases very well. But the fire gases in the back of the room will not get any interaction with the water droplets. So no gas cooling is done in a further to reach area of a room.

He also concludes that the time between the pulses must be kept as small as possible to obtain the best cooling efficiency. It is better to open the nozzle only once to achieve a longer pulse than to open it several times to flow the same amount of used water.

1.3 Application methods as used by firefighters

Gas cooling is performed in many countries around the world. Different methods are used to spray the water into the smoke layer. Two main methods are applied using a fog nozzle. In the Anglo-Saxon world pulsing is used by firefighters to put water into the smoke layer. Also in South-America, Hong Kong, West- and Central Europe etc. gas cooling is done using pulses. In the Scandinavian countries, gas cooling is done by sweeping the nozzle spray into the smoke layer. In the United States gas cooling is not that common. In many cases, they use a smooth bore nozzle that is forming a solid stream. If they want to cool the hot gases above them, they direct the stream to the ceiling and try to pour the solid stream in smaller droplets. This technique is not comparable with the techniques that using a fog nozzle.

1.3.1 Pulsing as used by firefighters

Short pulses are brought into the smoke layer. The nozzle is open for approximate one second. In some countries, they try to give as short as possible pulses. For example, in Germany they sometimes try to give bursts shorter than half a second. To have the same amount of water into the smoke layer they must open their nozzle multiple times. When a firefighter enters a compartment where a smoke layer is present, the goal is to distribute the pulses across the full width of the room. Figure 2 and Figure 3 give an image of how the firefighter distributes its pulses. Figure 4 shows a firefighter that performs a short pulse with an angle of 45°. The spray angle is set on 50°.

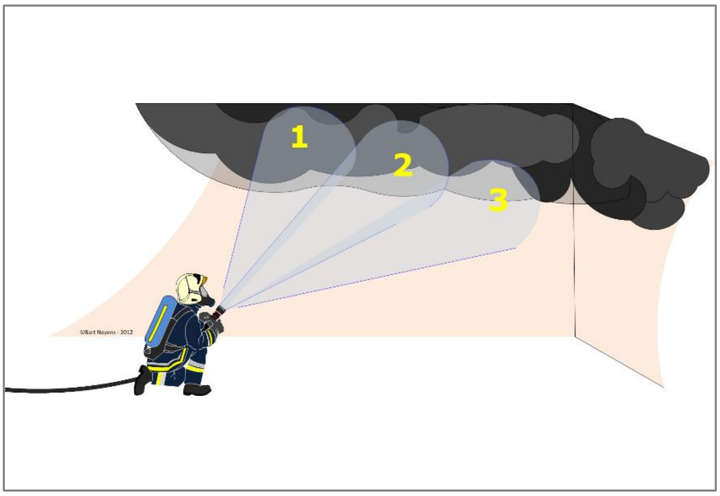

Figure 2: Pulsing from left to right (Third person view) - Image by Bart Noyens [7]

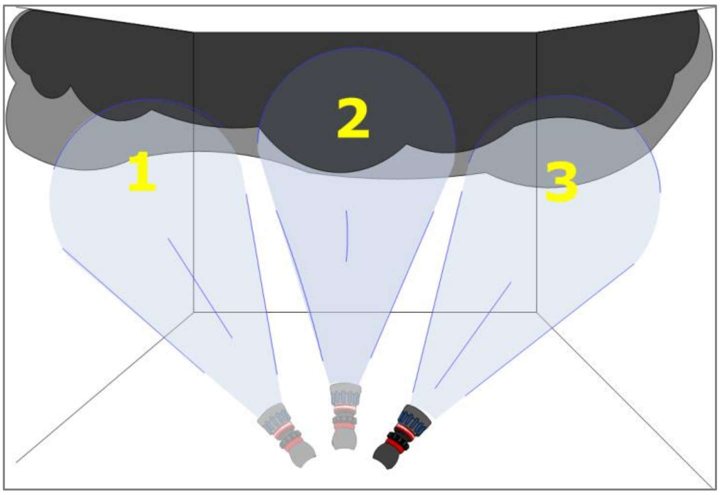

Figure 3: Pulsing from left to right (First person view) - Image by Bart Noyens [7]

Figure 4: Short Pulse - Picture by Geert Vandamme [7]

Figure 5: Long Pulse - Picture by Geert Vandamme [7]

In the pulsing method, the long pulse is an alternative for the short pulse. The reach of the short pulse is more limited than the long pulse. The long pulse can be used when the room is larger and the firefighter cannot reach the full room with the short pulse. It can also be used to have a more efficient cooling in case the smoke velocity is rather high. This can happen in a narrow corridor. For example, at the end of the corridor there is a fully developed room fire and the fire gases flow into the corridor, towards the approaching firefighter. Short pulses will not cool that efficient. The cooled smoke will flow fast out of the compartment. The approaching fire gases must be cooled further away, so the firefighter gets more time. The nozzle is opened for a longer time when a long pulse is used. The firefighter will open the nozzle for approximate 2 to 3 seconds [8]. Figure 5 shows a firefighter performing a long pulse.

Pulses are used because the most fire instructors that advocate this method have the experience that sweeping would result in disturbing the thermal layering. The smoke layer may drop down on top of the possible unconscious victim.

1.3.2 Sweeping as used by firefighters

In Sweden, they are used to cool the fire gases by sweeping a water spray into the smoke layer. The firefighter will open the nozzle when aiming the nozzle to one side of the room. Then he will sweep the nozzle over the full width of the room till the water spray reach the other side of the room. The nozzle will be closed when the full smoke layer has been cooled. Figure 6 and Figure 7 show a firefighter performing a sweep to cool the fire gases.

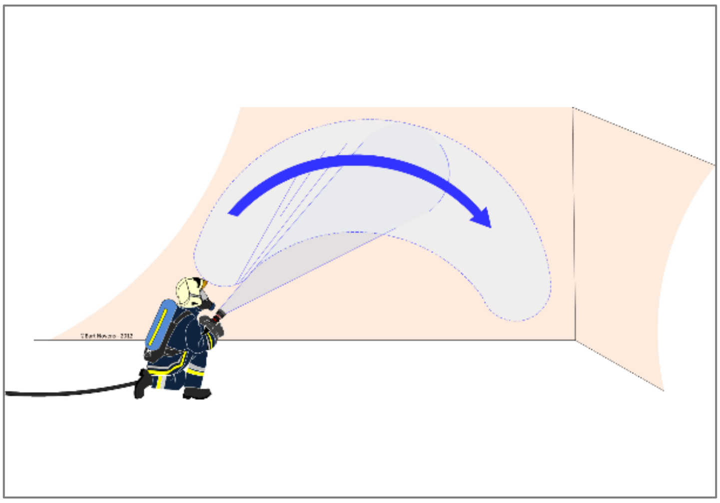

Figure 6: Sweep from left to right (Third person view) - Image by Bart Noyens [7]

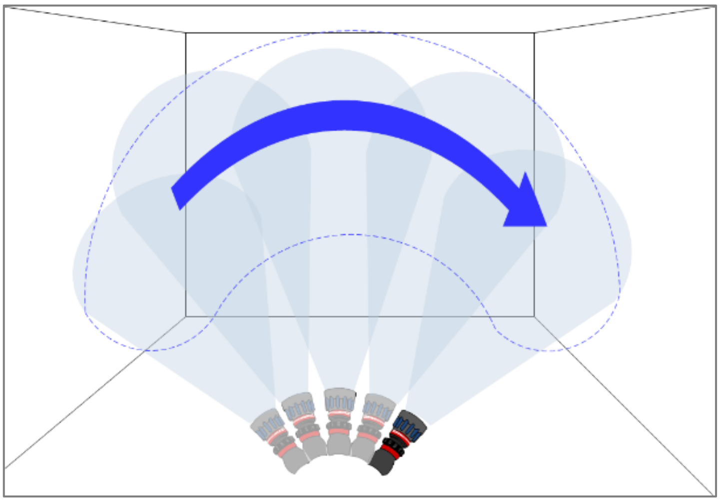

Figure 7: Sweep from left to right (First person view) - Image by Bart Noyens [7]

When you ask to a Swedish fire instructor why they use the sweep method and not the pulsing method and if they are not afraid to disturbed the thermal layering of the fire gases, they say that the sweep method is a better guarantee that all the fire gases in the room are well cooled. Performing a sweep action is easier for a firefighter. Putting water into the smoke layer will always disturb the thermal layering. Dropping the smoke layer down is more influenced by water that is not efficiently put into the smoke layer then by sweeping instead of pulsing. You will not 'cook' the possible victim on the floor. [9]

1.4 Research objectives

The goal of this work is to investigate different parameters that affect the efficiency of gas cooling. The comparative studies are realized using data of executed experiments. The most important parameters that were studied are the application method, spray angle, droplet size, flow rate, application time and total amount of applied water. This research only focuses on cooling the smoke layer. Extinguishing the fire is not a part of this research work.

The objective was to answer the following research questions:

- What is the influence of using different application methods of the water into the smoke layer?
- What is the influence of using different spray angles on the gas cooling efficiency?
- How does droplet size influence the gas cooling efficiency?
- Does flow rate affect gas cooling?
- What happens with the gas cooling efficiency when shorter water sprays are applied?

1.5 Methodology

This work was started with a background study on gas cooling used in the international fire service. An answer was searched on some questions about gas cooling. When do the firefighters use gas cooling? Why are they cooling the hot fire gases? And which techniques and methods are being used to cool fire gases? After this part of the literature study, the scientific background of the interaction between water and a smoke layer was studied. In general, they teach firefighters that 1L of water expands to 1700L of steam. Why is the smoke layer not expanding? A theoretical answer is sought for why water cools fire gases and makes it possible to keep the smoke layer height at the same level or even contracts it.

The next step was to setup a series of experiments. The experiments were made up to research some of the parameters that were revealed in the literature study.

The experiments took place in a lab environment. This excludes influences of some external factors. No large fluctuation in temperature or humidity are taking place in a lab environment when conducting experiments. The interaction between wind and the test room is also excluded.

The experimental study was made as a comparative study. After analysing and discussing the test results conclusions were drawn from this research work.

1.6 Limitations

The experiments were completed in a half-scale modified ISO9705 room. The used fire source was limited to a maximum, primarily based on structural integrity of the fire experimental setup. A to large fire could have resulted in cracking the walls of the test room. Because of the limited fire, the temperatures of the tested smoke were also limited. Smoke temperatures of approximate 180°C were realized to perform gas cooling. This temperature can be much higher in a real compartment fire. However, in an adjacent room, where gas cooling primarily should be applied, the gas temperatures are usually much lower. Therefore, the temperatures reached during the experiments were considered to be within a realistic range. Five spray nozzles were used. These were not actual nozzles used by firefighters in real settings.

An attached room is added to the half-scale ISO9705 room. A door opening made it possible for the smoke to flow into the half scale ISO9705 room. In the attached room the fire was ignited. The fire source was in the attached room, which ensured that the fire was not influenced by the water spray. Contact between water droplets and the fire could have resulted in large differences in the heat release rate of the fire. The wall also worked as shielding the thermocouples from the radiation created by the flames. The setup was a two-room construction only. Most houses have more rooms or floors that will make the fire dynamics and flow of smoke more complex. A final limitation was that there can be uncertainties in the interaction of water droplets with the thermocouples. The size of this problem is not known.

2 Theoretical approach

2.1 Cooling efficiency by water

Because no other extinguishing agent is available in such large quantities and at such a low price as water, it is the best extinguishing agent available in the fire service. The fire service can find water in rivers, lakes, water pipelines, … Also, water has good physical properties for fighting a fire. [10]

Table 1: Relevant properties of water and smoke [10]

			Water	**Smoke**
Boiling Point	T_B	[°C]	100	-
Specific Heat Capacity of Liquid Phase	c_p	[kJ/kg.K]	4,2	-
Specific Heat Capacity of Gaseous Phase	c_p	[kJ/kg.K]	2,0	1,0
Latent Heat of Vaporization	L_V	[kJ/kg]	2260	-

The cooling of a hot smoke layer is based on the heat transfer from the hot smoke to the water. The end temperature is not simply the average between the cold temperature of the water and the hot temperature of the smoke. A thermal energy balance will make sure the two substances will create an energy equilibrium [11].

Beside the temperature and the mass of a substance, the specific heat of that substance is an important parameter for the heat equation (eq. 1). The specific heat of a substance is the amount of heat required to raise 1kg of the substance with 1°C.

$$Q = m \cdot c_p \cdot \Delta T \qquad \text{(eq. 1)}$$

Q	Heat energy [kJ]
m	Mass [kg]
c_p	Specific heat capacity [kJ/kg.K]
ΔT	Temperature difference [K]

The specific heat capacity is the only material dependent parameter in equation 1. The specific heat capacity of smoke can be considered the same as the one of hot air [12]. Table 1 shows that the c_p of smoke is 1,0 kJ/kg.K. The one for liquid water is approximate four times higher.

This means if 1kg of water exchange heat with 1kg of hotter smoke, the temperature of the smoke will drop with 4°C if the temperature of water will rise with 1°C.

At the boiling point of water, the heat transfer does not stop. The water will keep its temperature while it vaporizes. It takes a lot of energy for water to change from the liquid phase to the gaseous phase. This energy is called latent heat of vaporization. For water the L_v is equal to 2260 kJ/kg.

$$Q = m \cdot L_V \qquad \text{(eq. 2)}$$

L_v Latent Heat of Vaporization [kJ/kg]

In most cases the created steam will continue heating up in case the energy equilibrium is not reached yet. The energy that will be totally collected by the water can be calculated with equation 3.

$$Q_{water} = \underbrace{m_w \cdot c_{p,w} \cdot (T_B - T_W)}_{Water\ heating} + \underbrace{m_w \cdot L_v}_{Vaporization} + \underbrace{m_w \cdot c_{p,st} \cdot (T_E - T_B)}_{Steam\ heating} \qquad \text{(eq. 3)}$$

T_B Boiling point [°C]

T_W Start temperature of the water [°C]

T_E Equilibrium temperature [°C]

$c_{p,w}$ Specific heat capacity of water [kJ/kg.K]

$c_{p,st}$ Specific heat capacity of steam [kJ/kg.K]

The energy that needed to be transferred from the smoke layer to the water droplets can be calculated with equation 4.

$$Q_{smoke} = m_s \cdot c_{p,sm} \cdot (T_S - T_E) \qquad \text{(eq. 4)}$$

T_S Start temperature of the smoke [°C]

$c_{p,sm}$ Specific heat capacity of smoke [kJ/kg.K]

The law of conservation of energy says that the released energy by the smoke must be equal to the collected energy of the water.

$$Q_{water} = Q_{smoke} \qquad \text{(eq. 5)}$$

$$m_w \cdot c_{p,w} \cdot (T_B - T_W) + m_w \cdot L_v + m_w \cdot c_{p,st} \cdot (T_E - T_B) = m_s \cdot c_{p,sm} \cdot (T_S - T_E) \qquad \text{(eq. 6)}$$

This is the equilibrium equation without considering the energy losses. To calculate how much water is theoretically needed to bring a hot smoke layer down to a desired temperature, equation 7 can be used.

$$m_{w,t} = \frac{m_S \cdot c_{p,sm} \cdot (T_S - T_E)}{c_{p,w} \cdot (T_B - T_W) + L_v + c_{p,st} \cdot (T_E - T_B)} \qquad \text{(eq. 7)}$$

To cool down one cubic meter of smoke with a starting temperature of 600°C to an equilibrium temperature of 100°C, only 77,88mL water is needed. This amount of water is calculated with a homogenous distribution of the water in the cubic meter of smoke and a 100% efficiency of the cooling capacity of the water.

2.2 Smoke layer contraction

In general, firefighters are taught that 1L of water creates 1700L of steam. In this chapter a theoretical explanation is given why the smoke layer does not drop till the floor because of the big expansion ratio of water to steam.

The expansion ratio of 1700:1 is only valid for a specific temperature. The expansion ratio changes depending on the temperature [4]. In Table 2 the typical expansion ratios of water to vapour are shown for different temperatures. Equation 8 shows the linear correlation between the expansion ratio and the temperature [°C].

$$Expansion\ Ratio = 4{,}765 \cdot Temperature + 1090 \qquad \text{(eq. 8)}$$

Table 2: Typical expansion ratios of water to vapour at various temperatures in a compartment fire. [4]

Temperature [°C]	Expansion Ratio	Temperature [°C]	Expansion Ratio
100	1600:1	500	3440:1
200	2060:1	600	3900:1
300	2520:1	800	4900:1
400	2980:1	1000	5900:1

Table 2 and equation 8 are a simplification of the reality used by Grimwood [4]. The Ideal Gas Law can be used to calculate the expansion ratios more exact for superheated steam.

The major reason why the smoke layer does not expand till the floor is that the cooling of the smoke layer results in a contraction of the smoke. When a good efficiency is used by the nozzle operator, the expansion of the created steam is compensated by the reduction in smoke volume due to smoke temperature reduction [13]. Grimwood [4] concludes that a 75% efficiency is a reliable value for a trained firefighter using a fog nozzle.

Before water is applied into the smoke layer, the smoke layer has some properties that will influence how much the smoke layer will contract or expand. Using volume V_{sm}^{0} and temperature T_S [K] of the smoke layer, an estimation for the mass of the smoke can be made with equation 9.

$$m_{sm} = \frac{V_{sm}^{0} \cdot 353}{T_S} \qquad \text{(eq. 9)}$$

After water is sprayed into the smoke layer an equilibrium temperature T_E [K] is reached. This temperature is also the new temperature of the smoke layer. This results in a smaller smoke volume V_{sm}^{1}. The equation 10 shows the calculation for the new volume the mass of smoke occupies.

$$V_{sm}^{1} = \frac{m_{sm} \cdot T_E}{353} \qquad \text{(eq. 10)}$$

To create the new equilibrium temperature an amount of water is needed. Equation 7 can be used. This equation gives the mass of water needed when the efficiency of the used water is 100%. To calculate the practical needed water to realise this new temperature can be calculated with the equation 11.

$$m_{w,p} = \frac{m_{w,t}}{\phi} \qquad \text{(eq. 11)}$$

$m_{w,t}$	Theoretical needed mass of water [kg]
$m_{w,p}$	Practical needed mass of water [kg]
ϕ	Efficient used water for cooling the smoke layer [-]
$(1-\phi)$	Part of water that vaporise on hot surfaces and does not cool the smoke [-]

The total volume of created steam V_{st}^{1} can be calculated by searching the expansion ratio for the equilibrium temperature T_E. After multiplying the $m_{w,p}$ with the expansion ratio, V_{st}^{1} is the result. The new total volume of the smoke layer after introducing the water into it, then becomes V_{Tot}^{1}.

$$V_{Tot}^{1} = V_{st}^{1} + V_{sm}^{1} \quad \text{(eq. 12)}$$

To obtain a theoretical contraction value for the smoke layer, V_{Tot}^{1} must be compared to V_{sm}^{0}. Figure 8 shows the contraction for different efficiencies used. The beginning temperature for the smoke layer is assumed on 600°C. And the equilibrium temperature after gas cooling is executed is assumed 100°C. The graph is based on the one that Särdqvist [10] made. In Figure 8 a change in expansion rate is used for every temperature. Not only the volume change at 100°C is calculated in Figure 8. The volume change for intermediate temperatures are also correctly shown.

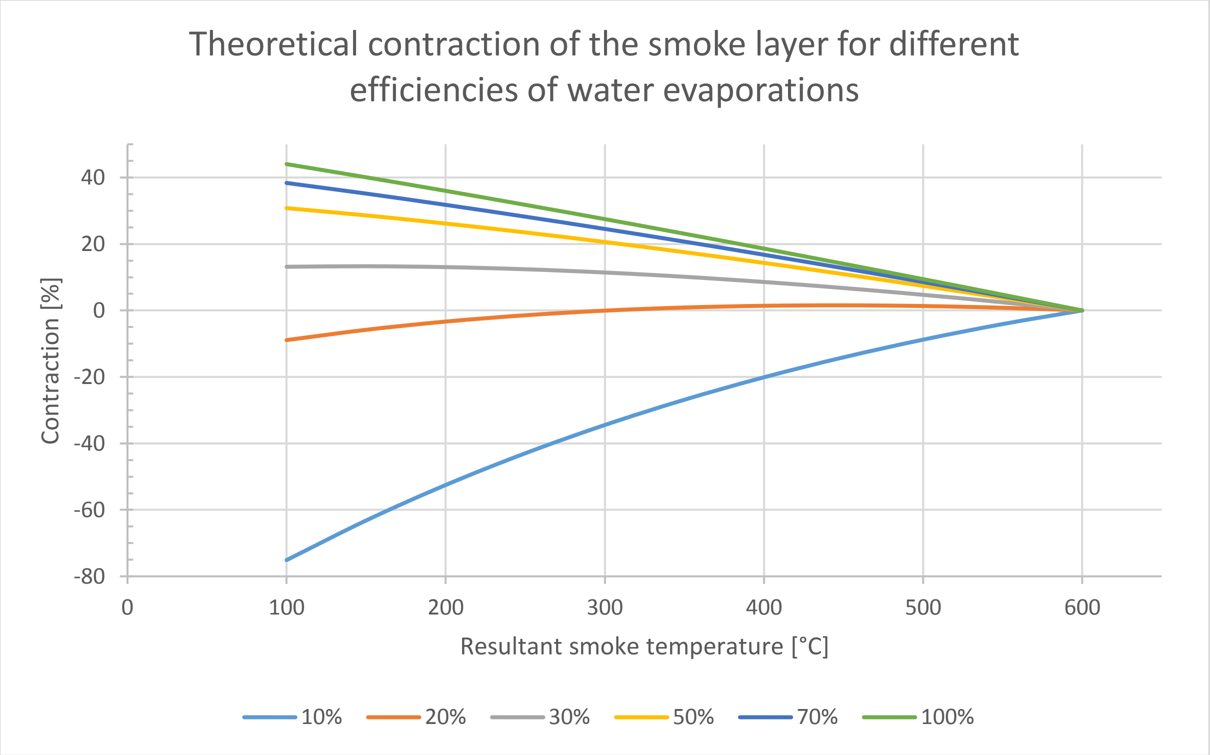

Figure 8: Theoretical approach for the contraction of the smoke layer for different efficiencies of water evaporations.

When the nozzle operator does not use the spray correctly and the efficiency of the water he/she used is to low and hits to many hot surfaces, an expansion of the smoke layer can be the result. An expansion of the smoke layer can have a lot of problems. This can cause less visibility for the firefighters. Also, the humidity of the steam can be uncomfortable for the firefighter. Even that uncomfortable that the firefighter must withdraw. When the smoke layer is expanded to floor level, possible victims can encounter the smoke layer. The smoke layer is toxic and has still a high temperature for unprotected persons.

2.3 Thermal ballast of steam in smoke layer

The smoke in a compartment fire is a fuel source and at some point the smoke layer might become flammable. At this point, the smoke layer starts to burn and flames will be visible in the smoke layer. In the fire service, this phenomenon is also called roll-over when the smoke layer turns into flames. After a roll-over occurs, the radiant heat of the smoke layer will increase massively. It will not take long before the full compartment takes part of the combustion and a so called flashover will happen inside it. [14]

Not only reducing the temperature is an advantage of putting water droplets into the smoke layer and holding back the scenario described above. The flammability of a smoke layer can also be reduced because of the thermal ballast of the steam [15]. A smoke layer is a complex composition of different gases. Not all the components of the smoke layer participate in the combustion process, but the gases are heated by the available energy. This means more activation energy is needed to ignite the smoke layer. Gases not participating in the combustion process are called thermal ballast. Steam does not participate either in a combustion. The steam that is formed by spraying water inside the smoke layer will work as a thermal ballast.

2.4 Droplet size

Droplet size has a large influence on the cooling capacity of a water spray. As earlier mentioned in the chapter 1.2 about previous work, the smaller the droplet size, the faster evaporation and the better cooling efficiency is obtained. For cooling the full room sometimes a larger droplet size is wanted, simply because a larger droplet size has a further reach. For the physics behind the vaporizing time and the falling velocity of droplets is referred to the work of Van de Veire [6].

All the water droplets in a spray does not have the same diameter for all the droplets and the spray has a distribution of water droplets diameters. Different quantities exist to characterize the droplet size of a spray. The quantity that is used in this work is the volume median diameter (VMD or $D_{v0,5}$). This statistical value for droplet size means that half of the water volume has a smaller diameter then the VMD. So, half of the volume of the water has a larger diameter than VMD.

Droplet size depends on flow rate. An increase in flow rate will increase the droplet size. So, a decrease in flow rate will result in a smaller droplet size.

The parameter that is mainly used in this work to change the droplet size is pressure of the outflowing water. The pressure has an inverse influence on the droplet size. An increase of pressure will reduce the droplet size. Reducing the pressure will result in a larger droplet size for the used nozzles in this work.

According to the Spray Technology Reference Guide [16], the spray angle has an influence on the droplet size. An increase in spray angle will reduce the droplet size. When performing the experiments, there was a visible difference when using the nozzle with a 15° spray angle. This nozzle had significant larger droplets than the other nozzles. The difference between the droplet sizes of the other nozzles was not visibly noticeable.

Liquid properties also influence the droplet size. Increasing the viscosity and the surface tension will increase the amount of energy that is required to split the water spray in droplets. An increase in any of these properties will increase the droplet size.

3 Experimental setup

3.1 Test room

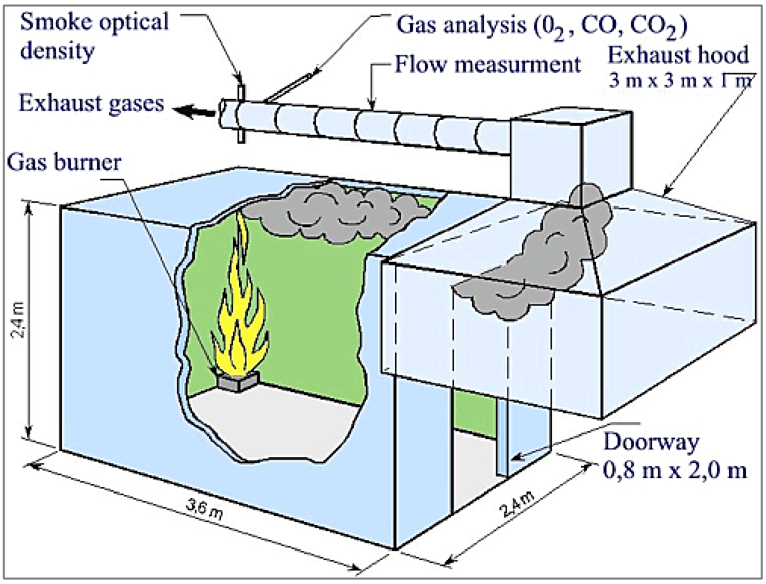

Figure 9: ISO9705 room - room corner test SP [17]

The experiments were conducted in an adjusted half-scale ISO9705 room (below denoted “test room”). Every dimension of the room was scaled, except the door opening. The opening was scaled using the ventilation opening factor. Using this factor has the advantage that ventilation induced effects are kept the same as the full-scale ISO9705 room [12]. A small room was added to the half-scale ISO9705 room (below denoted “fire room”). The opening between the burn room and the test room was scaled with the same ventilation factor as the front door opening. In the fire room the fire source was located. The added fire room ensured that the fuel source would not be influenced by the water spray. Contact between water droplets and the fuel source could result in large differences in heat release rate of the fire. The wall also worked as shielding the thermocouples from the radiation by the flames.

Figure 10: Test room placed under the hood.

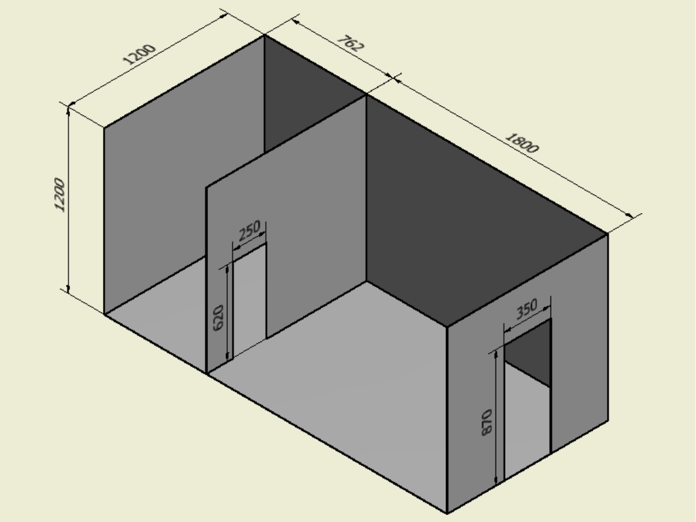

Figure 11: Dimensions test room.

3.2 The fire

Heptane was used as fuel for all the experiments. The size of the fire source was chosen based on the need for high gas temperatures in the test room and on the structural integrity of the fire room. A 330mm square fuel pan was selected. The flame height of the fire was approximate 1,2m. The fuel source resulted in a fire with a heat release rate of approximately 165kW [18].

There is a different fuel in this work then in the work of Matthias Van de Veire [6]. Here the fuel is heptane, in the previous work a propane burner is used. In case of a pool fire the formed smoke layer contains more sooth then the formed smoke layer of a gas burner. The heat release rate for the previous work was 90kW. For this work a heat release rate is realised of 165kW.

3.3 Nozzles

In the experiments five different nozzles were used. All the nozzles were delivered from Spraying Systems Co.® [19]. Only full cone nozzles were used in this work, with larger droplets size than other type nozzles [16]. A full cone nozzle creates a spray angle range that is fully distributed with water droplets. The better distribution of the water droplets make the spray more efficient for cooling the smoke layer [6]. A full cone nozzle is also the best to compare with an actual firefighters' nozzle. Figure 14 shows a common used firefighter nozzle in Belgium.

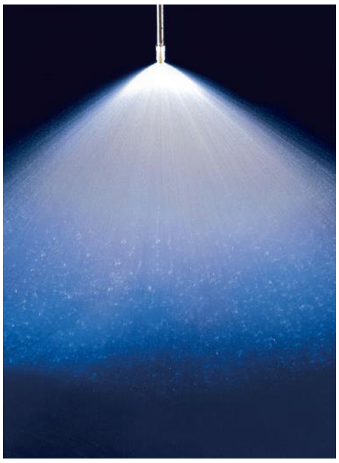

Figure 12: Spray pattern [19]

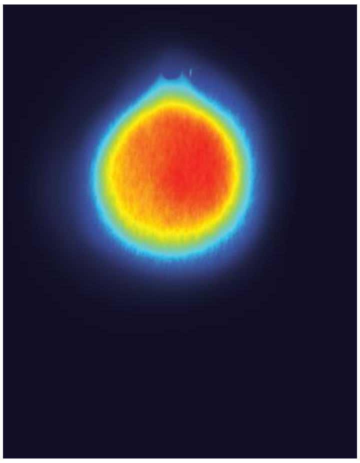

Figure 13: Spray angle range [19]

Figure 14: Low pressure (8 bar) Firefighting fog nozzle - TFT G-Force

Three nozzles used in this work were selected in one flow rate range. This means that the flow rate is approximate the same when the same working pressure is used. Two nozzles were used in another flow rate range. One nozzle was selected with a slightly higher flow rate and one mist nozzle that is only used for creating very small water droplets. The difference between the three nozzles from the main flow rate range is the spray angle. From the used nozzles, changes in droplet size and flow rates are created by changing the pressure in the supply.

3.3.1 GG16 nozzle – 50° spray angle

The GG16 is a nozzle with a 50° spray angle. Table 3 shows the mechanical dimensions of the nozzle. Table 4 shows the spray properties for the pressure range that the nozzle will be used in. The spray of the nozzle resembles the most used spray angle firefighters in Europe use to perform gas cooling.

Figure 15: GG16 nozzle

Table 3: Dimensional properties of the GG16 nozzle [19].

Type	Inlet Connection [inch]	Capacity Size [L/min]	Orifice Diameter Nominal [mm]	Maximum Free Passage Diameter [mm]
GG16	1/2	16	3,5	3,2

Table 4: Spray properties for work pressure range of the GG16 nozzle [19].

Pressure [bar]	Flow Rate Capacity [L/min]	VMD [μm]
1	7,1	1530
1,5	8,7	1460
2	9,8	1340
3	11,9	1080
4	13,4	990

3.3.2 GG25 nozzle – 60° spray angle

The GG25 is a nozzle with a 60° spray angle. This nozzle is similar to the GG16 nozzle but is not located in the same flow rate range. The flow rate will be higher for the GG25 nozzle. Table 5 shows the mechanical dimensions of the nozzle. Table 6 shows the spray properties for the pressure range that the nozzle will be used in.

Figure 16: GG25 nozzle

Table 5: Dimensional properties of the GG25 nozzle [19].

Type	Inlet Connection [inch]	Capacity Size [L/min]	Orifice Diameter Nominal [mm]	Maximum Free Passage Diameter [mm]
GG25	1/2	25	4,6	3,2

Table 6: Spray properties for work pressure range of the GG25 nozzle [19].

Pressure [bar]	Flow Rate Capacity [L/min]	VMD [µm]
1	11	1780
1,5	13,5	1710
2	15,2	1560
3	18,6	1230
4	21,1	1130

3.3.3 GG3030 nozzle – 30° spray angle

The GG3030 is a nozzle with a 30° spray angle. Table 7 shows the mechanical dimensions of the nozzle. Table 8 shows the spray properties for the pressure range that the nozzle will be used in. In the firefighter service a narrower angle is used to reach further in the room. For example, when a long-pulse is performed, the spray angle is set on a 30°-angle [7].

Figure 17: GG3030 nozzle

Table 7: Dimensional properties of the GG3030 nozzle [19].

Type	Inlet Connection [inch]	Capacity Size [L/min]	Orifice Diameter Nominal [mm]	Maximum Free Passage Diameter [mm]
GG3030	1/2	30	3,2	-

Table 8: Spray properties for work pressure range of the GG3030 nozzle [19].

Pressure [bar]	Flow Rate Capacity [L/min]	VMD [µm]
1	6,8	1510
1,5	8,4	1450
2	9,5	1330
3	11,8	1080
4	13,5	990

3.3.4 GG1530 nozzle – 15° spray angle

The GG3030 is a nozzle with a 15° spray angle. The work pressure for this nozzle is changed to 6 bar. On 4 bar the nozzle needed time, after opening the valve, before the 15° spray angle was realized. This start-up phenomenon was acceptably short with a working pressure of 6 bar. Table 9 shows the mechanical dimensions of the nozzle. Table 10 shows the spray properties for the pressure range that the nozzle will be used in.

Figure 18: GG1530 nozzle

Table 9: Dimensional properties of the GG1530 nozzle [19].

Type	Inlet Connection [inch]	Capacity Size [L/min]	Orifice Diameter Nominal [mm]	Maximum Free Passage Diameter [mm]
GG1530	1/4	30	3,2	-

Table 10: Spray properties for work pressure range of the GG1530 nozzle [19].

Pressure [bar]	Flow Rate Capacity [L/min]	VMD * [μm]
1	6,8	1510
1,5	8,4	1450
2	9,5	1330
3	11,8	1080
4	13,5	990
6	16,8	910

*Observation: The GG1530 nozzle had visually larger droplets than the other nozzles.

3.3.5 HH1 nozzle – mist nozzle

The HH1 is a nozzle with a 50° spray angle. The nozzle produces a water spray with a VMD of 500µm. Table 11 shows the mechanical dimensions of the nozzle. Table 12 shows the spray properties for the pressure range that the nozzle will be used in. The setup of the HH1 nozzle is different than the other four nozzles. The nozzle stand is not located at the door opening, but the stand is moved inside the room for 80cm. This is done because the reach of the HH1 nozzle is very limited. By changing the stand its position, a reflection can be done of what happens in behind the nozzle operator.

Figure 19: HH1 nozzle

Table 11: Dimensional properties of the HH1 nozzle [19].

Type	Inlet Connection [inch]	Capacity Size [L/min]	Orifice Diameter Nominal [mm]	Maximum Free Passage Diameter [mm]
HH1	1/8	1	0,79	0,64

Table 12: Spray properties for work pressure range of the HH1 nozzle [19].

Pressure [bar]	Flow Rate Capacity [L/min]	VMD [µm]
1	0,44	na.
1,5	0,54	na.
2	0,61	na.
3	0,74	na.
4	0,83	na.
6	1,0	500

3.3.6 Nozzle setup

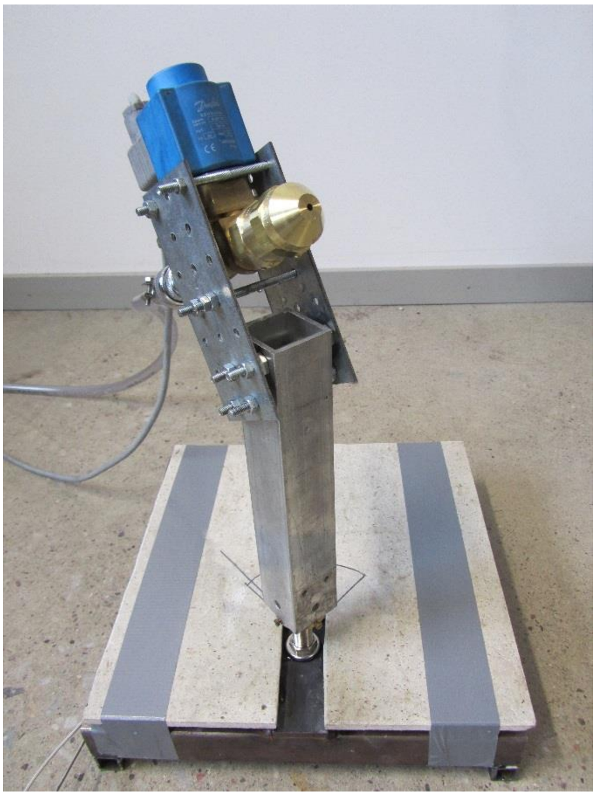

Figure 20: Nozzle stand - front view

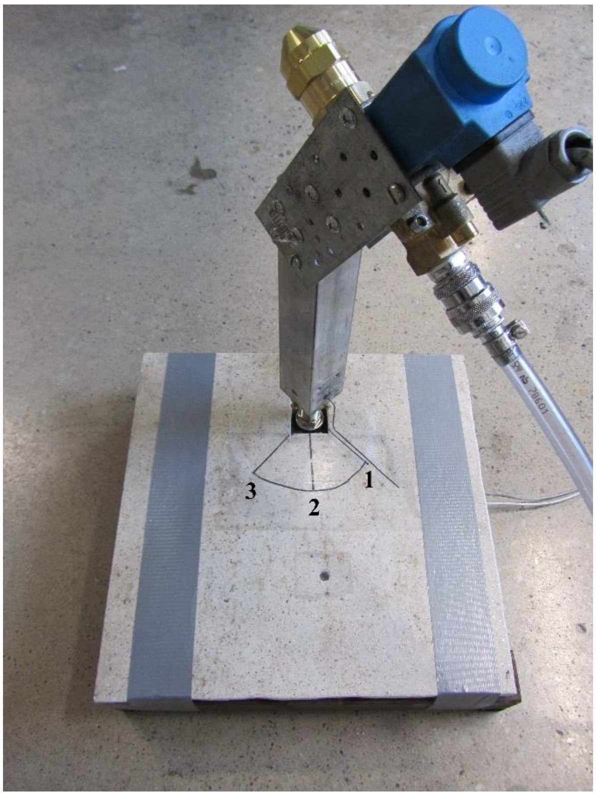

Figure 21: Nozzle stand with pointer on direction 1.

The nozzle was mounted on a stand that could rotate around its Z-axis. Figure 20 shows the stand in front view. For the experiments, the stand was placed in the door opening with the axis aligned with the front wall. The height of the nozzle was approximate the half of the door opening. This would resemble a crouching firefighter. The nozzle is oriented at an angle of 45° upwards. An electric motor mounted underneath the Z-axis made the nozzle turnable. The turning speed was adjusted by changing the voltage.

On Figure 21 a pointer mounted to the axis of the nozzle stand can be seen. Also, a direction disk is visible. This disks shows the full available range for the nozzle. The angle from direction 1 to direction 3 is equal to 83°. Direction 1 is pointing the nozzle to the left side of the room. Direction 2 points to the middle of the room. And direction 3 points to the right side of the room. These directions will be referred to, throughout the rest of this report.

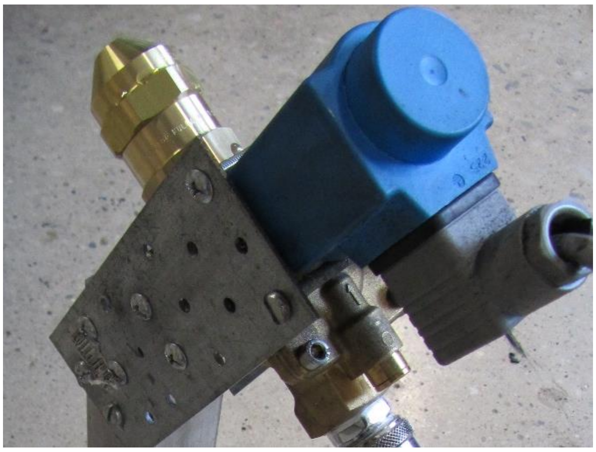

Figure 22: Valve with GG3030 nozzle mounted.

Figure 23: Timer.

The water flow is controlled by a valve (Figure 22) that is connected to a timer (Figure 23). Two different times can be set on the timer, one for the valve open time and one for the valve closed time. The time the valve is open is the spraying time of one spray. The time between two sprays is the time the valve is closed.

3.4 Measurements

To collect the data of the tests, the 'DT85 dataTaker' logger (Figure 24 and Figure 25) was used. All the thermocouples, bidirectional probes and a 12V DC-switch was connected to the logger. The collection time step was set to two seconds [20].

Figure 24: Data logger - DT85 dataTaker

Figure 25: Data logger expansion - CEM20 dataTaker

3.4.1 Temperatures

The thermocouples that were used during the experiments were K-type thermocouples. These thermocouples have a range of -200°C till +1260°C. In total 26 thermocouples were mounted inside the test room.

Figure 26: Thermocouples inside the test room.

Figure 27 shows the location of the thermocouples inside the room. Table 13 shows the height above the floor where the thermocouples are located.

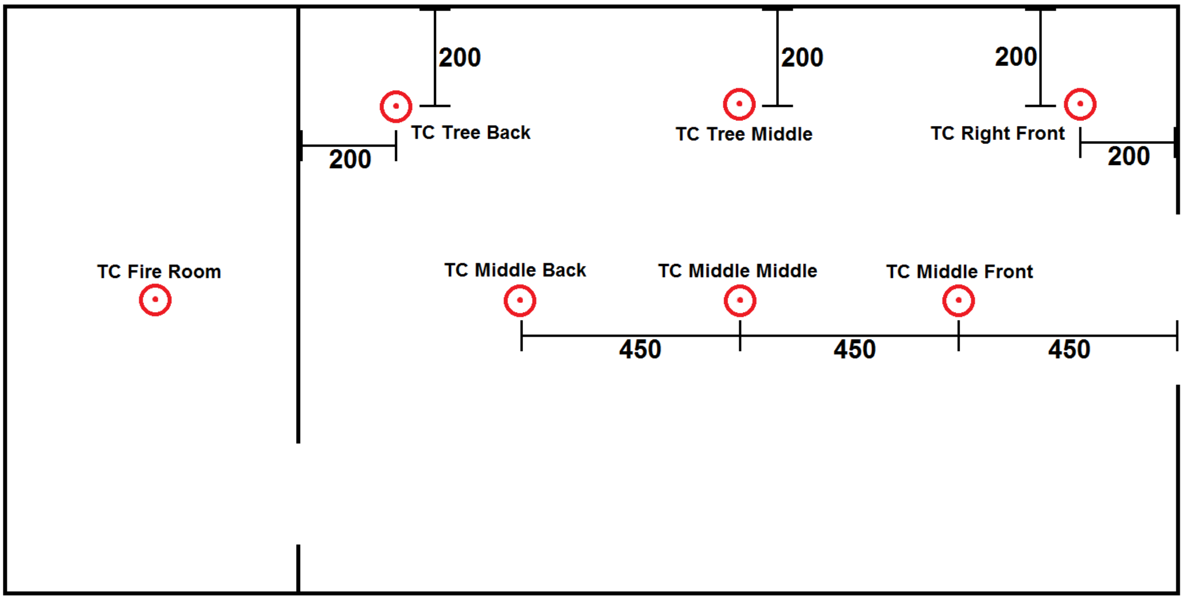

Figure 27: Location thermocouples in the room.

Table 13: Height of the mounted thermocouples.

Name	Distance to Floor [mm]	Name	Distance to Floor [mm]
TC Tree Back 1	1050	TC Tree Middle 4	800
TC Tree Back 2	950	TC Tree Middle 5	750
TC Tree Back 3	850	TC Tree Middle 6	700
TC Tree Back 4	800	TC Tree Middle 7	650
TC Tree Back 5	750	TC Tree Middle 8	600
TC Tree Back 6	700	TC Tree Middle 9	500
TC Tree Back 7	650	TC Tree Middle 10	350
TC Tree Back 8	600	TC Right Front 1	1100
TC Tree Back 9	500	TC Right Front 2	1000
TC Tree Back 10	350	TC Middle Front	1000
TC Tree Middle 1	1050	TC Middle Middle	1000
TC Tree Middle 2	950	TC Middle Back	1000
TC Tree Middle 3	850	TC Fire Room	1000

3.4.2 Velocities

Four bidirectional probes were installed in the opening to the test room, of which three bidirectional probes were mounted on the upper half of the opening. These bidirectional probes measured the outgoing smoke velocities. One bidirectional probe was mounted on the lower part of the door opening. This bidirectional probe measured the velocities for air entering the compartment. Table 14 shows the positioning of the bidirectional probes in the door opening.

Table 14: Positions bidirectional probes.

	Distance to…		Measuring:
	Floor	**Top of door opening**	**Outlet/Inlet**
Door opening	-	870 mm	-
Bidirectional Probe 1	-	50 mm	Outlet
Bidirectional Probe 2	-	150 mm	Outlet
Bidirectional Probe 3	-	250 mm	Outlet
Bidirectional Probe 4	150 mm	-	Inlet

3.4.3 Smoke contraction

A window was mounted in the right wall of the test room. Next to the window there was a measuring scale. Two cameras were positioned filming the experiments. One of the cameras was focused on the window to analyse the smoke contraction. The other camera was filming the door opening and the nozzle stand. The video footages can be retrieved from the author of this work.

Figure 28: Window in test room.

3.5 Procedure

A procedure was created to make sure that the tests would run smoothly and correctly. Each experiment followed the procedure. The procedure consists of the following chronological steps.

1. Mount the desired nozzle on the valve.
2. Set the preselected pressure on the water reservoir.
3. Determine the amount of spray patterns the nozzle will conduct. The amount of sprays is dependent on the spray angle. The full room must be covered by the range of the nozzle.
4. Determine the time the valve must be open for one single spray. The summation of all the water sprayed should be approximate 250mL.
5. Fix the rotation speed of the nozzle by changing the voltage on the DC-engine. A maximum break of 1,5 seconds can be accepted between two different sprays. The rotation time of the nozzle must be set equal to the spraying time when a sweep is applied.
6. Place the nozzle in the doorway.
7. Prepare and start the logger and cameras.
8. Put the desired amount of fuel in the pan and ignite the fuel. The total amount of fuel is calculated for a 110 seconds burn.
9. Pre-burn for 90 seconds.
10. Operate the nozzle after the pre-burn. Turn on a switch when the first water is applied into the smoke layer. Turn off the switch when all the sprays are executed.
11. Let the rest of the fuel burn out.
12. Cool down till the fire room below 75°C, measured with the thermocouple mounted in the fire room.

3.6 Test series

Table 15: Test series.

Test no.	Nozzle	Pressure [bar]	Spray Method	Amount of Sprays	Water per Spray [mL]	Total Amount of Water [mL]	Time per Spray [s]	Time between sprays [s]	Spray Direction Scenario
1	GG16	4	Static	1	250	250	1,5	/	2
2	GG3030	4	Static	1	240	240	1,5	/	2
3	GG1530	6	Static	1	245	245	1,2	/	2
4	GG25	4	Static	1	250	250	1,5	/	2
5	GG16	4	Sweep	1	250	250	1,5	/	1→3
6	GG3030	4	Sweep	1	240	240	1,5	/	1→3
7	GG1530	6	Sweep	1	245	245	1,2	/	1→3
8	GG25	4	Sweep	1	250	250	1,5	/	1→3
9	GG16	4	Pulsing	2	123	246	0,7	1,5	1 - 3
10	GG3030	4	Pulsing	3	82	246	0,4	1,5	1 - 2 - 3
11	GG1530	6	Pulsing	3	81	243	0,3	1,5	1 - 2 - 3
12	GG25	4	Pulsing	2	125	250	0,6	1,5	1 - 3
13	GG16	4	Pulsing	4	62	248	0,3	1,5	1 - 3 - 1 - 3
14	GG3030	4	Pulsing	6	42	252	0,2	1,5	1 - 2 - 3 - 1 - 2 - 3
15	GG1530	6	Pulsing	6	42	252	0,1	1,5	1 - 2 - 3 - 1 - 2 - 3

Test no.	Nozzle	Pressure [bar]	Spray Method	Amount of Sprays	Water per Spray [mL]	Total Amount of Water [mL]	Time per Spray [s]	Time between sprays [s]	Spray Direction Scenario
16	GG25	4	Pulsing	4	62	248	0,2	1,5	1 - 3 - 1 - 3
17	GG16	4	Sweep	2	125	250	0,7	1,2	1→3 - 1→3
18	GG3030	4	Sweep	2	125	250	0,7	1,2	1→3 - 1→3
19	GG1530	6	Sweep	2	123	246	0,6	1,4	1→3 - 1→3
20	GG25	4	Sweep	2	125	250	0,6	1,4	1→3 - 1→3
21	GG16	3	Sweep	1	245	245	1,8	/	1→3
22	GG16	2	Sweep	1	245	245	2,5	/	1→3
23	GG16	3	Pulsing	2	124	248	0,8	1,5	1 - 3
24	GG16	2	Pulsing	2	125	250	1,1	1,5	1 - 3
25	GG3030	3	Sweep	1	245	245	1,8	/	1→3
26	GG3030	2	Sweep	1	250	250	2,5	/	1→3
27	GG3030	3	Pulsing	3	82	246	0,5	1,5	1 - 2 - 3
28	GG3030	2	Pulsing	3	83	249	0,7	1,5	1 - 2 - 3
29	GG16	4	Sweep	1	150	150	0,9	/	1→3
30	GG3030	4	Sweep	1	155	155	0,9	/	1→3

Test no.	Nozzle	Pressure [bar]	Spray Method	Amount of Sprays	Water per Spray [mL]	Total Amount of Water [mL]	Time per Spray [s]	Time between sprays [s]	Spray Direction Scenario
31	GG16	4	Pulsing	2	77	154	0,4	1,5	1 - 3
32	GG3030	4	Pulsing	3	50	150	0,2	1,5	1 - 2 - 3
33	GG16	4	Sweep	1	250	250	1,5	/	1→3
34	GG3030	4	Sweep	1	245	245	1,5	/	1→3
35	GG16	4	Pulsing	2	124	248	0,7	1,5	1 - 3
36	GG3030	4	Pulsing	3	125	250	0,4	1,5	1 - 2 - 3
37	HH1	6	Static	1	38	38	2	/	2
38	HH1	6	Sweep	1	38	38	2	/	1→3
39	HH1	6	Pulsing	2	20	40	1	1,5	1 - 3
40	GG16	4	Sweep	1	255	255	1,5	/	1→3
41	GG16	4	Sweep	1	255	255	1,5	/	1→3
42	GG16	4	Sweep	1	255	255	1,5	/	1→3

4 Results

4.1 Static nozzle position

The first experiments were executed with a fixed nozzle direction, with the nozzle pointing to the middle of the room. This position corresponds to direction 2 (Figure 21).

The GG16 nozzle (Figure 29 & Figure 30) provides the best cooling results overall. The GG3030 (Figure 31 & Figure 32) has an equal cooling effectiveness in the back of the room as the GG16. But the cooling in the middle and in the front part of the room is less drastic. The cooling that is visible on Figure 32 is more stable and smoother than the one visible on Figure 31. This may be explained that the smoke is only effectively cooled by the water droplets in the back of the room. The cooling that is visible in the middle and front areas is most likely due to the flow of cooled smoke that is heading to the door opening.

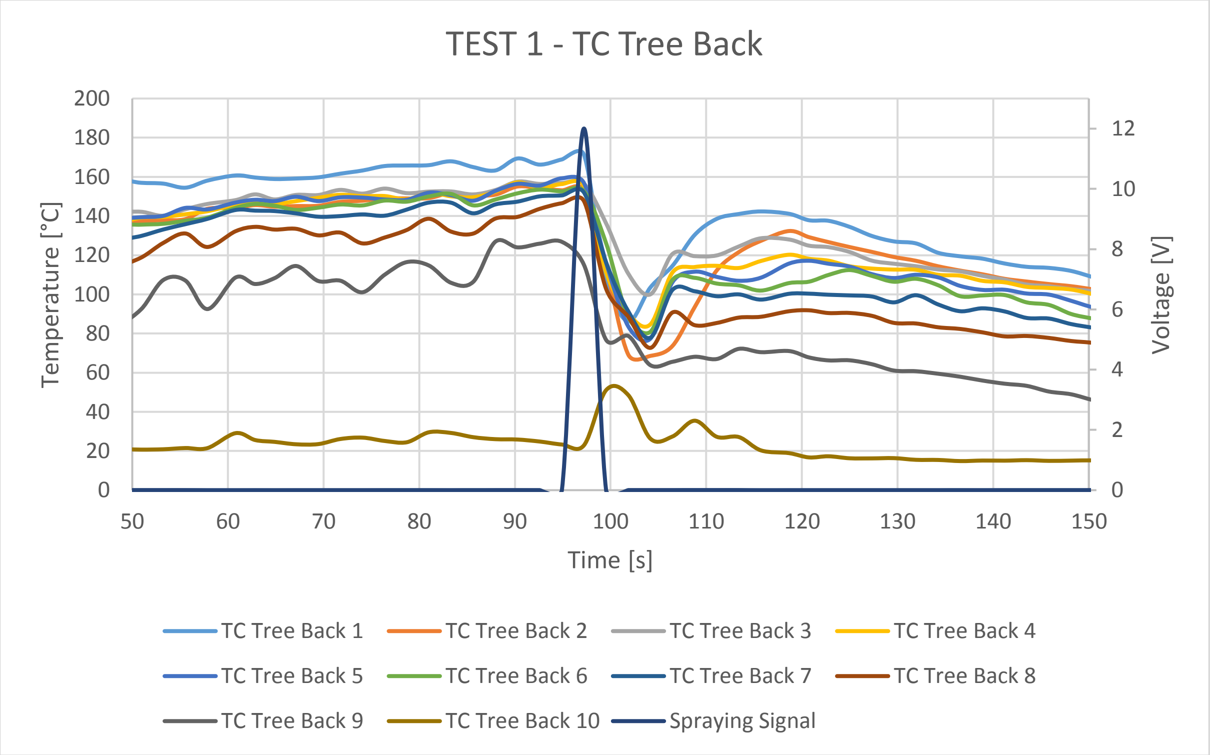

Figure 29: Test with GG16 at 4 bar. One spray of 250mL was applied in direction 2. A drop from 170°C to 100°C can be seen. A raise till 50°C can be seen on the lowest thermocouple at 35cm.

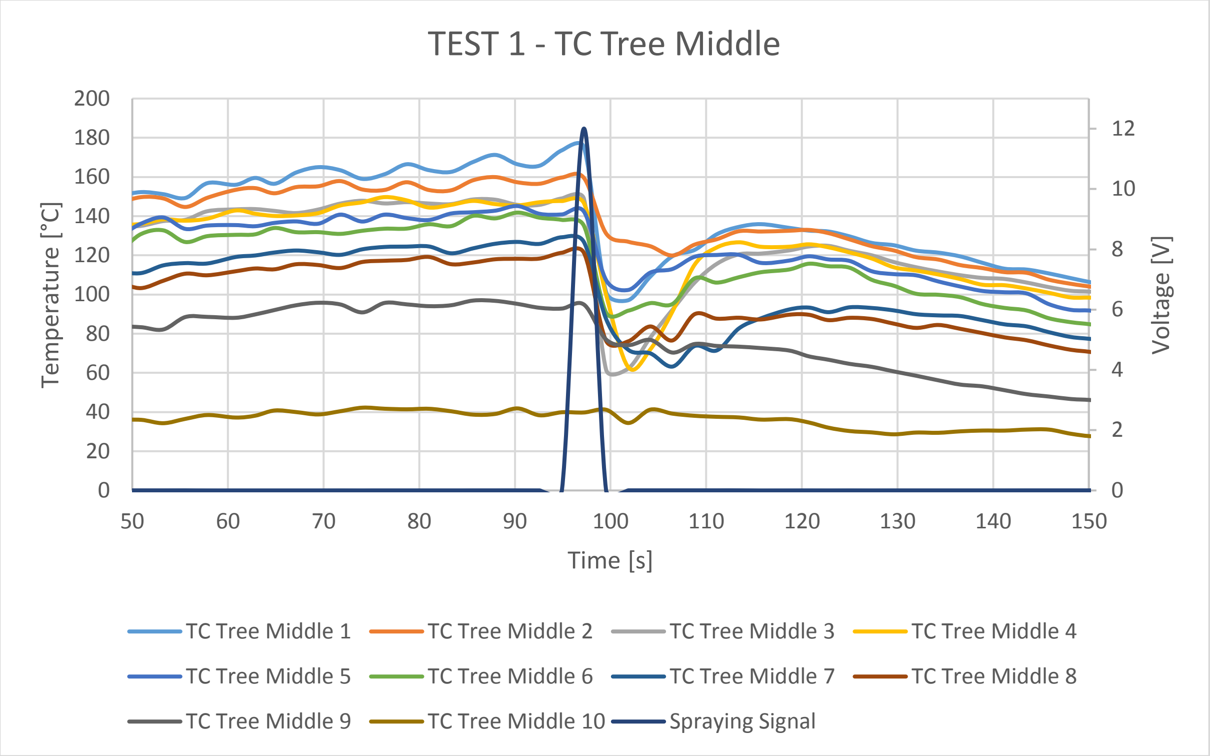

Figure 30: Test with GG16 at 4 bar. One spray of 250mL was applied in direction 2. A drop from 180°C to 120°C can be seen. A small temperature drop can be seen on the lowest thermocouple at 35cm.

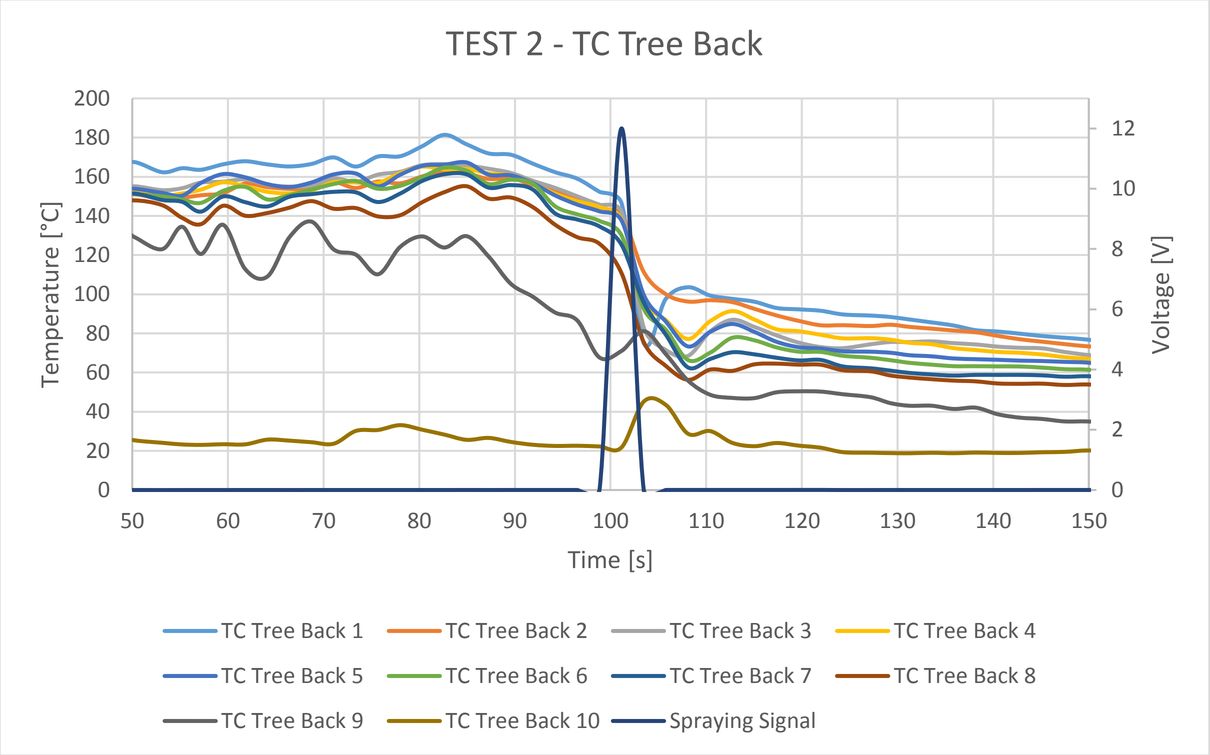

Figure 31: Test with GG3030 at 4 bar. One spray of 240mL was applied in direction 2. A drop from 160°C to 100°C can be seen. A raise till 50°C can be seen on the lowest thermocouple at 35cm.

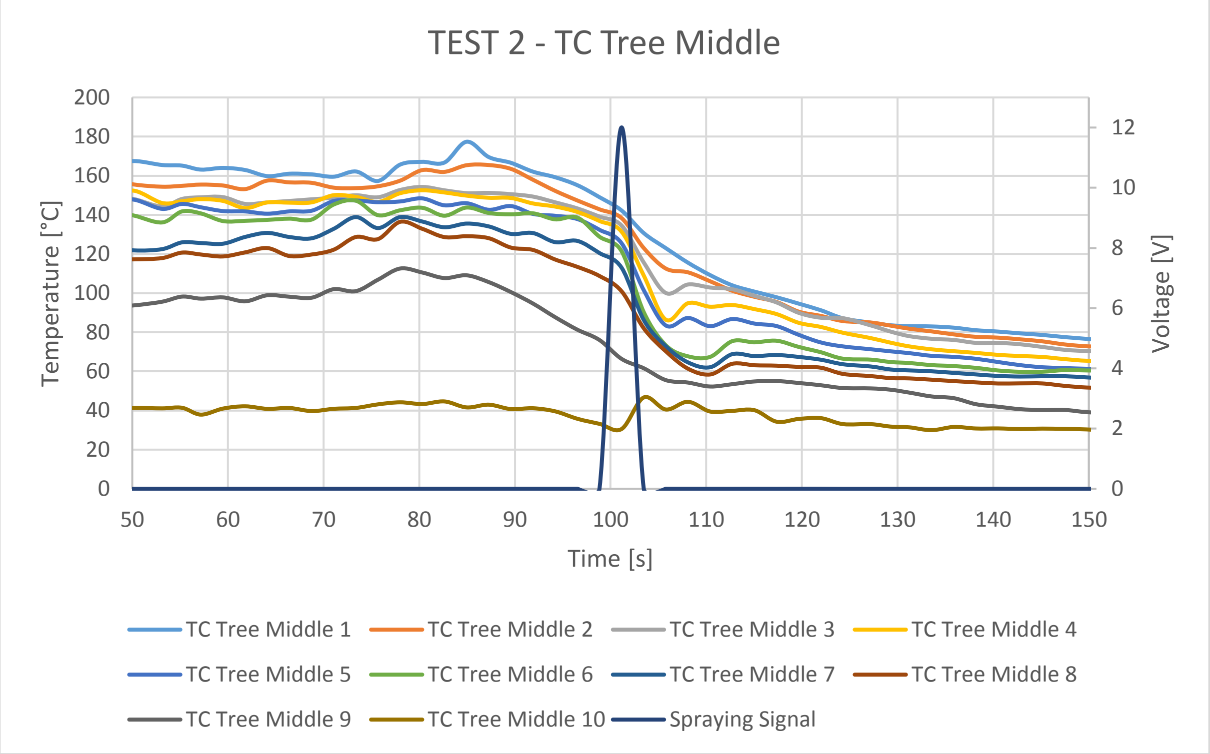

Figure 32: Test with GG3030 at 4 bar. One spray of 240mL was applied in direction 2. A small raise till 50°C can be seen on the lowest thermocouple at 35cm.

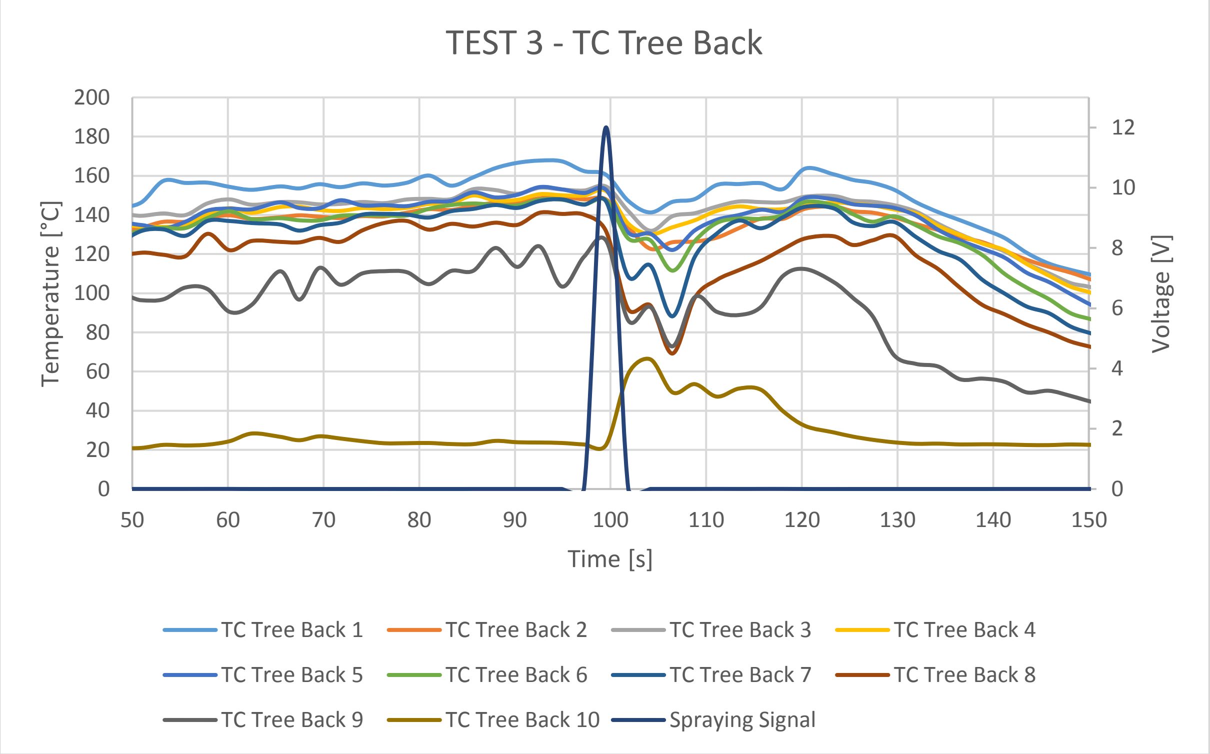

Figure 33: Test with GG1530 at 6 bar. One spray of 245mL was applied in direction 2. A raise till 75°C can be seen on the lowest thermocouple at 35cm.

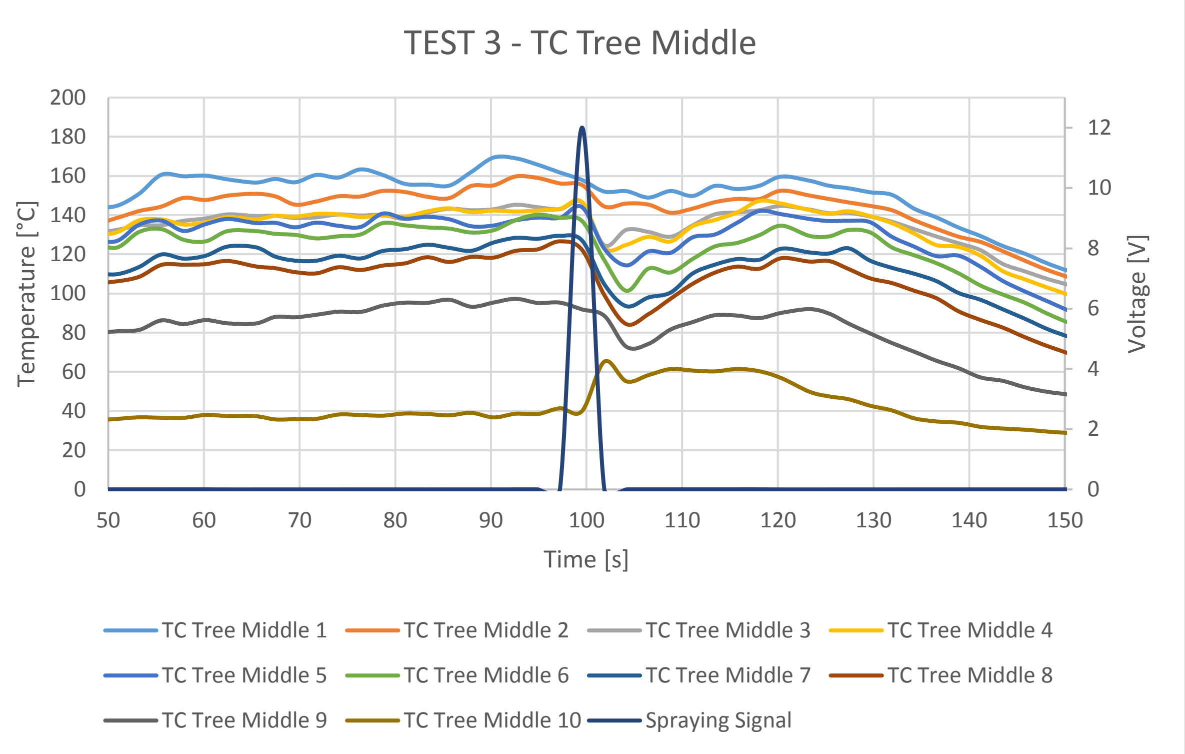

Figure 34: Test with GG1530 at 6 bar. One spray of 245mL was applied in direction 2. Only the lower smoke layers have a temperature drop. A raise till 70°C can be seen on the lowest thermocouple at 35cm.

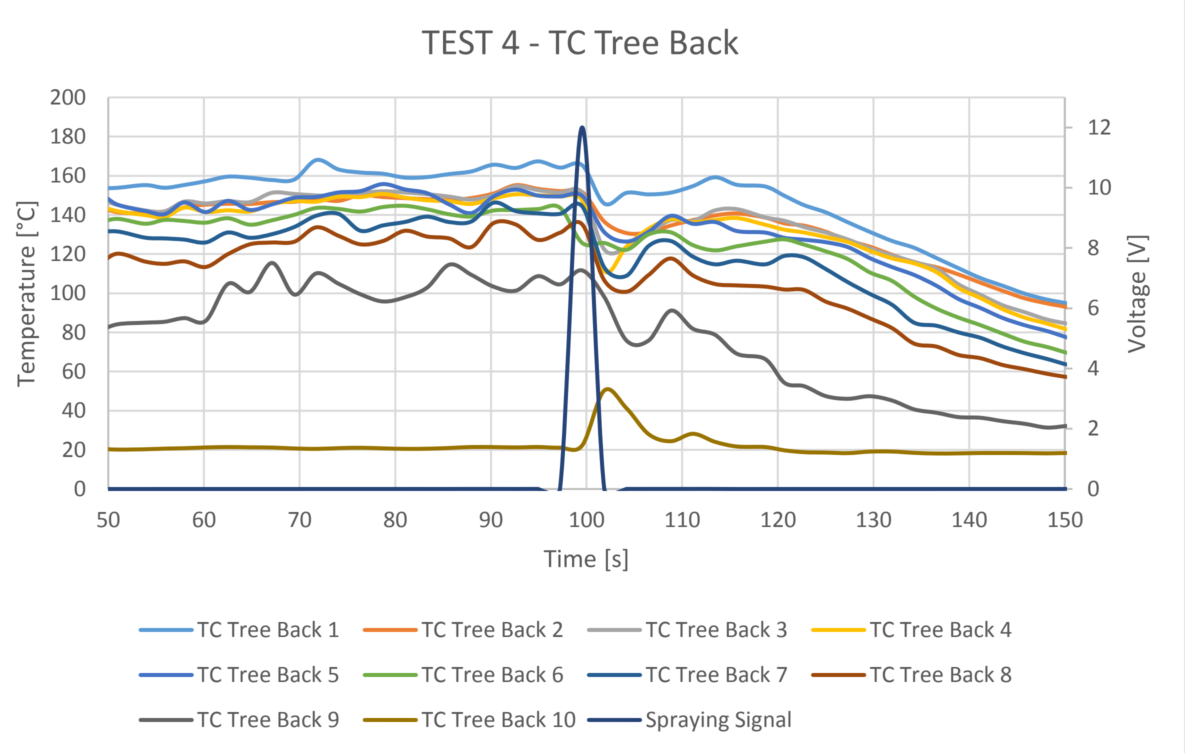

Figure 35: Test with GG25 at 4 bar. One spray of 250mL was applied in direction 2. A drop from 170°C to 150°C can be seen on the thermocouple at 105cm. A raise till 50°C can be seen on the lowest thermocouple at 35cm.

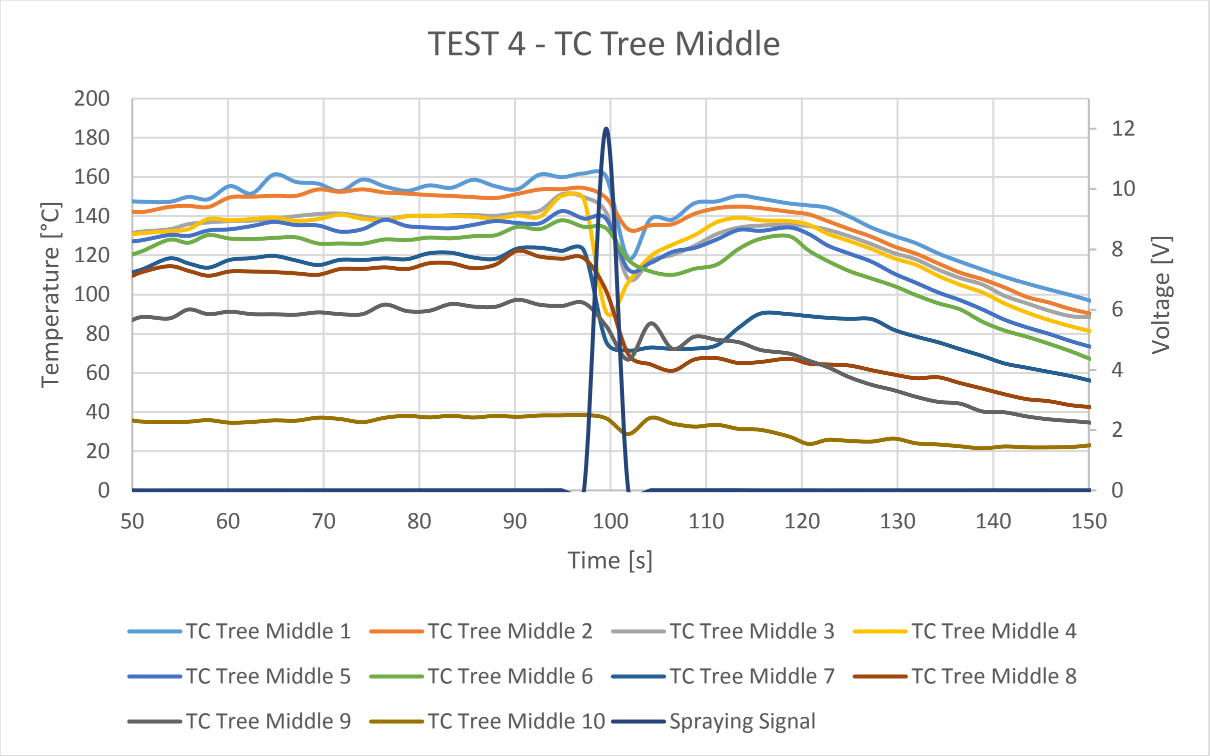

Figure 36: Test with GG25 at 4 bar. One spray of 250mL was applied in direction 2. A drop from 170°C to 130°C can be seen. A temperature drop can be seen on the lowest thermocouple at 35cm.

With the GG25 nozzle (Figure 35 & Figure 36) the smoke is less cooled then the GG16 nozzle (Figure 29 & Figure 30). The different between the GG16 and the GG25 is the spraying angle, flow rate and the VMD droplet size. For the GG25 a spray angle of approximate 60° is realized. The GG16 has a smaller spray angle of 50°. More water droplets are vaporized on hot surfaces with the GG25 then the GG16. Also, the cooling efficiency is lower because of the bigger water droplets that are produced by the GG25 nozzle. The GG25 nozzle has a bigger flow rate then the GG16, this results in a slightly shorter application time of the water spray.

A smoke layer can get unstable when water is applied into it. Because of this, an influence on the lower thermocouples on a height of 35cm above the floor can be observed. The temperature raise on the lower thermocouple and the time is important. The GG1530 nozzle causes the worst instability of the smoke. Figure 34 shows that GG1530 has a negative influence on the conditions 35cm above the floor. This was the only nozzle that influence the middle area negatively. The temperature in the back and middle area raised above 60°C and it kept this temperature constant until the fire is burned out. With the GG16 and GG25 there was even a small decrease in temperature visible in the middle area of the room.

4.2 Basic application methods

Two main different dynamic application methods have been examined. The first method was the sweep method. This was a continuous spray from the left side of the room (direction 1) to the right side (direction 3). The nozzle starts turning on the moment water comes out of the nozzle. All water was sprayed on the moment the nozzle points to direction 3.

The second method was the pulsing method. Two or three bursts were sprayed into the smoke layer. Every burst pointed in a different direction. The total range of the room was sprayed. Two pulses were enough to reach the full width of the room with the GG16 and the GG25 nozzles. The GG16 had a spray angle of 50° and the GG25 had one of 60°.The first pulse was pointed to direction 1 and the second pulse was pointed to direction 3. For the GG1530 and the GG3030 nozzle with a narrower spray angle, three pulses were sprayed. The first pulse was pointed to direction 1, the second pulse was pointed to direction 2 and the third was pointed to direction 3. The nozzle was fixed while the valve was open and it executed a pulse. Between two pulses a break of 1,5 seconds was set to move the nozzle from the first direction to the second direction. And if applicable to move from the second to the third direction. After every break, the nozzle executed the next pulse.

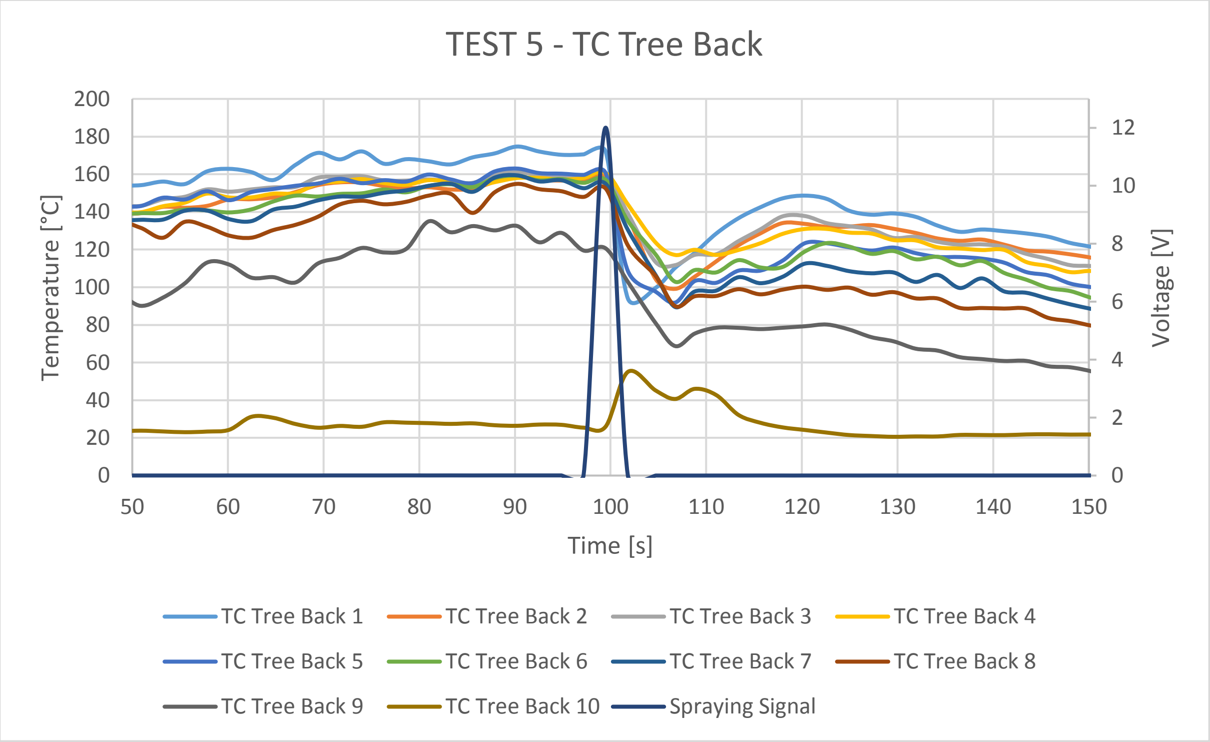

Figure 37: Test with GG16 at 4 bar. One sweep of 250mL was applied from direction 1 to 3. A drop from 180°C to 120°C can be seen. A raise up to 60°C can be seen on the lowest thermocouple at 35cm.

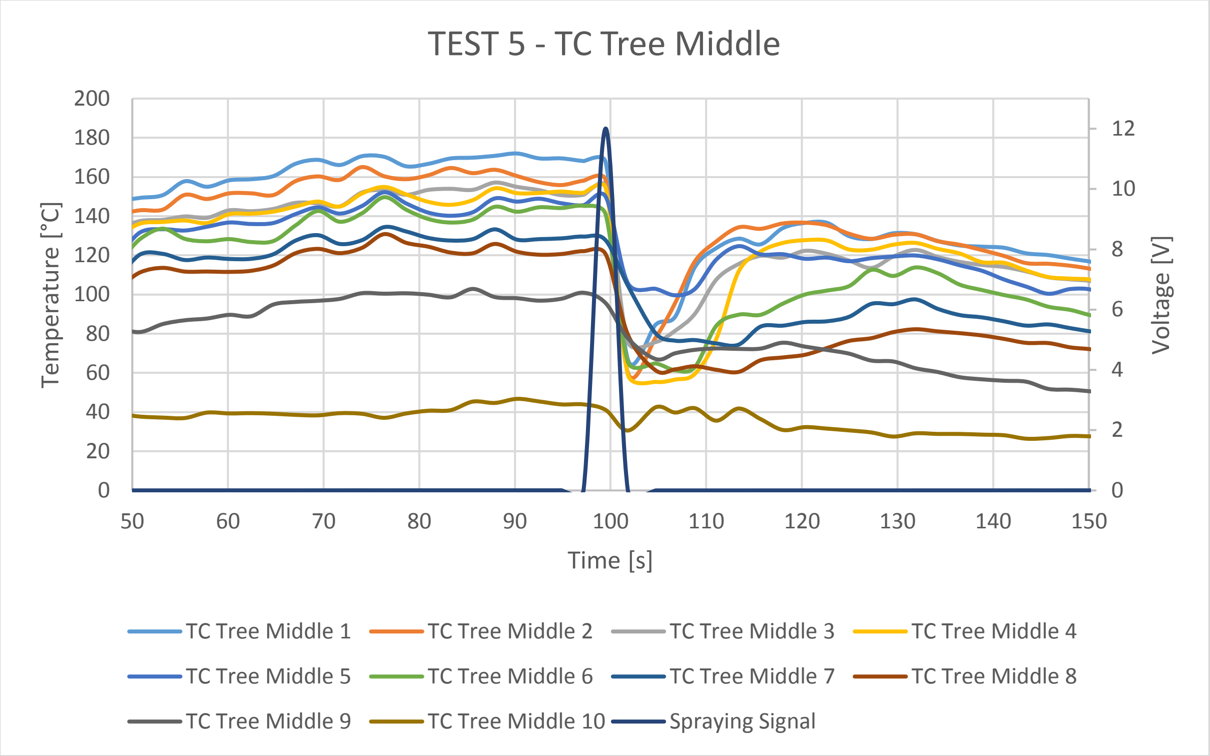

Figure 38: Test with GG16 at 4 bar. One sweep of 250mL was applied from direction 1 to 3. A drop from 170°C to 100°C can be seen. A temperature drop can be seen on the lowest thermocouple at 35cm.

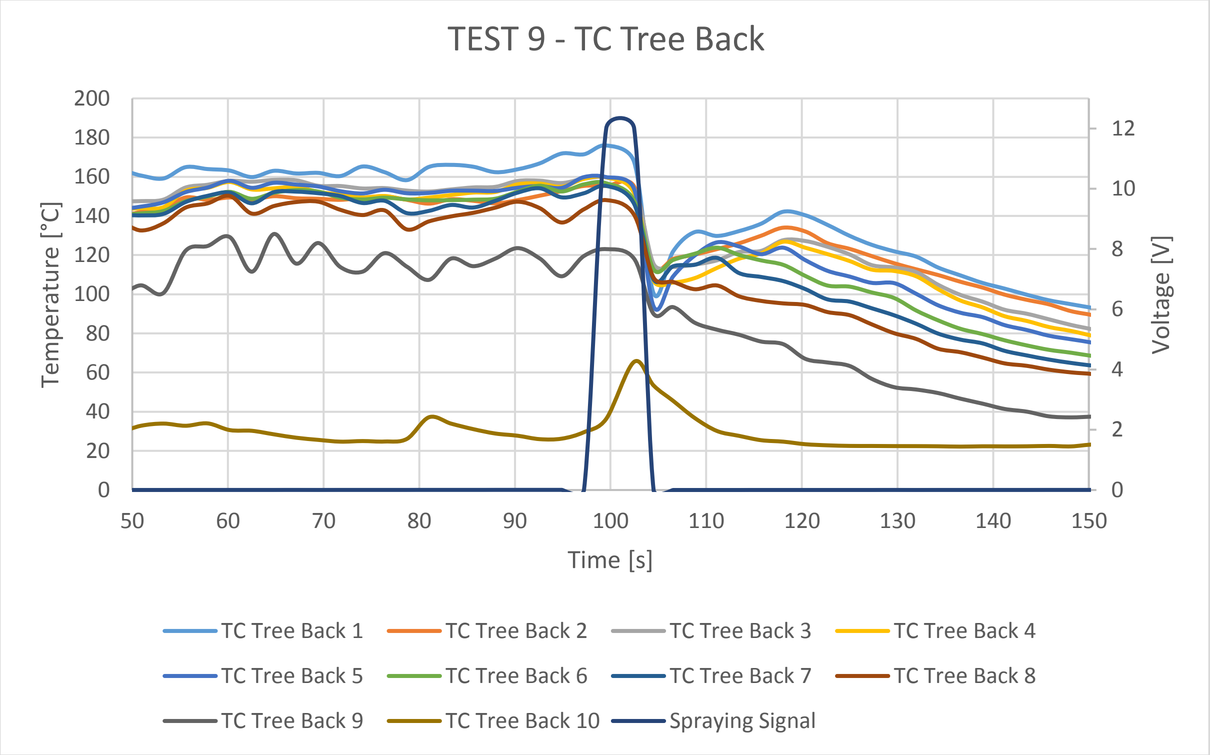

Figure 39: Test with GG16 at 4 bar. Two pulses of 123mL were applied in direction 1 and 3. A drop from 180°C to 120°C can be seen. A raise up to 65°C can be seen on the lowest thermocouple at 35cm.

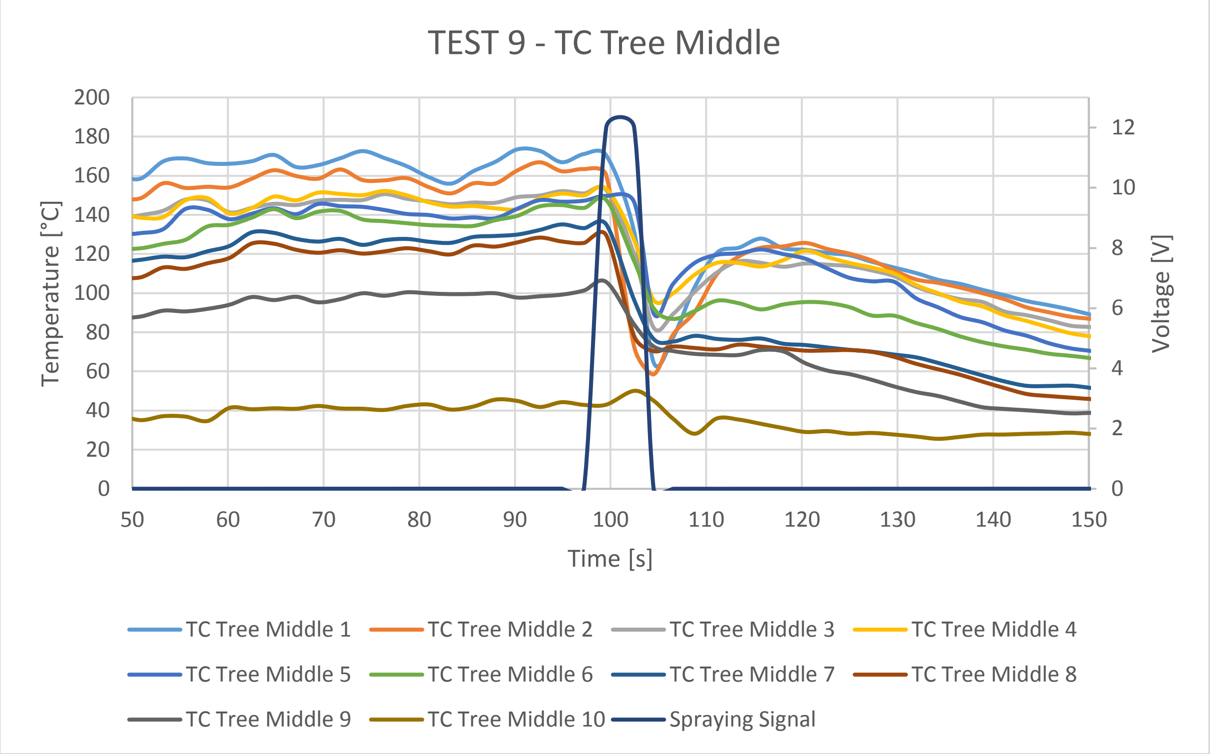

Figure 40: Test with GG16 at 4 bar. Two pulses of 123mL were applied in direction 1 and 3. A drop from 170°C to 100°C can be seen. A temperature drop can be seen on the lowest thermocouple at 35cm.

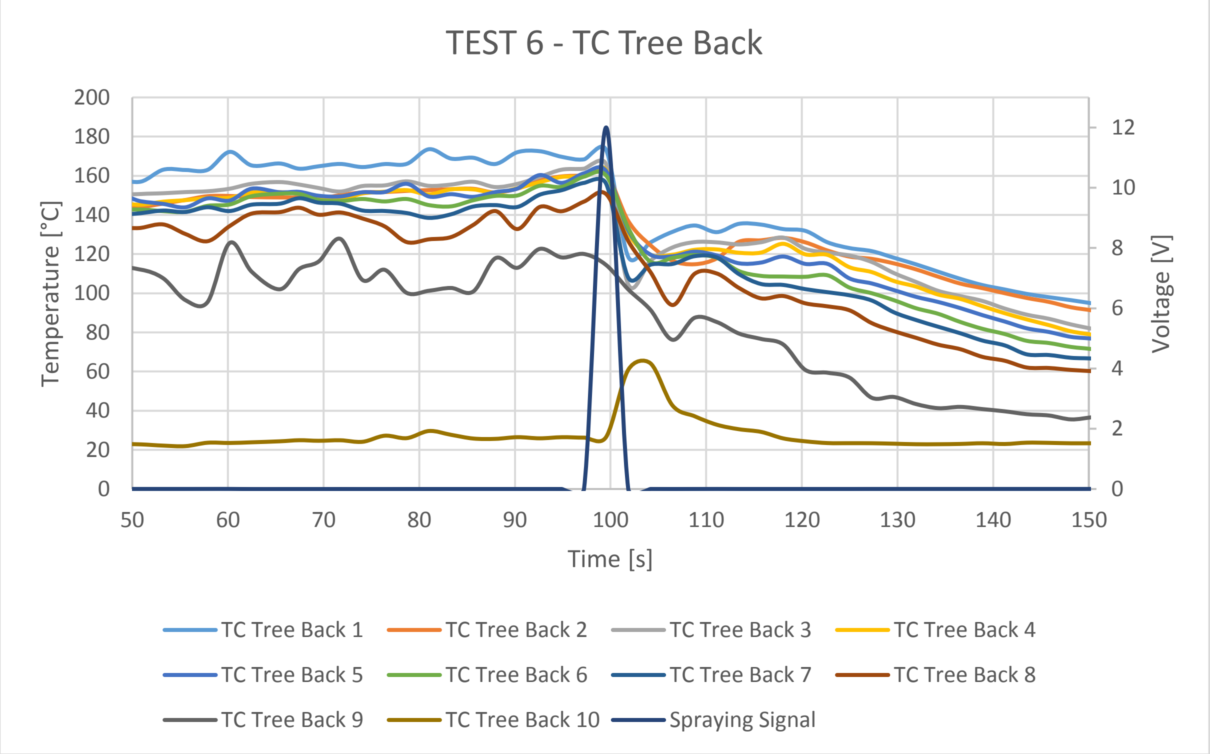

Figure 41: Test with GG3030 at 4 bar. One sweep of 240mL was applied from direction 1 to 3. A drop from 170°C to 130°C can be seen. A raise up to 65°C can be seen on the lowest thermocouple at 35cm.

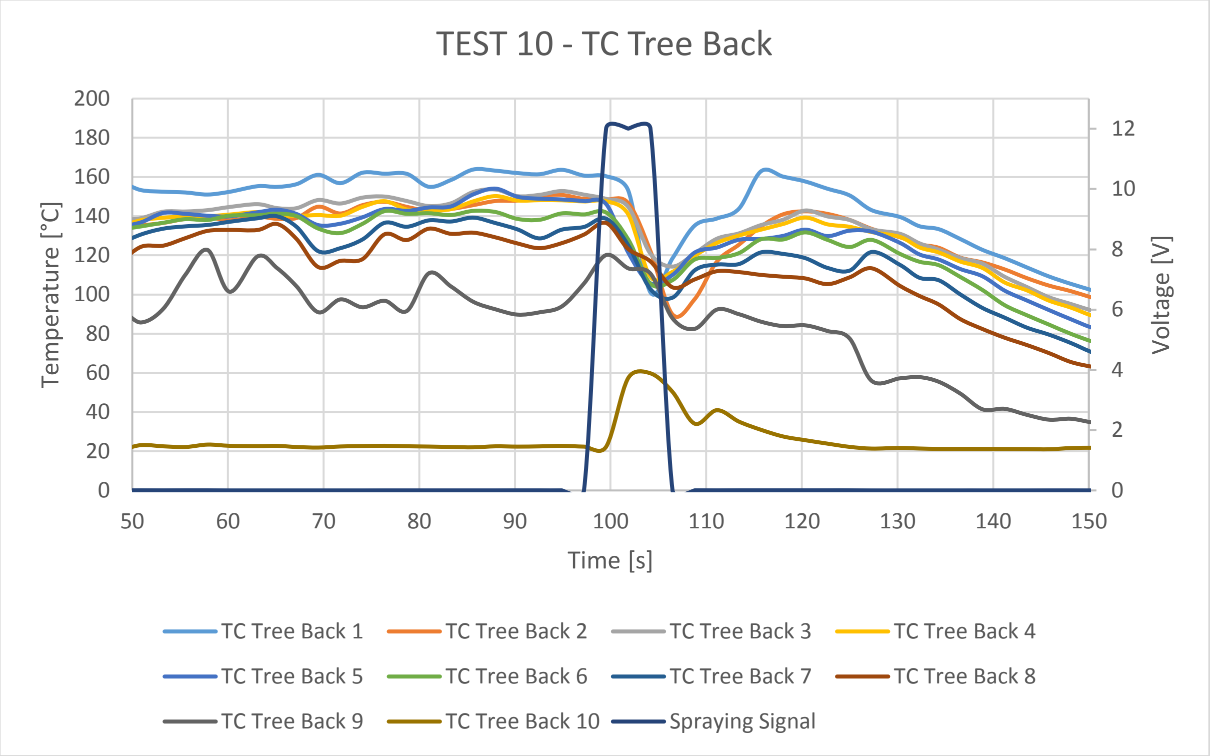

Figure 42: Test with GG3030 at 4 bar. Three pulses of 82mL were applied in direction 1, 2 and 3. A drop from 160°C to 120°C can be seen. A raise up to 60°C can be seen on the lowest thermocouple at 35cm.

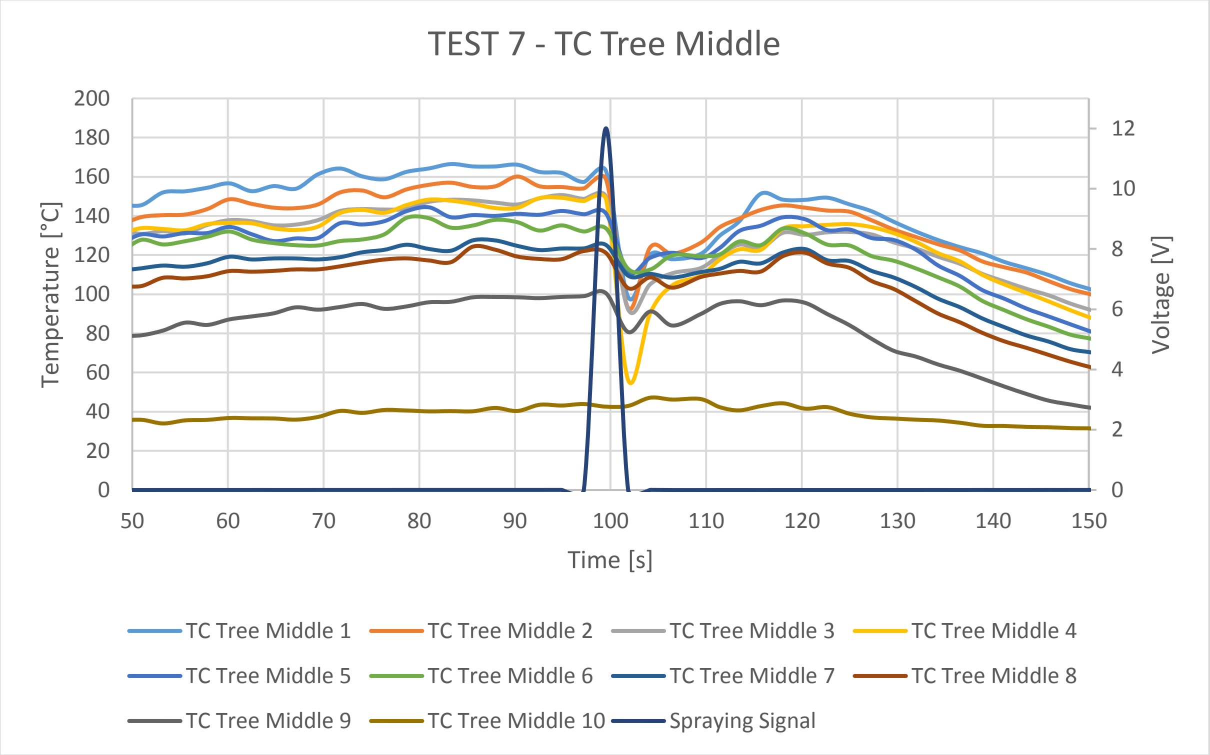

Figure 43: Test with GG1530 at 6 bar. One sweep of 245mL was applied from direction 1 to 3. A drop from 170°C to 110°C can be seen.

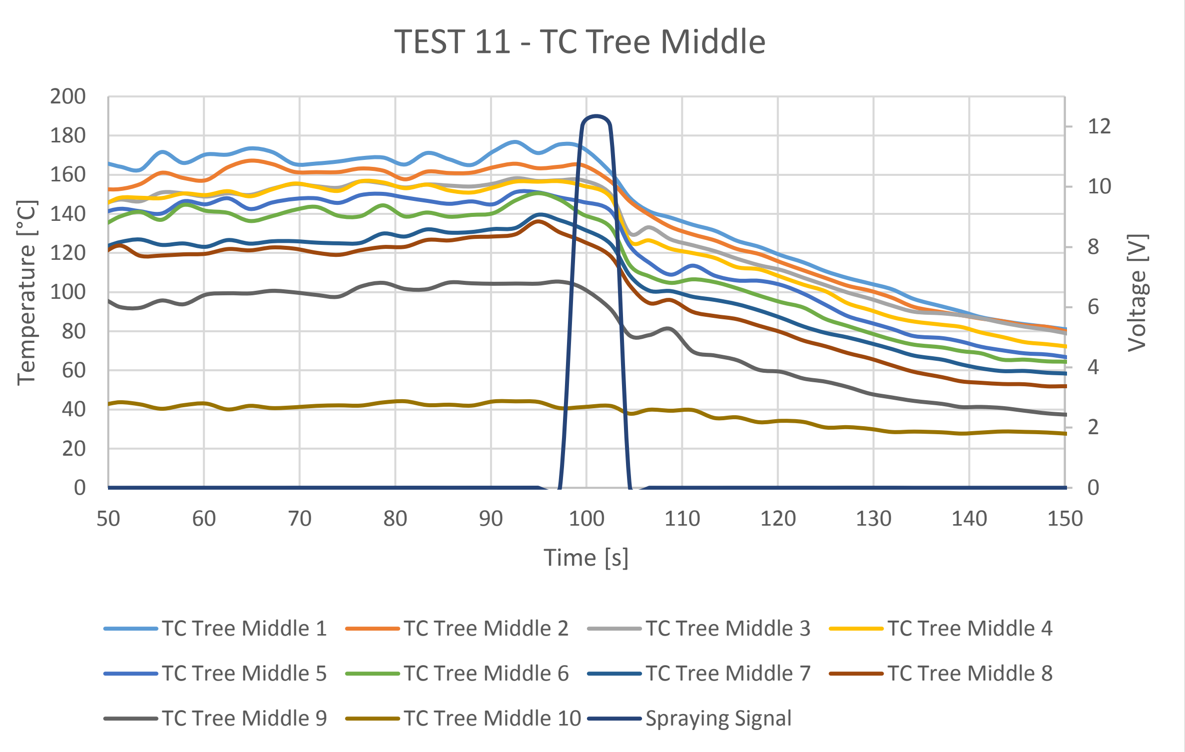

Figure 44: Test with GG1530 at 6 bar. Three pulses of 81mL were applied in direction 1, 2 and 3.

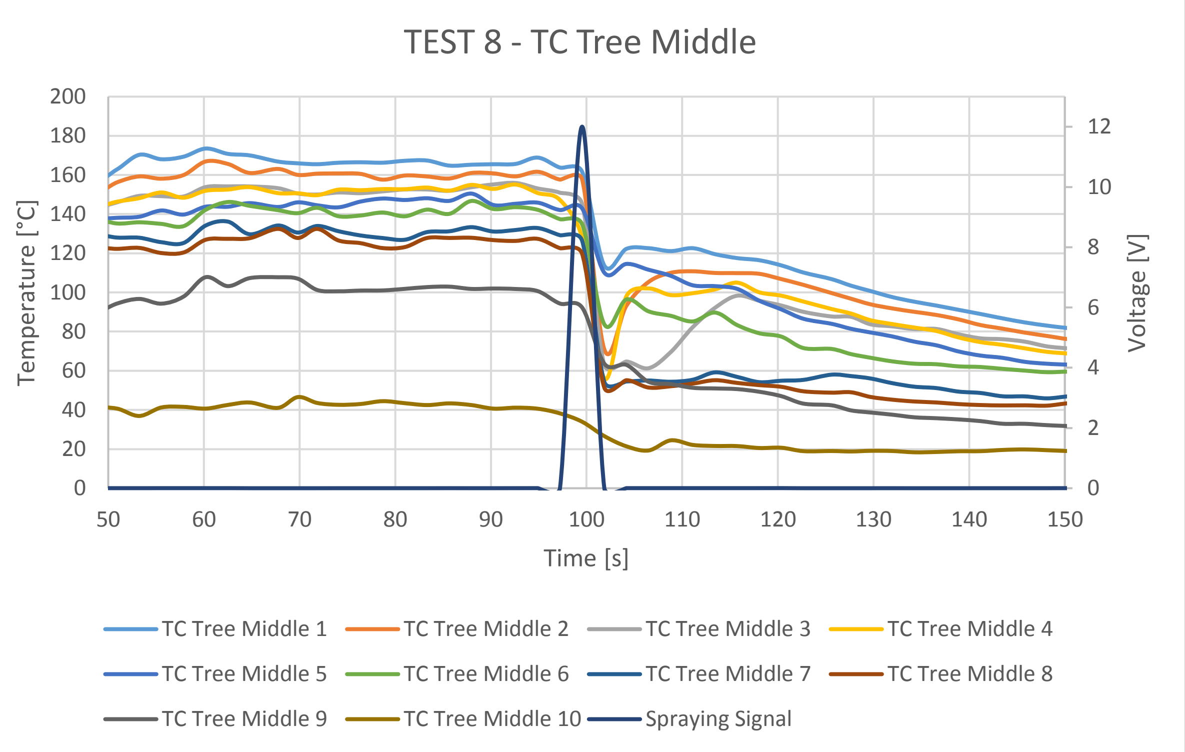

Figure 45: Test with GG25 at 4 bar. One sweep of 250mL was applied from direction 1 to 3. A drop from 170°C to 120°C can be seen. A temperature drop can be seen on the lowest thermocouple at 35cm.

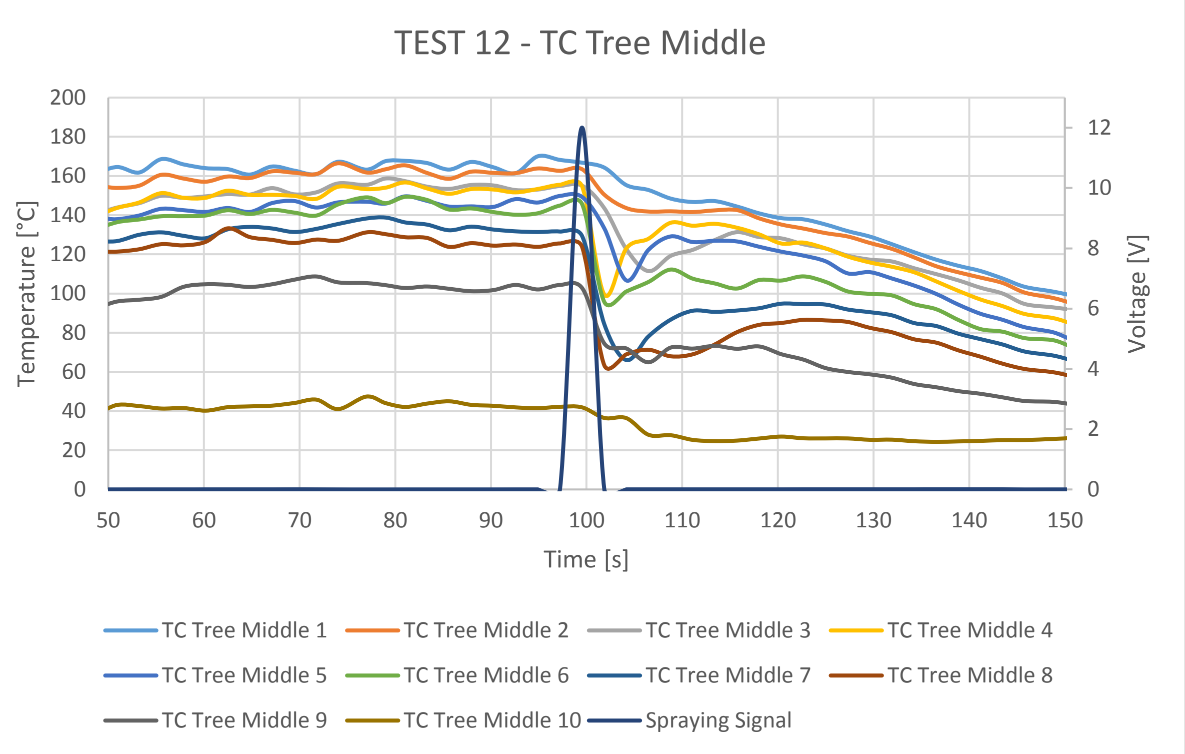

Figure 46: Test with GG25 at 4 bar. Two pulses of 125mL were applied in direction 1 and 3. A temperature drop can be seen on the lowest thermocouple at 35cm.

The efficiency of cooling the smoke layer was similar when the pulsing method was applied or the sweep method with a 50° spray angle of the GG16. There were no big differences measured during test 5 (Figure 37 & Figure 38) and test 9 (Figure 39 & Figure 40). However, there was a small difference in stability of the smoke layer. The temperature on the thermocouple at 35cm of the floor was 65°C in case pulsing was applied. When the sweep method was used, the temperature was nearly 60°C. But this raised temperature for the pulsing method stabilize faster back to the temperature before pulsing was done than for the sweep method.

In test 6 (Figure 41) and test 10 (Figure 42) where the GG3030 nozzle was used, the pulsing method got a slightly better gas cooling efficiency. The smoke layer was also more stable when pulsing was applied.

When comparing test 5 with test 6, a difference can be seen in the middle area of the room. In test 5 were the GG16 nozzle is used there is a better overall cooling in this area then when the GG3030 nozzle is used with a 30° spray angle.

In test 7 (Figure 43), the temperature of the smoke layer in the middle area of the room drops from 180°C to 110°C when a sweep was executed with the GG1530 nozzle. However, there was no visible gas cooling in test 11 (Figure 44) where pulsing was used with this 15° spray angle nozzle. In this same area, there was no change measured on the thermocouple at 35cm above the floor.

In test 8 (Figure 45) and test 12 (Figure 46), there was a noticeable difference when compared to the GG25 nozzle. The sweep method lowered the overall temperatures in the smoke layer more. The upper thermocouples in the smoke layer were not measuring immediate cooling. Not the entire smoke layer got cooled.

4.3 Short spray bursts

In following group of experiments (test 13 till test 20), shorter spray bursts will be executed. Thereby smaller packages of water will be put into the smoke layer with each spray. The total amount of used water must be equal to enable comparison with the basic application methods of chapter 4.2. More sprays will then be needed to reach approximate 250mL.

The two spraying methods, pulsing or sweeping, were used. In case the sweep method was tested, two sweeps were executed. The time of one sweep was less than the tests of chapter 4.2. The nozzle therefore turned faster. The time of the break between the two sweeps was 1,5 seconds. This was also the time it took for the nozzle to go back to the starting position. The start position for the second sweep was still direction 1.

When the pulsing method was tested, the amount of pulses were doubled in comparison with the tests of chapter 4.2. For the tests with the GG16 and the GG25 nozzle four pulses were executed. This resulted in six pulses for the tests with the GG3030 and the GG1530 nozzle. The spray direction scenario for all the tests can be found in Table 15: Test series.

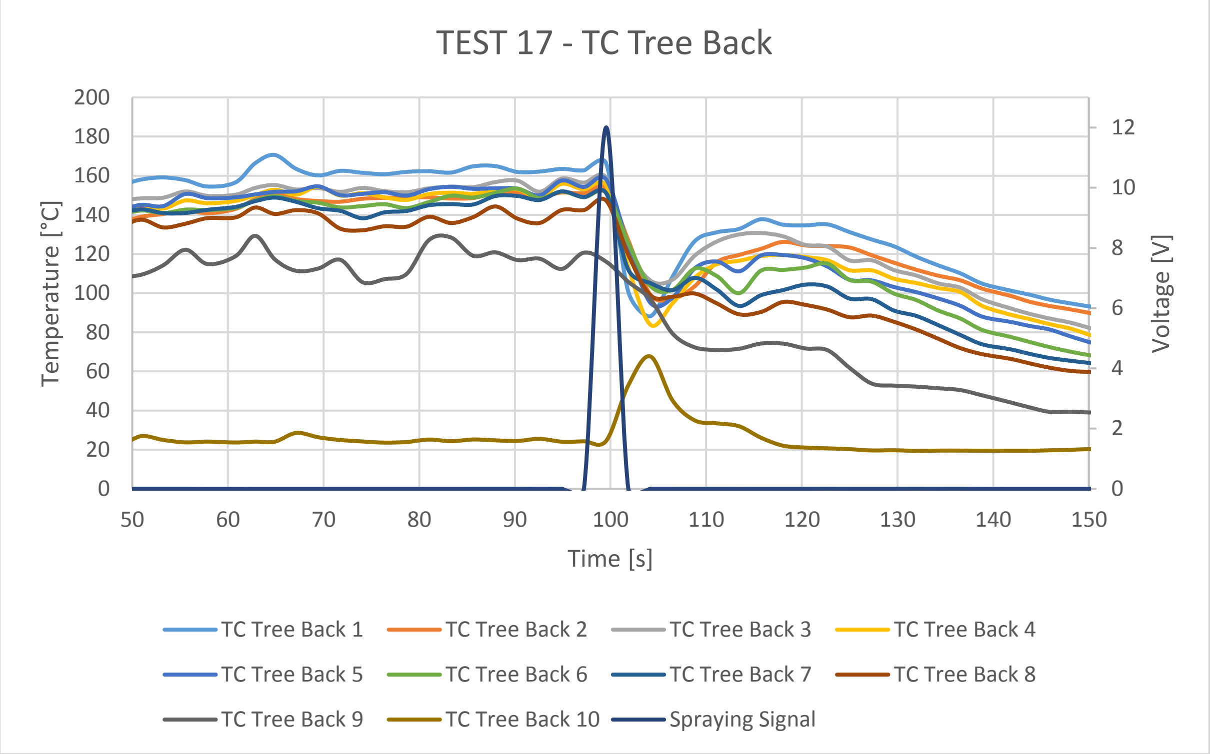

Figure 47: Test with GG16 at 4 bar. Two sweeps of 125mL was applied from direction 1 to 3. A drop from 170°C to 110°C can be seen. A raise up to 70°C can be seen on the lowest thermocouple at 35cm.

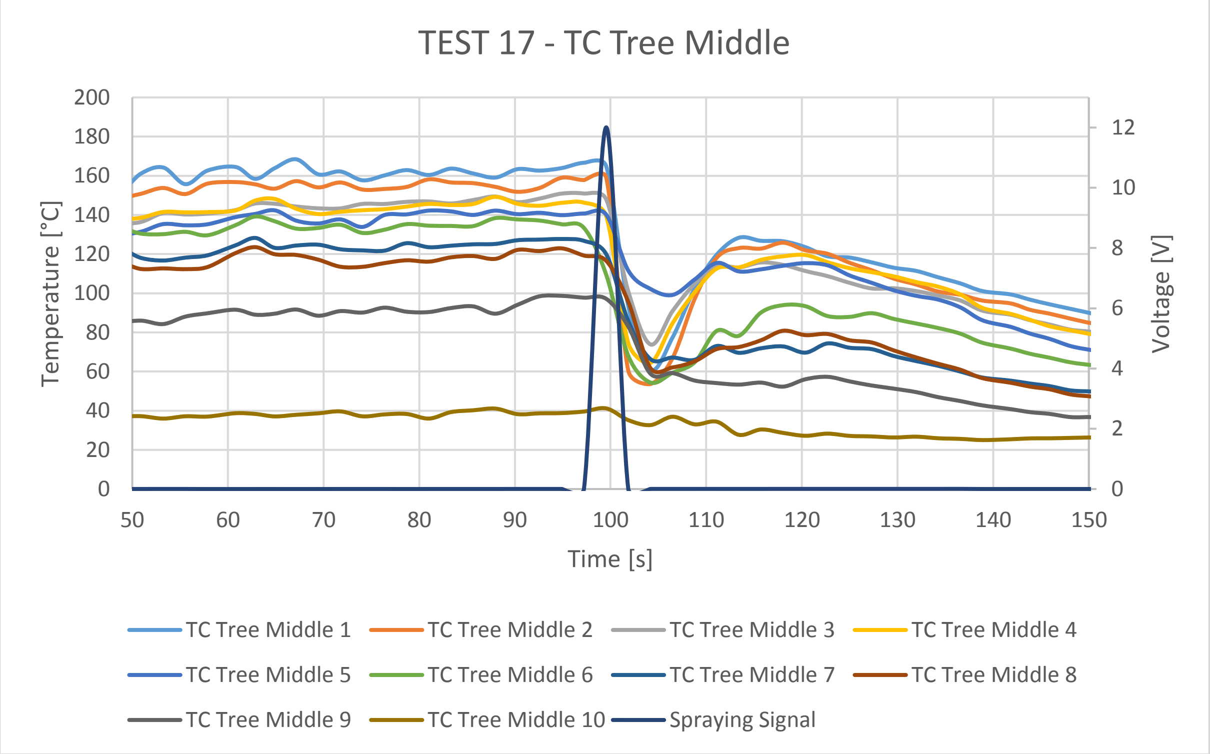

Figure 48: Test with GG16 at 4 bar. Two sweeps of 125mL was applied from direction 1 to 3. A drop from 170°C to 100°C can be seen. A small temperature drop can be seen on the lowest thermocouple at 35cm.

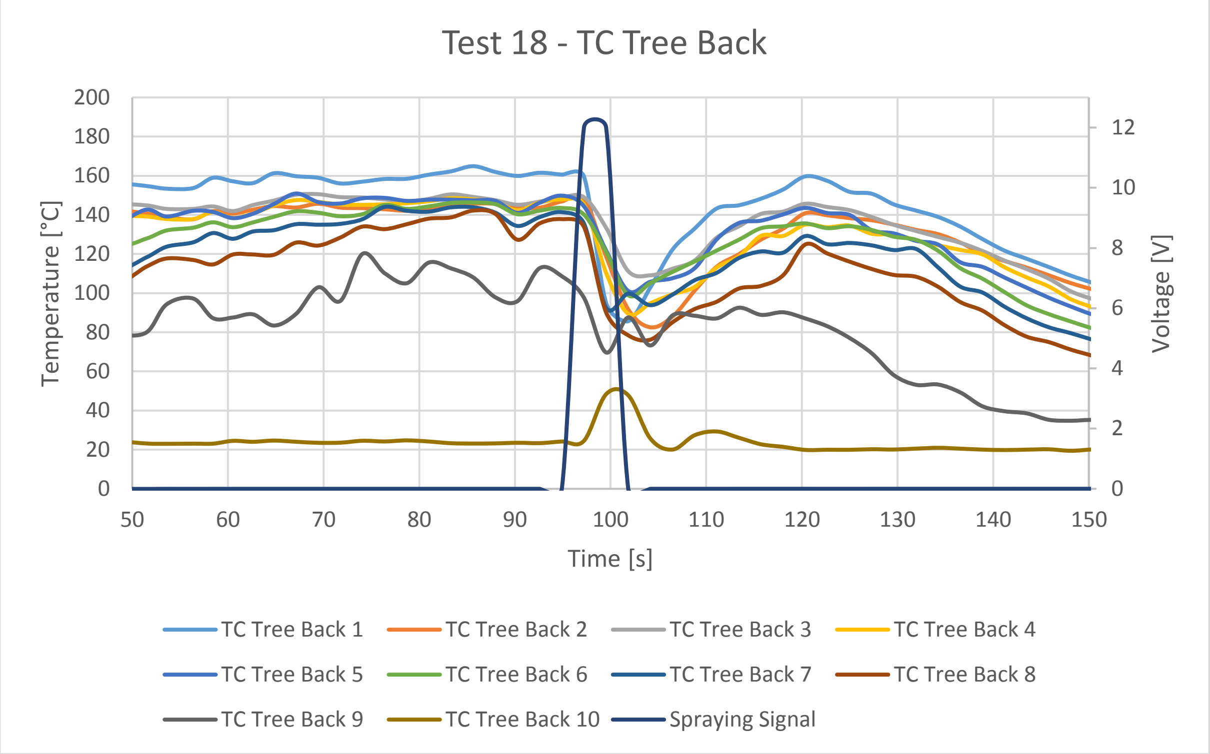

Figure 49: Test with GG3030 at 4 bar. Two sweeps of 125mL was applied from direction 1 to 3. A drop from 160°C to 110°C can be seen. A raise up to 50°C can be seen on the lowest thermocouple at 35cm.

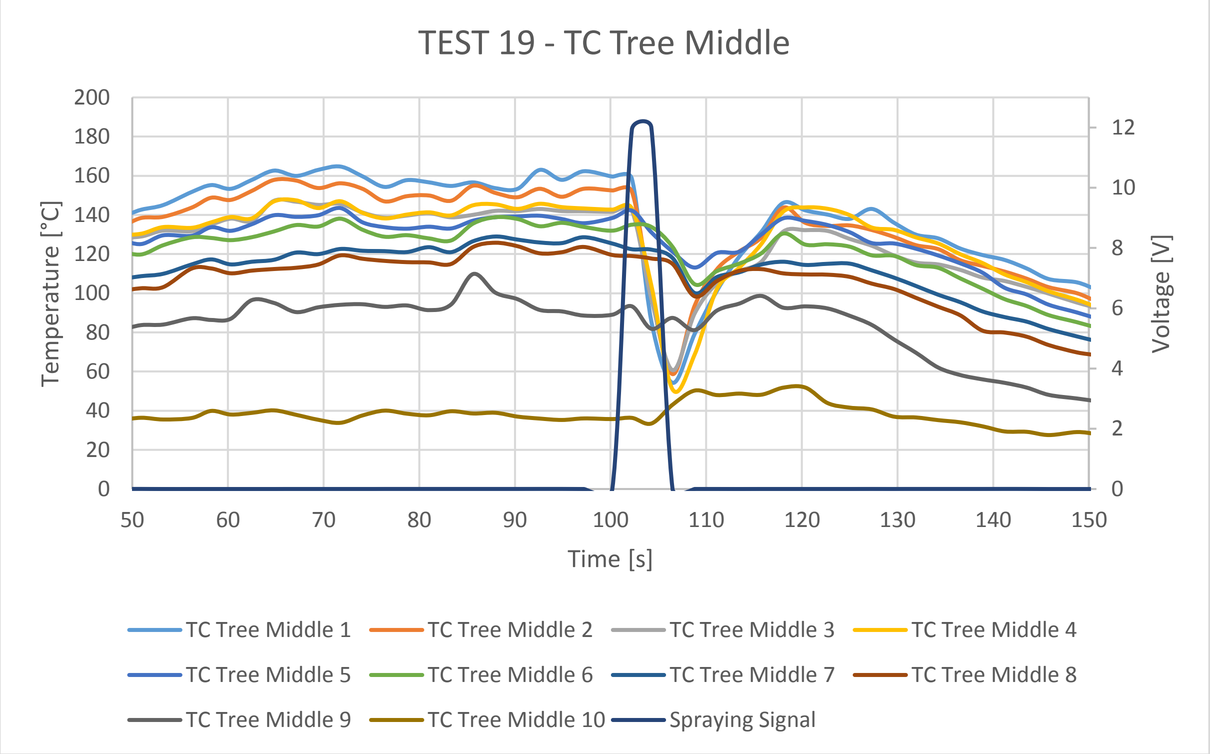

Figure 50: Test with GG1530 at 6 bar. Two sweeps of 123mL was applied from direction 1 to 3. A drop from 160°C to 120°C can be seen.

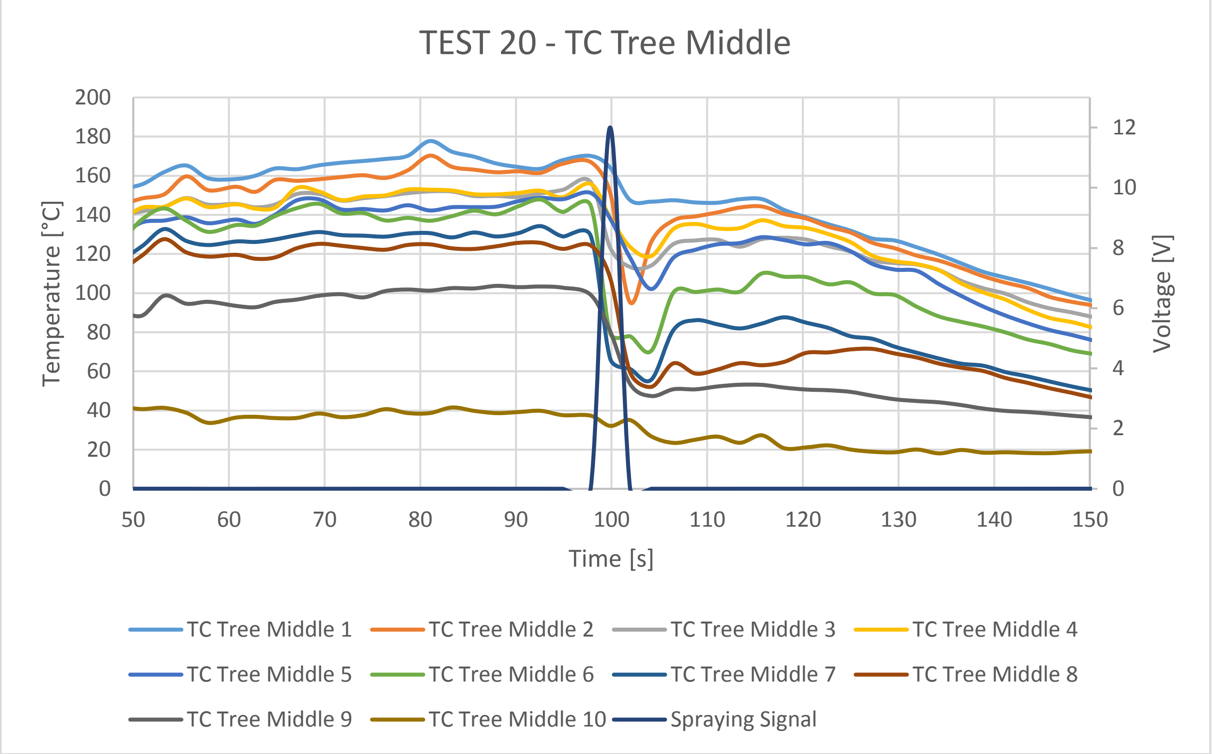

Figure 51: Test with GG25 at 4 bar. Two sweeps of 125mL was applied from direction 1 to 3. A drop from 170°C to 150°C can be seen on the thermocouple at 105cm. A temperature drop can be seen on the lowest thermocouple at 35cm.

There were no differences in gas cooling efficiency observed when comparing test 17 (Figure 47 & Figure 48) with test 5 (Figure 37 & Figure 38). In the back area of the room, a higher temperature was measured on the thermocouple at 35cm above the floor.

For test 18 (Figure 49) with the GG3030 nozzle, a maximum temperature drop of 50°C for the upper thermocouple at 105cm was measured. This temperature difference was equal to the one of test 6 (Figure 41).

For test 19 (Figure 50) with the GG1530 nozzle, only the upper half (approximate 40cm) of the smoke layer was cooled down. Almost no temperature difference was measured on the lower half.

Not the entire smoke layer was cooled of test 20 (Figure 51) with the GG25 nozzle. The two sprays did not have enough penetration ability to reach the upper layers of the smoke. Test 8 (Figure 45) with the basic sweep method resulted in better cooling in the smoke layer.

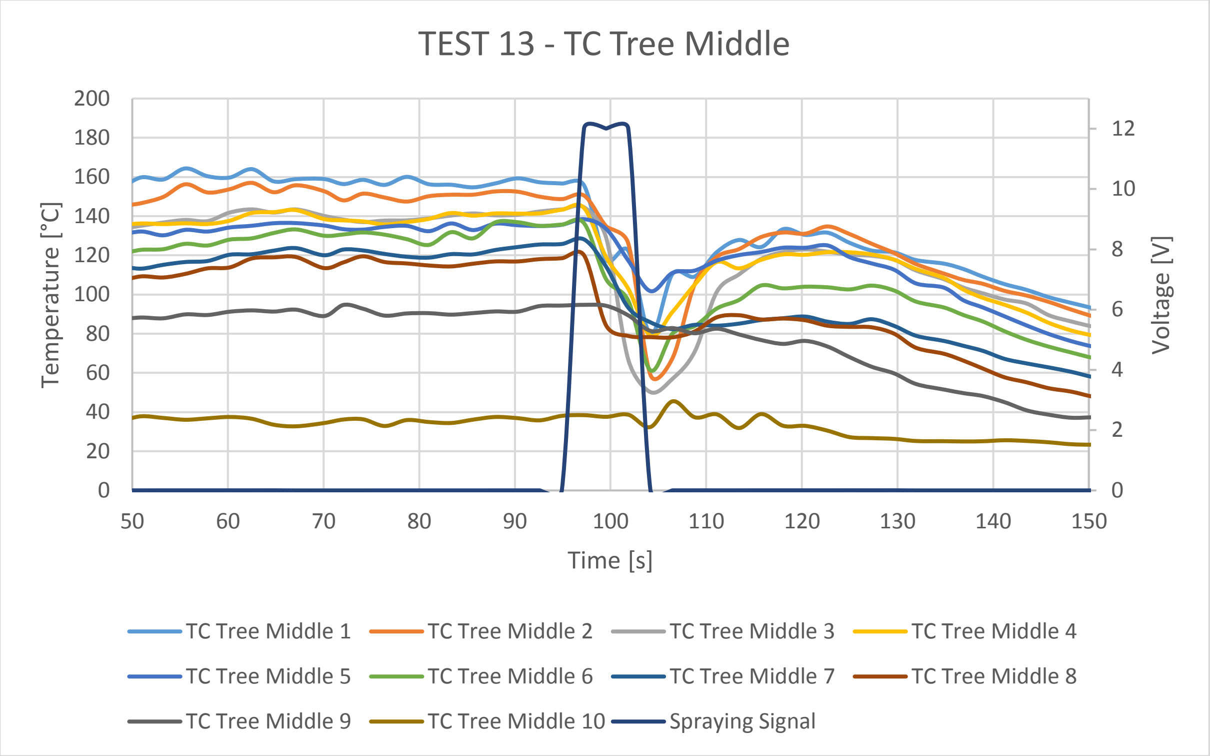

Figure 52: Test with GG16 at 4 bar. Four pulses of 62mL were applied in direction 1 and 3. A drop from 160°C to 110°C can be seen.

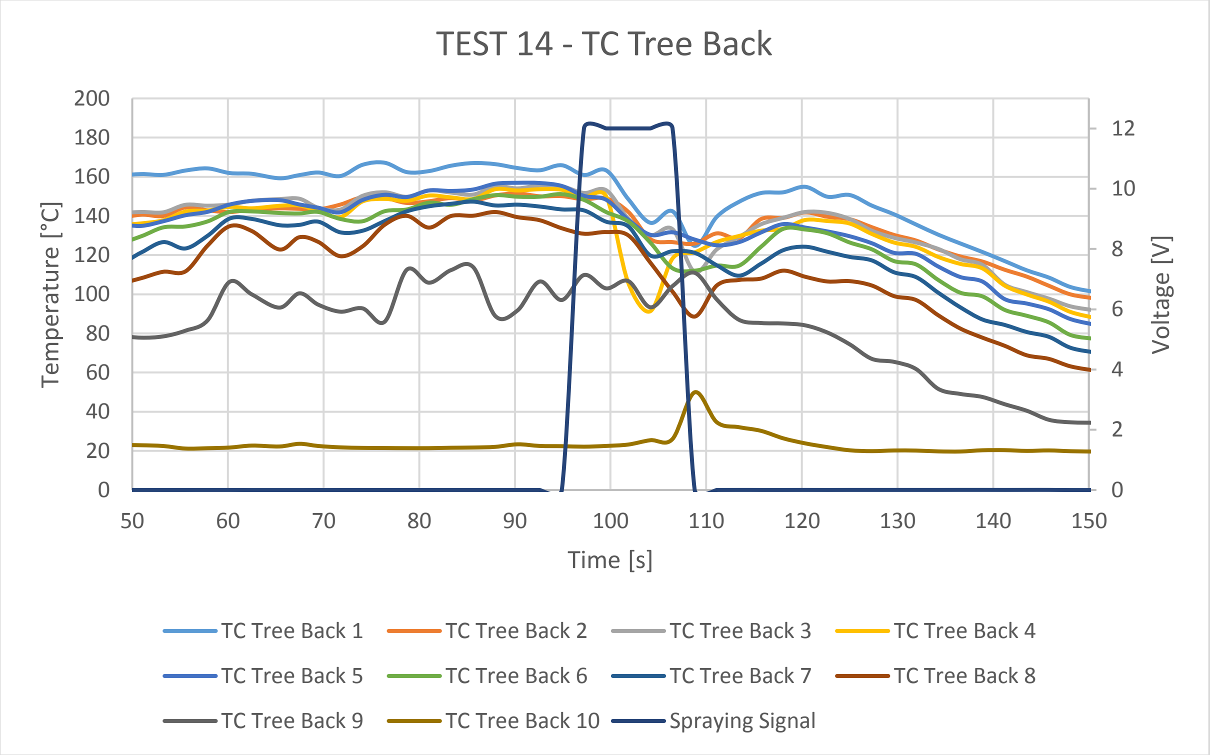

Figure 53: Test with GG3030 at 4 bar. Six pulses of 42mL were applied in direction 1, 2 and 3. A drop from 170°C to 130°C can be seen. A raise up to 50°C can be seen on the lowest thermocouple at 35cm.

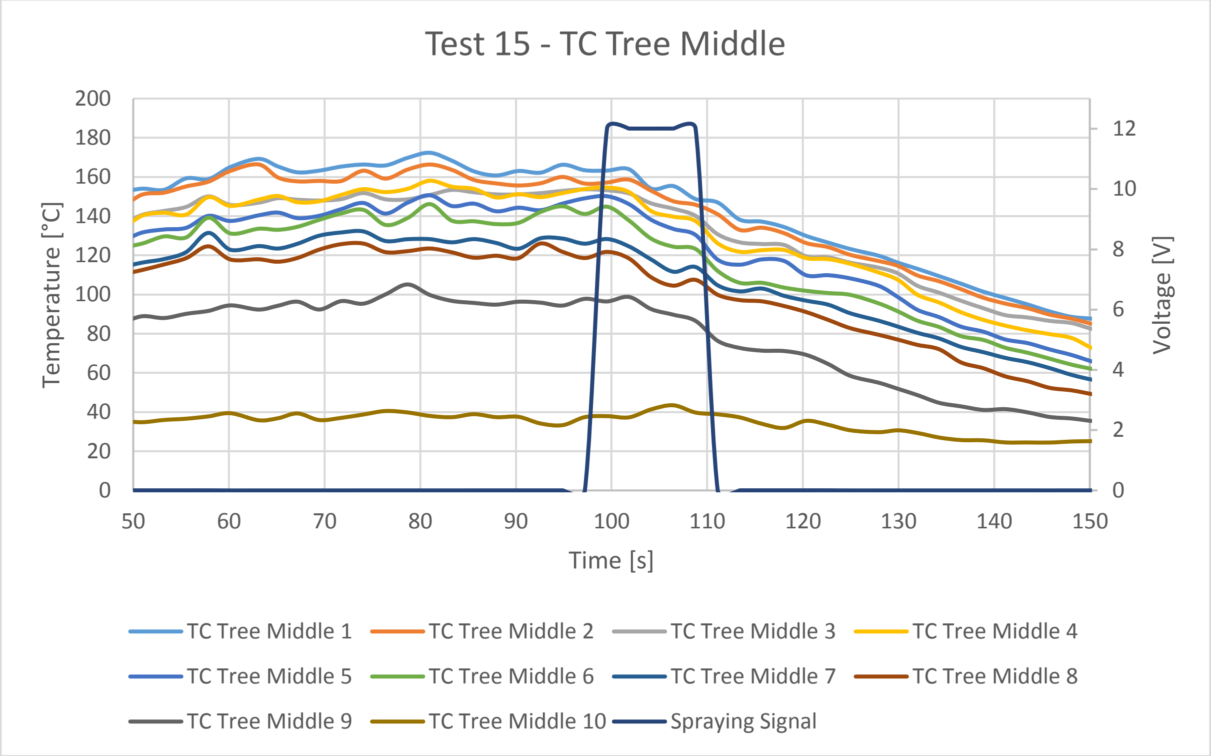

Figure 54: Test with GG1530 at 6 bar. Six pulses of 42mL were applied in direction 1, 2 and 3.

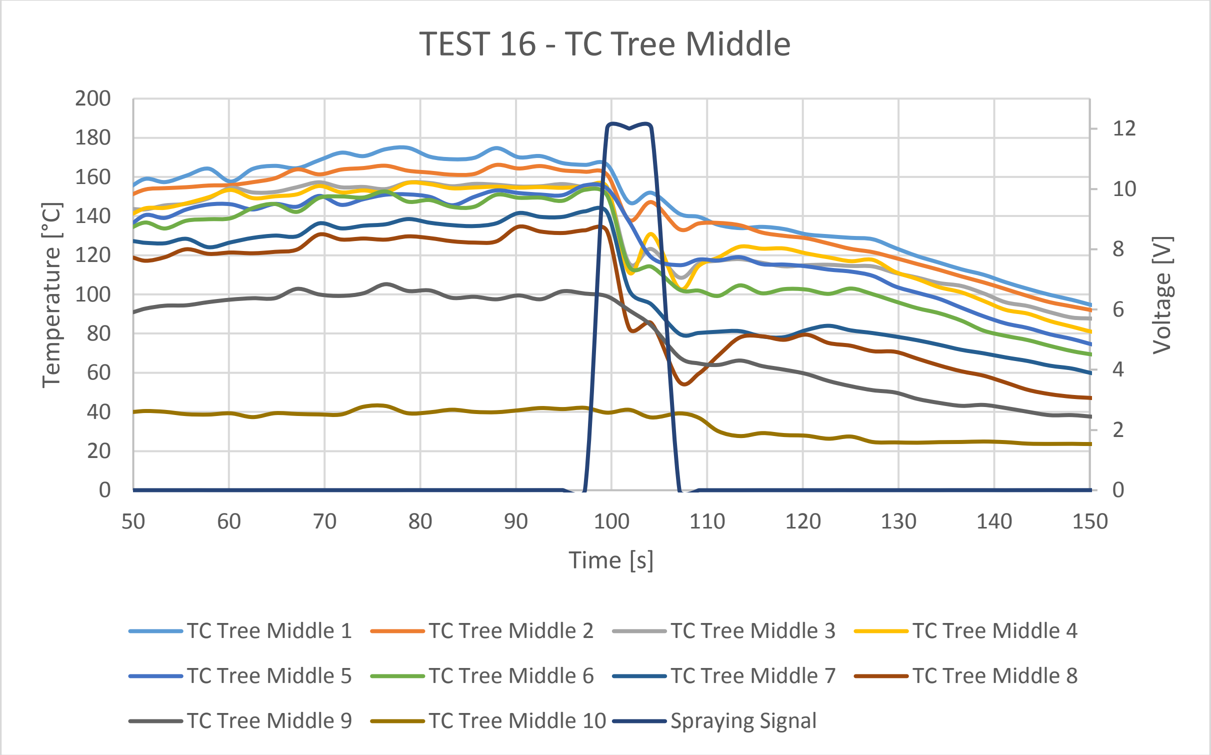

Figure 55: Test with GG25 at 4 bar. Four pulses of 62mL were applied in direction 1 and 3. A drop from 170°C to 150°C can be seen.

Test 13 (Figure 52) shows that the temperature drop was slower than with test 9 (Figure 40). In some thermocouples, the temperature of the smoke was rising again while the nozzle turned to the next position. It was more efficient to open the nozzle once in every direction then twice with a smaller amount of water. Every time the nozzle changed direction between two pulses, a break of 1,5 seconds took place. This is in total 4,5 seconds where no water was flowing true the nozzle.

The same phenomenon occurred in test 14 (Figure 53) as in test 13. The temperature dropped slower than the one of test 10 (Figure 41). The cooling of the smoke layer was also less efficient. For test 14 the smoke layer is more stable than test 10. The thermocouple 35cm above the floor had a smaller raise in temperature.

There is also almost no cooling of the smoke in test 15 (Figure 54).

The phenomenon of slower and less temperature drop also occurred in test 16 (Figure 55). There were on all the thermocouples also a raise in temperature noticeable as in test 13 (Figure 52).

4.4 Droplet size variation

In the next group of experiments, the influence of different droplet sizes were examined. The droplet size was altered by changing the work pressure. For the nozzles used, a higher pressure resulted in smaller droplets coming out of the nozzle. Three different work pressures used in the experiments for comparing the influence of the droplet size (4, 3 and 2 bar). All the tests were executed with the GG16 and the GG3030 nozzle. The tests with the GG3030 are not discussed in this report because the same conclusion can be made as for the tests with the GG16 nozzle. All the test results can be found in the annex on page 95. Table 16 shows all the performed tests with their corresponding drop size.

Table 16: Working pressure with resulting droplet size.

Pressure [bar]	Spray method	GG16		GG3030	
		Test no.	VPM [µm]	Test no.	VPM [µm]
4	Sweep	5	990	6	990
3	Sweep	21	1080	25	1080
2	Sweep	22	1340	26	1330
4	Pulsing	9	990	10	990
3	Pulsing	23	1080	27	1080
2	Pulsing	24	1340	28	1330

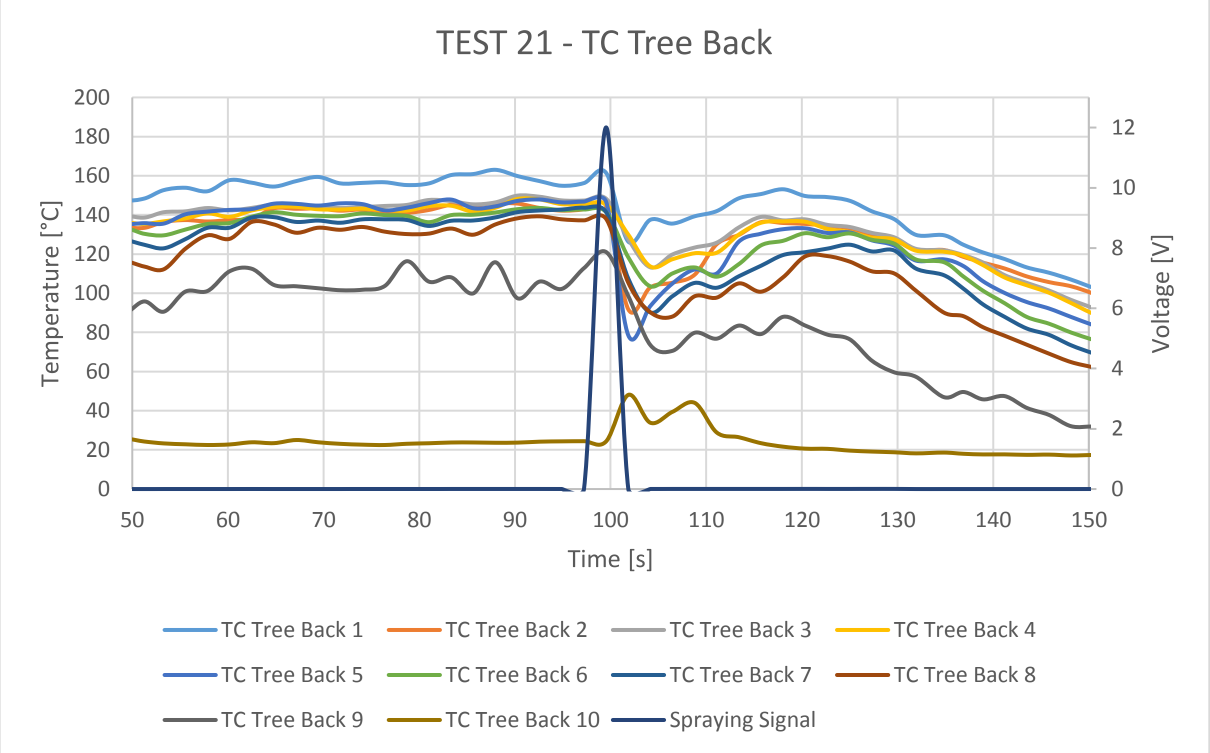

Figure 56: Test with GG16 at 3 bar. One sweep of 245mL was applied from direction 1 to 3. A drop from 160°C to 130°C can be seen. A raise up to 50°C can be seen on the lowest thermocouple at 35cm.

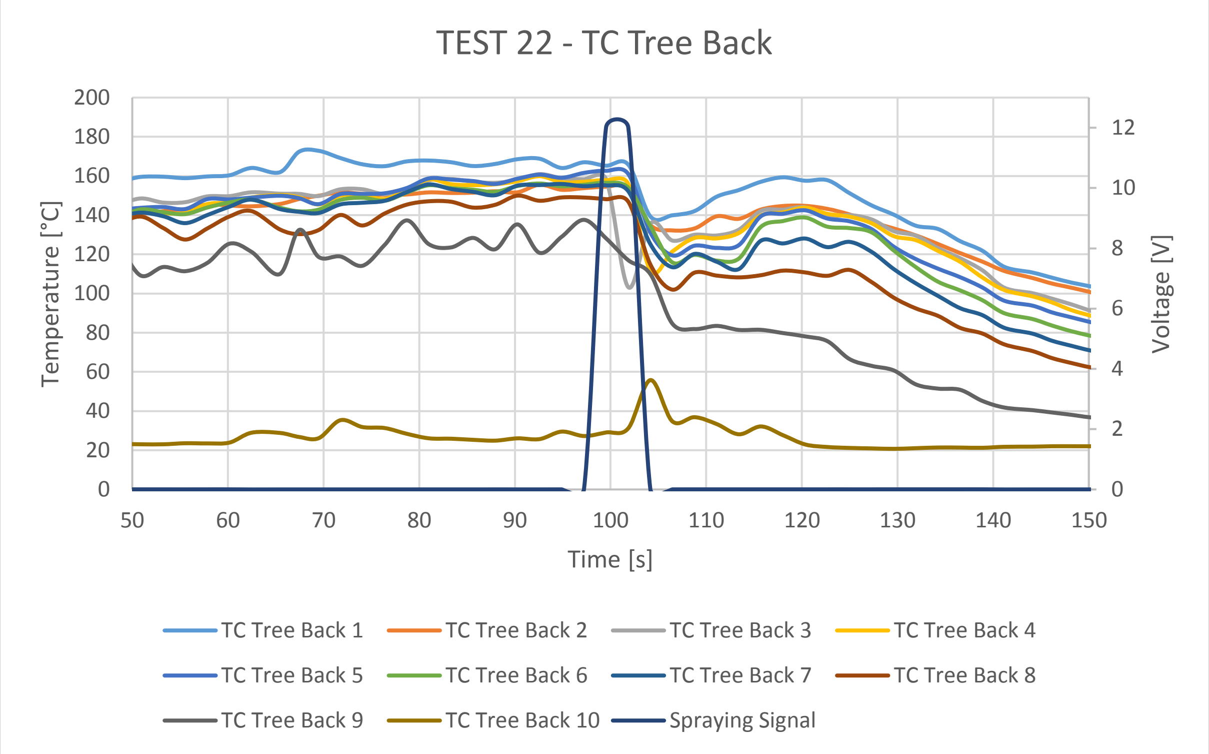

Figure 57: Test with GG16 at 2 bar. One sweep of 245mL was applied from direction 1 to 3. A drop from 170°C to 140°C can be seen. A raise up to 60°C can be seen on the lowest thermocouple at 35cm.

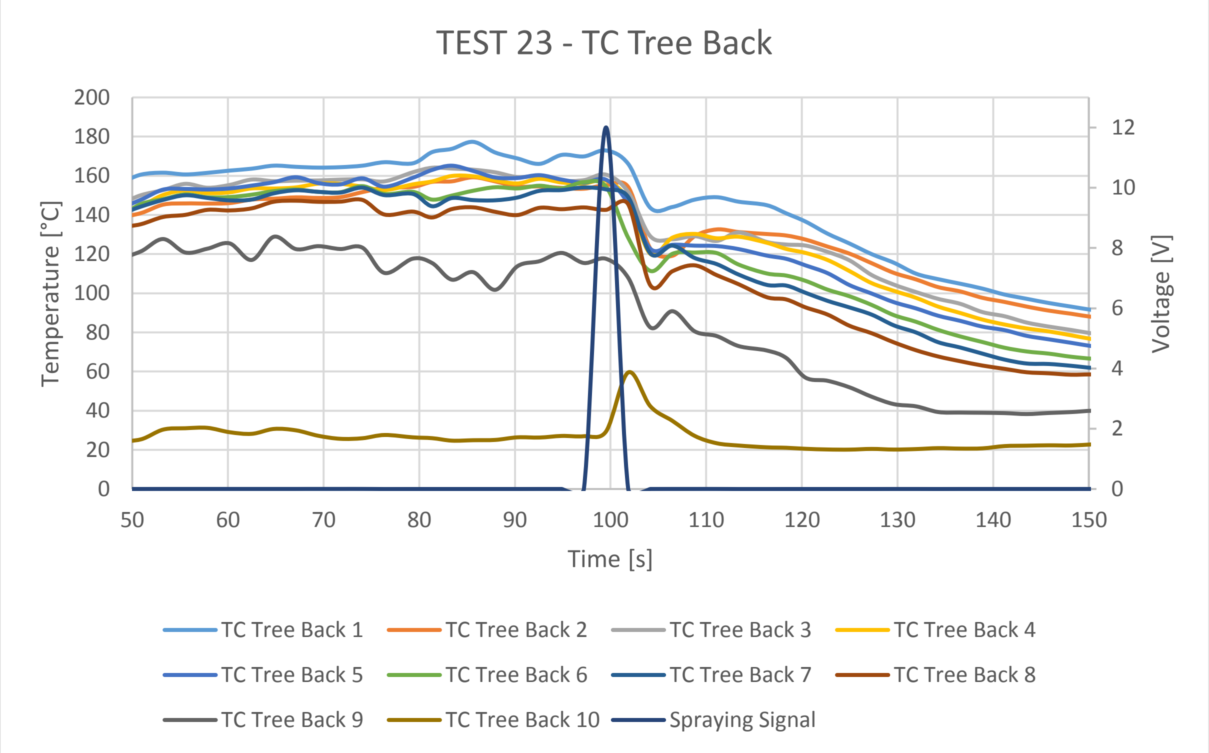

Figure 58: Test with GG16 at 3 bar. Two pulses of 124mL were applied in direction 1 and 3. A drop from 170°C to 140°C can be seen. A raise up to 60°C can be seen on the lowest thermocouple at 35cm.

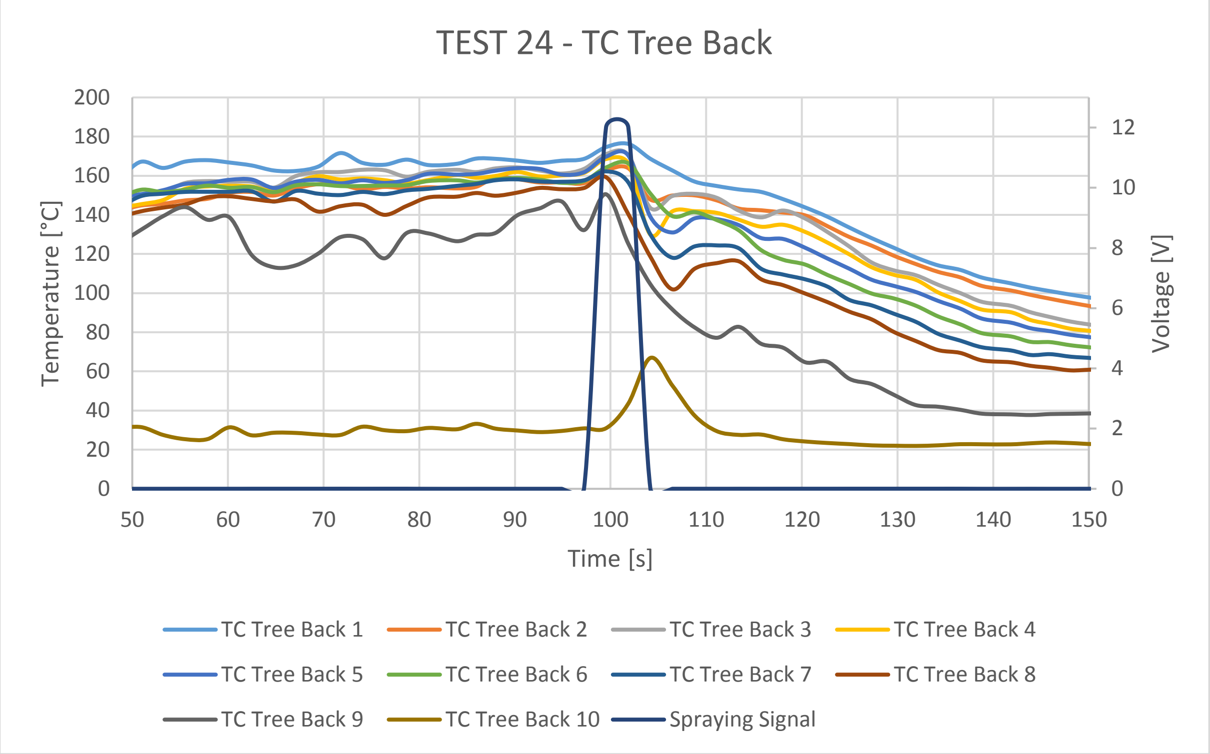

Figure 59: Test with GG16 at 2 bar. Two pulses of 125mL were applied in direction 1 and 3. A raise up to 60°C can be seen on the lowest thermocouple at 35cm.

As mentioned in section 1.2 about previous research, droplet size has a big influence on the cooling efficiency of a water spray. When the mean droplet size of a water spray decrease then the cooling efficiency will increase. There was also a difference noticeable between using the sweep method or the pulsing method. When comparing test 5 (Figure 37), test 21 (Figure 56) and test 22 (Figure 57) with test 9 (Figure 39), test 23 (Figure 58) and test 24 (Figure 59), that the efficiency is more influenced by the droplet size when the pulsing method is used. This does not mean that the sweep method is not affected by the droplet size. Less cooling capacity is also still visible for the sweep method when the droplet size increases.

4.5 Smaller total amount of water

The GG16 nozzle was tested in test 29 (Figure 60) and test 31 (Figure 62) and the GG3030 nozzle was tested in test 30 (Figure 61) and test 32 (Figure 63). These tests are executed with approximate 150mL total amount of used water. Because less water is used, the nozzle valve will also be open for a shorter period. The smoke in test 29 and test 30 was cooled using one sweep of approximate 150mL of water. In test 31, two pulses of approximate 75mL were sprayed into the smoke layer. Three pulses of approximate 50mL were used in test 32.

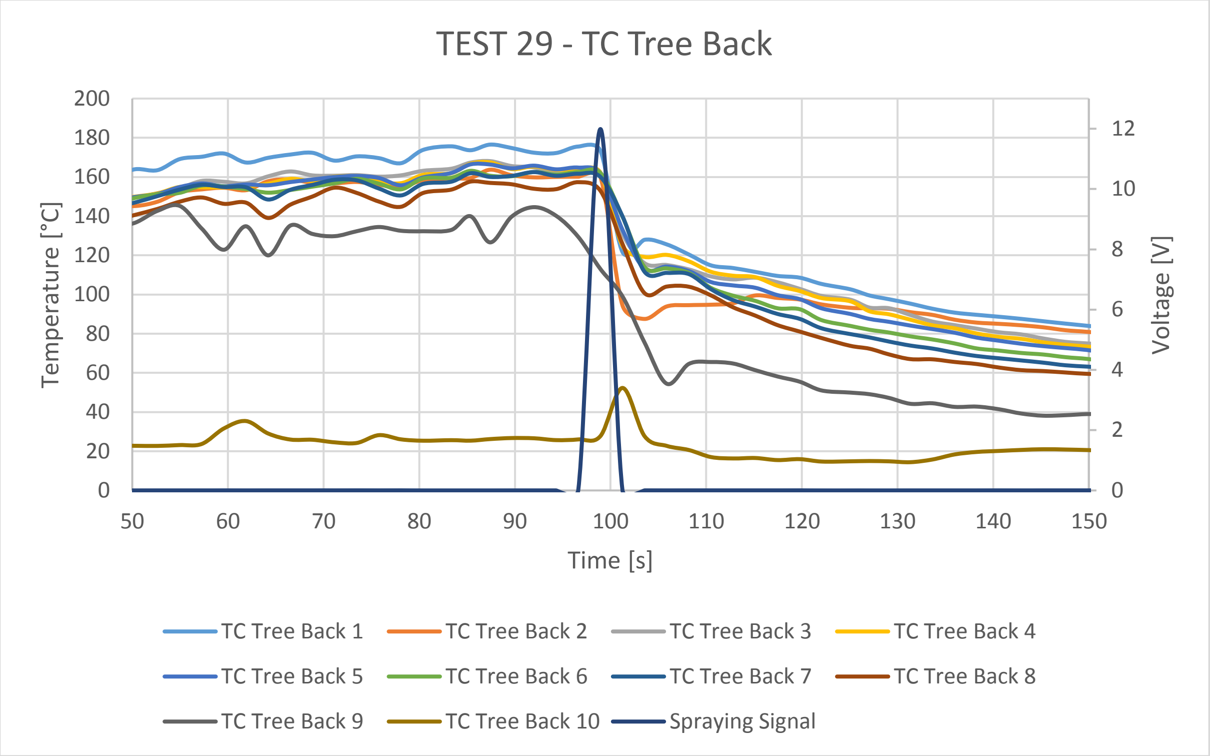

Figure 60: Test with GG16 at 4 bar. One sweep of 150mL was applied from direction 1 to 3. A drop from 180°C to 130°C can be seen. A raise up to 50°C can be seen on the lowest thermocouple at 35cm.

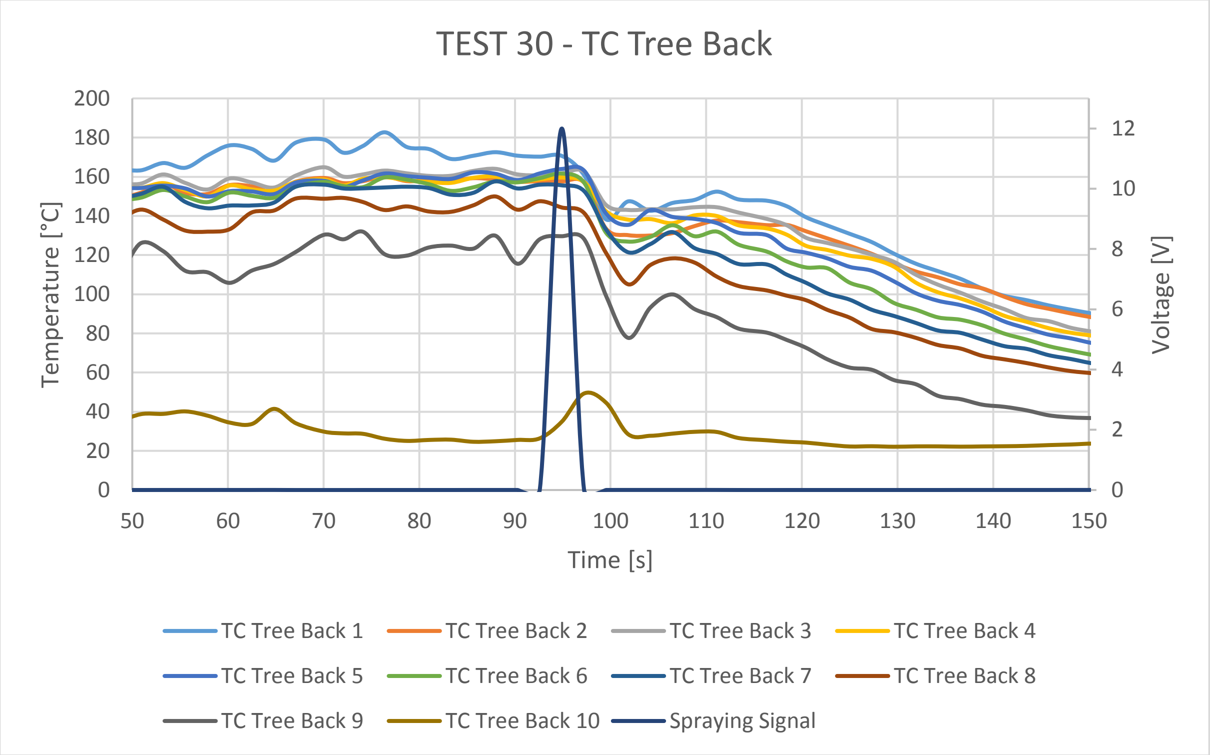

Figure 61: Test with GG3030 at 4 bar. One sweep of 155mL was applied from direction 1 to 3. A drop from 180°C to 150°C can be seen. A raise up to 50°C can be seen on the lowest thermocouple at 35cm.

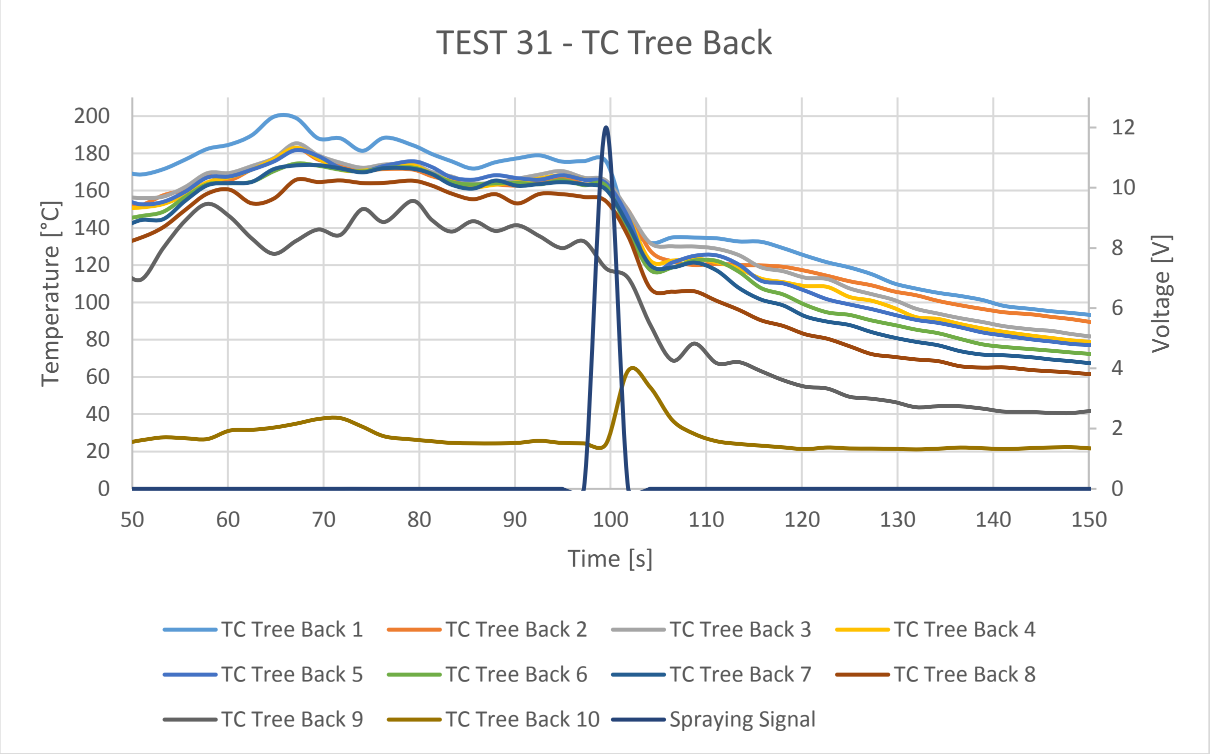

Figure 62: Test with GG16 at 4 bar. Two pulses of 77mL were applied in direction 1 and 3. A drop from 180°C to 140°C can be seen. A raise up to 65°C can be seen on the lowest thermocouple at 35cm.

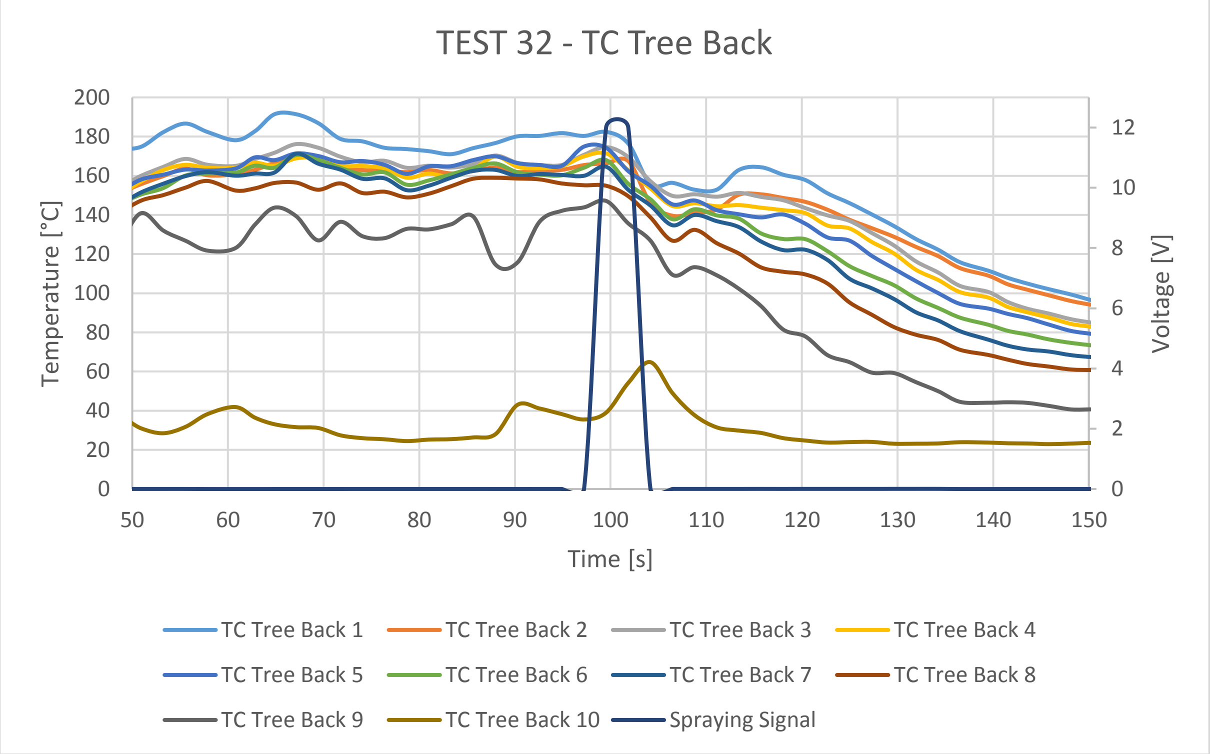

Figure 63: Test with GG3030 at 4 bar. Three pulses of 50mL were applied in direction 1, 2 and 3. A drop from 180°C to 160°C can be seen. A raise up to 65°C can be seen on the lowest thermocouple at 35cm.

The maximum temperature in test 5 (Figure 37) dropped with 60°C. In test 29 (Figure 60) there was a 50°C drop for the maximum temperature. In test 5 and test 29 the sweep method was used with the GG16 nozzle. When comparing the tests of the GG16 nozzle where the pulsing method was used there is a bigger difference visible. In test 9 (Figure 39) where approximate 250mL water was used, a temperature drop of 70°C was registered. In test 31 (Figure 62) with only 150mL water, the temperature difference was maximum 40°C.

Test 30 (Figure 61) shows that when with the GG3030 nozzle the sweep method was used with approximate 150mL, the maximum temperature decreases with 30°C. In test 6 (Figure 41) where the same method was used with 250mL of water there was a temperature drop of 60°C.

Using less water does not result directly in a more stable smoke layer. This can be seen when observing the thermocouple at 35 cm above the floor from test 29, test 30, test 31 and test 32.

4.6 Mist nozzle

The nozzle placement is different for the tests with the HH1 mist nozzle then the tests with all the other nozzles. The nozzle stand was moved one meter into the compartment, measured from the door opening till the axis on which the nozzle is mounted. By moving the nozzle inside the room, some effects were seen in the back of the nozzle. This represents an advancing firefighter that is cooling the smoke in front of him. The smoke keeps on flowing above the firefighter till it reach the front area of the room and escapes true the door opening. The choice of putting the HH1 nozzle one meter inside the room was because the spray distance of the nozzle was limited. If the nozzle would be setup in the door opening of the room, the back area would not be affected by the spray of the HH1 nozzle.

Three tests were executed with the HH1 nozzle. Test 37 (Figure 64) was a test with a static nozzle position. The nozzle did not turn and pointed continuously in direction 2. The nozzle did one spray of 38mL. In test 38 (Figure 65 & Figure 66), the sweep method was examined with 38mL of water. In test 39, two pulses of 20mL are sprayed in direction 1 and 3.

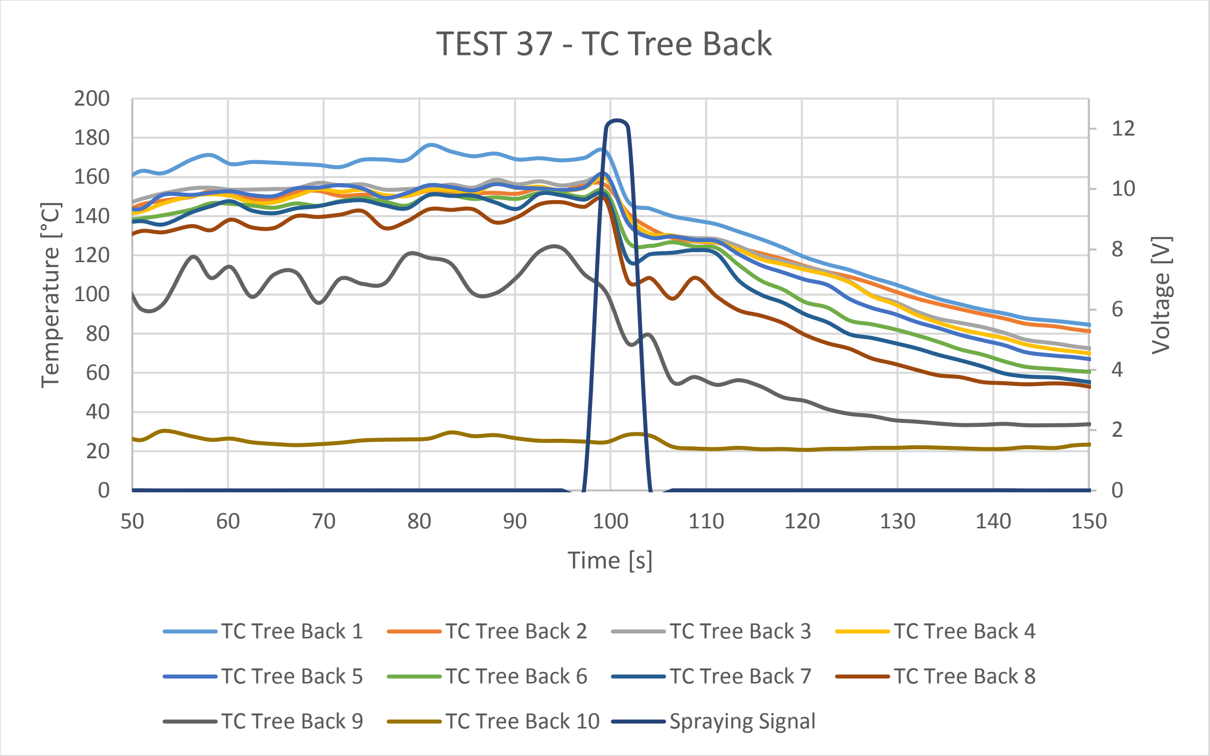

Figure 64: Test with HH1 at 6 bar. One spray of 38mL was applied in direction 2. A drop from 175°C to 150°C can be seen.

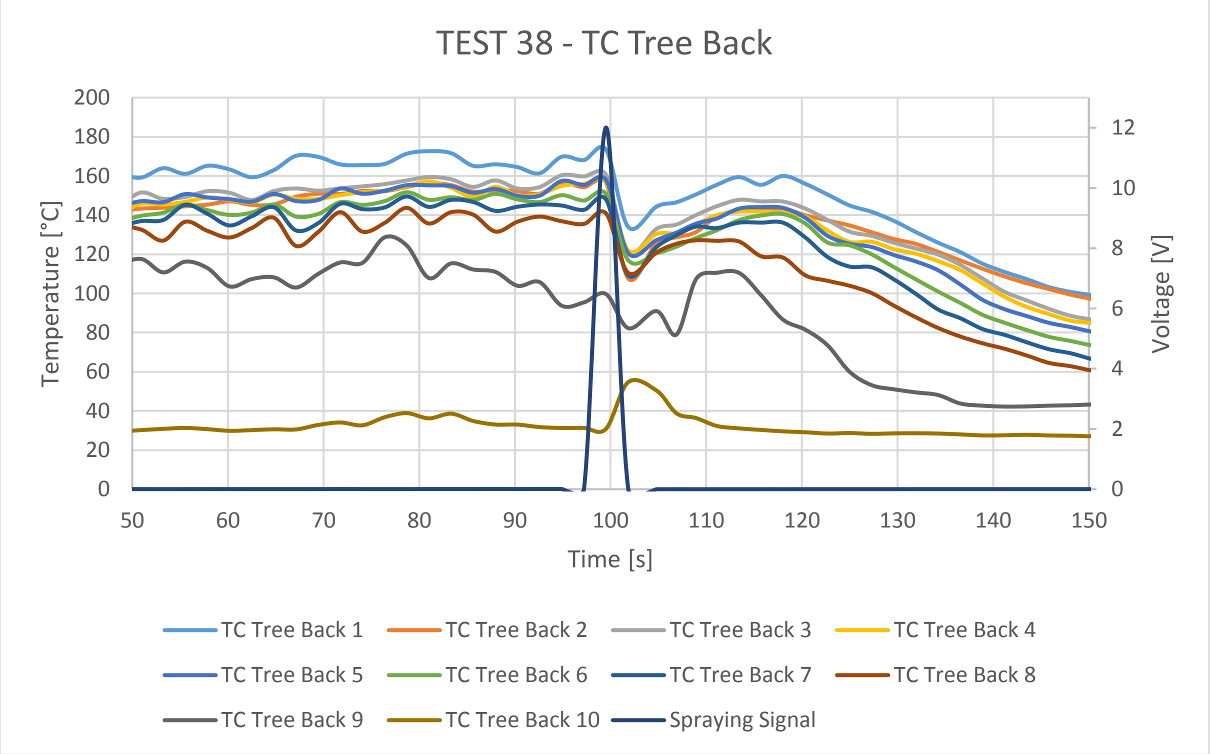

Figure 65: Test with HH1 at 6 bar. One sweep of 38mL was applied from direction 1 to 3. A drop from 180°C to 130°C can be seen. A raise up to 55°C can be seen on the lowest thermocouple at 35cm.

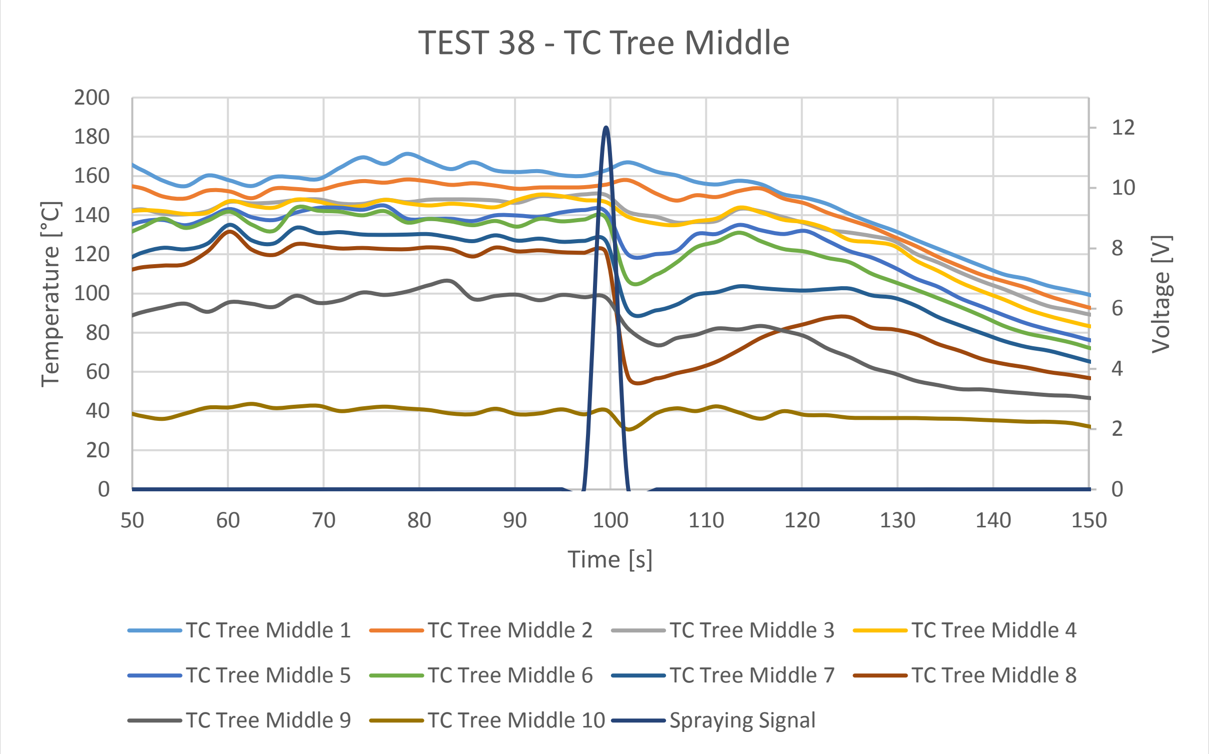

Figure 66: Test with HH1 at 6 bar. One sweep of 38mL was applied from direction 1 to 3.

A 25°C temperature drop of the highest thermocouple can be seen in Figure 64. Figure 65 shows that one sweep of 38mL with the HH1 nozzle, the temperature in front of the nozzle dropped from 180°C back to 130°C. Figure 66 shows what happens behind the nozzle. There was a cooling of the smoke observed in the front area of the room. The temperature of the upper half of the smoke layer showed minor temperature changes. On the other hand, the lower half of the smoke layer was significant cooler. The thermocouple 60cm above the floor was cooled down from 120°C to less than 60°C. The same observations as test 38 can be made for test 39 where gas cooling was done by pulsing. The results can be found in the annex starting from page 955.

For test 37, test 38 and test 39, a homogenous cooling was achieved. All the measured temperatures of thermocouples dropped equally.

4.7 Larger fire – 200kW

The following three experiments came with the following thought:

If the room breaks because a to large fire is used, it is not a disaster. Data for 39 tests were already collected successfully.

In the last tests that were executed in the fire room, a larger fuel pan was used, a circular Ø400mm pan instead of a square 330x330 pan (165kW). This fuel pan with heptane gave approximately 200kW in rate of heat release. In these experiments, the smoke was cooled using the sweep method. The same procedure and spray scenario was used as test 5.

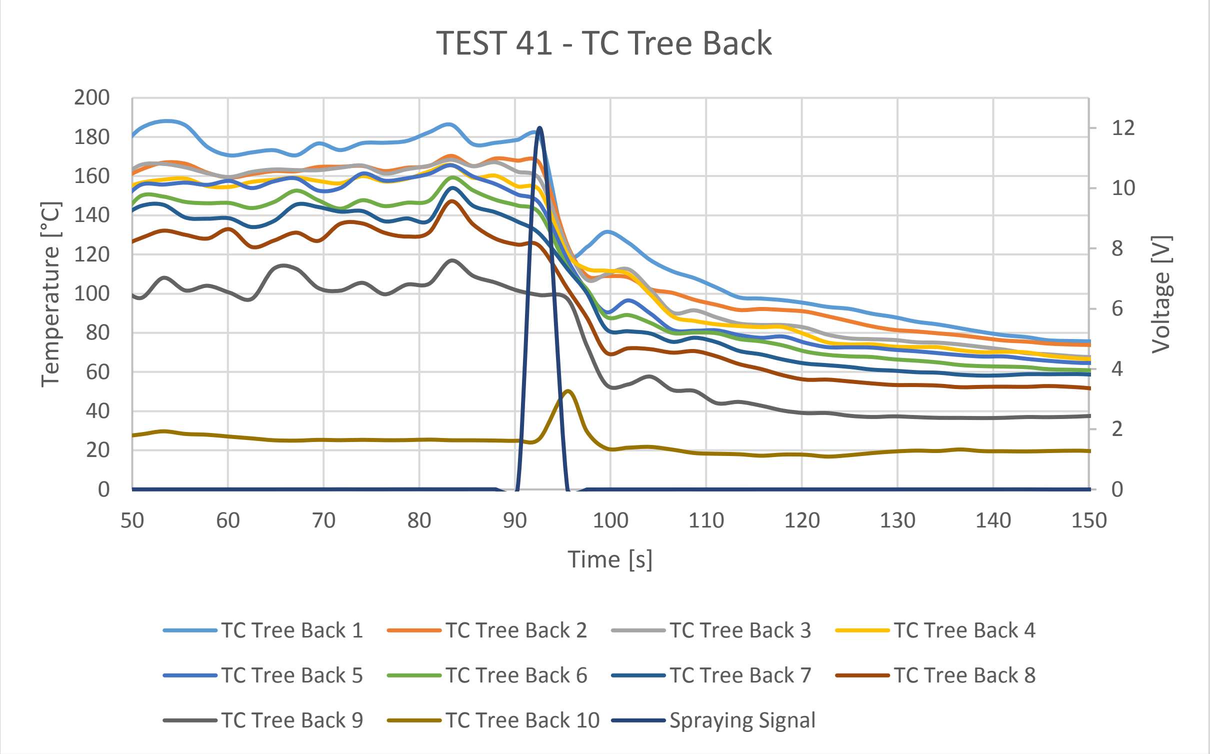

Figure 67: Test with GG16 at 4 bar. One sweep of 255mL was applied from direction 1 to 3. A drop from 180°C to 120°C can be seen. A raise up to 50°C can be seen on the lowest thermocouple at 35cm.

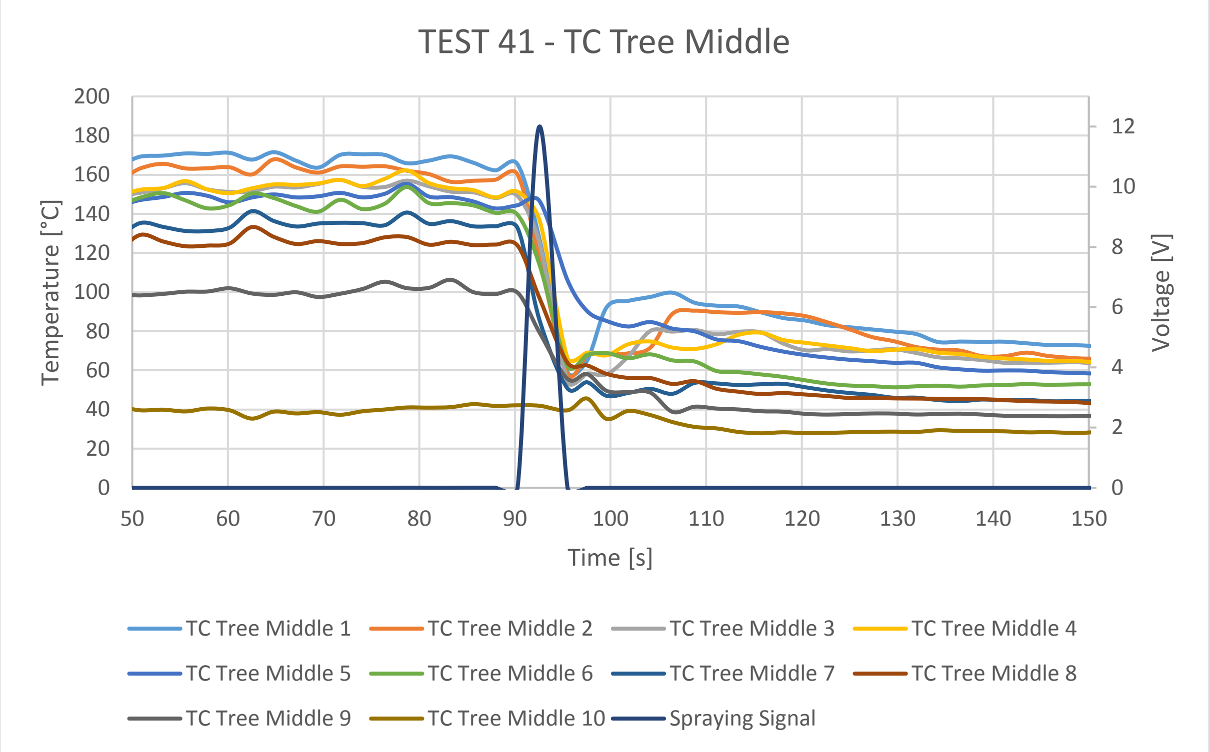

Figure 68: Test with GG16 at 4 bar. One sweep of 255mL was applied from direction 1 to 3. A drop from 170°C to 90°C can be seen. A temperature drop can be seen on the lowest thermocouple at 35cm.

When the test 40, test 41 (Figure 67 & Figure 68) and test 42 were conducted, a denser and more sooty smoke layer was observed. The calculation was made for a same burn time as the 165kW fire. Nevertheless, the total fire time was shorter than expected. This resulted in no afterburn for test 40. In Figure 67 & Figure 68, the thermocouples located in the smoke layer have a higher temperature. The maximum temperature was not significantly higher.

The sweep method worked as good as the test with the 165kW fire. Cooling the smoke layer was visible in Figure 67 & Figure 68. In the back area of the room (Figure 67) the maximum temperature dropped from 180°C to 120°C. In the middle area of the room (Figure 68) the maximum temperature dropped below 100°C. It goes from 170°C to 90°C.

4.8 Velocities

Changes in the velocity of the smoke can be caused by the combination of some events. One reason for a decrease of velocity is the impulse of the water spray which creates a momentum on the smoke layer. When the smoke layer is contracted by gas cooling, the pressure profile in the door opening will change. This will result in a decrease of measured velocity.

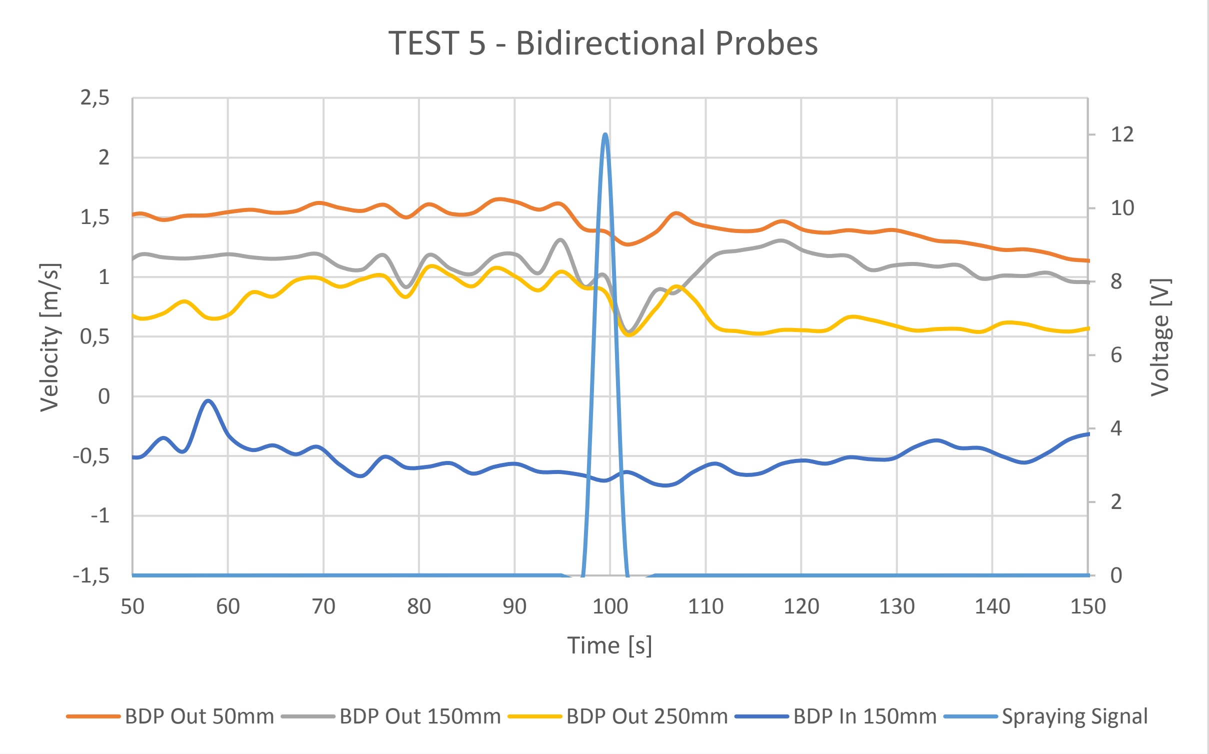

Figure 69: Test with GG16 at 4 bar. One sweep of 250mL was applied from direction 1 to 3.

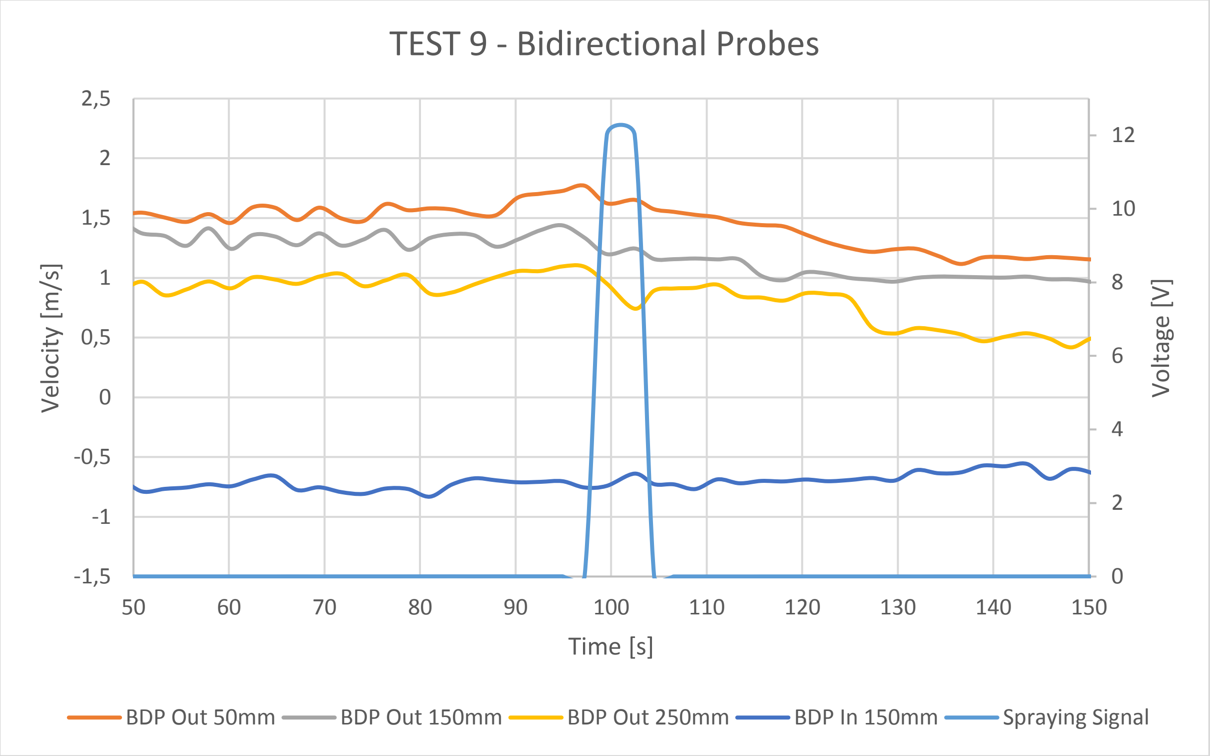

Figure 70: Test with GG16 at 4 bar. Two pulses of 123mL were applied in direction 1 and 3.

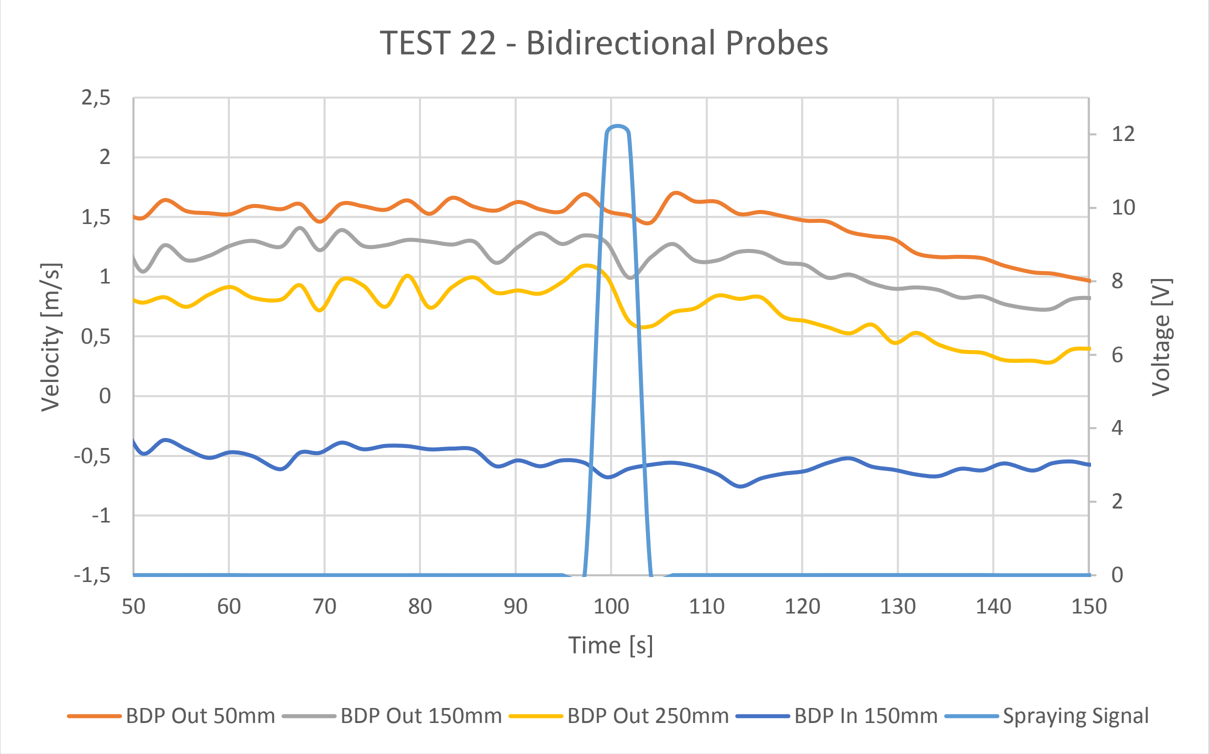

Figure 71: Test with GG16 at 2 bar. One sweep of 245mL was applied from direction 1 to 3.

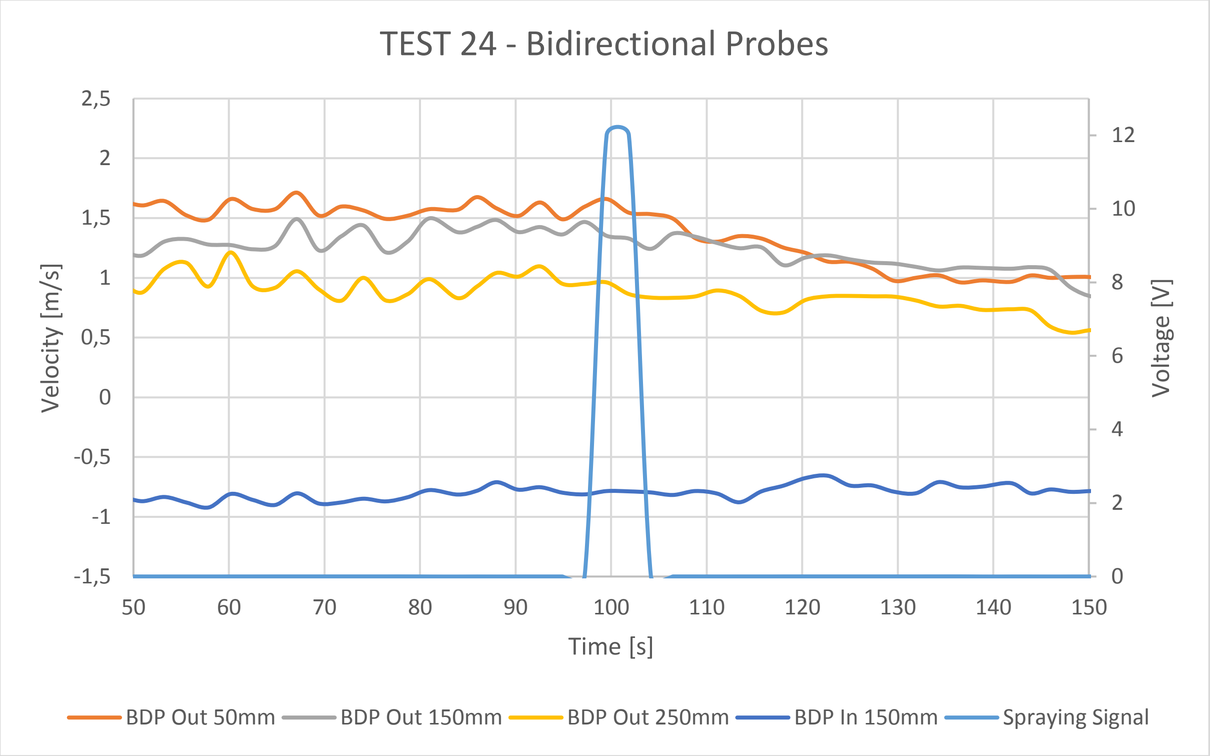

Figure 72: Test with GG16 at 2 bar. Two pulses of 125mL were applied in direction 1 and 3.

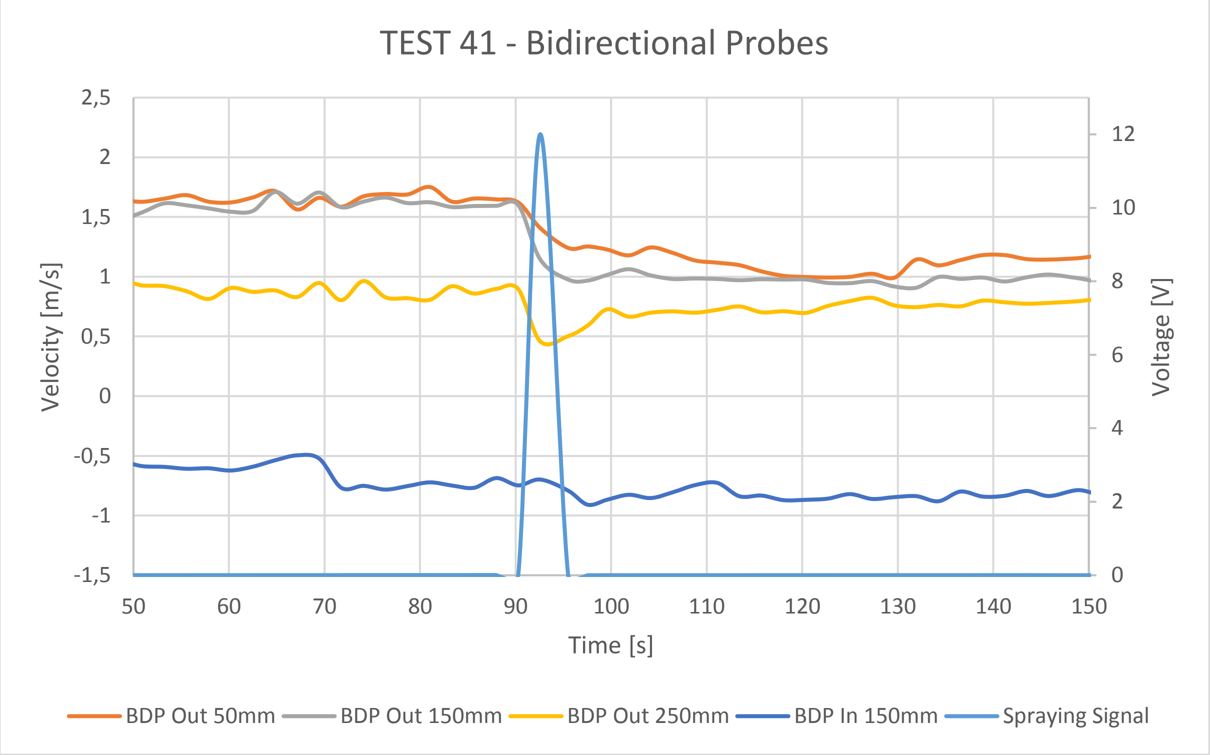

Figure 73: Test with GG16 at 4 bar. One sweep of 255mL was applied from direction 1 to 3.

In all the tests, there was a decrease in outgoing smoke velocity noticeable when the water was sprayed into the smoke layer. The velocity of the ingoing air does not change much. No conclusion for the ingoing air can be made.

Test 5 (Figure 69) and test 9 (Figure 70) showed that the velocity of the outgoing smoke decrease more when a sweep was used than when pulses are applied in the smoke layer. This observation was also confirmed with test 33 and test 35. When the working pressure was adjusted and a smaller droplet size was used, this observation is still correct. Test 22 (Figure 71) and test 24 (Figure 72) shows this with a working pressure of 2 bar. Test 21 and test 23 confirmed this with a working pressure of 3 bar (measurements are included in the annex on page 95).

Figure 73 shows the velocity changes when gas cooling was applied on smoke from the 200kW heptane fire. The velocity of the bidirectional probe 150mm from the top of the door opening is significant higher for the larger fire. The velocity decrease for the outgoing smoke was larger than for the tests with the standard used fire.

4.9 Smoke contraction

The analysis of the video footages for the measurements of the smoke contraction was very difficult noticeable. The waving pattern of the smoke layer when water is sprayed into the smoke layer makes the measurement not possible. Larger contraction may have been observable if the differences in smoke temperature were larger.

5 Discussion

5.1 Application method

The experiments gave some good results on differences between using a sweep to cool the fire gases or using pulses. Between the two application methods there is not one that has clearly a better cooling efficiency. There are still some small differences.

When a further reach is required, keeping the nozzle in the same direction will result in better cooling efficiency in remote areas of a room. The long pulse with a spray angle of 30° is better than a sweep with the same spray angle and same reach distance.

If the droplet size of a spray gets larger, the cooling efficiency will be more influenced for a pulsing spray than when a sweep is performed.

In almost all the tests, the thermocouple that was located 35cm above the floor and was used to do an estimation of the stability of the smoke layer, there is almost no large differences when comparing the sweep method to the pulsing method.

5.2 Efficiency of the used nozzles

The full cone nozzles had a good efficiency in vaporization. All the droplets evaporate in the smoke layer or when hitting hot walls. In all the tests, almost no water droplets are seen on the floor of the test room. In the tests where the narrow angle of the GG1530 nozzle was applied, water hitting the walls was audible. Also a steamy cloud was visible in the lower no-smoke layer of the room when the GG1530 nozzle was used.

5.3 Influence of the spray angle

The main advantage of using a narrower angle is the reach of the spray. The cooling efficiency was slightly decreased when the GG3030 nozzle with a spray angle of 30° is used. Consequently, when entering a large compartment, where a smoke layer is formed, a far reach is needed to cool all the gases. Setting a fog nozzle for a spray angle of 30° will still result in enough heat absorption by the water spray to be able to cool the smoke layer.

5.4 No water, no gas cooling

In the tests of chapter 4.5 and 4.6, limited amount of water was used to cool the smoke gases. The obvious conclusion can be made: You need sufficient water to cool the hot smoke layer.

5.5 Stability of the smoke layer

Disturbing the thermal layering or the stability of the smoke layer may cause contact between the hot and toxic fire gases and the possible victim that is laying on the ground. Swedish fire instructors think that you won't 'cook' the victim when cooling the fire gases effectively, even if there is some instability of the smoke layer [9].

As already mentioned before, the stability of the smoke layer was checked using the lowest thermocouples that were located 35cm above the floor. Seen in the measurements of the performed tests is that there is no major difference between a sweep or pulses. The time that a small raise in temperature is measured is very limited. In most tests, there is only a short peak of approximate three seconds. In some cases the temperature is slightly higher, than the temperature before spraying water, for approximate six to eight seconds.

5.6 Translation to reality

The experiments were conducted in a half-scale ISO9705 room. If the tests were done in a full-scale ISO9705 room some parameters would definitely change. In a real compartment fire, more complex structures and even larger rooms are possible.

The equation for calculating the theoretical amount of water needed (eq. 7) can be used to scale the used water in the test room to the water that would be needed in a full scaled compartment. That formula shows that the amount of water is influenced by the total mass of the smoke and the temperature of the smoke. The flow rate that was used for the GG16 nozzle with a work pressure of 4 bar is 13,4L/min. If the smoke temperature of a larger room is the same as the temperatures of the smoke in the tests, then only the increase of smoke mass will influence the scaling of the flow rate. In this case the amount of smoke will directly influence the scaled flow rate. In case the flow rate of the tests should be scaled to a full-scale ISO9705 room. The amount of smoke would be eight (2^3) times more than the half-scale ISO9705 room. This will result in a scaled flow rate of eight times 13,4L/min or 107,2L/min.

6 Conclusion

This work and experiments gave several insights that can give a better understanding of gas cooling. A possible further development and optimizing of the gas cooling technique.

All the nozzles achieved a temperature difference by cooling the smoke layer with a water spray. When the fire gases must be cooled on a larger distance, pulsing will result in better cooling of the fire gases. The sweep is less influenced by the droplet size. When the desired work pressure is not possible on the firefighter’s nozzle, and the ideal droplet sizes are not created, the cooling efficiency of the sweep method will be less influenced. Overall there can be concluded that there is no such thing as the one method that is the best way to apply the water spray to cool the overhead fire gases.

The time between every spray should be kept as small as possible. It is better to open the nozzle once until enough water is applied into the smoke layer than open the nozzle multiple times for the same amount of total used water. The time when no water is flowing out of the nozzle will result in reheating of the smoke layer. This will make that the total cooling capacity of the used water will be smaller. A long pulse will have more cooling efficiency then using multiple short pulses when the same total amount of used water is flowing through the nozzle.

Still the main goal of performing an internal attack is putting the fire out, gas cooling is to create a safer environment for the firefighters. Due to scientific reasons a ‘robot’ is used to conduct the water sprays in the experiments. The final conclusion of this work is that a firefighter always should think when he is in a compartment fire. Watch what is happening, read the fire smoke and flow patterns. React, reflect and adjust where needed. The world does not need firefighters that will just do procedures like a robot.

Or as the Irish firefighter John Chubb mentioned:

> “I’ve seen many guys robotically cooling gases”

To all firefighters, don’t be that guy.

7 Future work

Although this work delivered a lot of results, information and insight on gas cooling, the outcome was still limited. Future research is recommended into gas cooling to help to improve the understanding of it.

Creating a larger opening between the room where the fire is burning and where the fire gases are being cooled can result in higher temperatures in the smoke layer. Creating higher temperatures in the smoke layer can result in larger smoke contractions and the observation for this contraction could be easier.

The performed experiments where limited in burn time. This is done to reduce the heat stress on the room. With limiting the heat stress to the room the risk of cracking or damaging the room was reduced. Tests with longer pre-burns and post-burns could give more information about what happens with the cooled smoke and how long the cooling effect works.

Research can be done for the se of A-foam in the sprayed water. Sometimes A-foam is added to the extinguishing water in the fire service. This additive changes some of the water properties. The surface tension and the viscosity will be reduced. This would theoretically result in smaller droplets.

One major advantage of gas cooling is the thermal ballast that the formed steam creates inside the smoke layer. The steam can inert the smoke layer for making roll-overs and flashovers impossible. A study focused on the flammability of a smoke layer that is affected by a fog nozzle can bring more information on this.

The experiments were executed in a half-scale ISO9705 room. The layout and the size of the rooms in realistic buildings are totally different. A full-scale test is necessary to get a better understanding how gas cooling works.

8 Acknowledgments

This master thesis is submitted to be able to graduate from the International Master of Science in Fire Safety Engineering.

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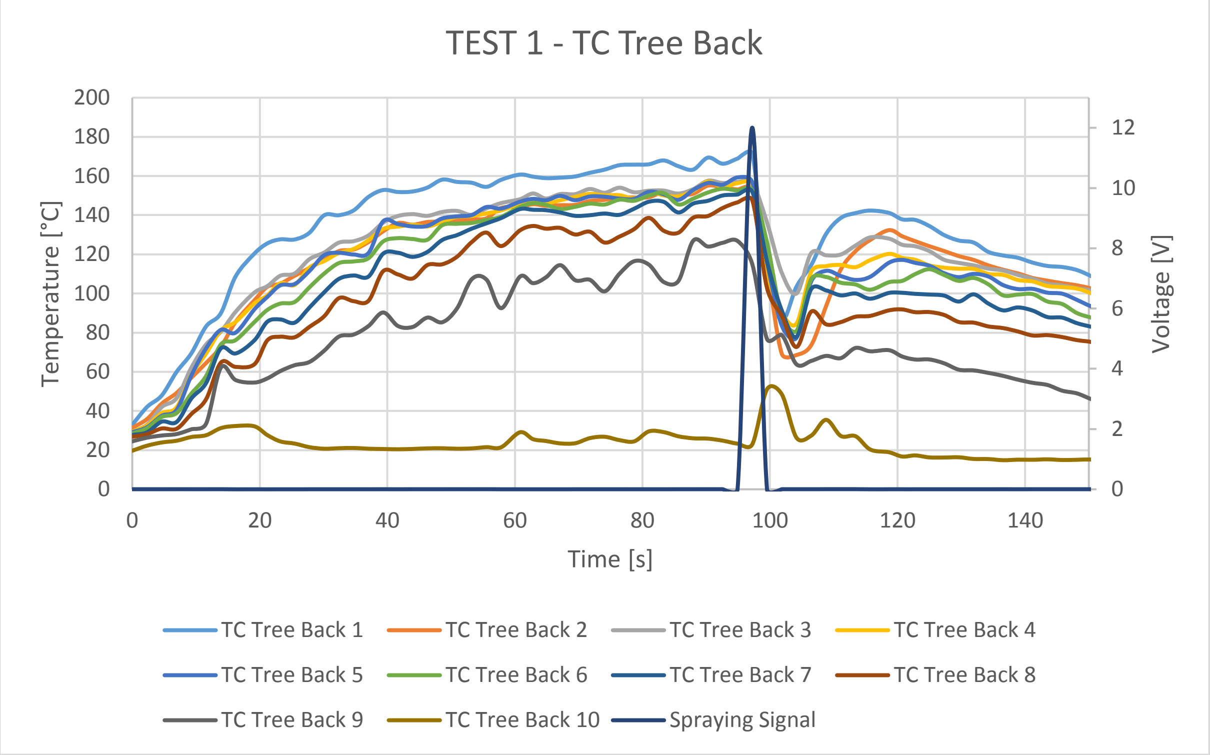
10 Annex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Voltage [V]
Time [s]
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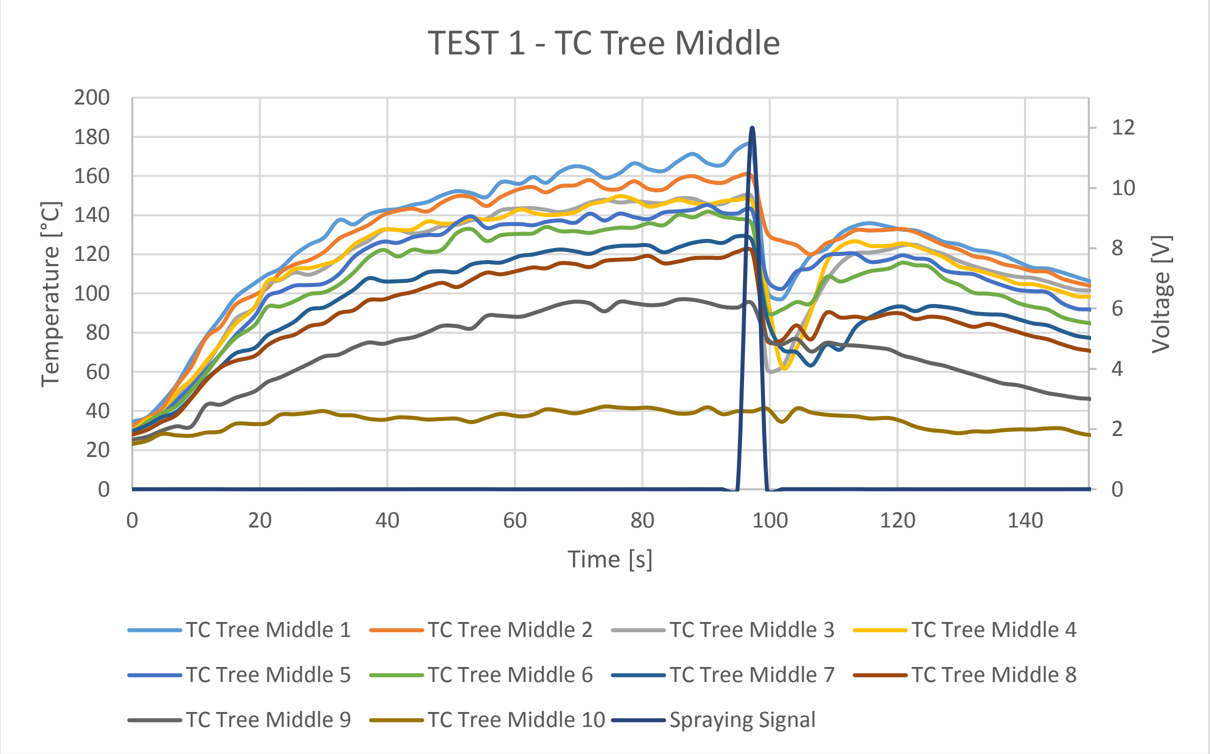
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal


TEST 1 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
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180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
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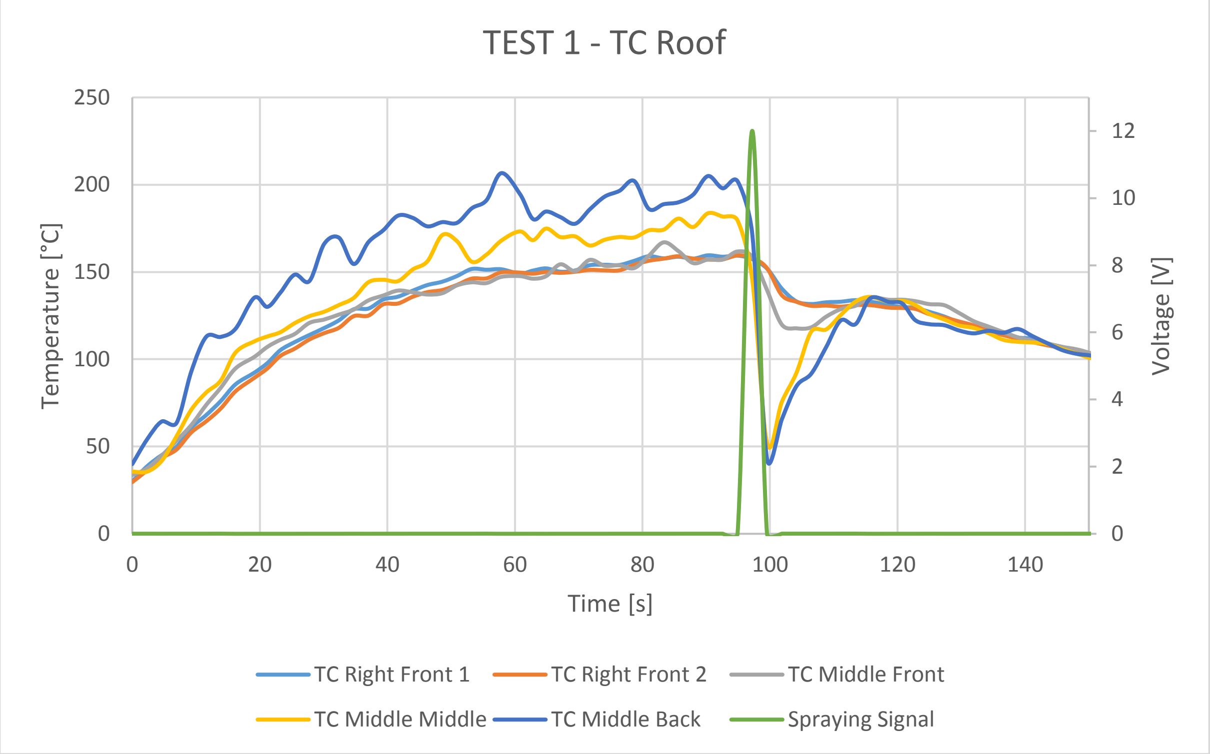
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal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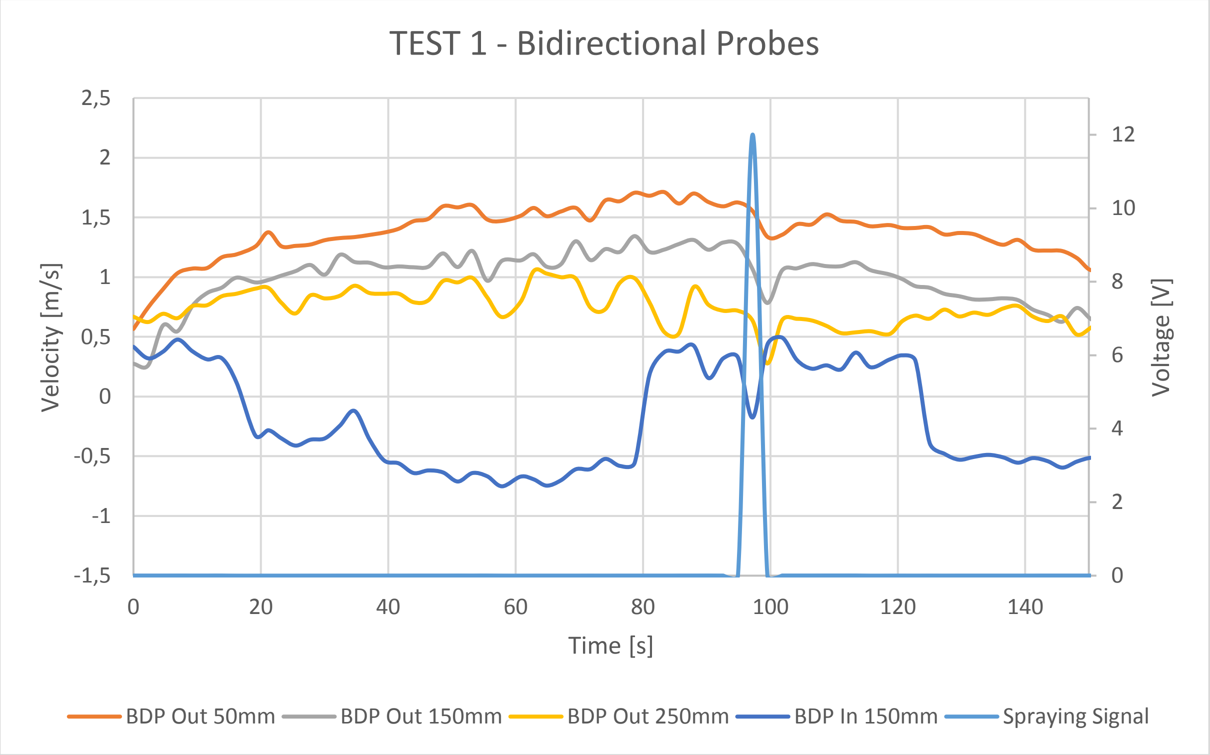
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal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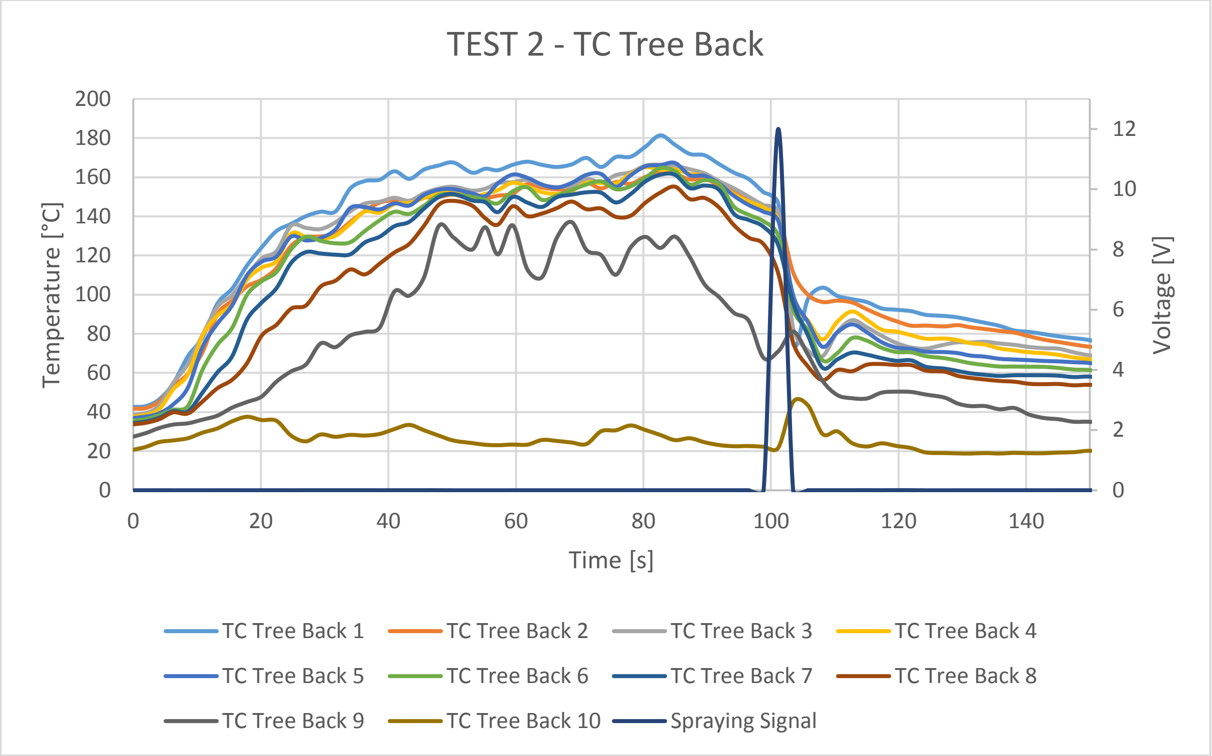
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal


TEST 2 - TC Tree Back
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Voltage [V]
Time [s]
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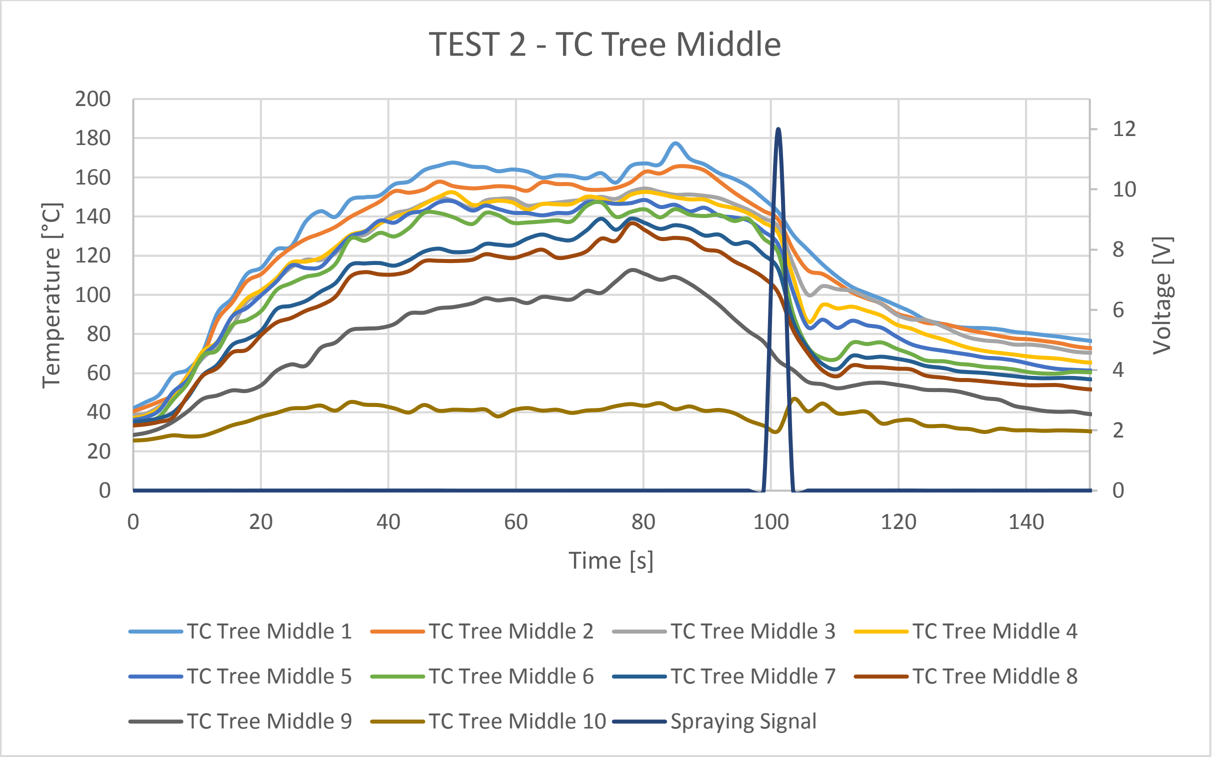
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal


TEST 2 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
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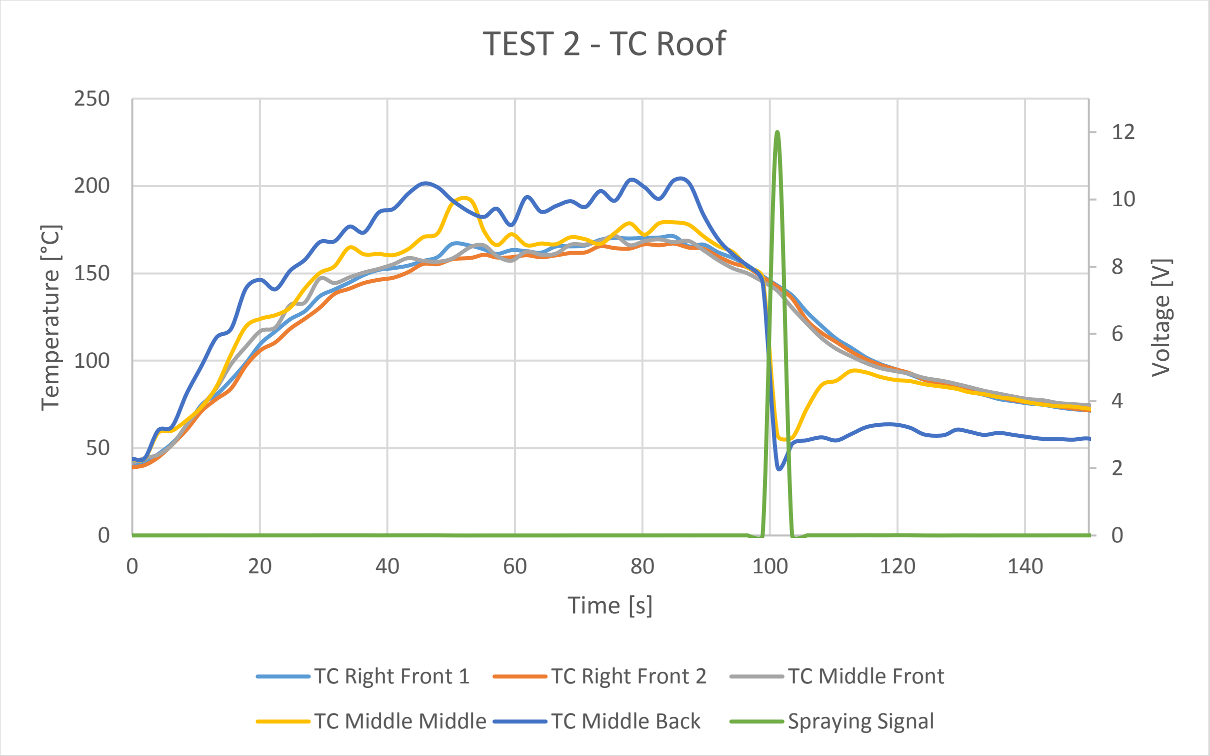
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal


TEST 2 - TC Roof
Temperature [°C]
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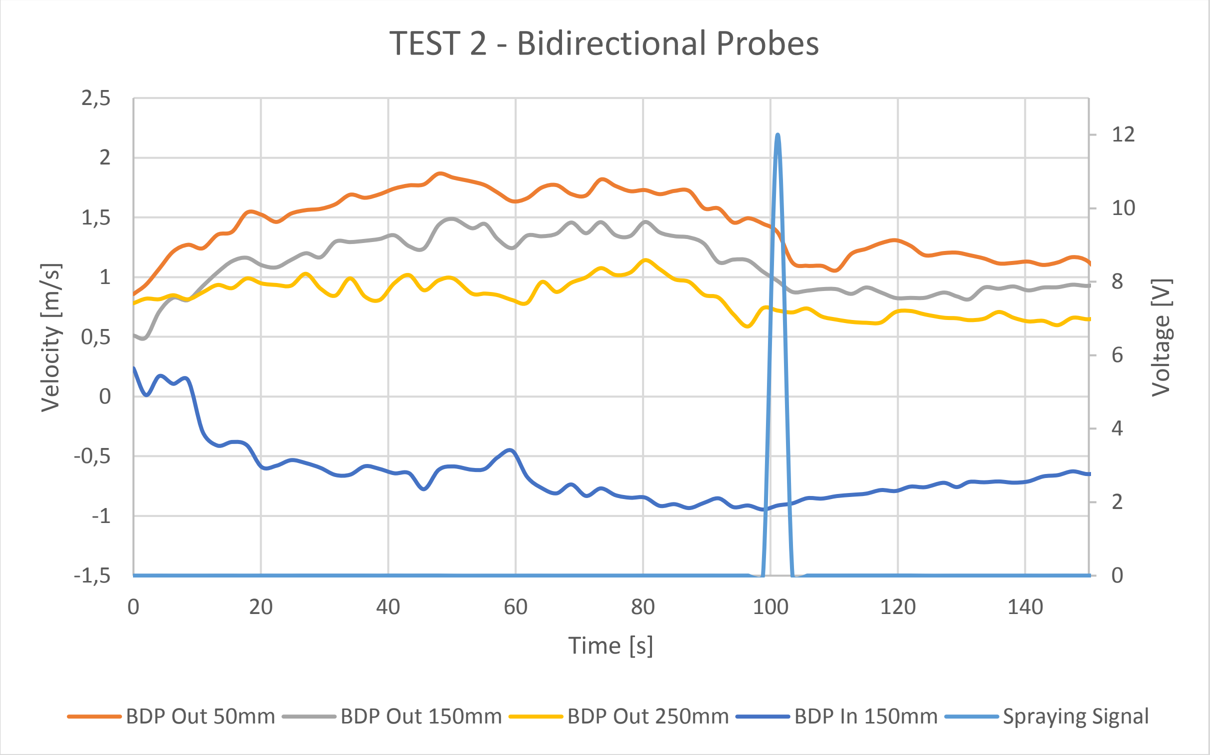
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal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Velocity [m/s]
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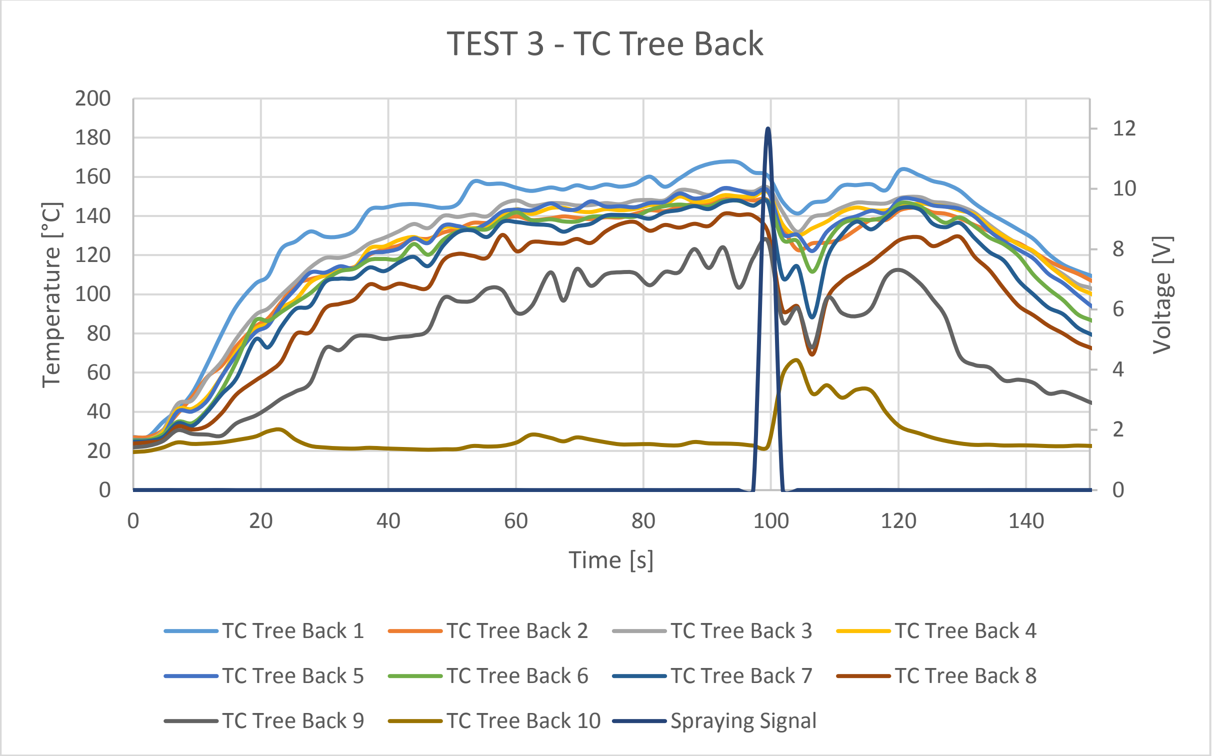
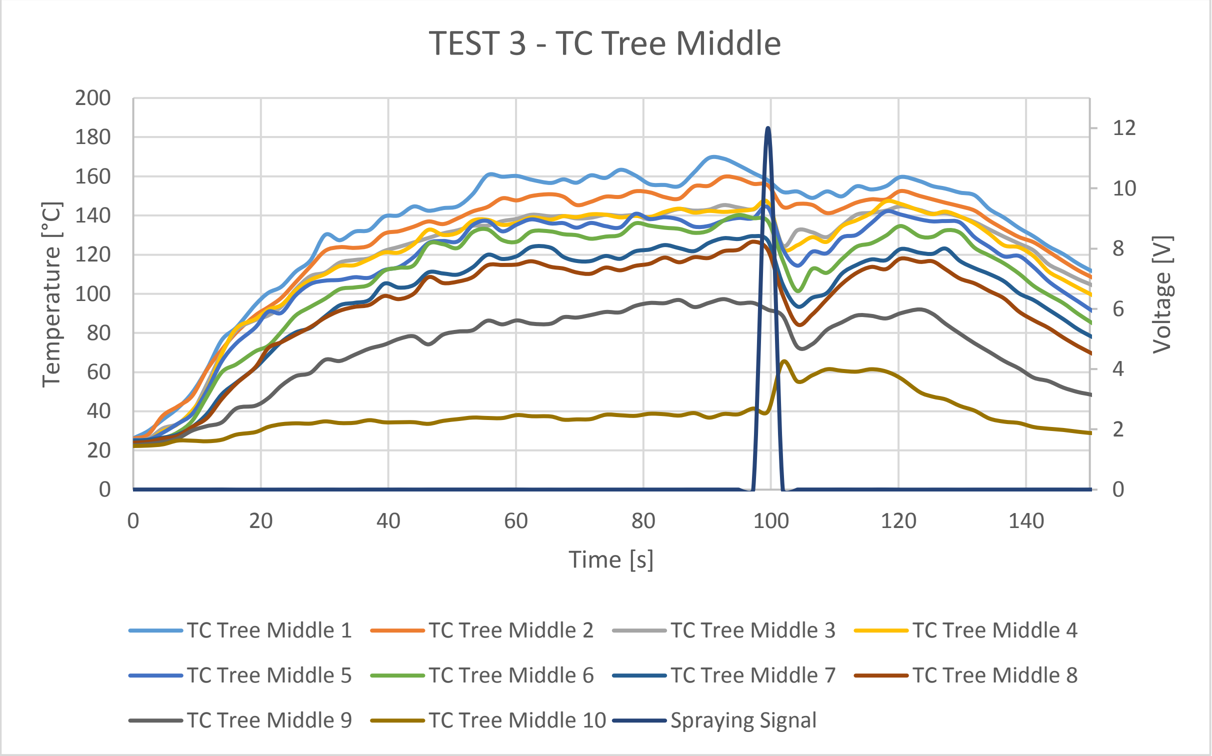
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal


TEST 3 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal


TEST 3 - TC Tree Middle
Temperature [°C]
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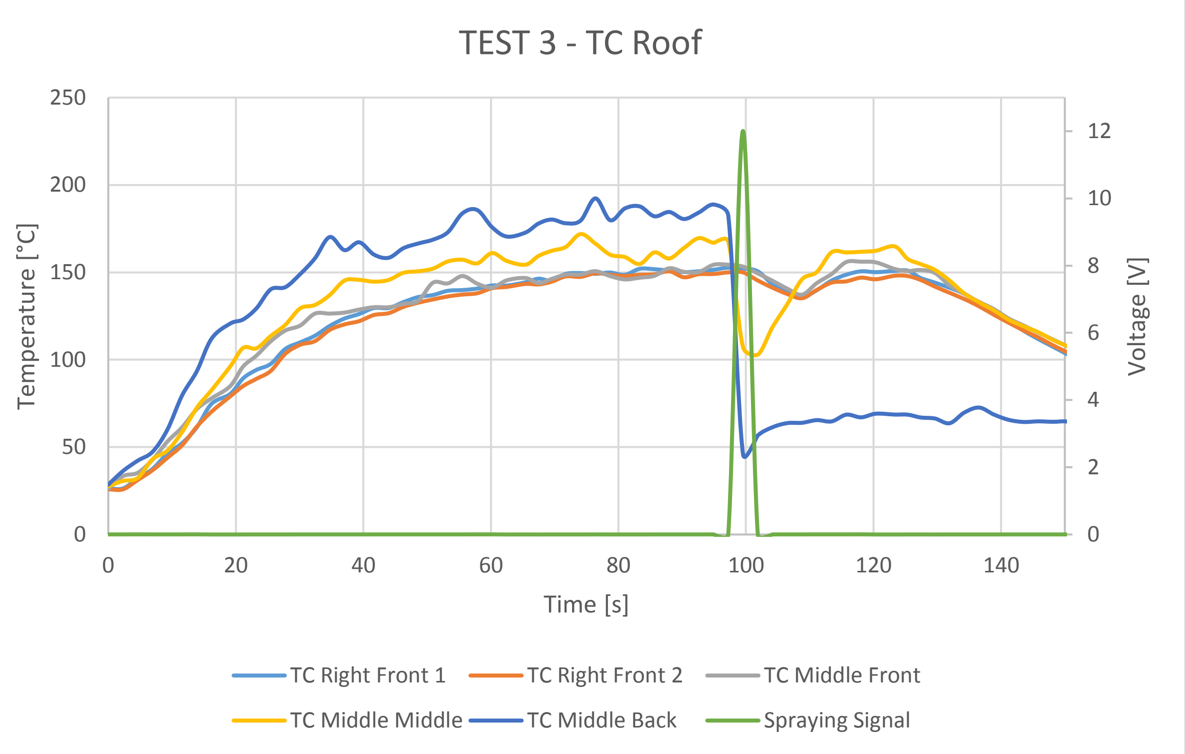
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal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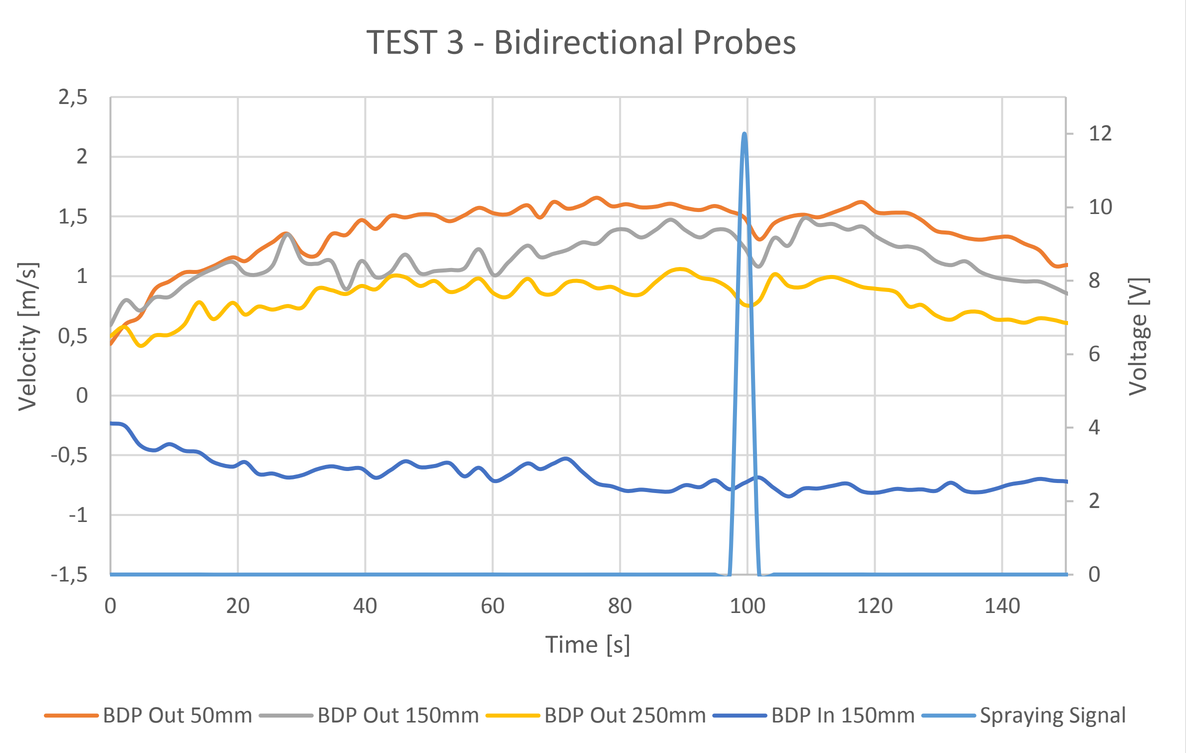
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal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Velocity [m/s]
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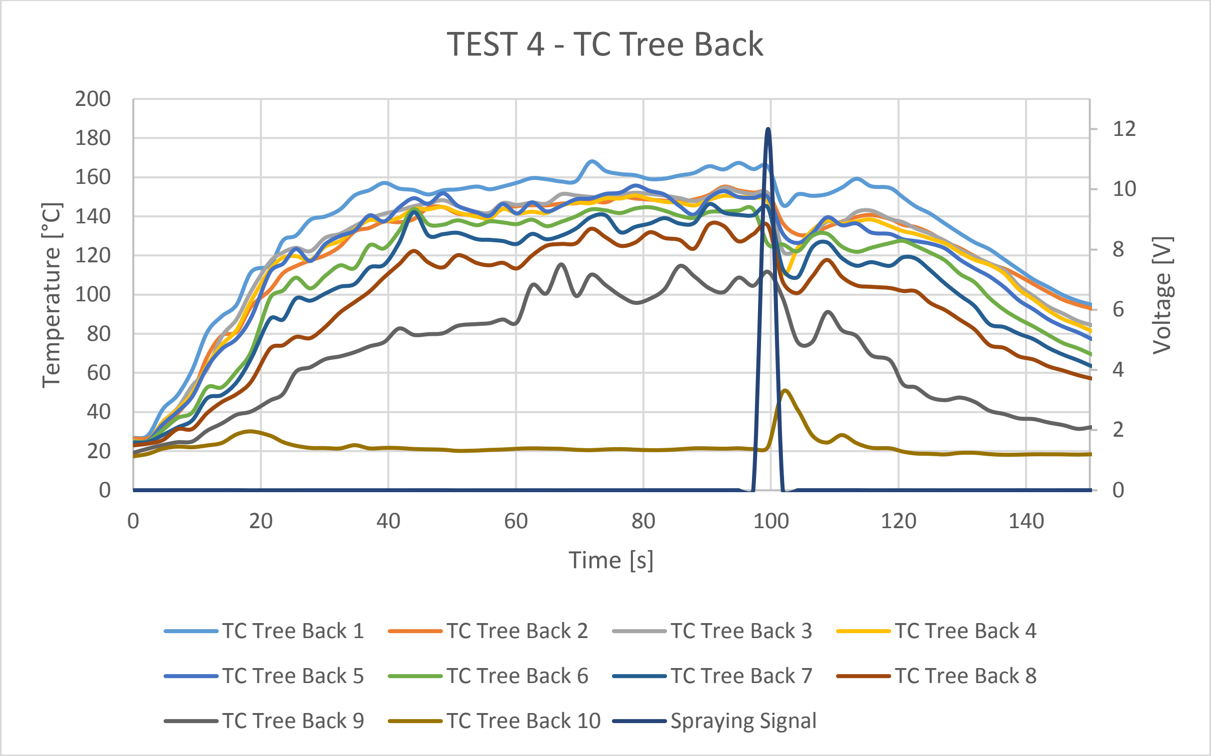
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal


TEST 4 - TC Tree Back
Temperature [°C]
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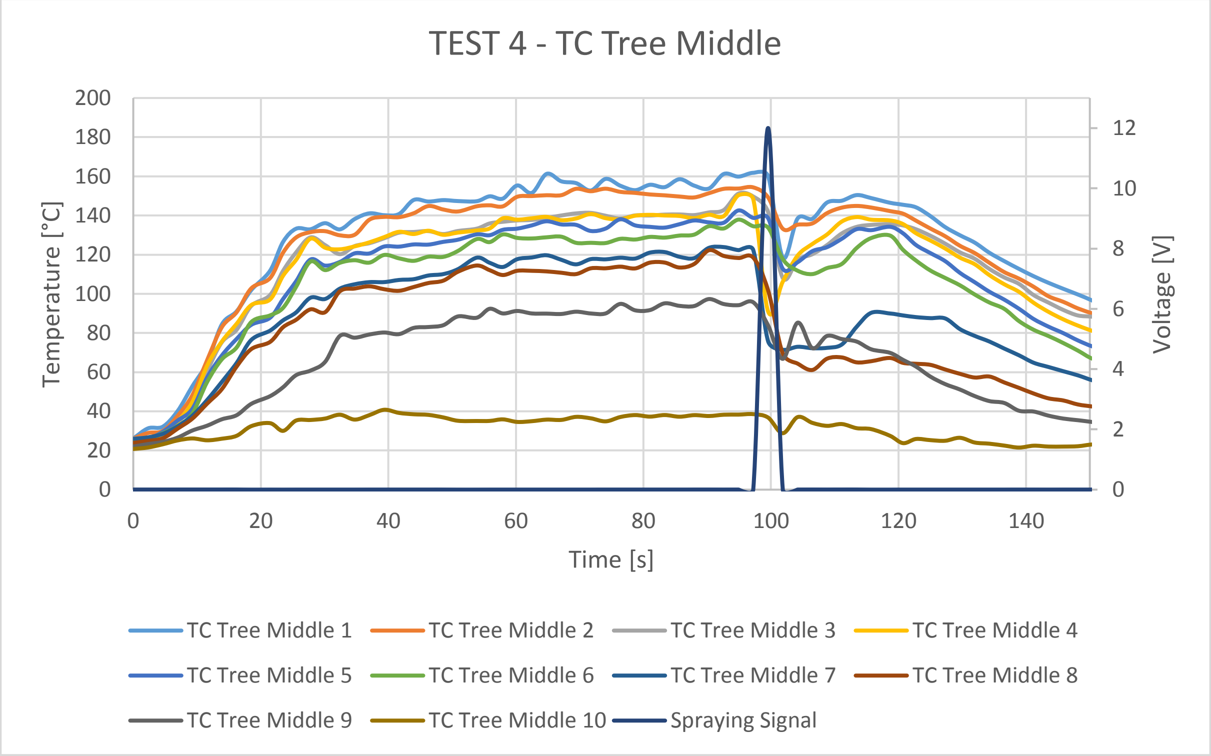
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal


TEST 4 - TC Tree Middle
Temperature [°C]
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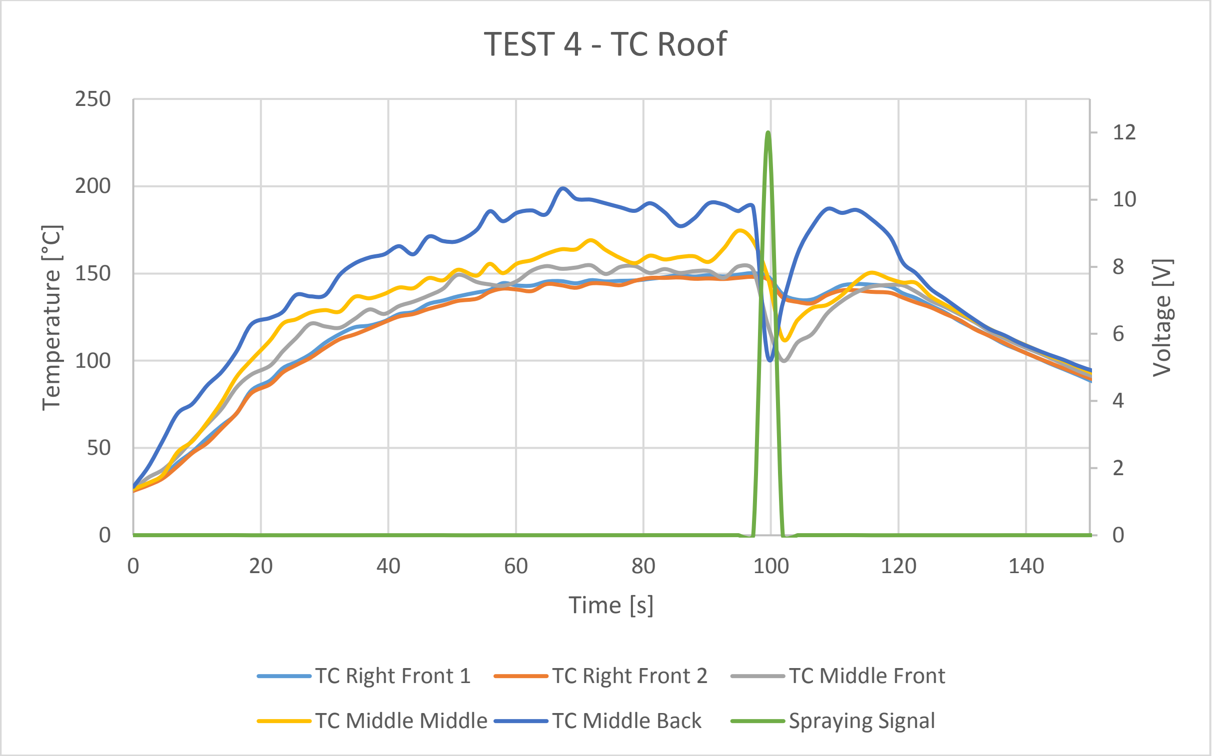
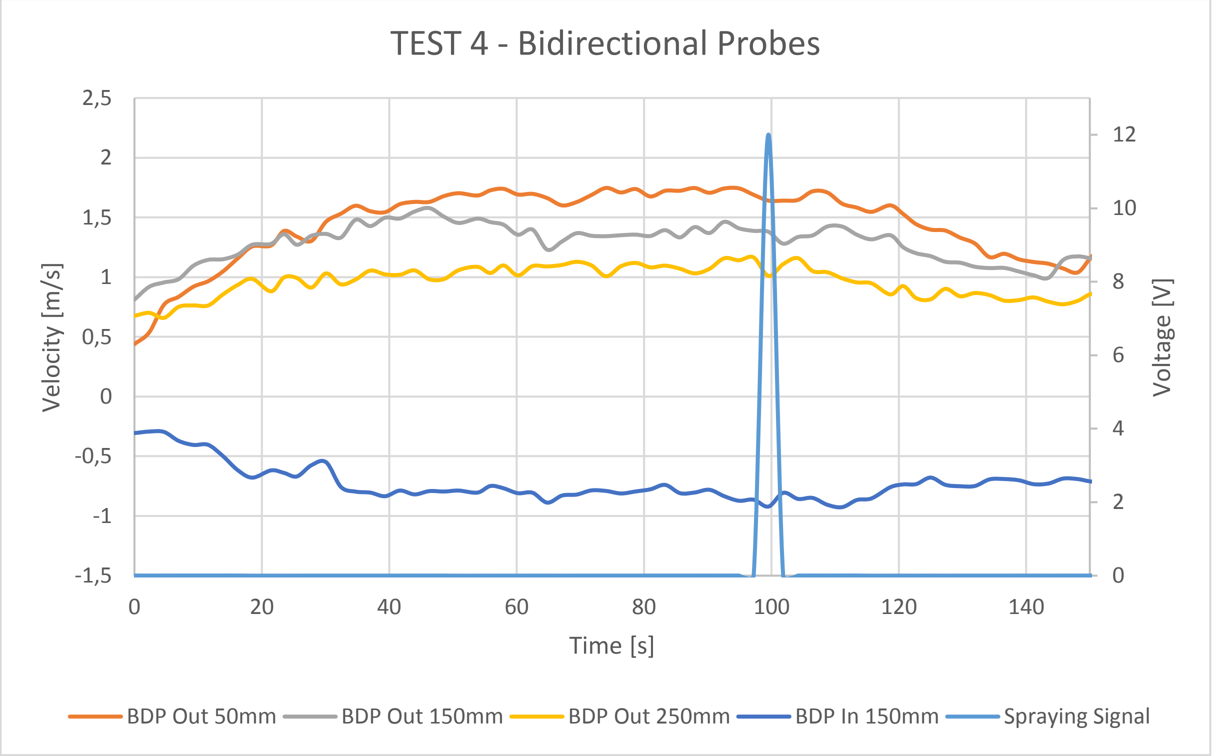
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal


TEST 4 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal


TEST 4 - Bidirectional Probes
Velocity [m/s]
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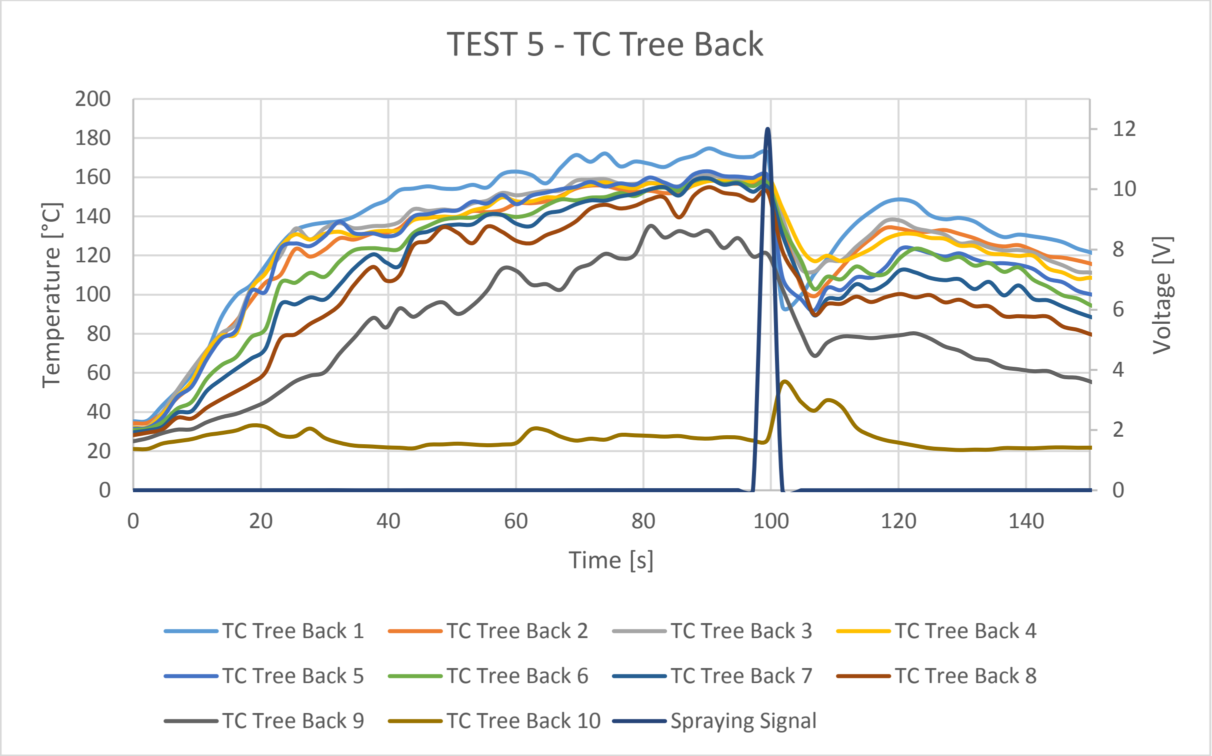
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal


TEST 5 - TC Tree Back
Temperature [°C]
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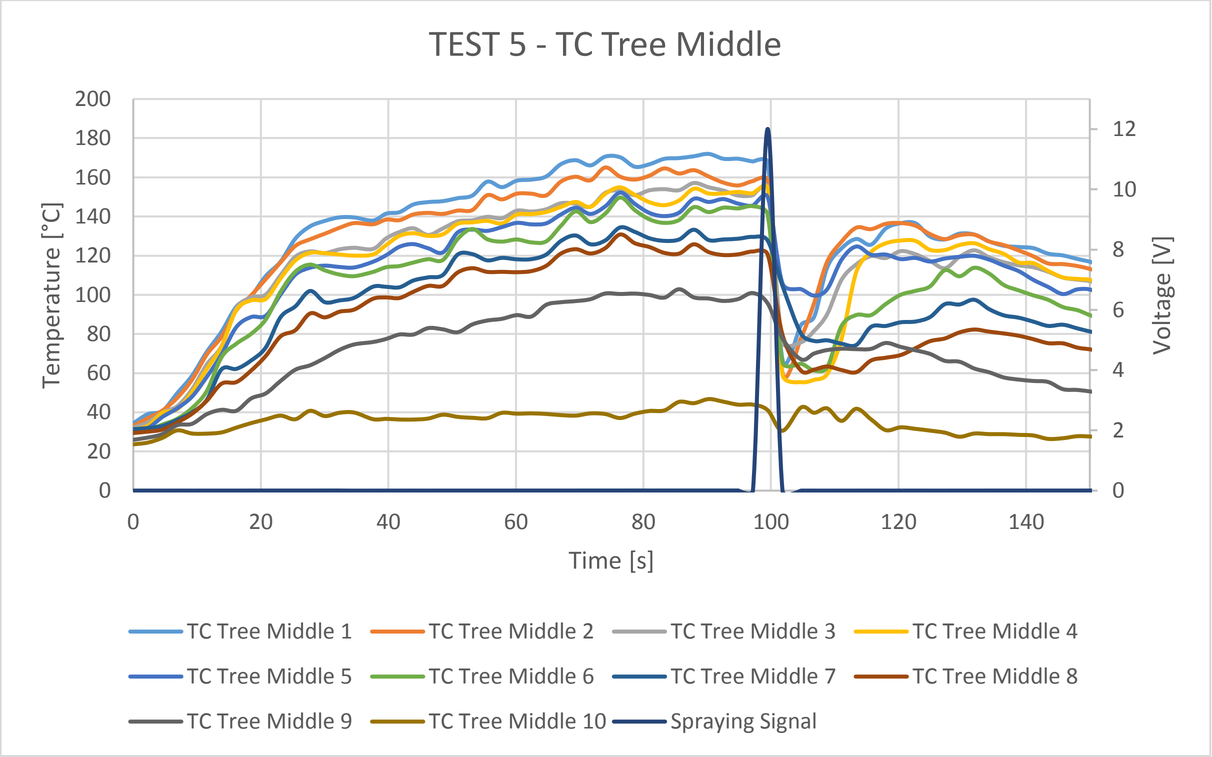
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal


TEST 5 - TC Tree Middle
Temperature [°C]
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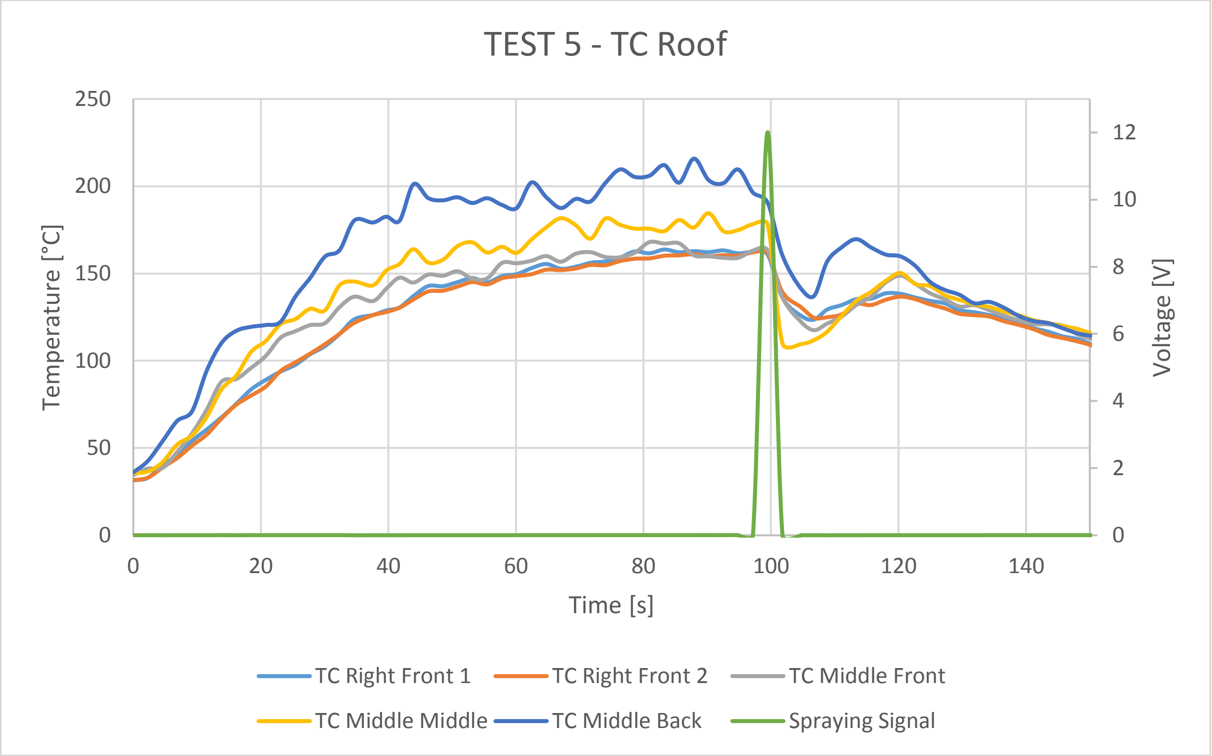
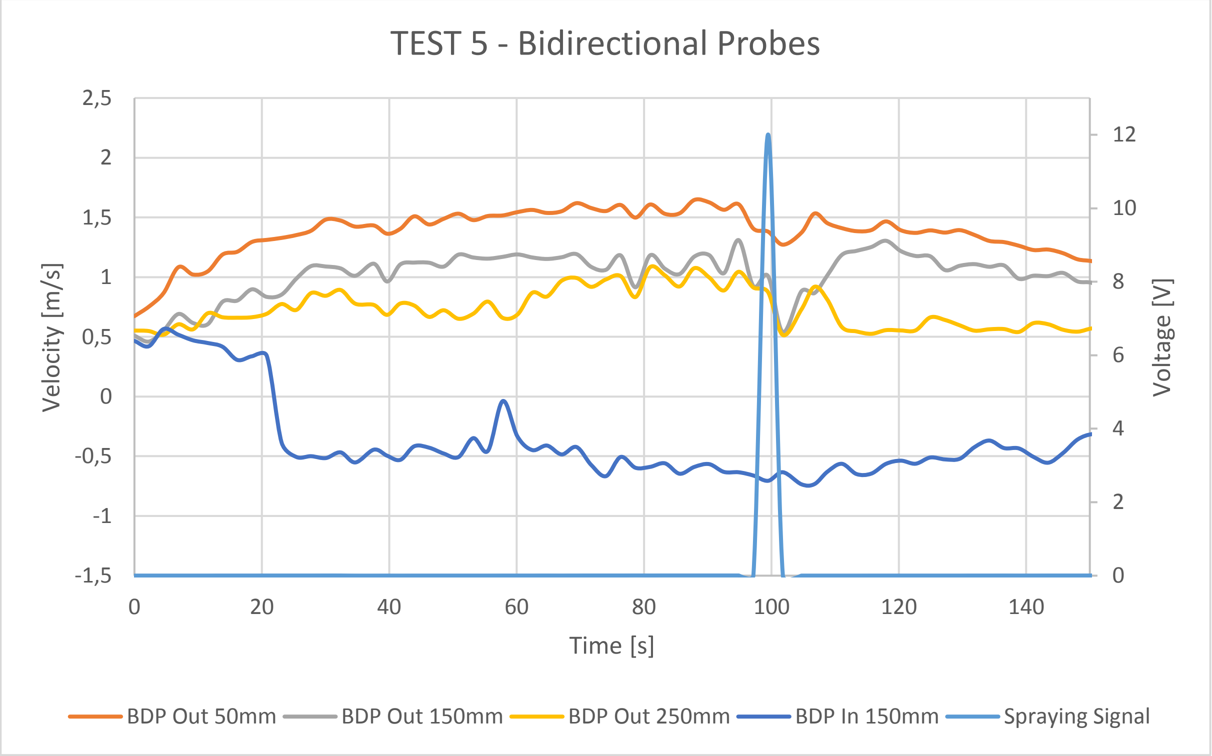
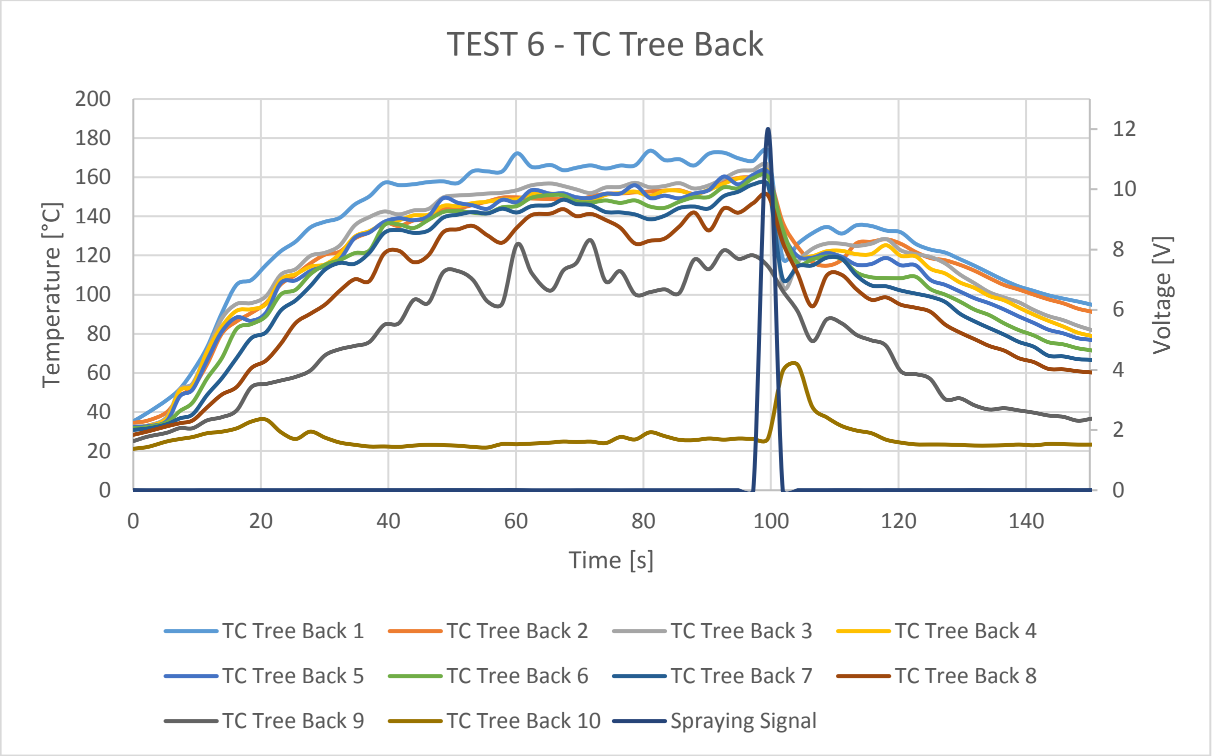
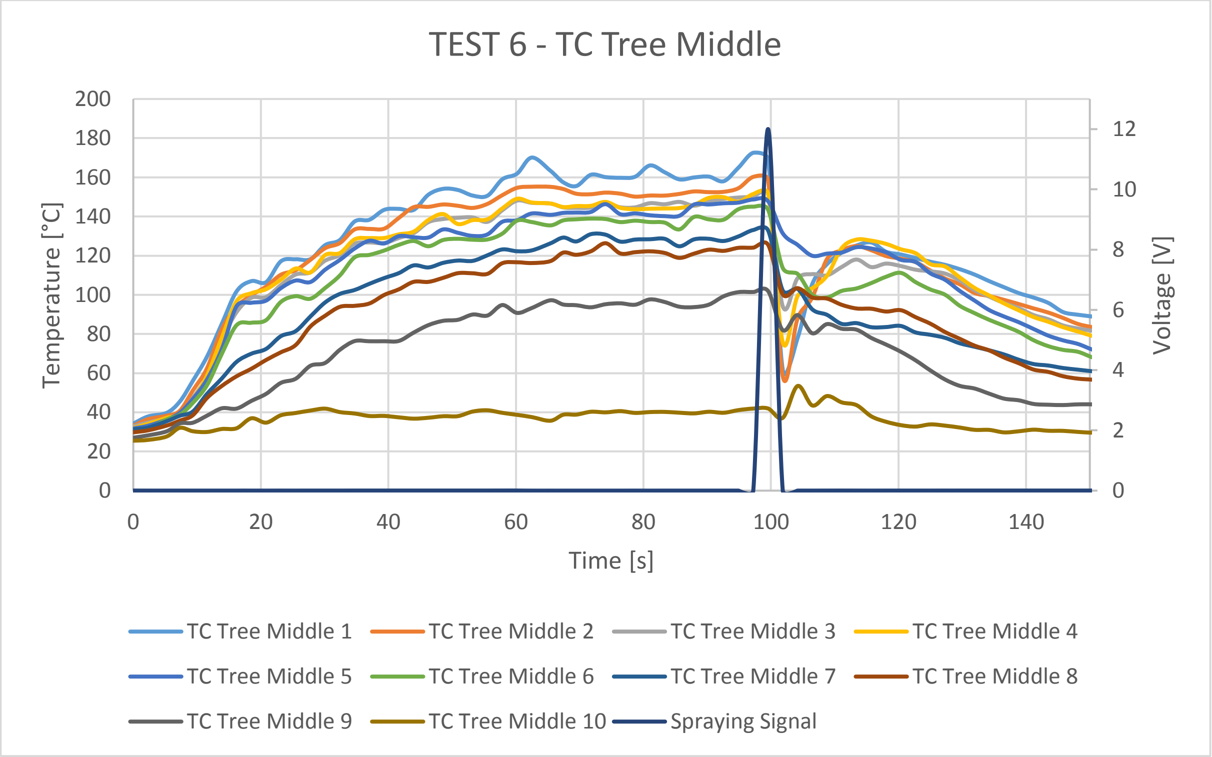
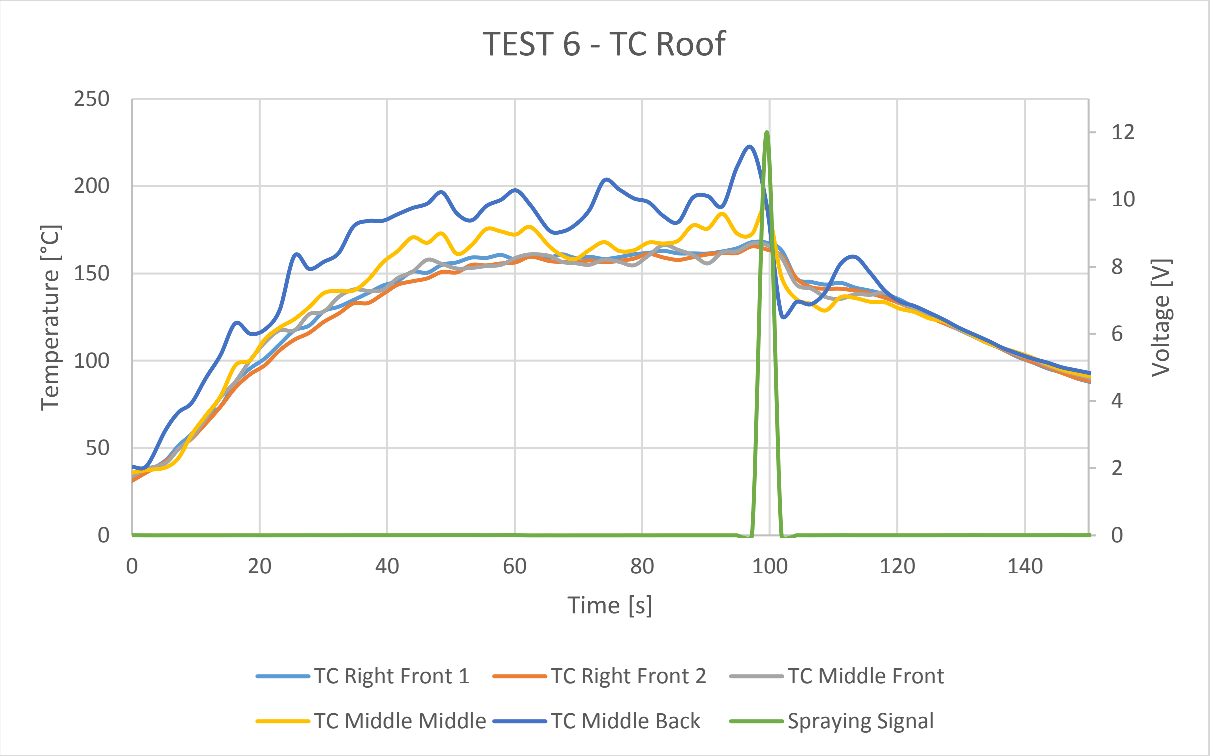
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

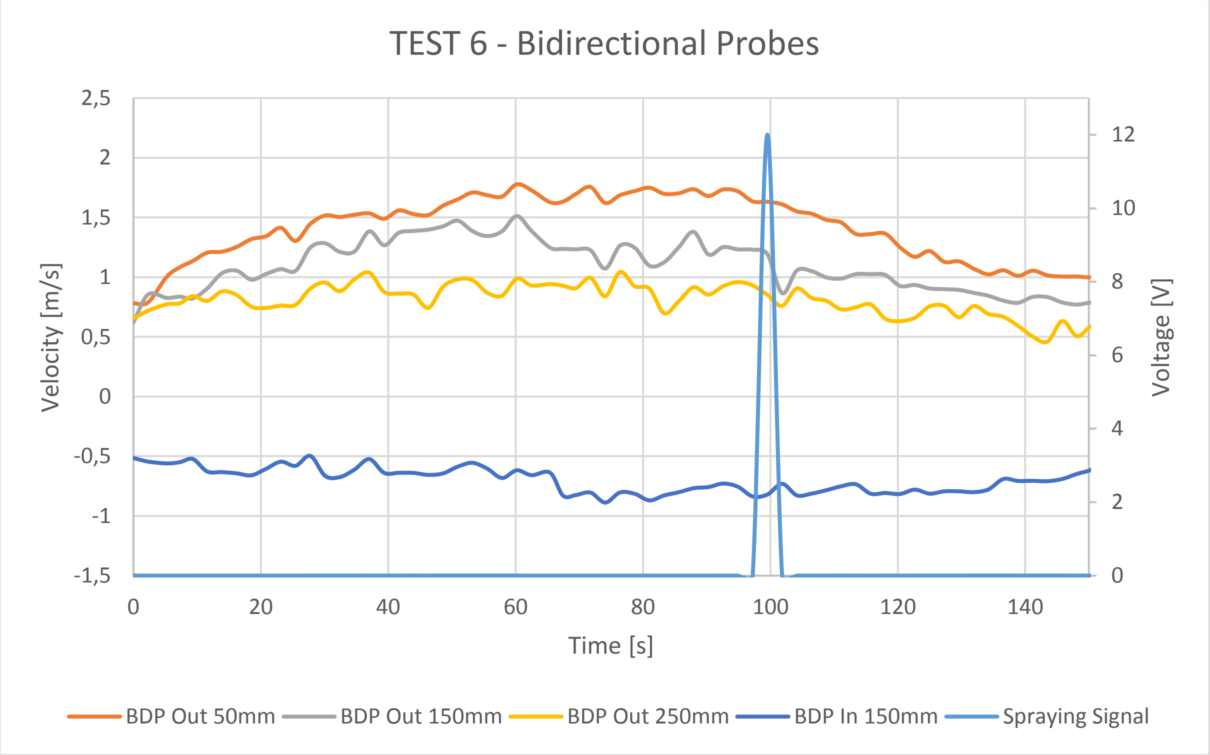

TEST 5 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

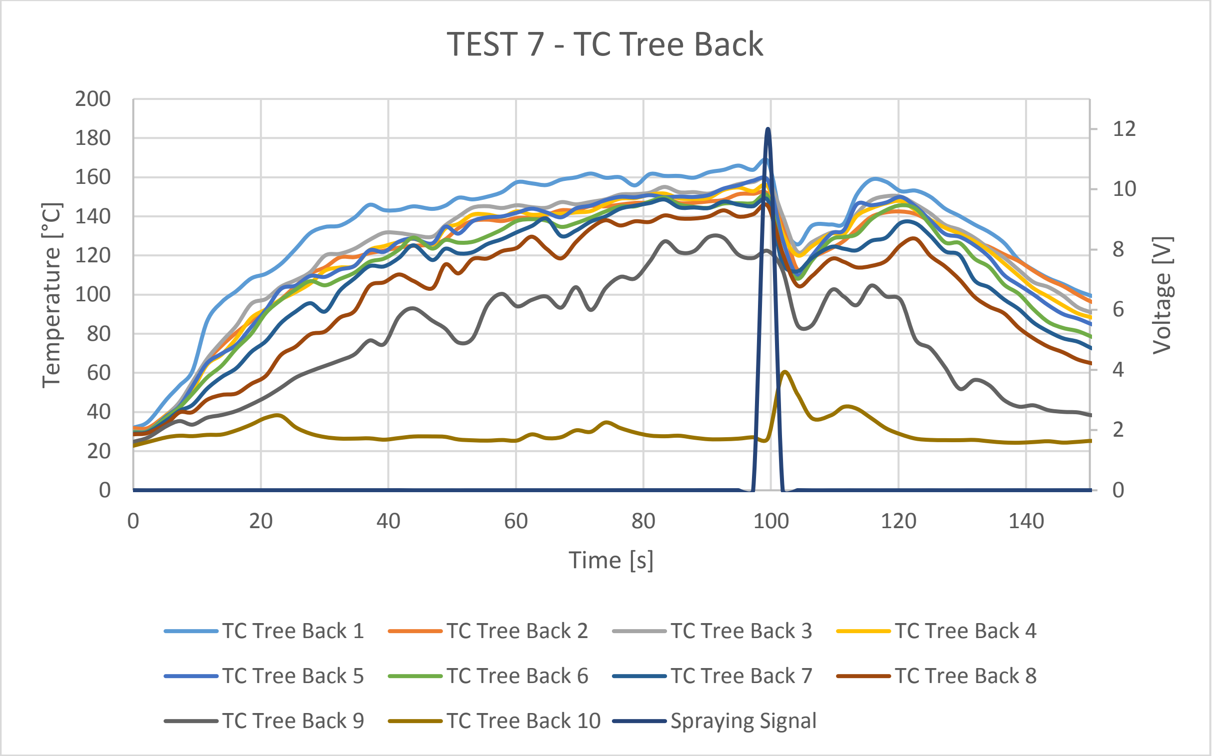

TEST 5 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

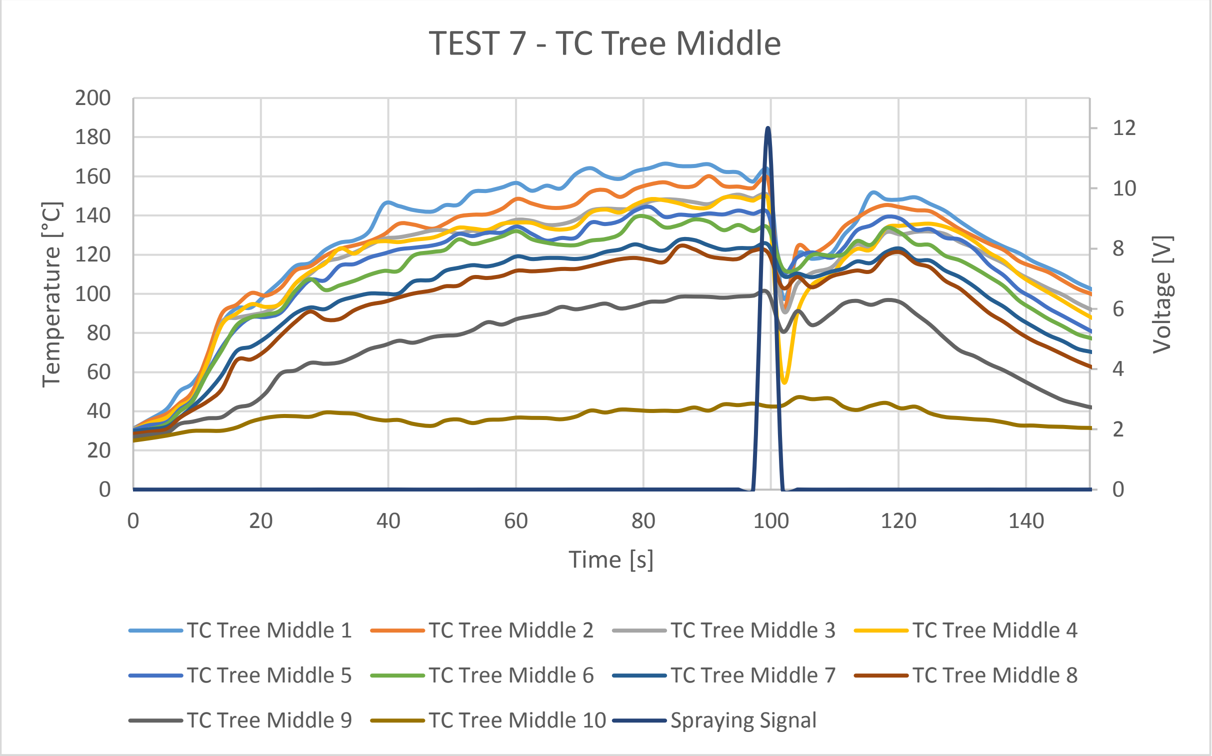

TEST 6 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

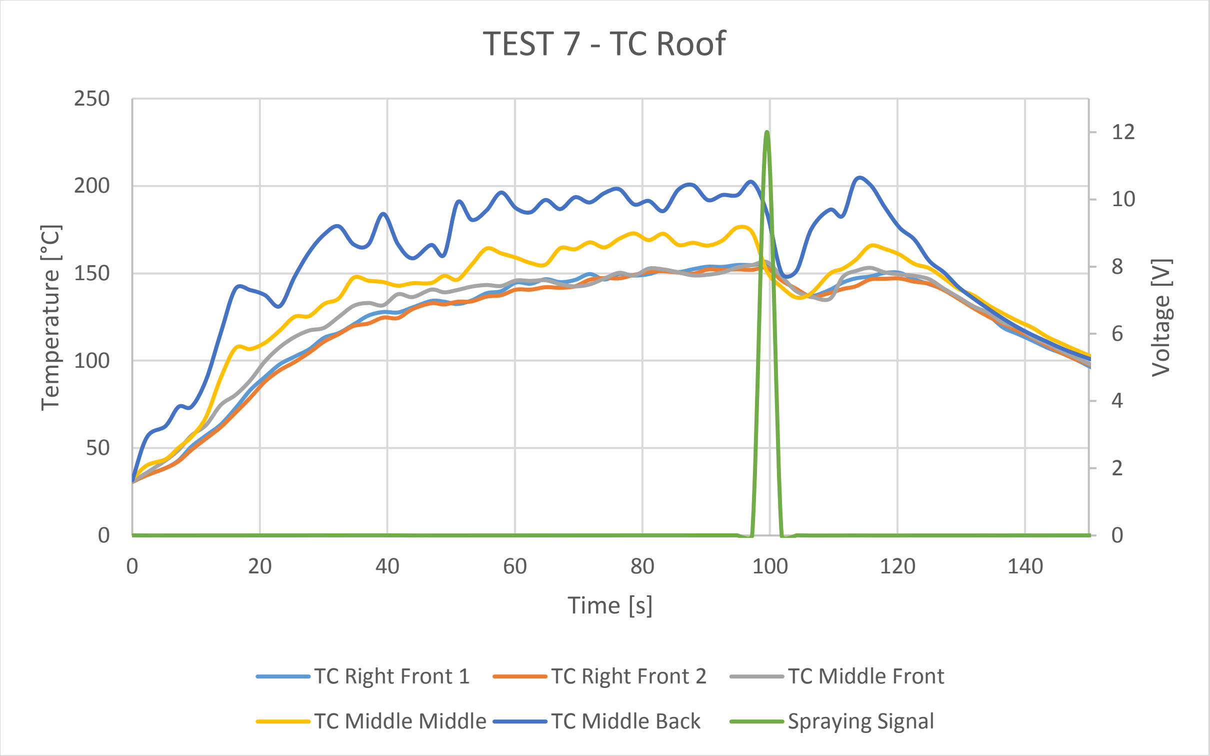

TEST 6 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

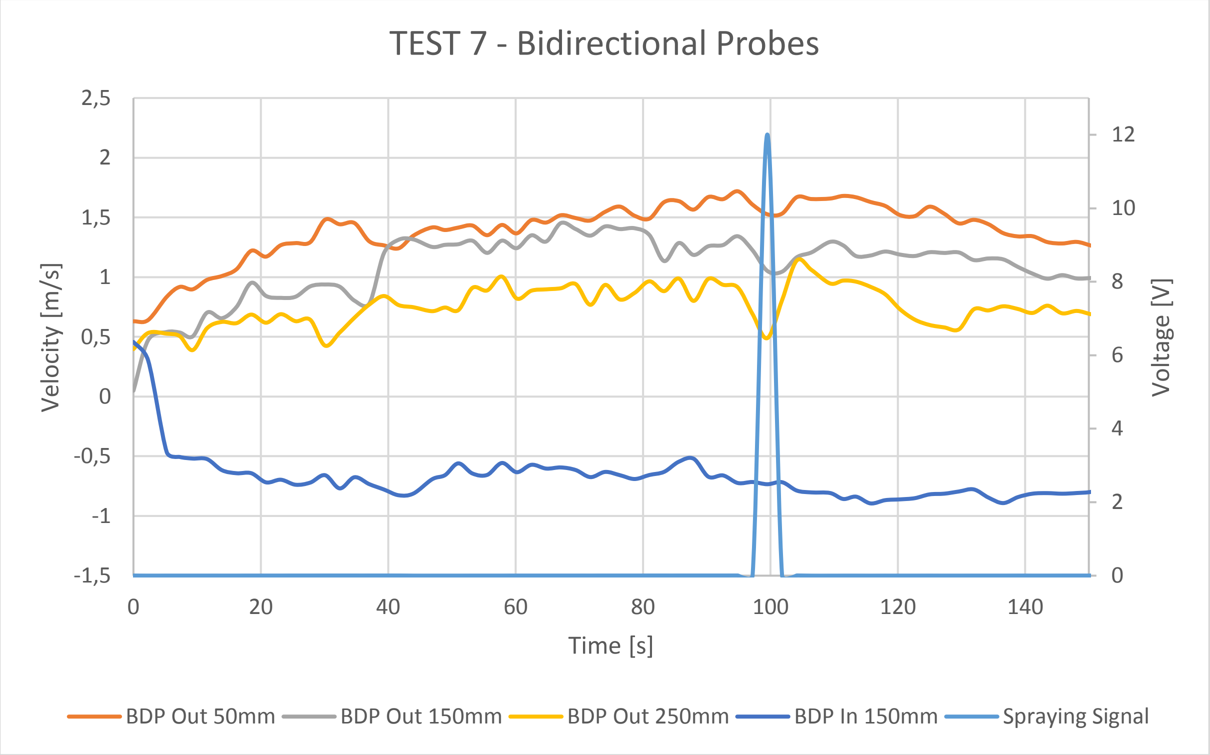

TEST 6 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

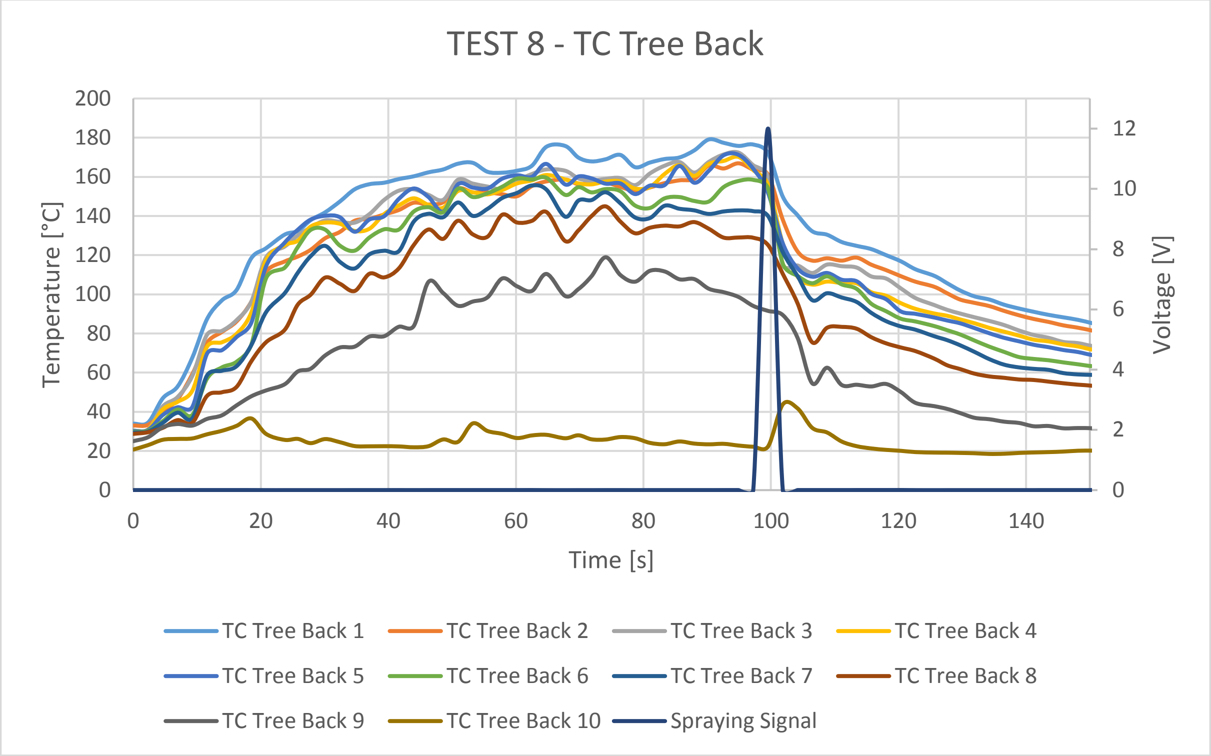

TEST 6 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

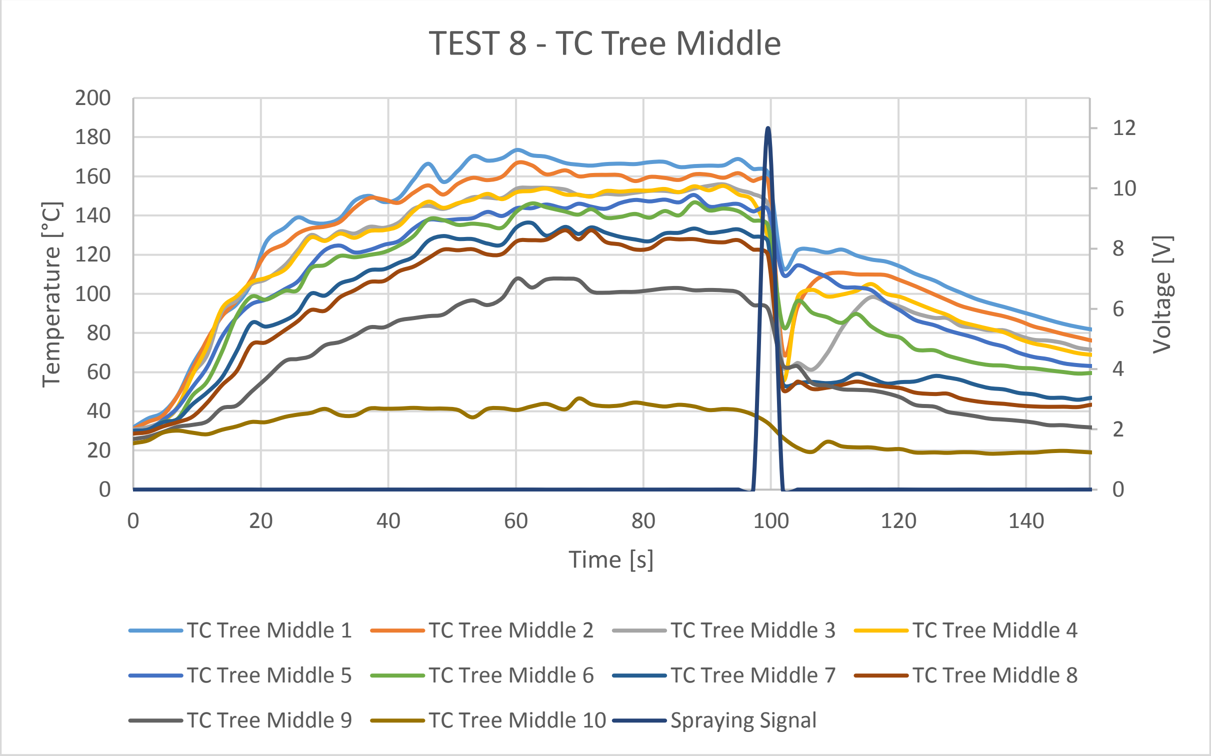

TEST 7 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Time [s]
0
20
40
60
80
100
120
140
Voltage [V]
12
10
8
6
4
2
0
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

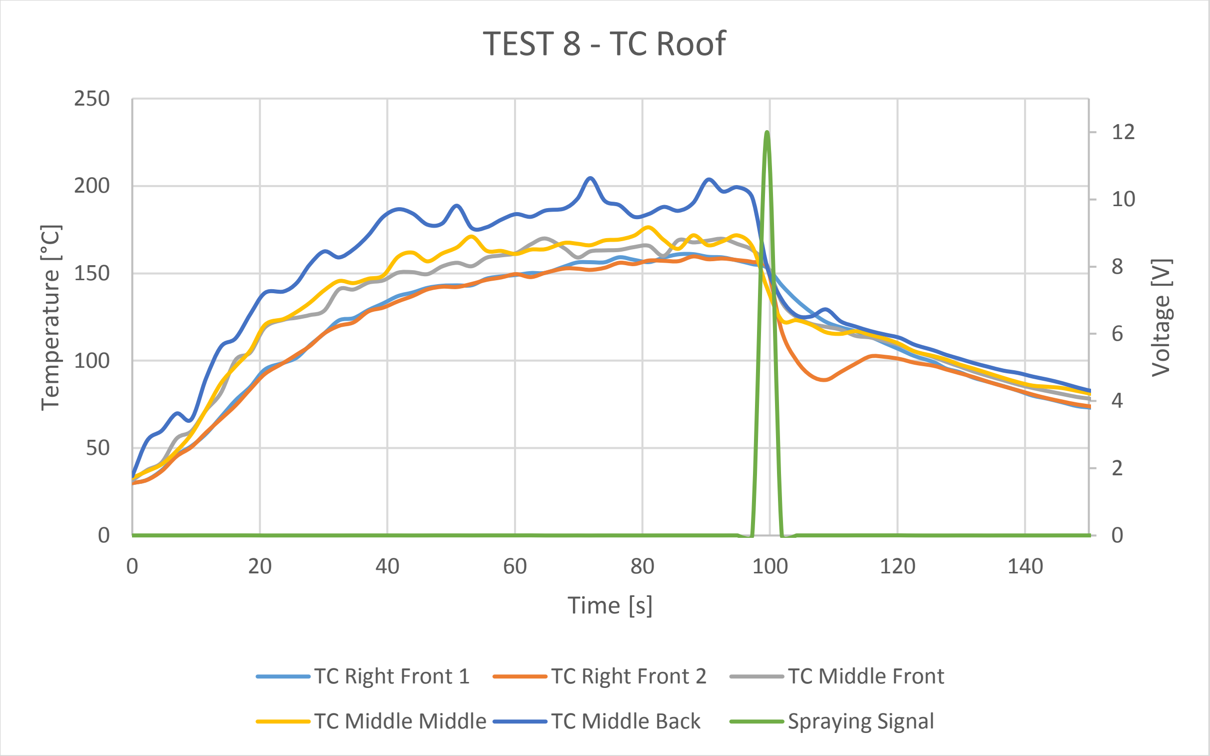

TEST 7 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Time [s]
0
20
40
60
80
100
120
140
Voltage [V]
12
10
8
6
4
2
0
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

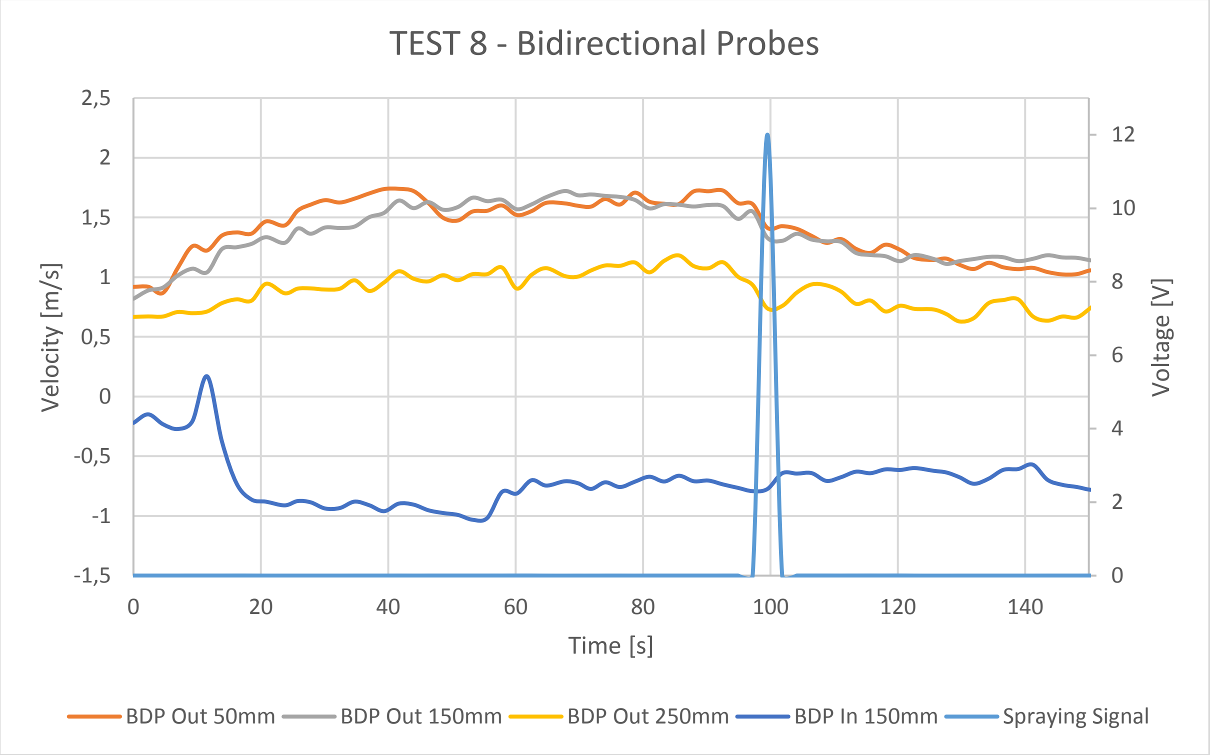

TEST 7 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

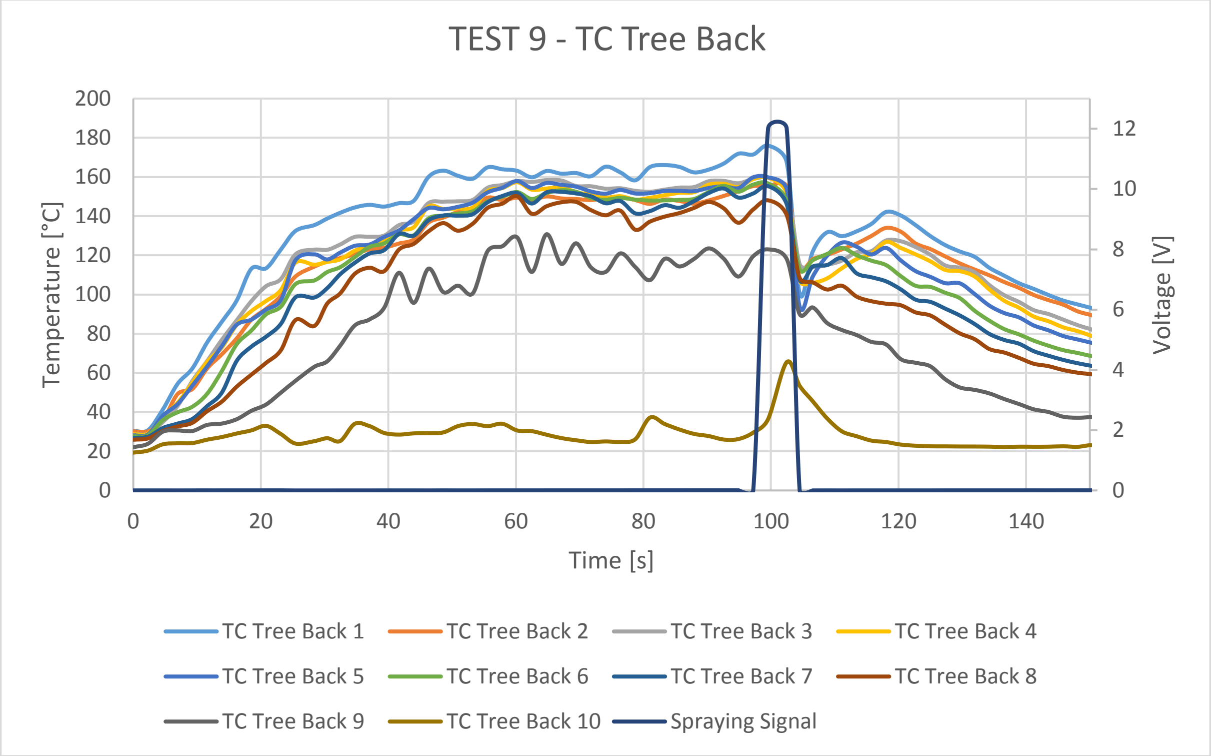

TEST 7 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

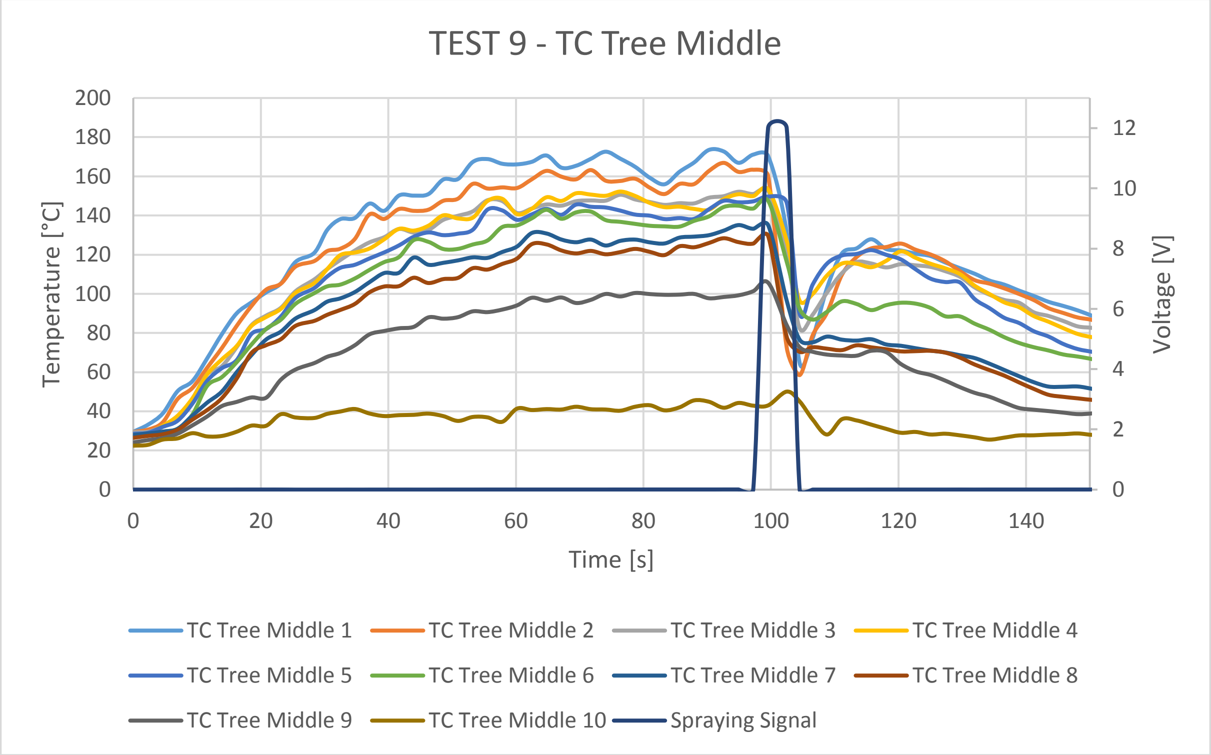

TEST 8 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

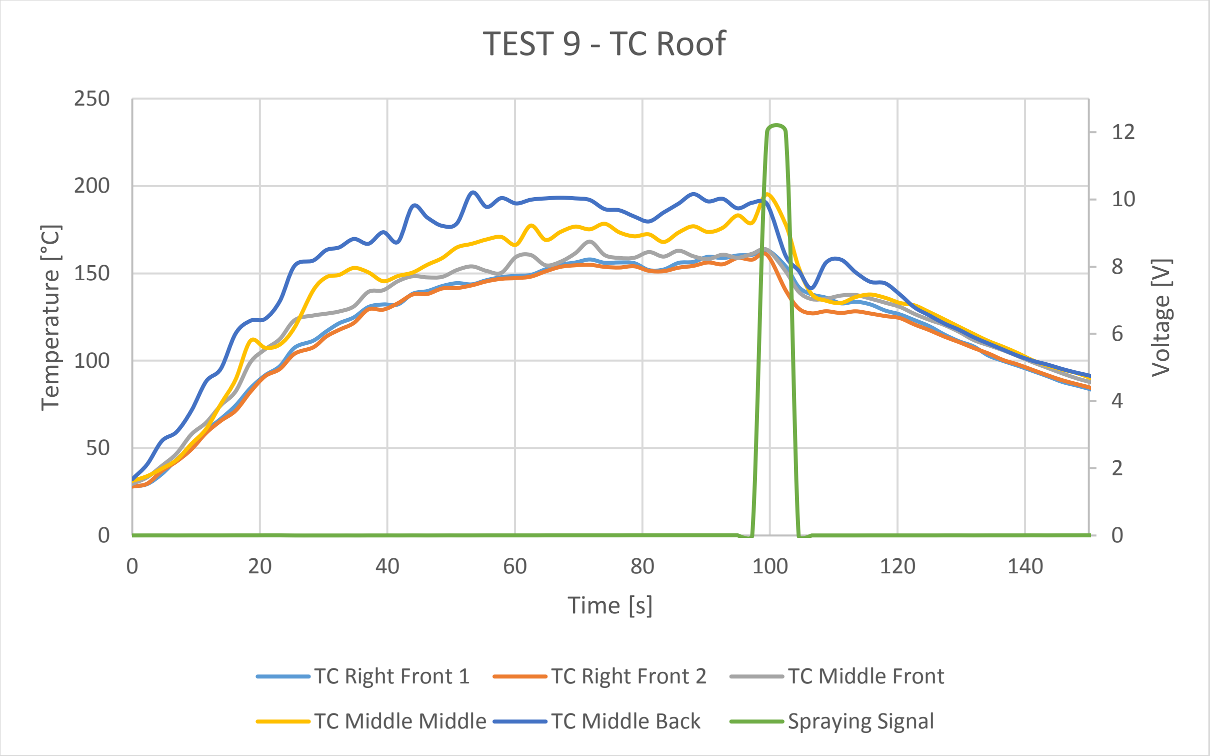

TEST 8 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

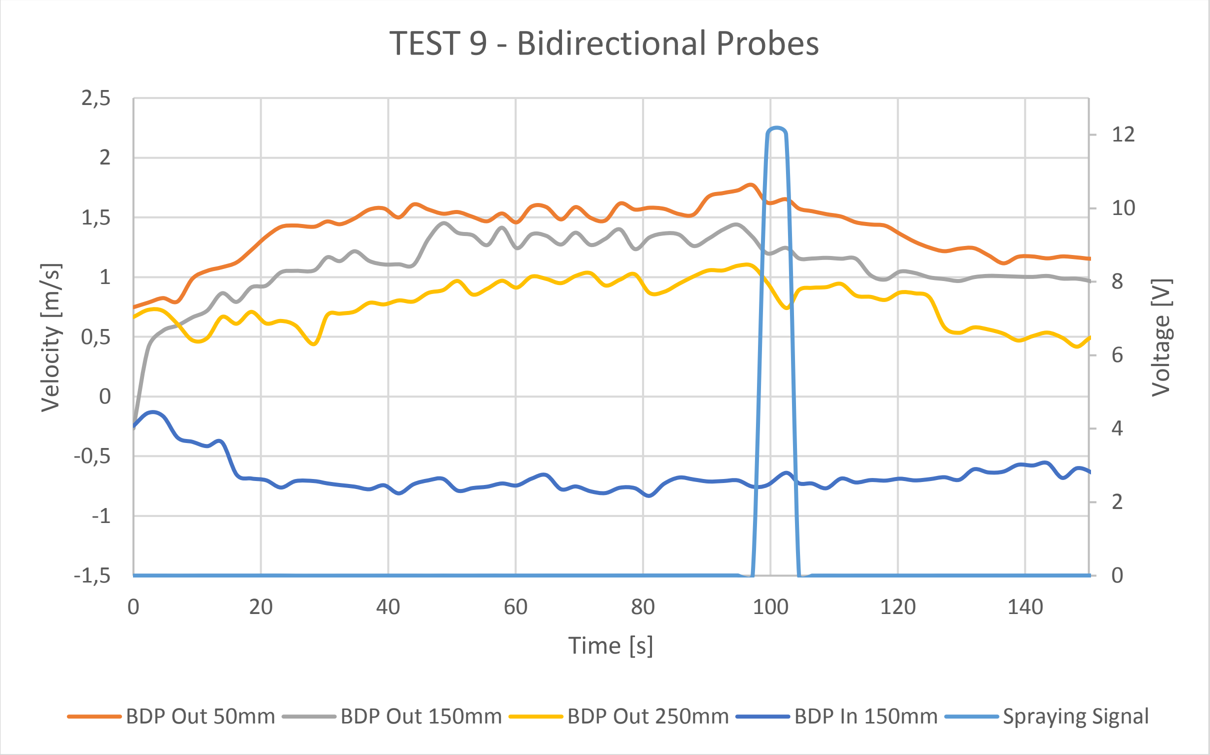

TEST 8 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

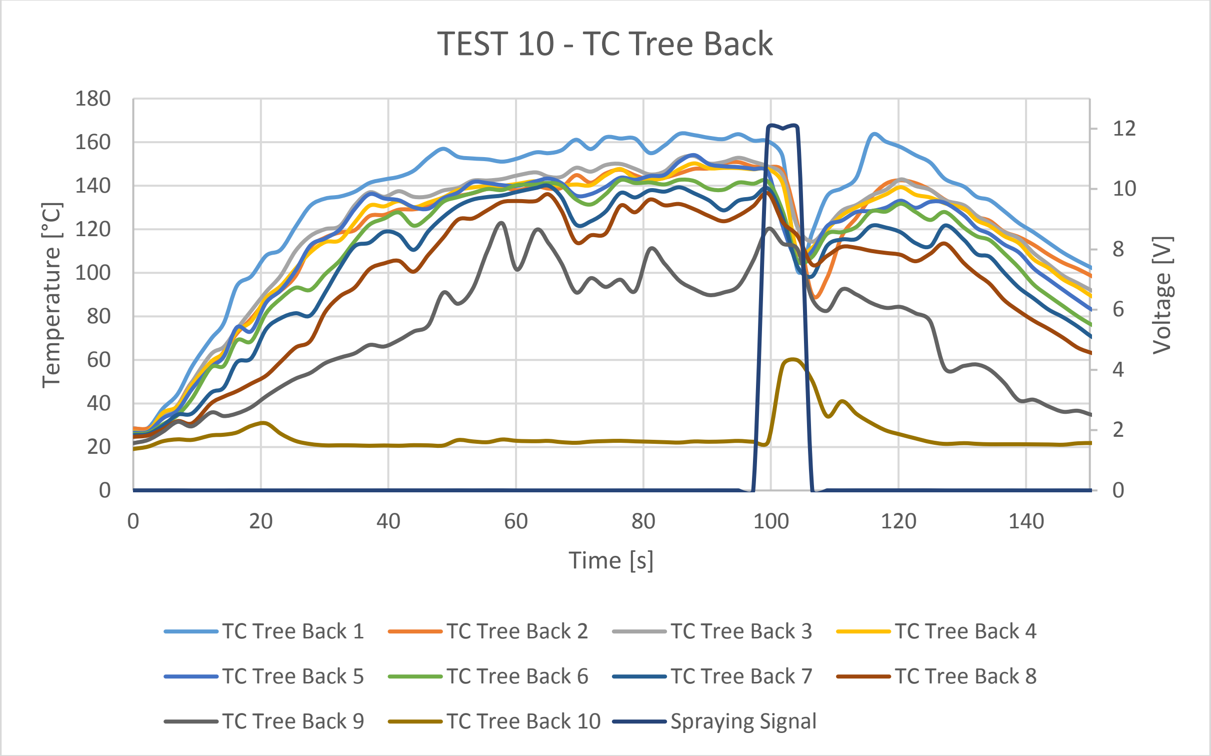

TEST 8 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

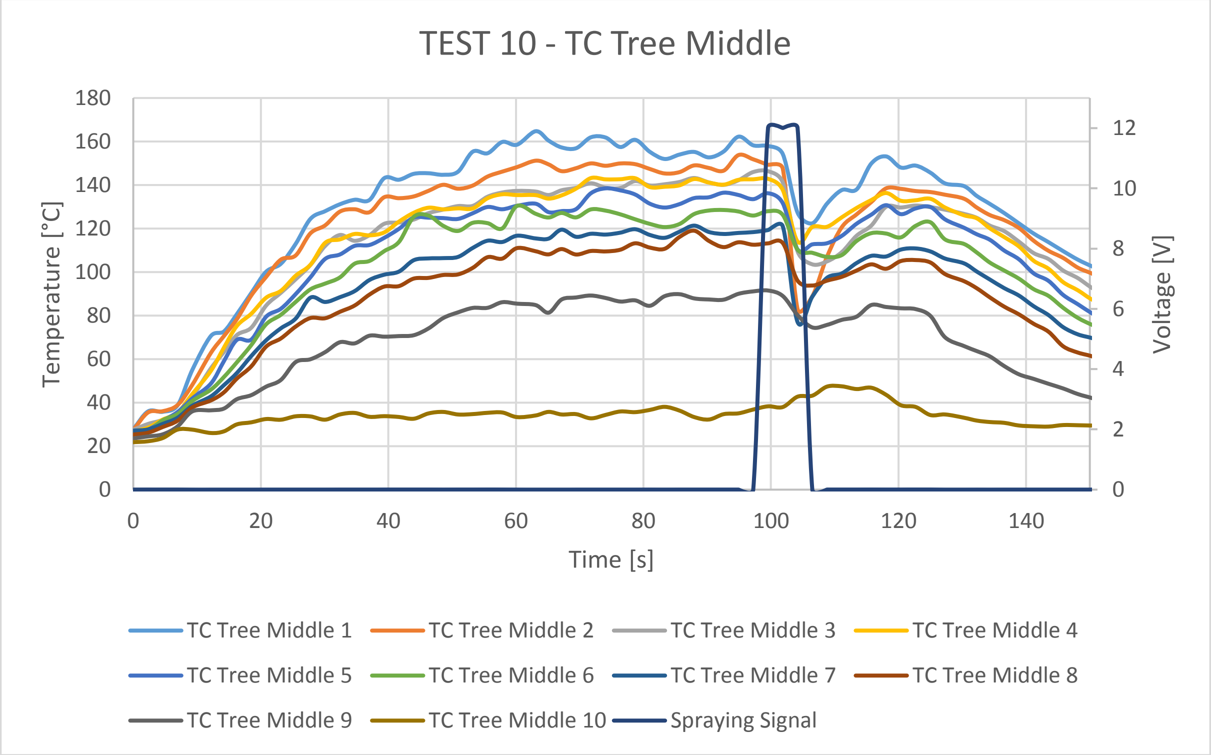

TEST 9 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

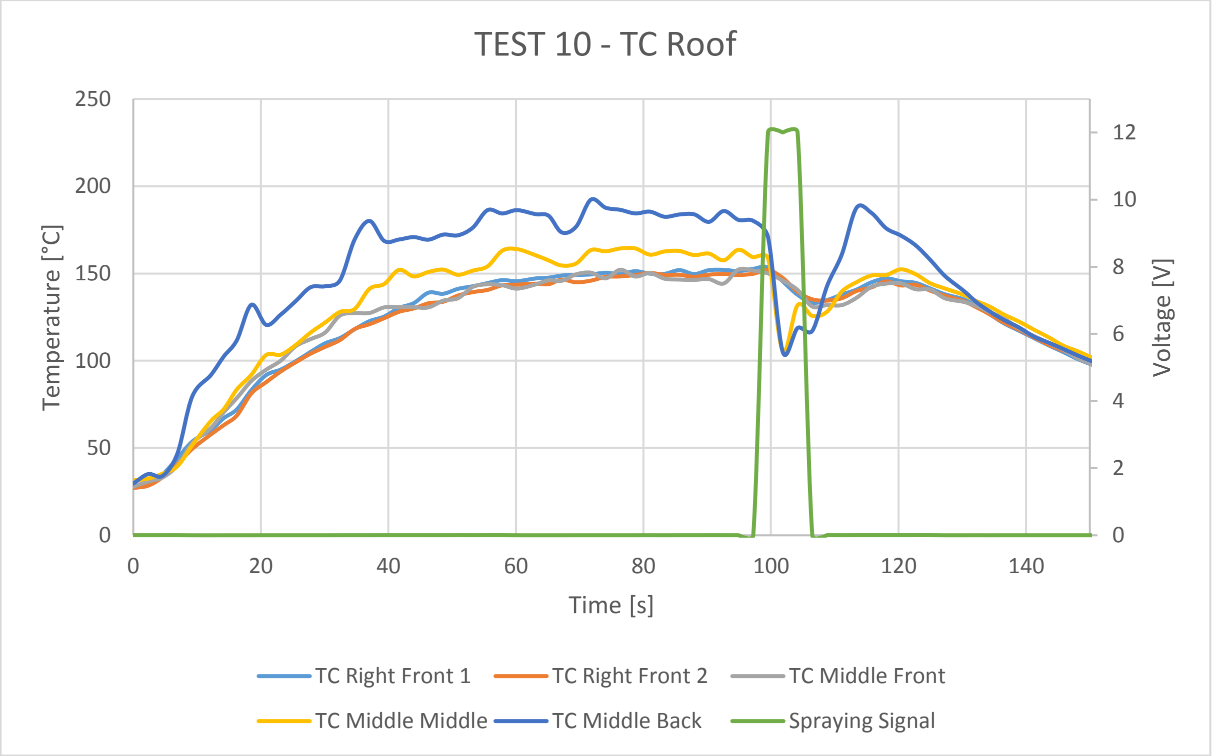

TEST 9 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

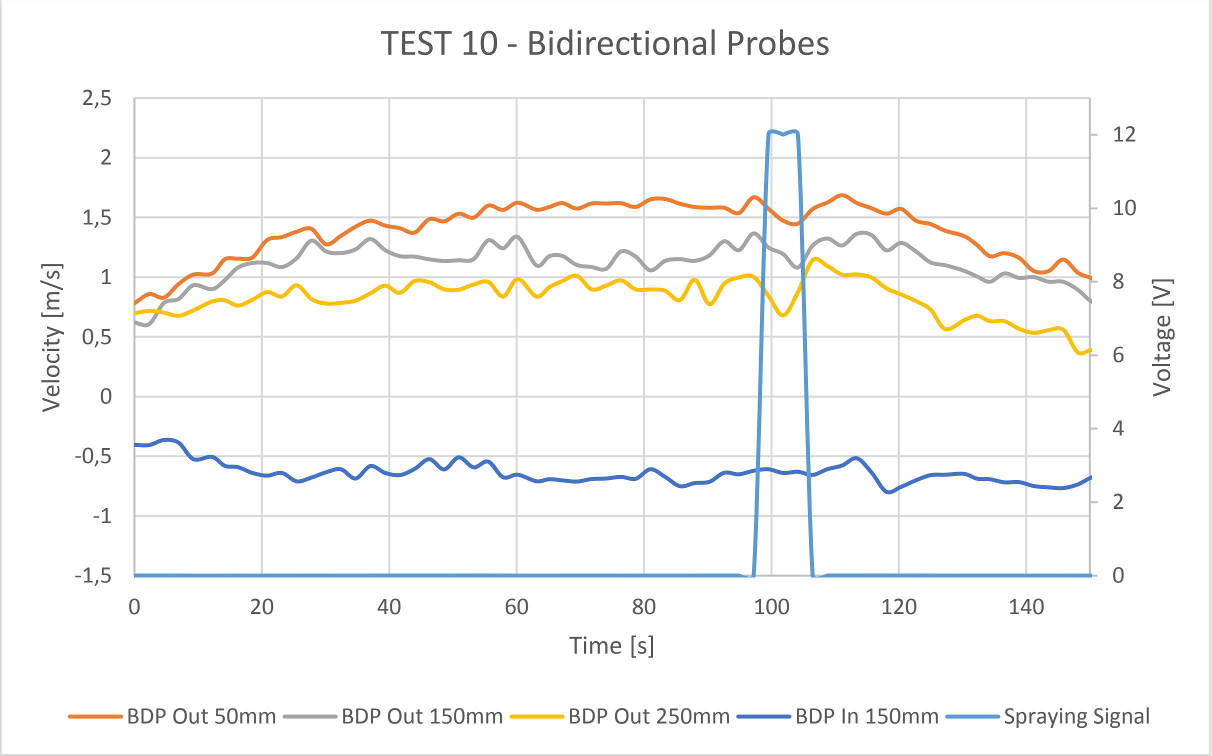

TEST 9 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

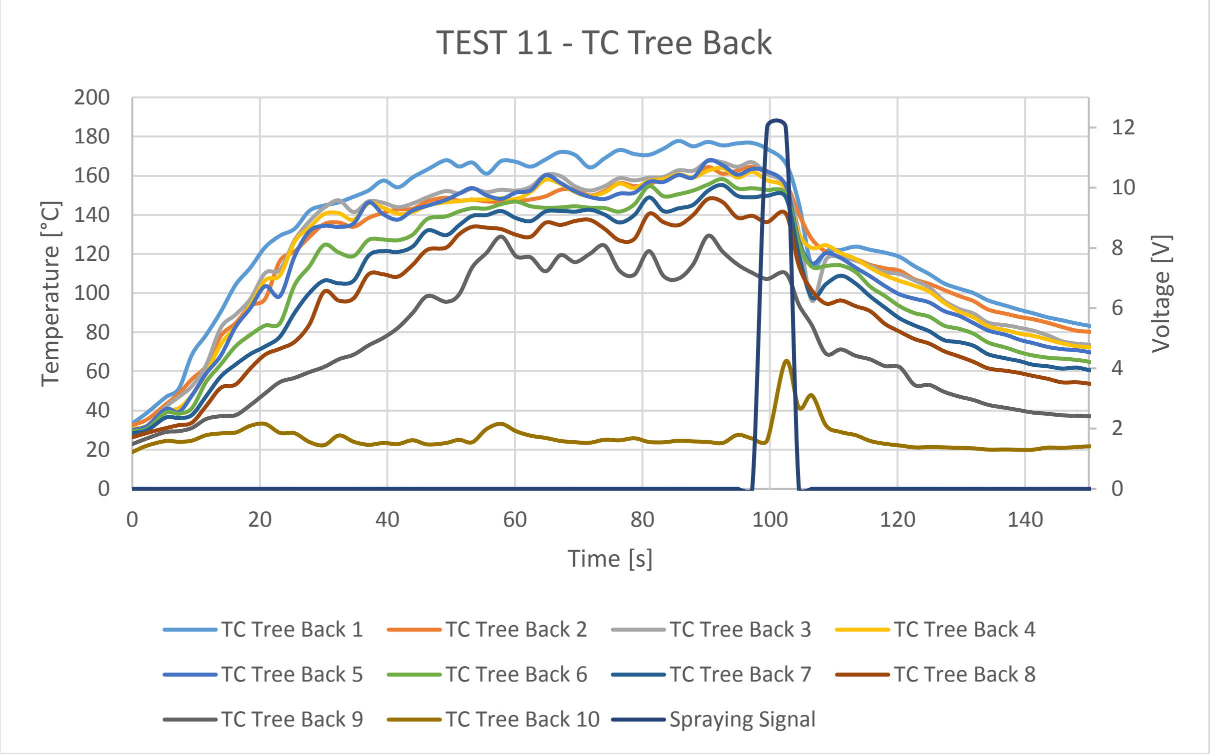

TEST 9 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

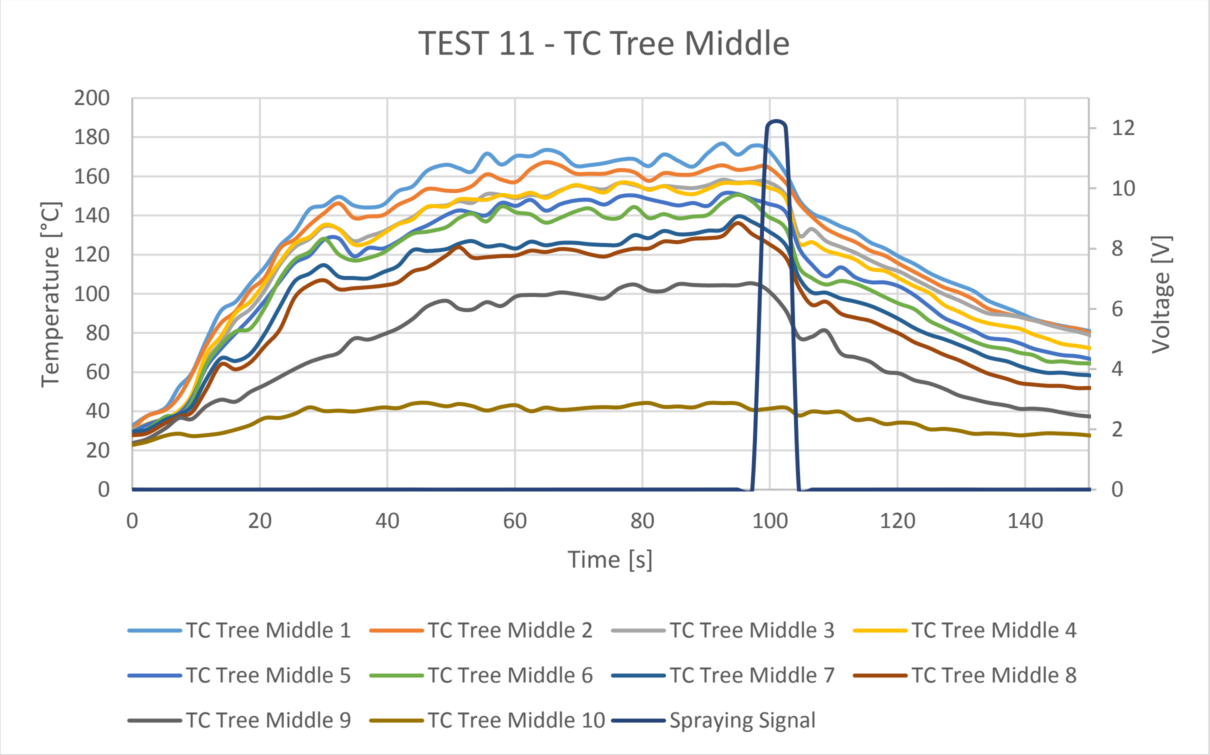

TEST 10 - TC Tree Back
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

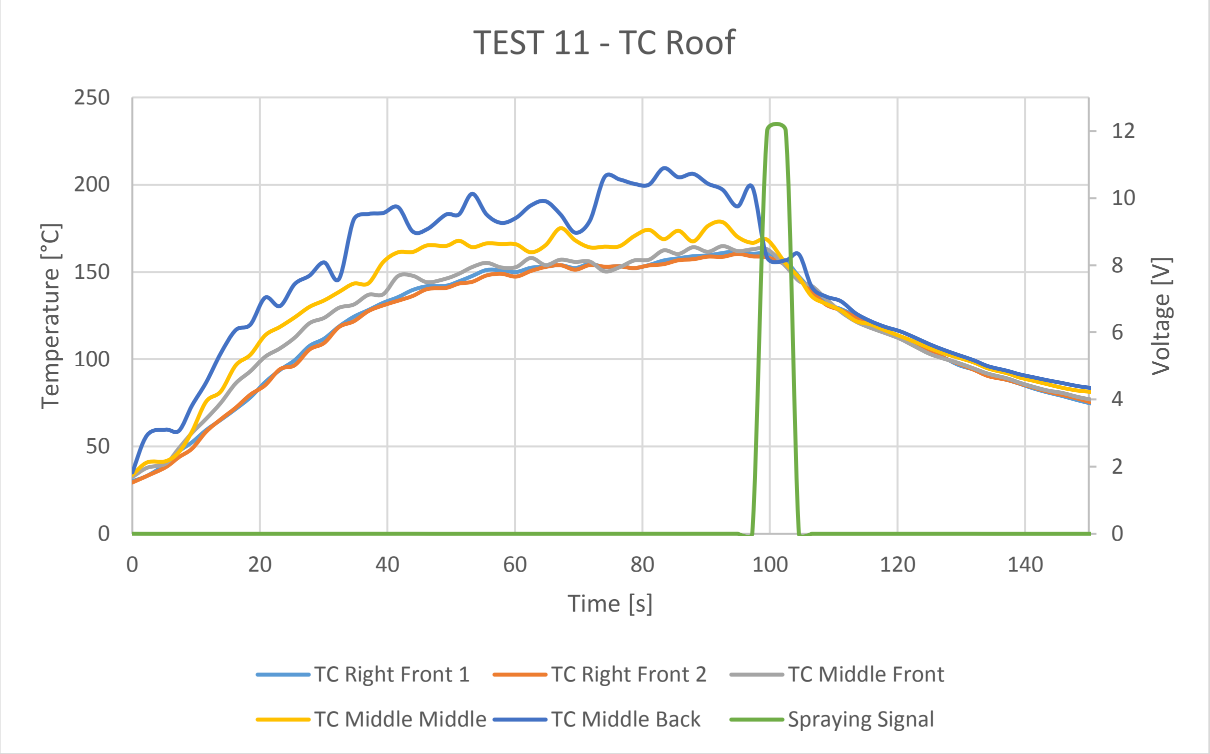

TEST 10 - TC Tree Middle
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

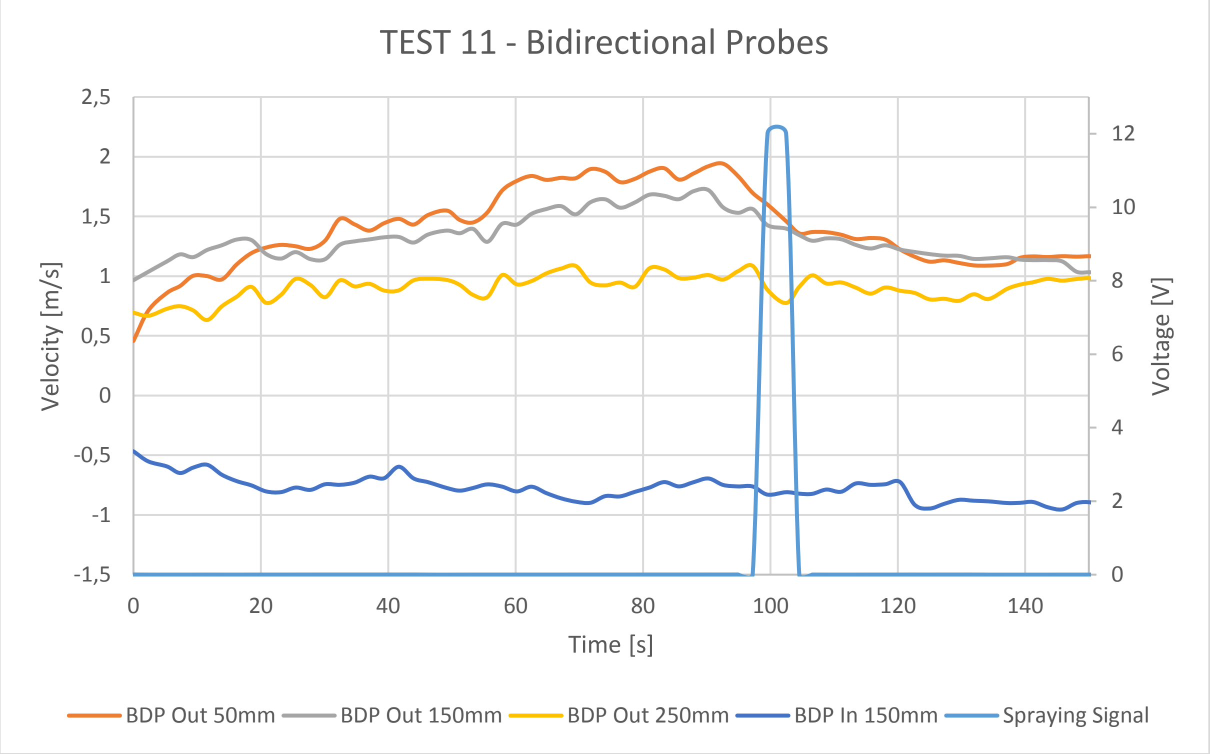

TEST 10 - TC Roof
Temperature [°C]
Voltage [V]
Time [s]
250
200
150
100
50
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

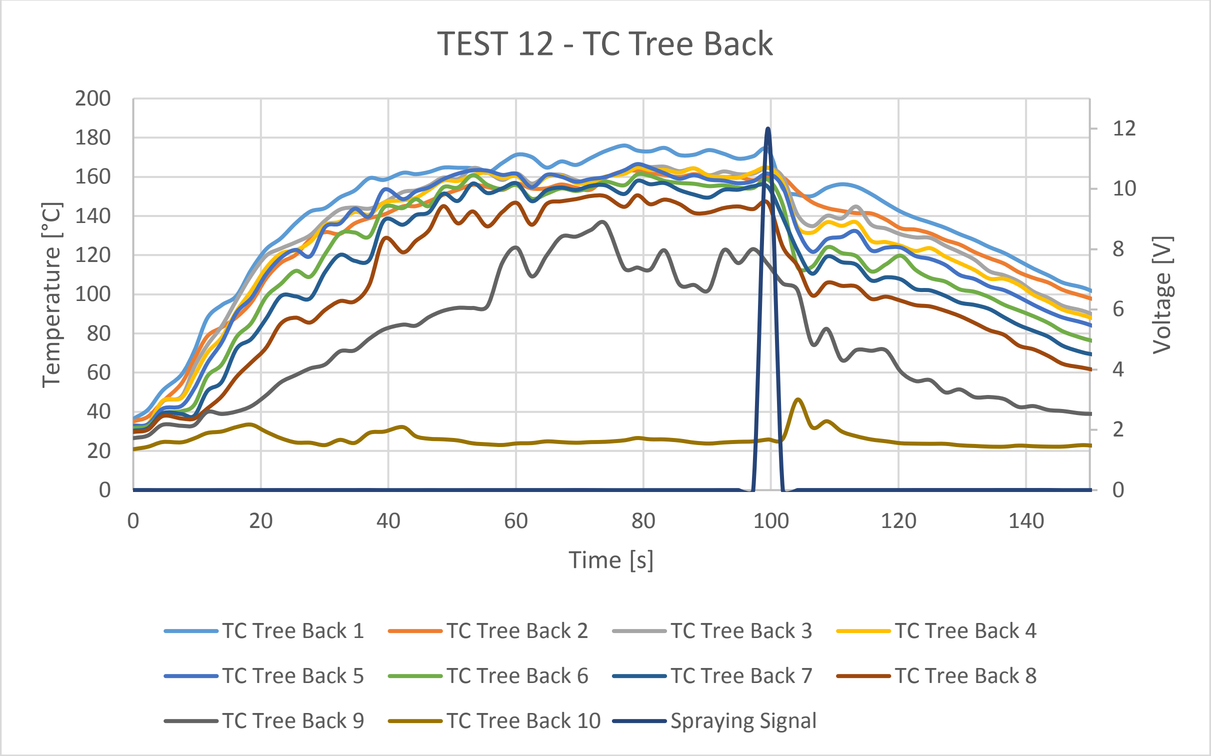

TEST 10 - Bidirectional Probes
Velocity [m/s]
Voltage [V]
Time [s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

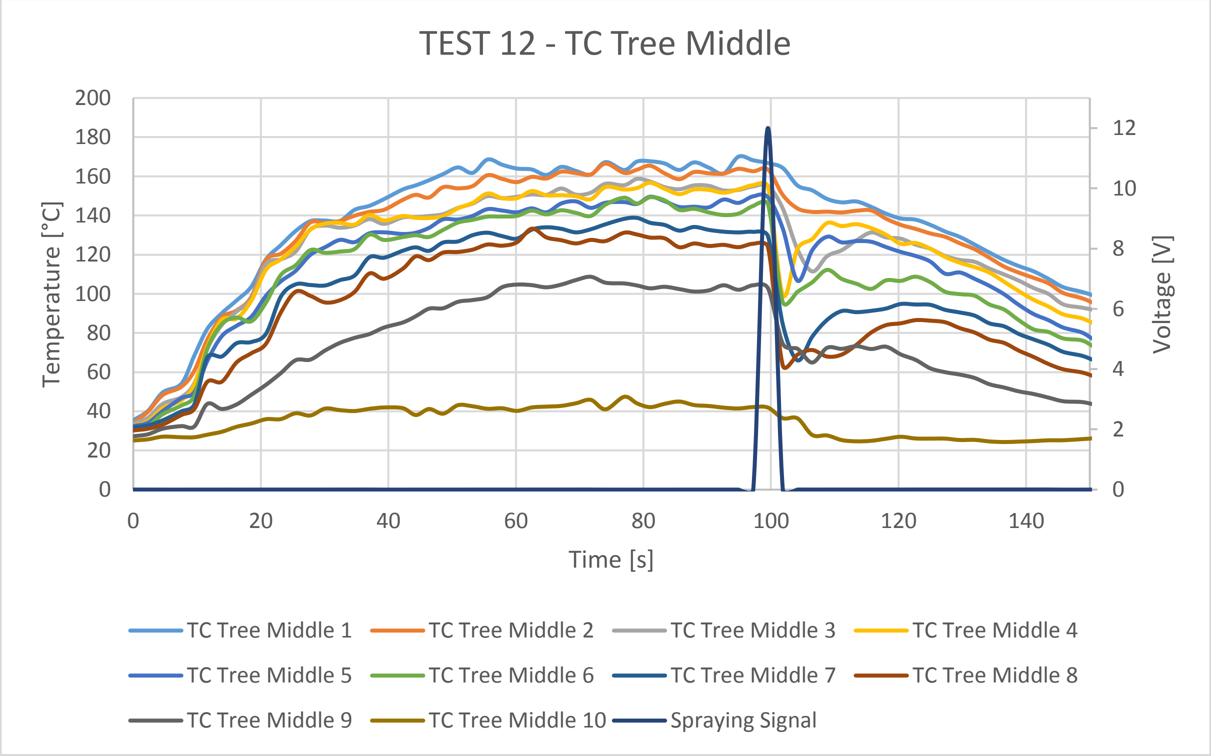

TEST 11 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Time [s]
Voltage [V]
12
10
8
6
4
2
0
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

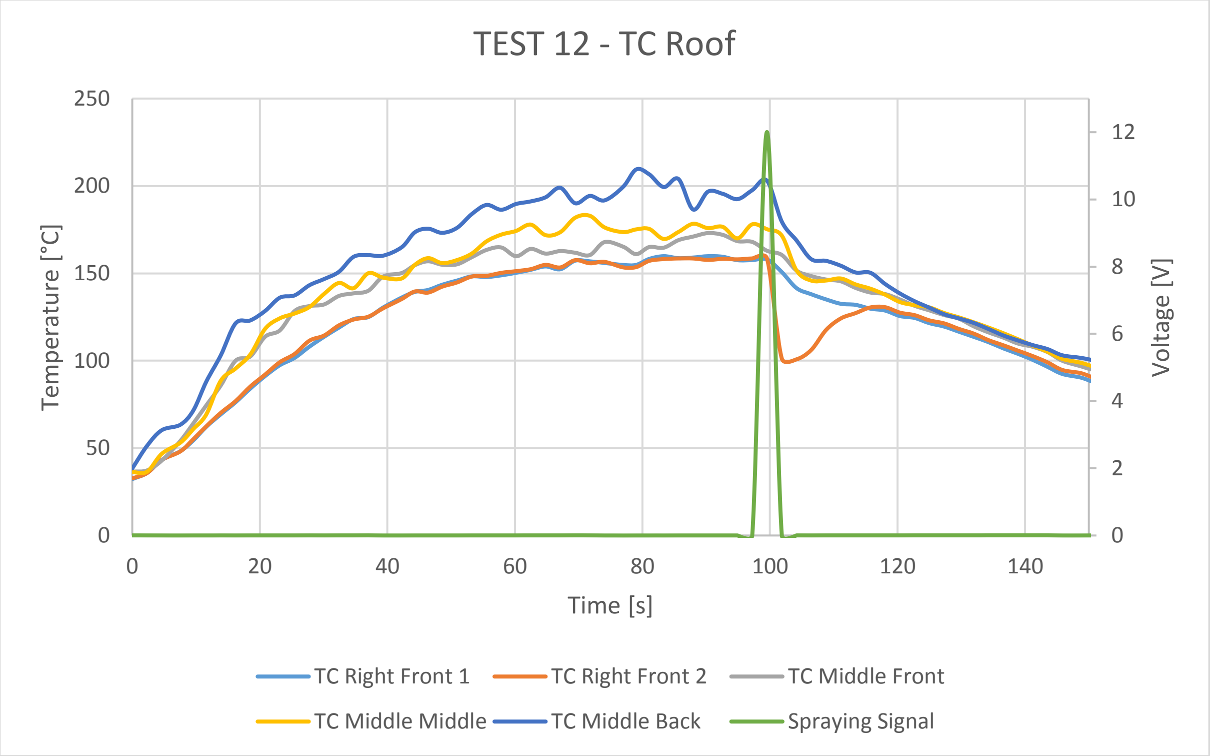

TEST 11 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Time [s]
Voltage [V]
12
10
8
6
4
2
0
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

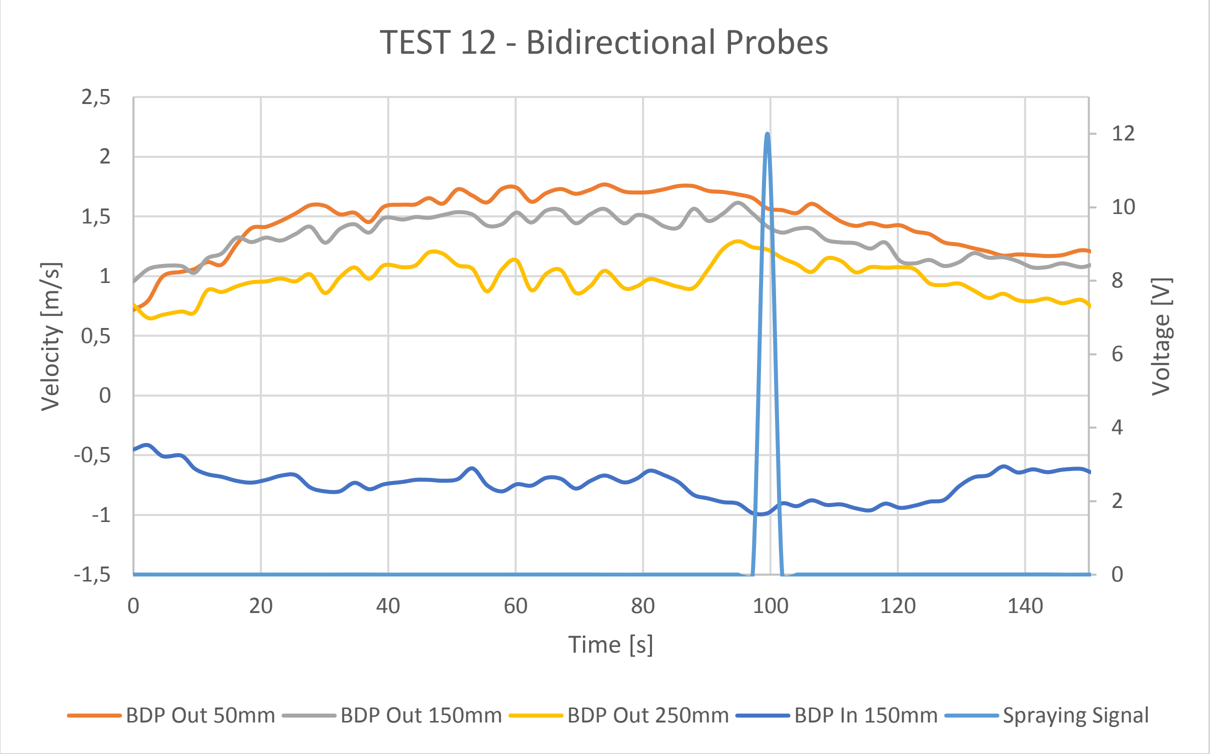

TEST 11 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

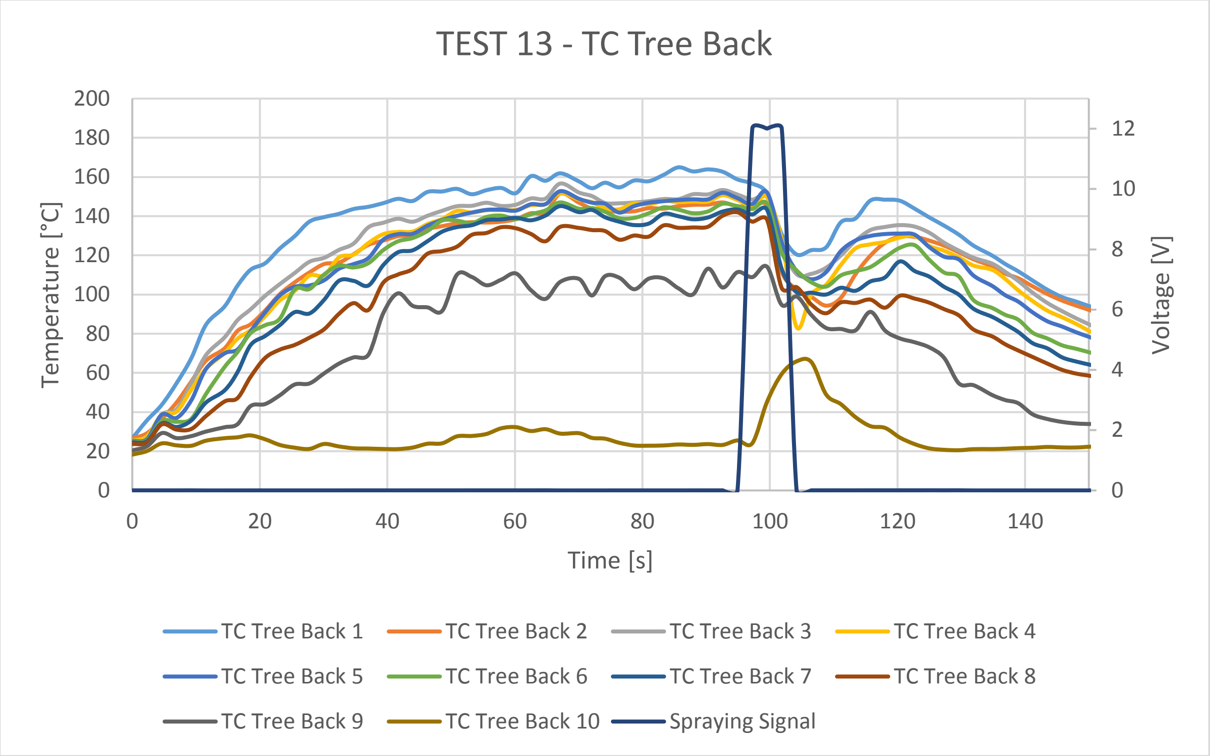

TEST 11 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

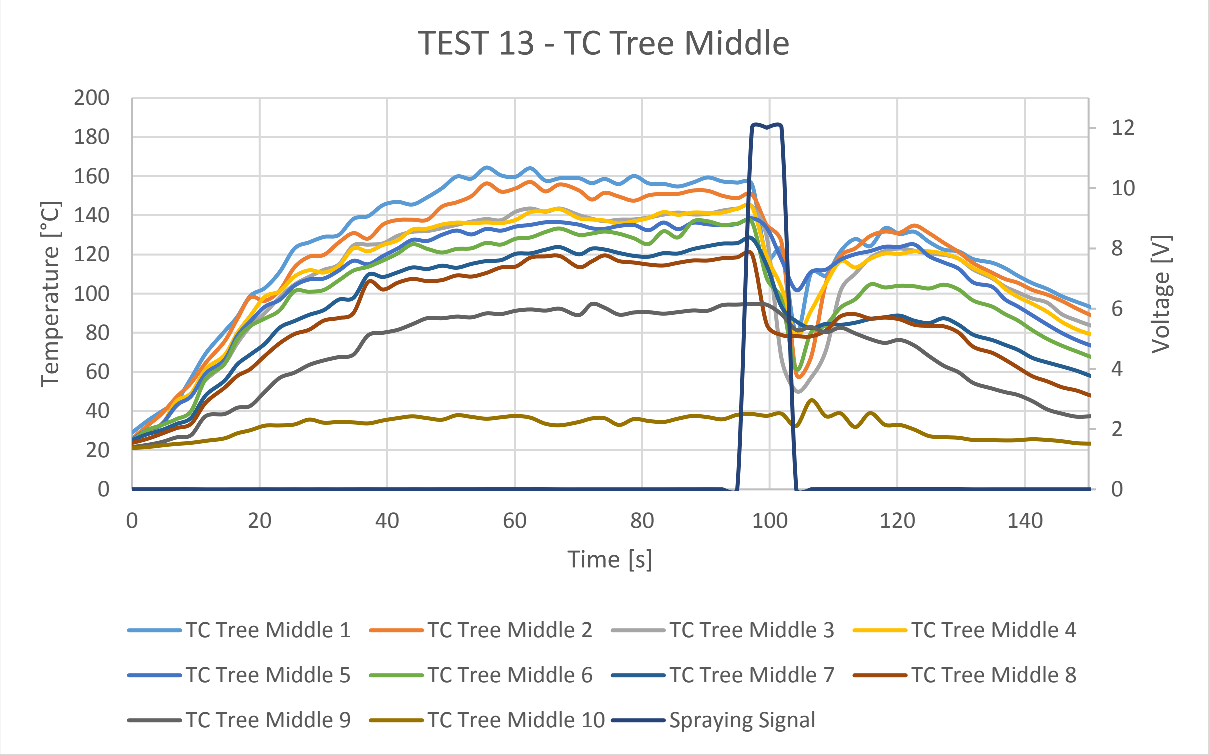

TEST 12 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

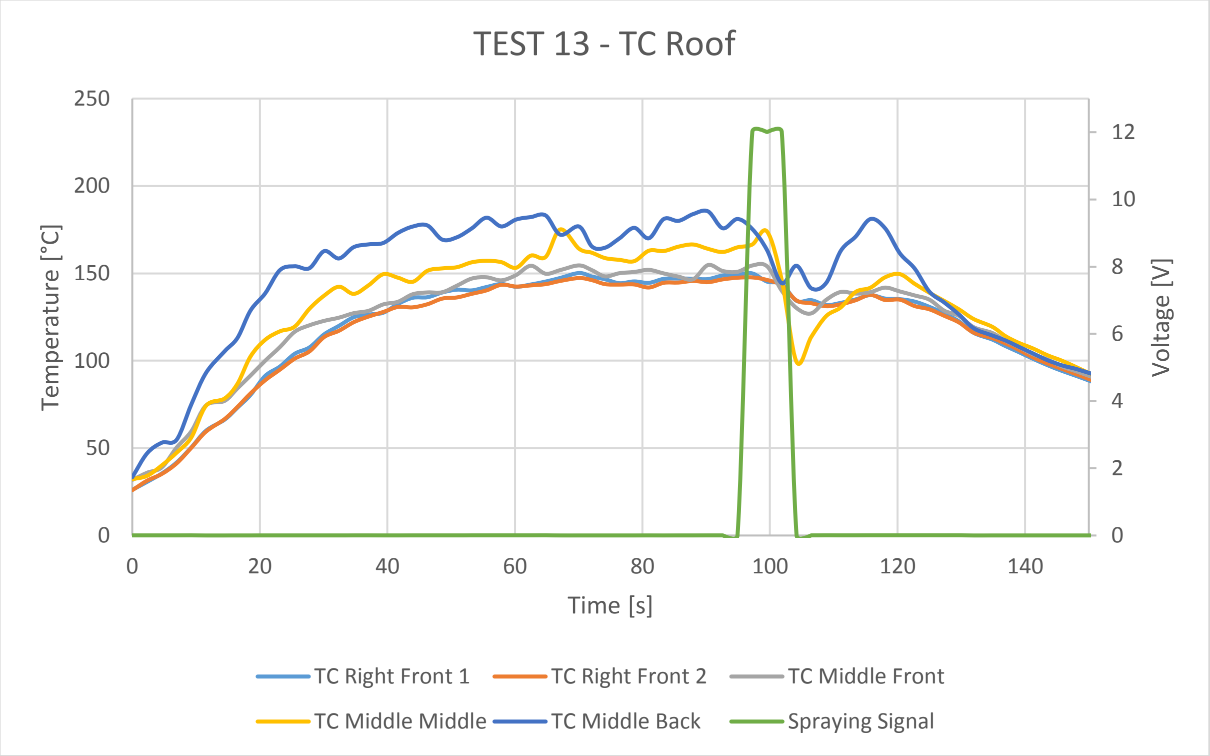

TEST 12 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

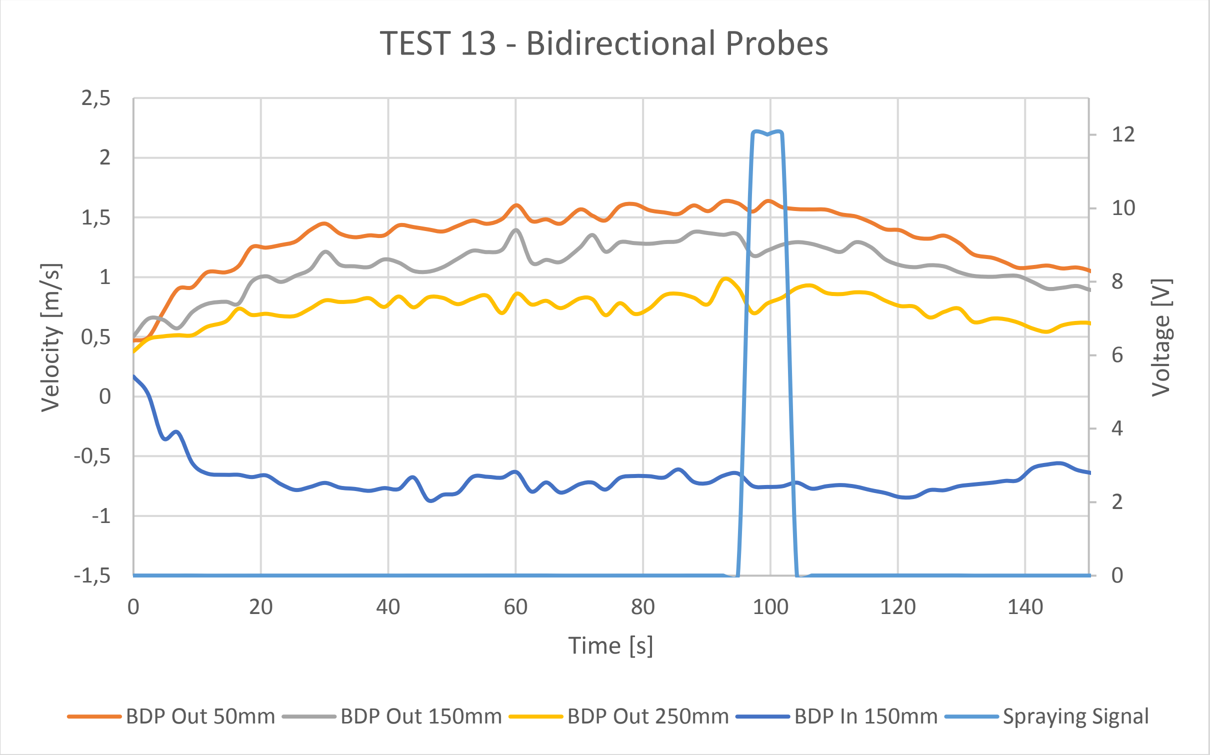

TEST 12 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

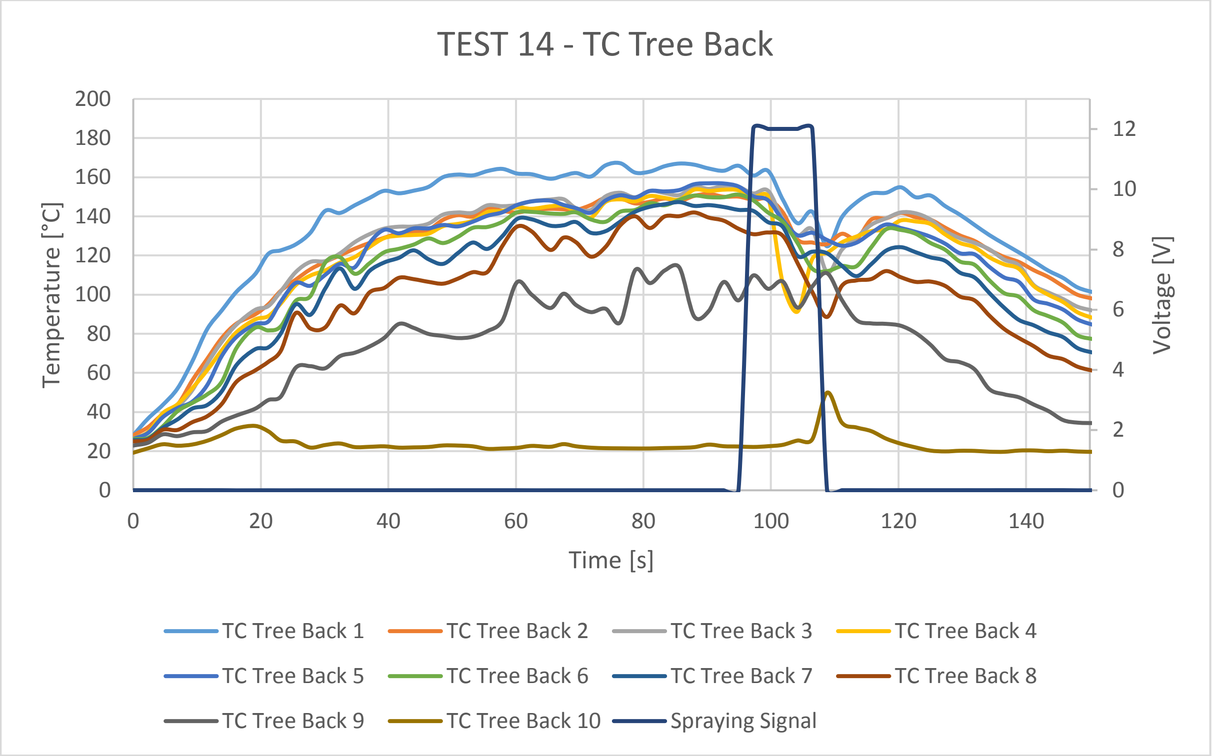

TEST 12 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

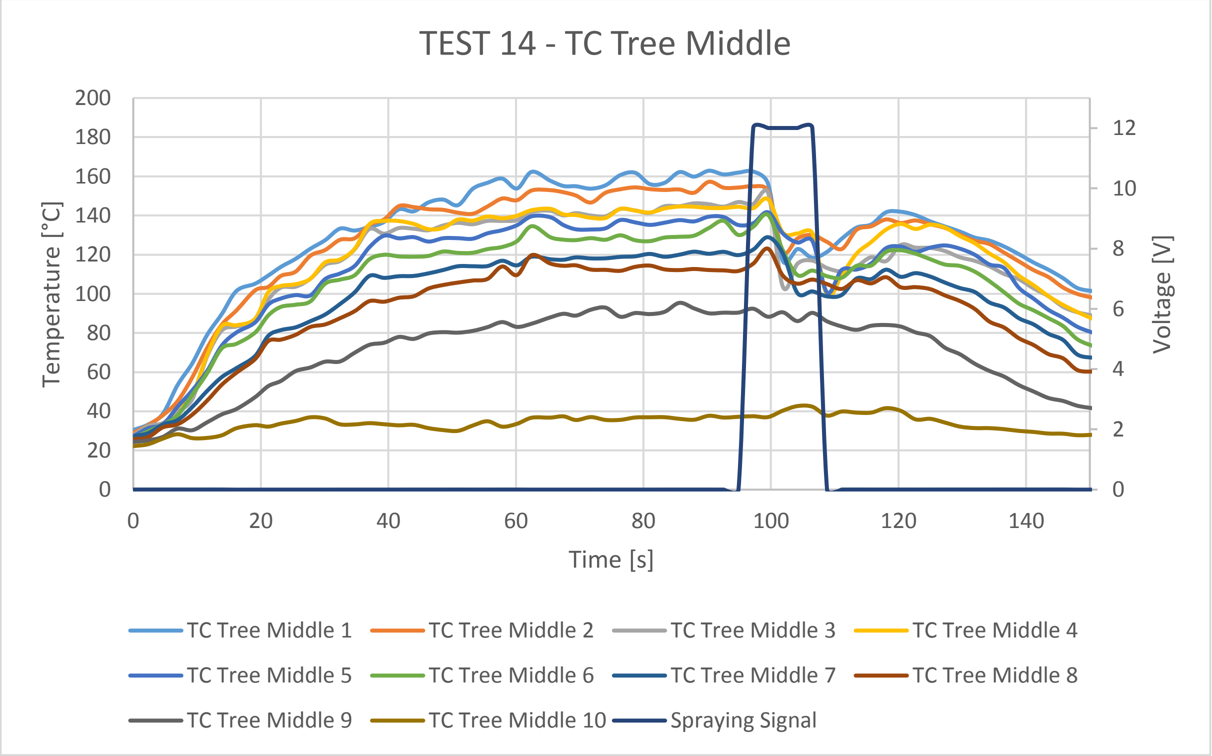

TEST 13 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Time [s]
12
10
8
6
4
2
0
Voltage [V]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

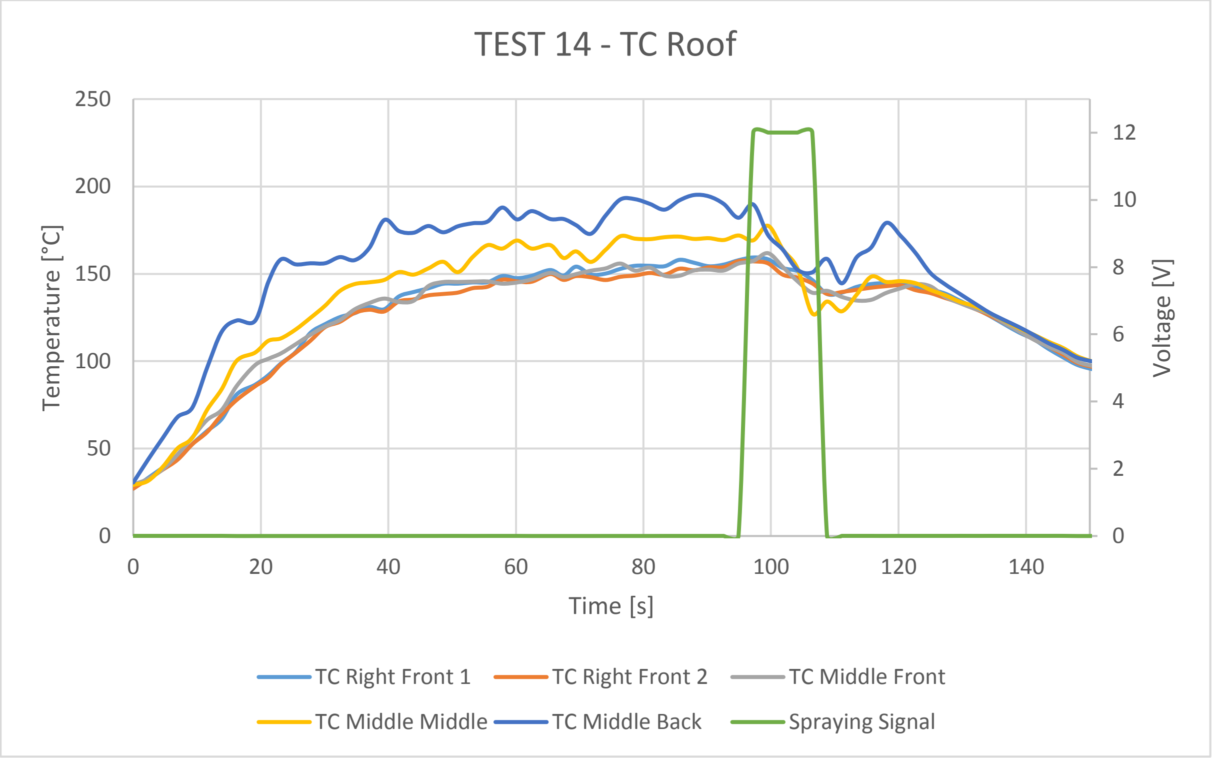

TEST 13 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
Time [s]
12
10
8
6
4
2
0
Voltage [V]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

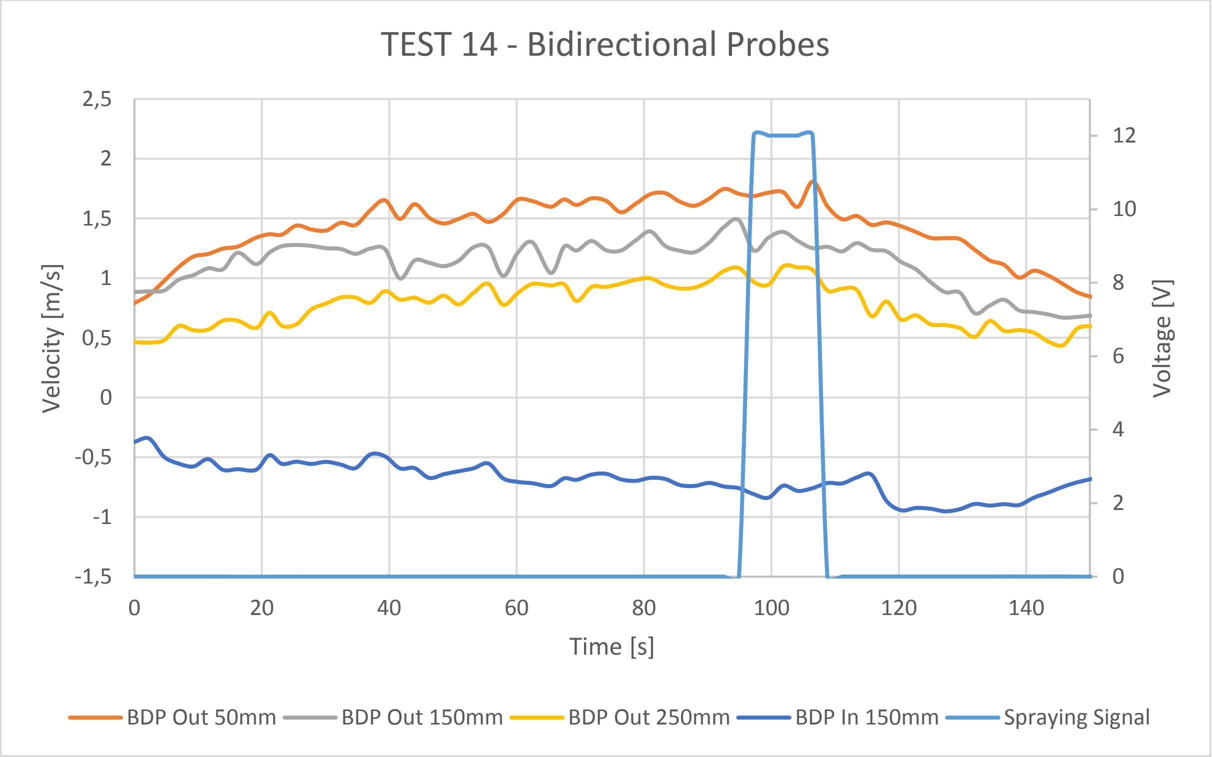

TEST 13 - TC Roof
Temperature [°C]
Voltage [V]
Time [s]
250
200
150
100
50
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

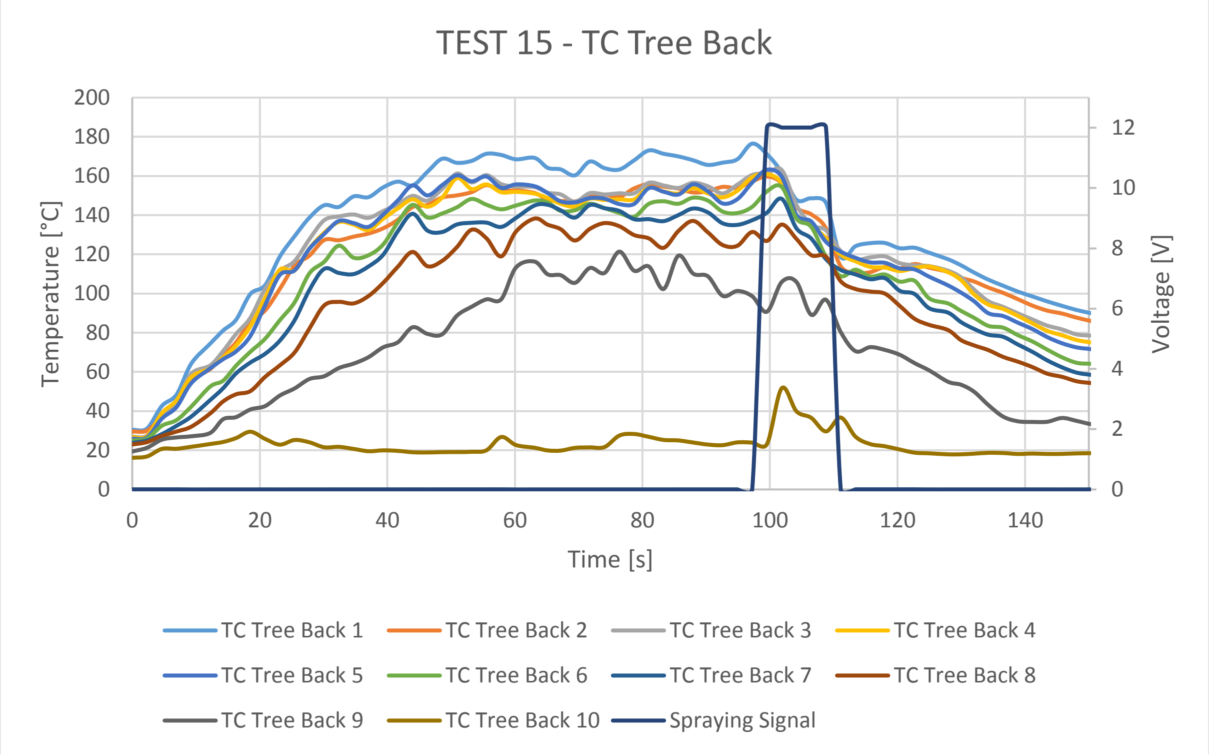

TEST 13 - Bidirectional Probes
Velocity [m/s]
Voltage [V]
Time [s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

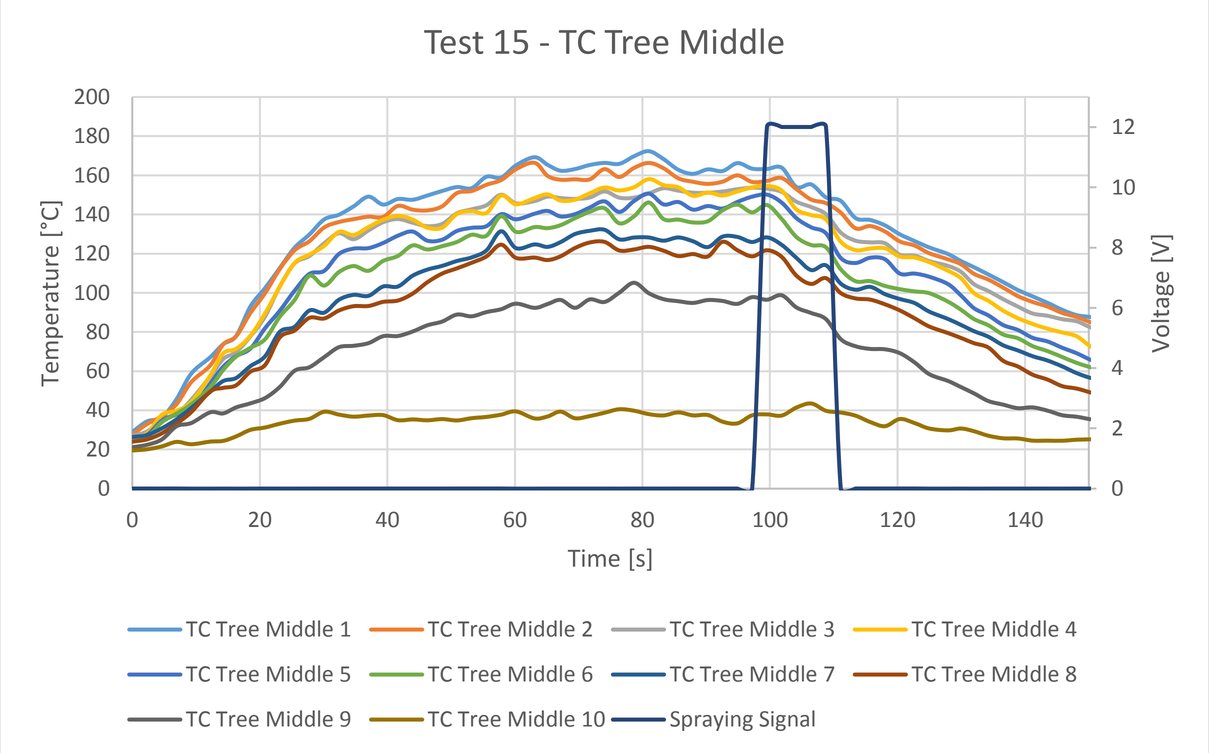

TEST 14 - TC Tree Back
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
200
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

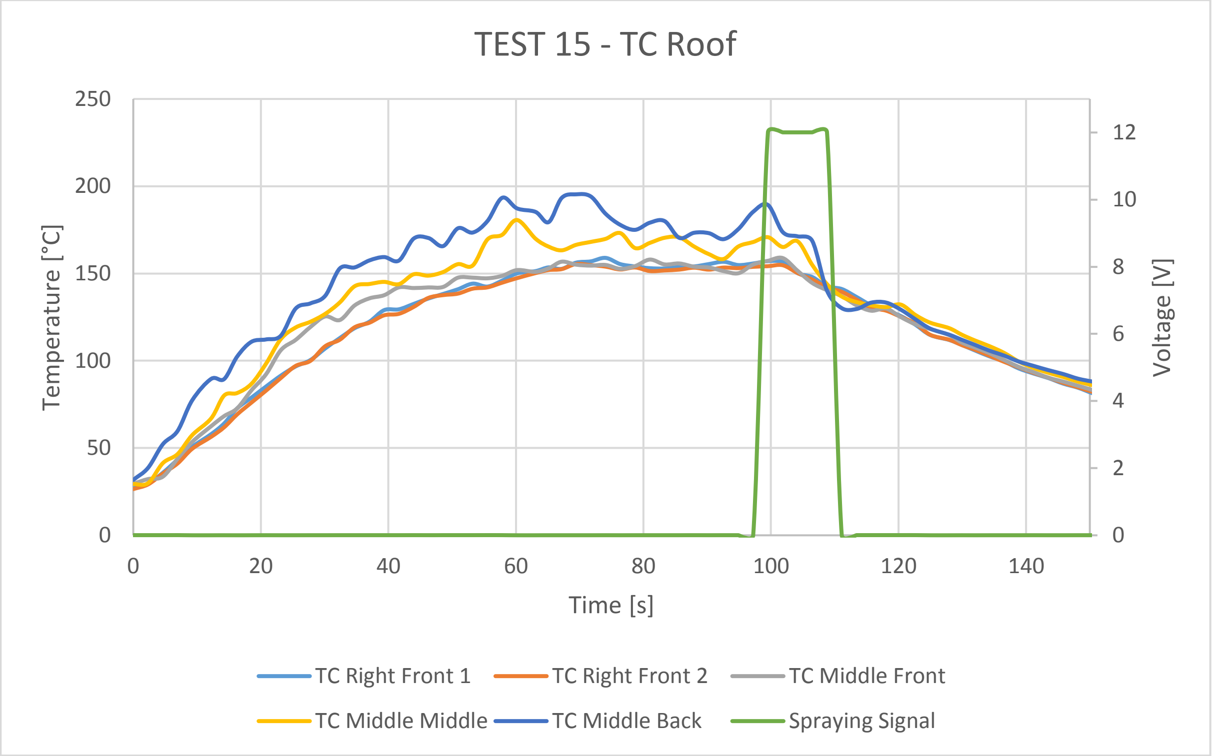

TEST 14 - TC Tree Middle
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
200
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

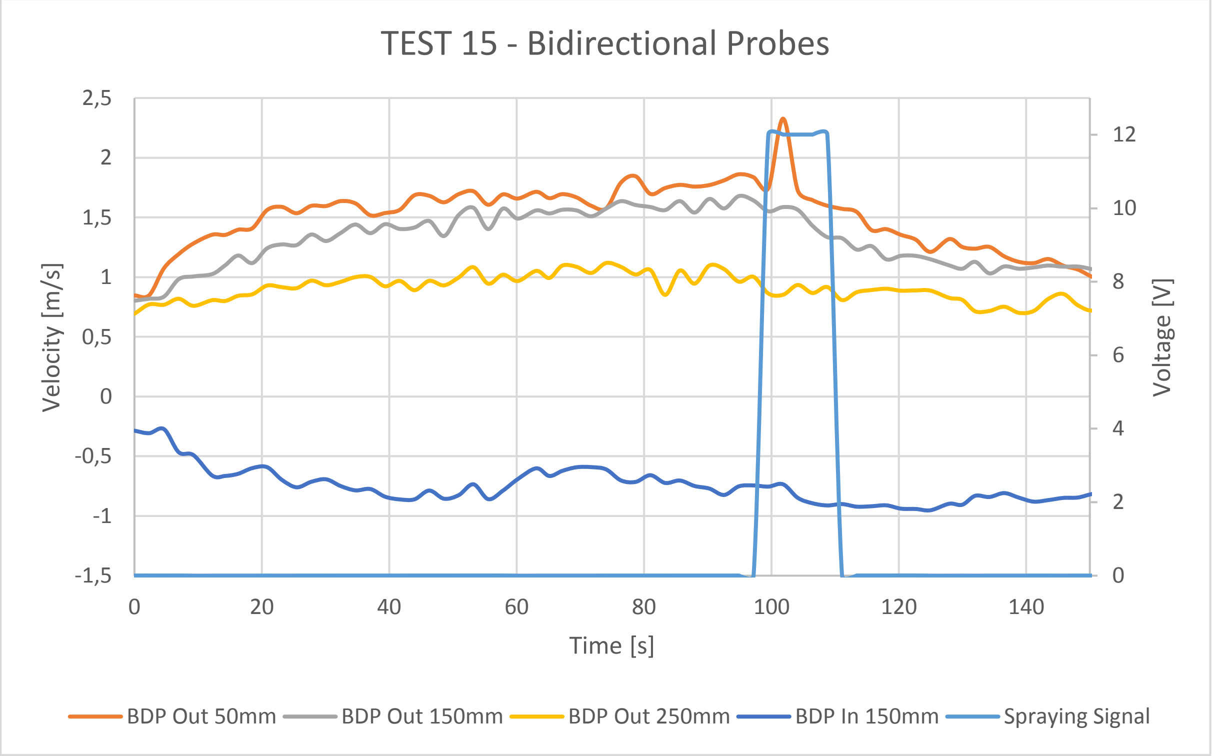

TEST 14 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

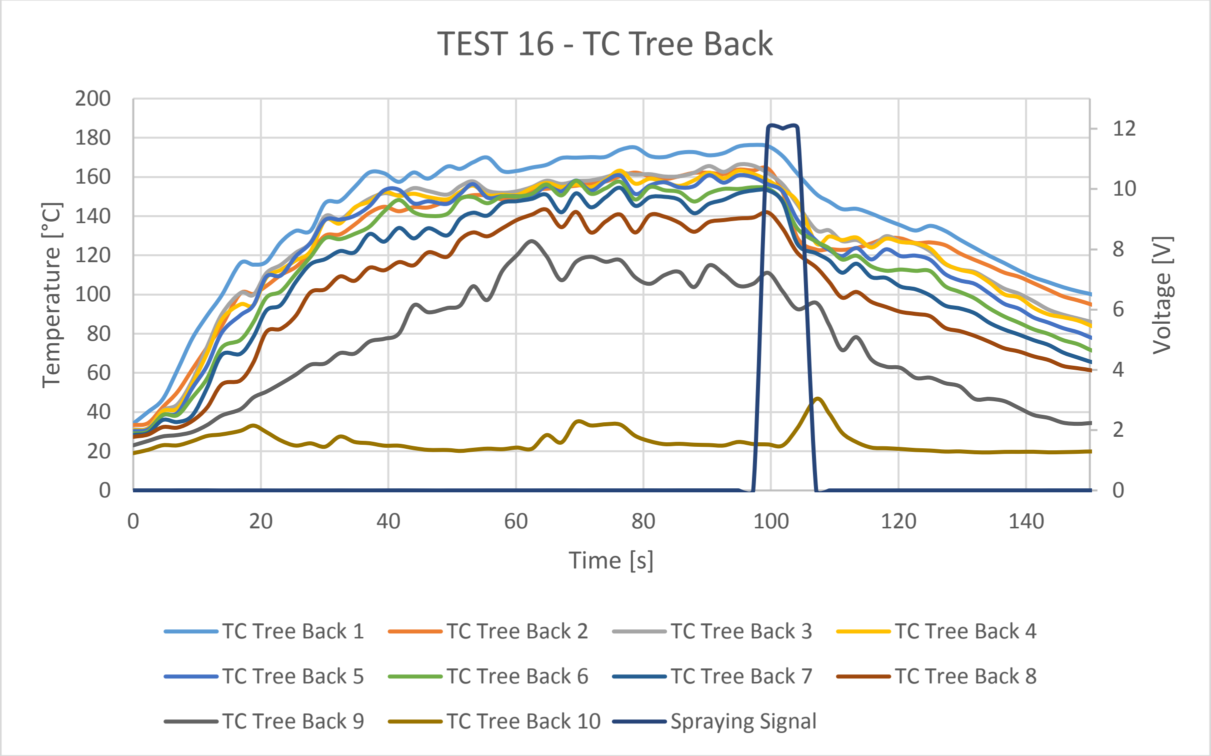

TEST 14 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

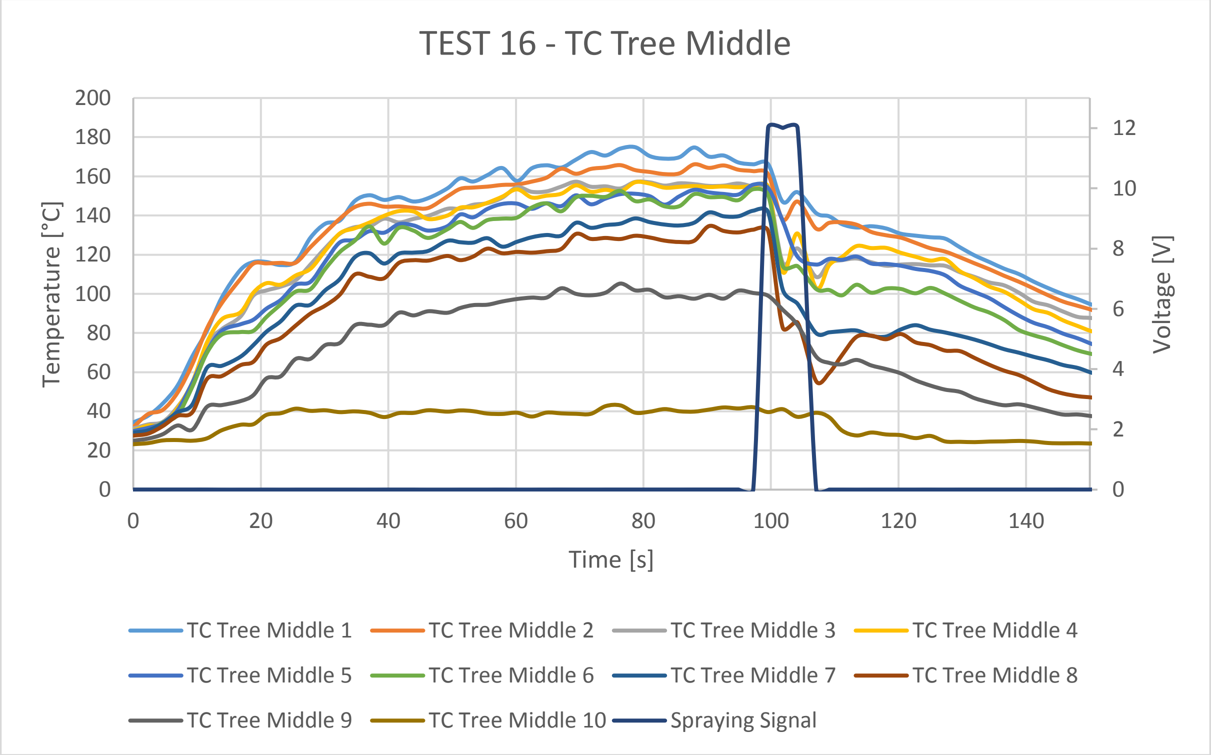

TEST 15 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

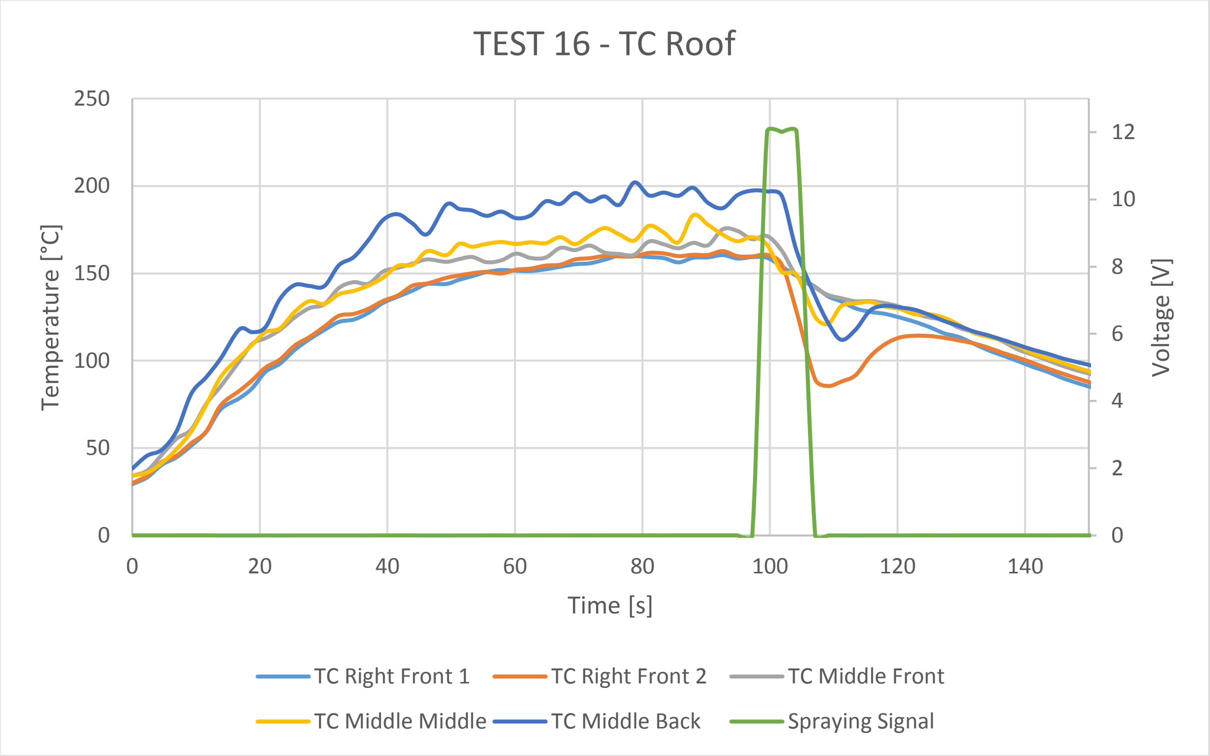

Test 15 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

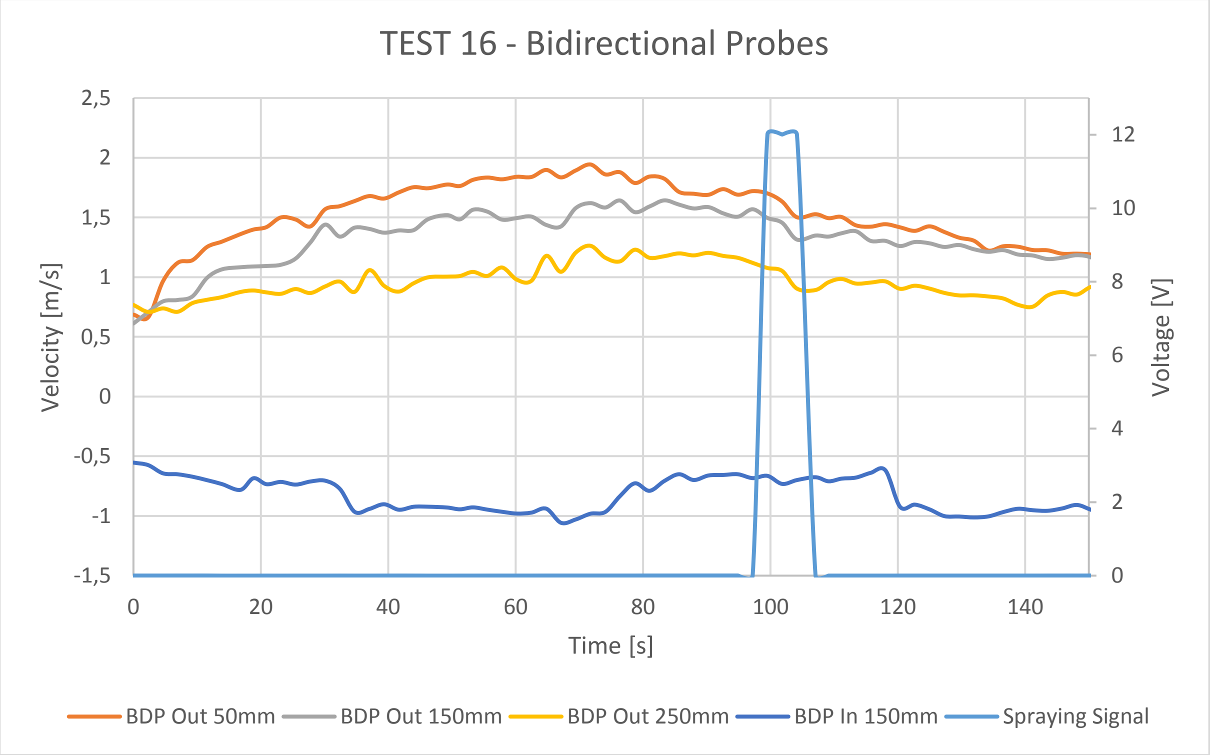

TEST 15 - TC Roof
Temperature [°C]
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Time [s]
12
10
8
6
4
2
0
Voltage [V]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

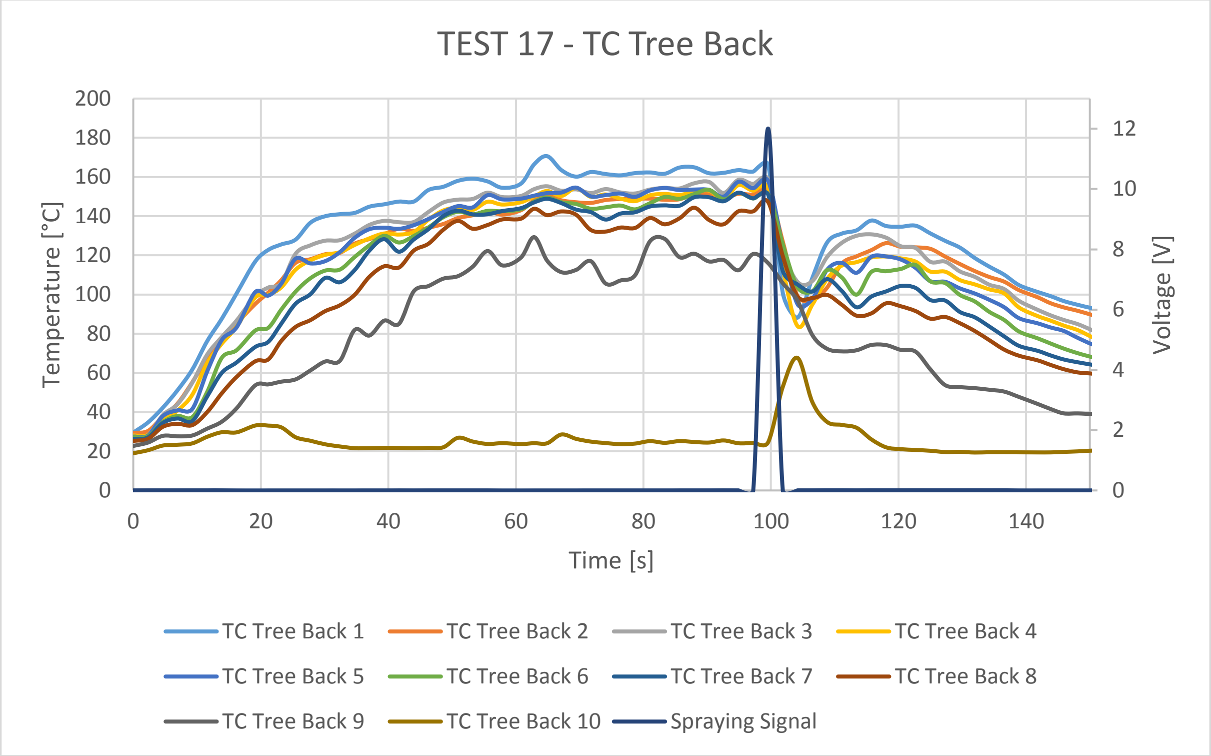

TEST 15 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
0
20
40
60
80
100
120
140
Time [s]
12
10
8
6
4
2
0
Voltage [V]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

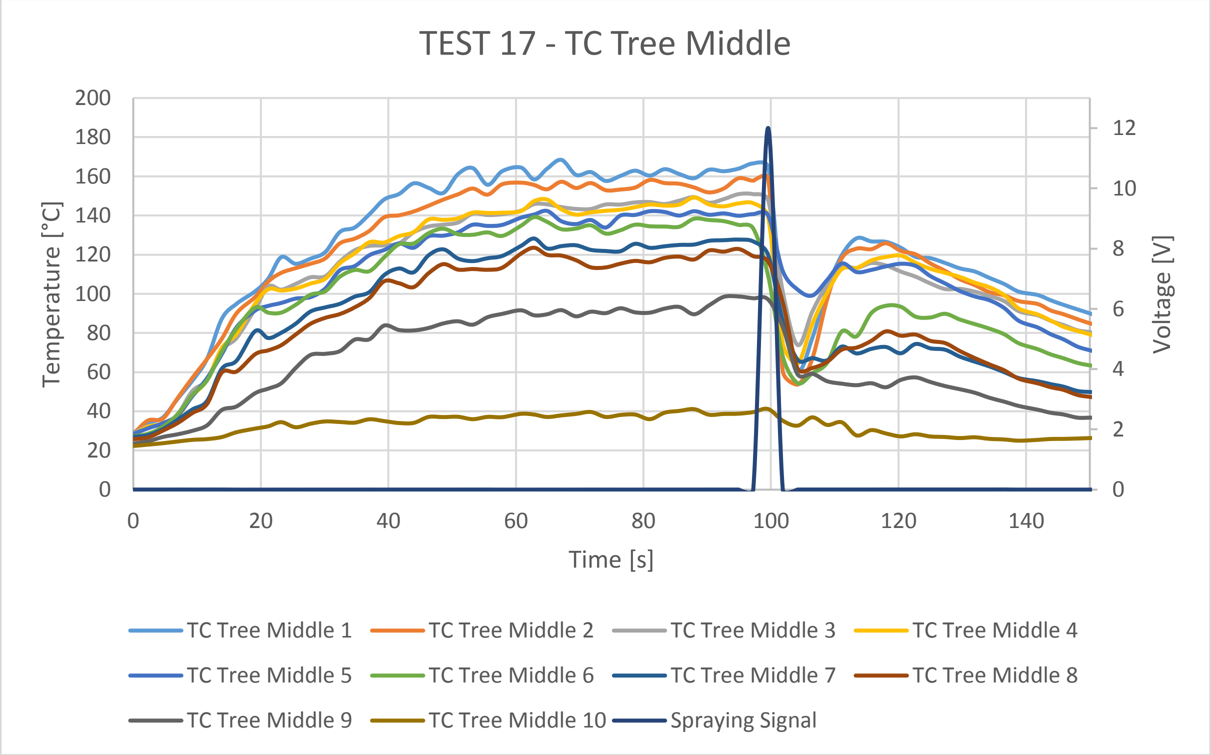

TEST 16 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

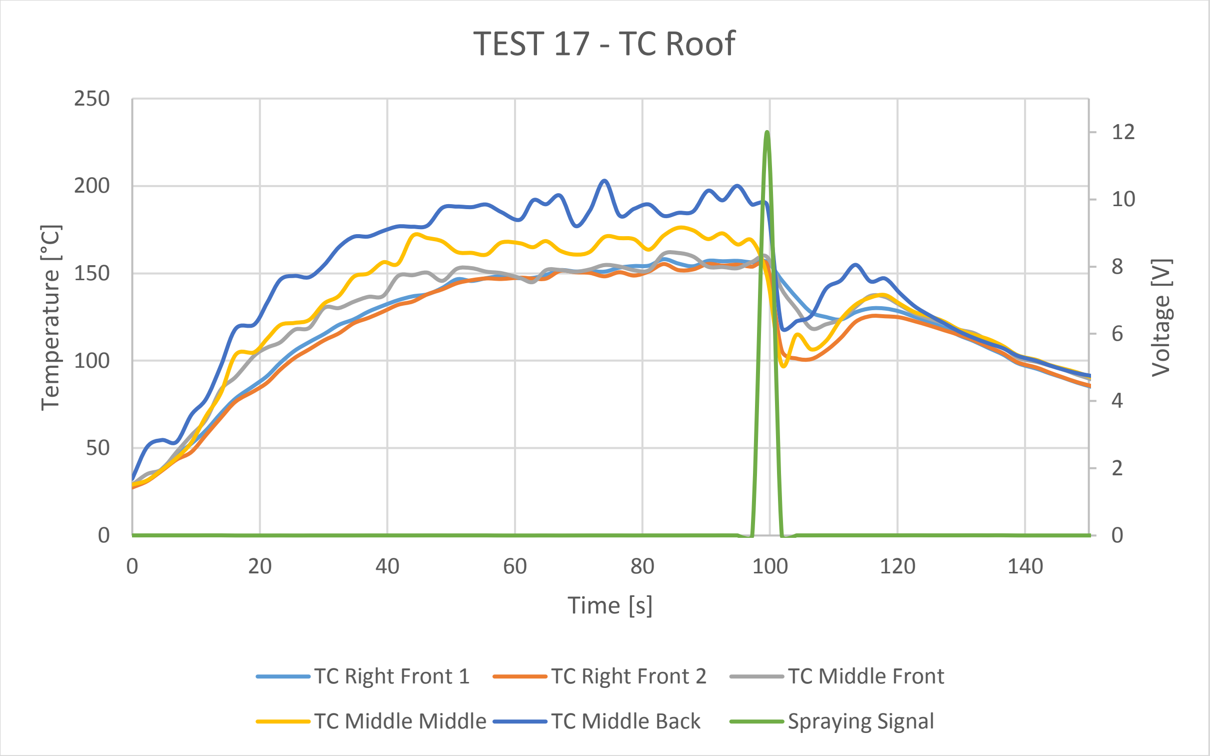

TEST 16 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

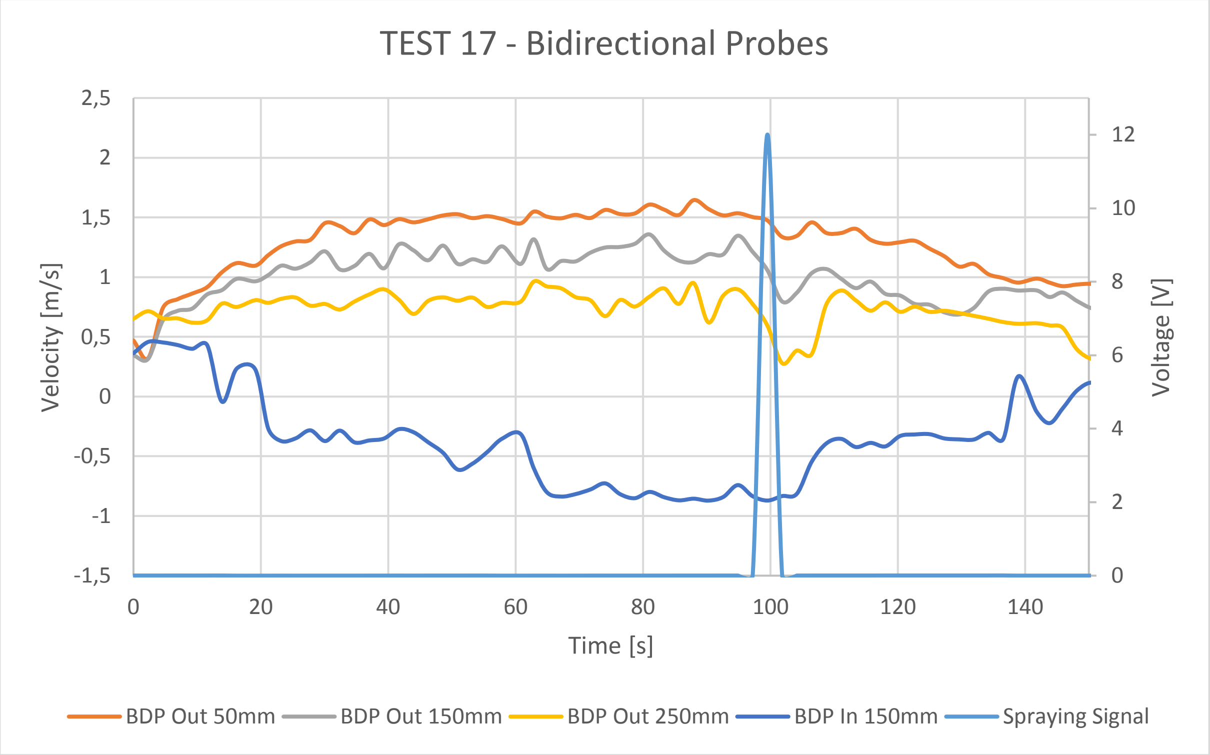

TEST 16 - TC Roof
Temperature [°C]
Voltage [V]
Time [s]
250
200
150
100
50
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

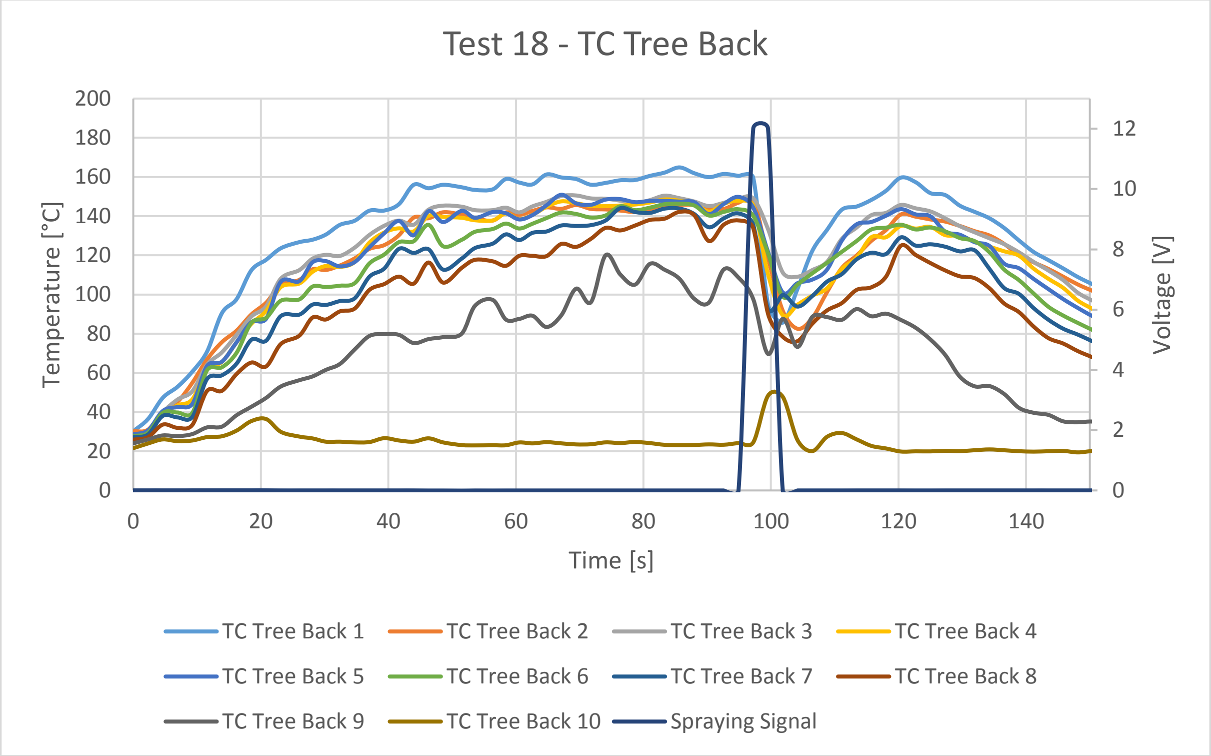

TEST 16 - Bidirectional Probes
Velocity [m/s]
Voltage [V]
Time [s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

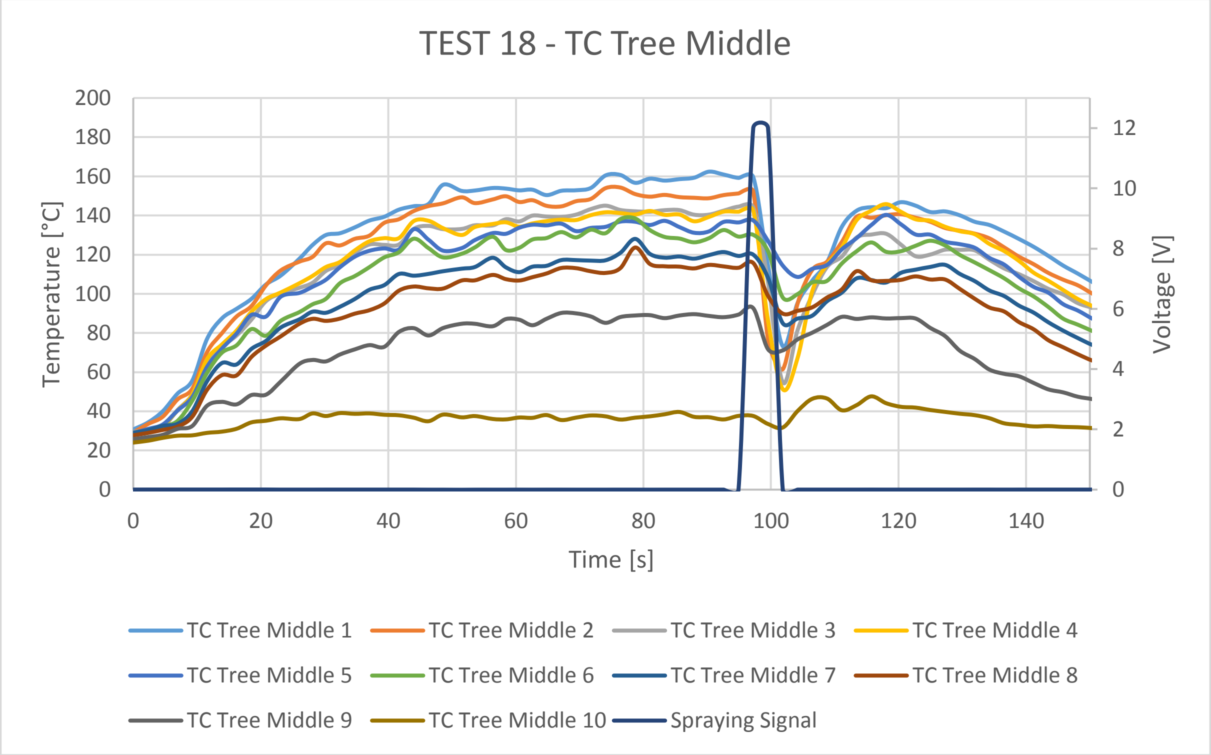

TEST 17 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

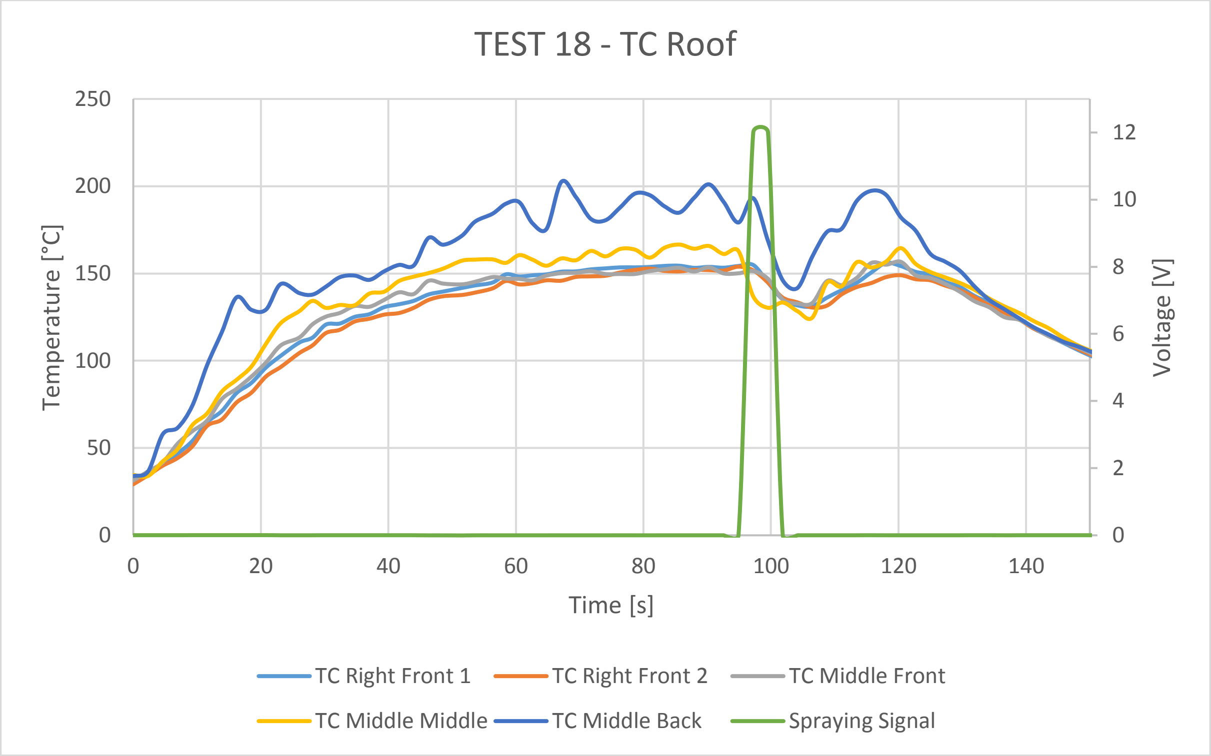

TEST 17 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

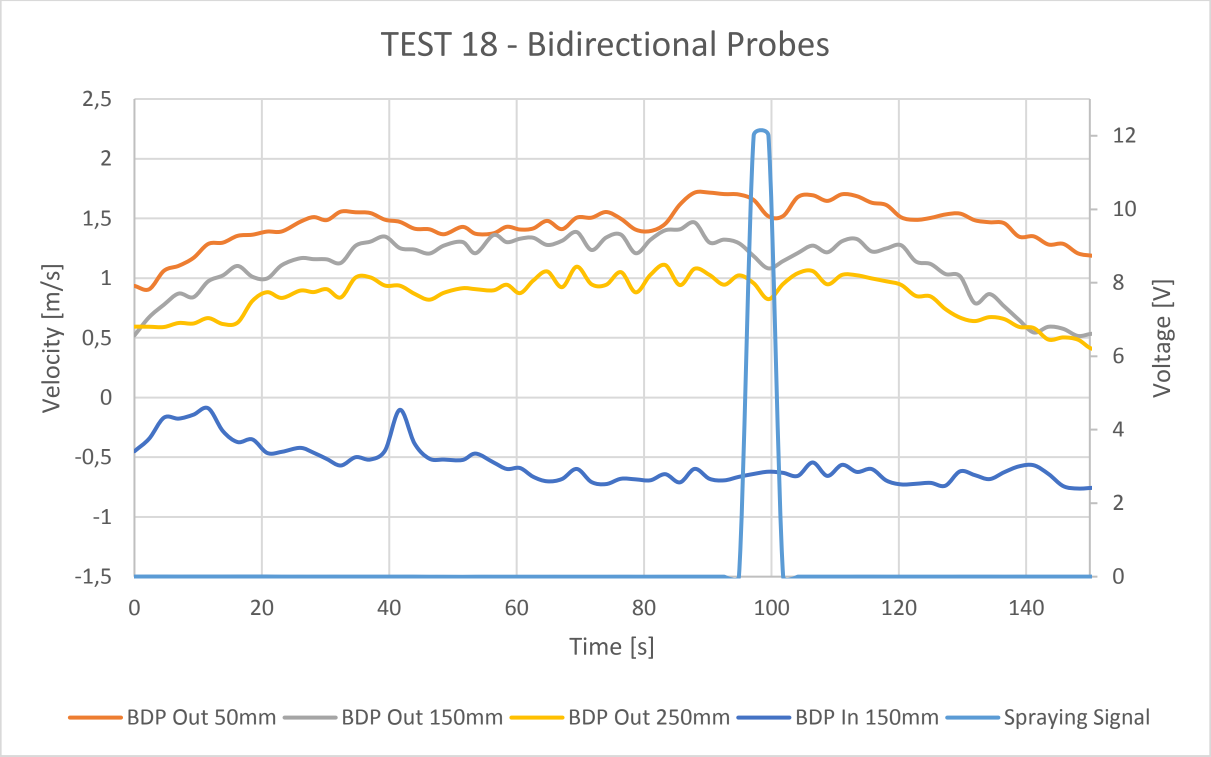

TEST 17 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

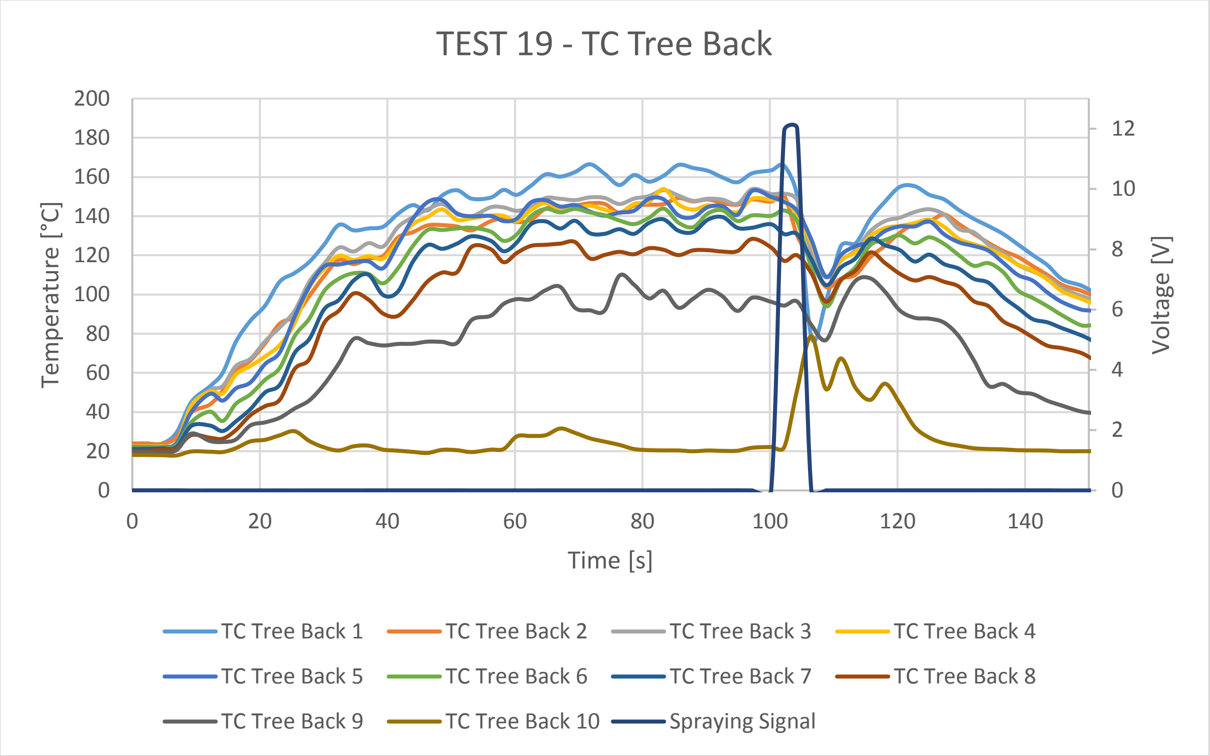

TEST 17 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

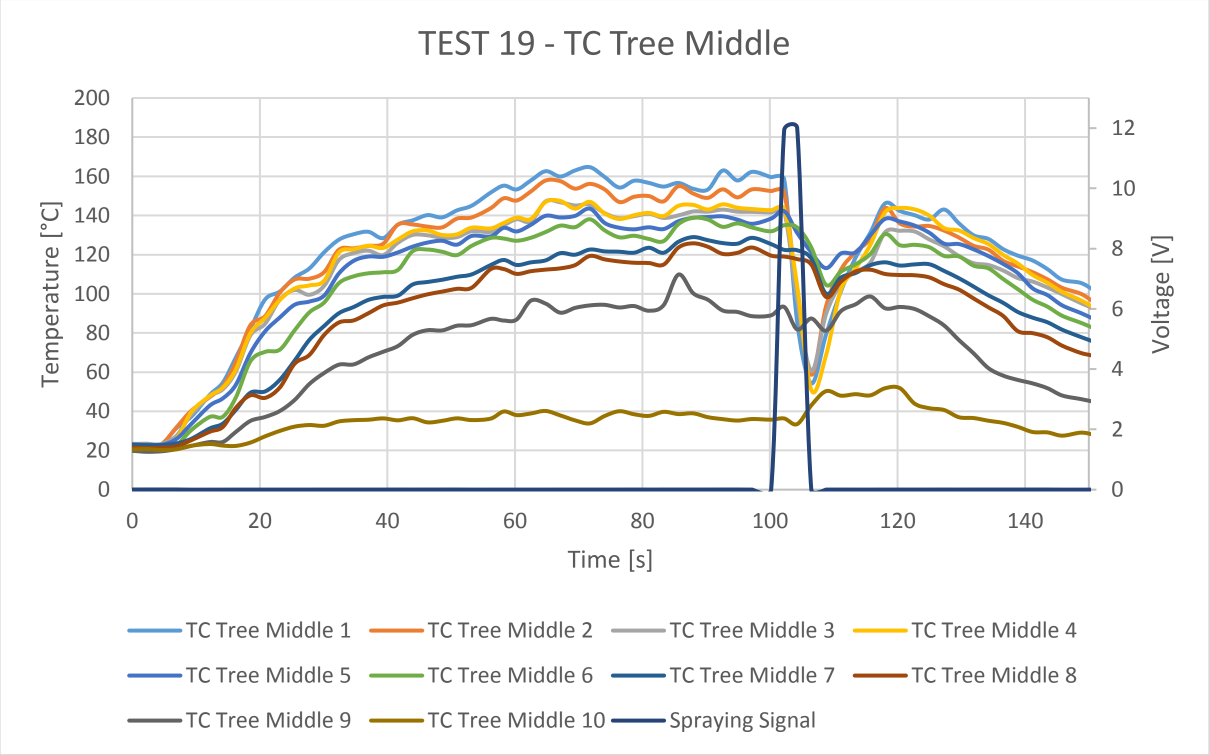

Test 18 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

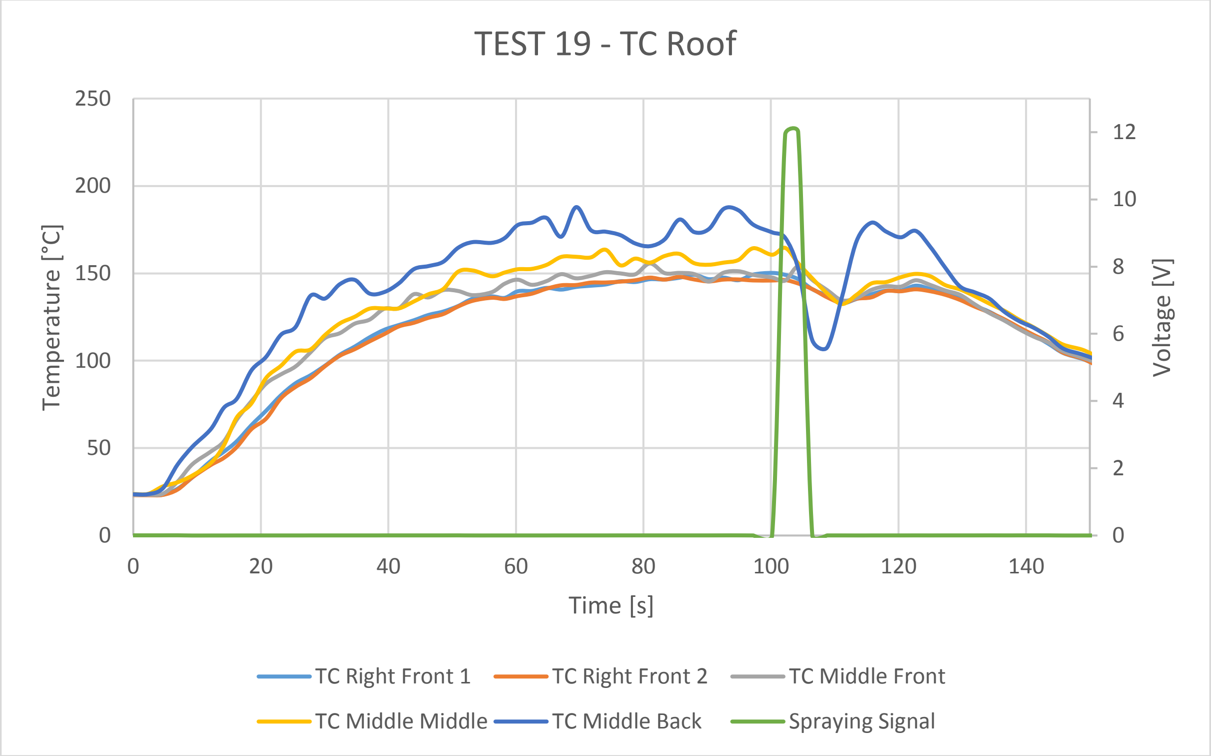

TEST 18 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

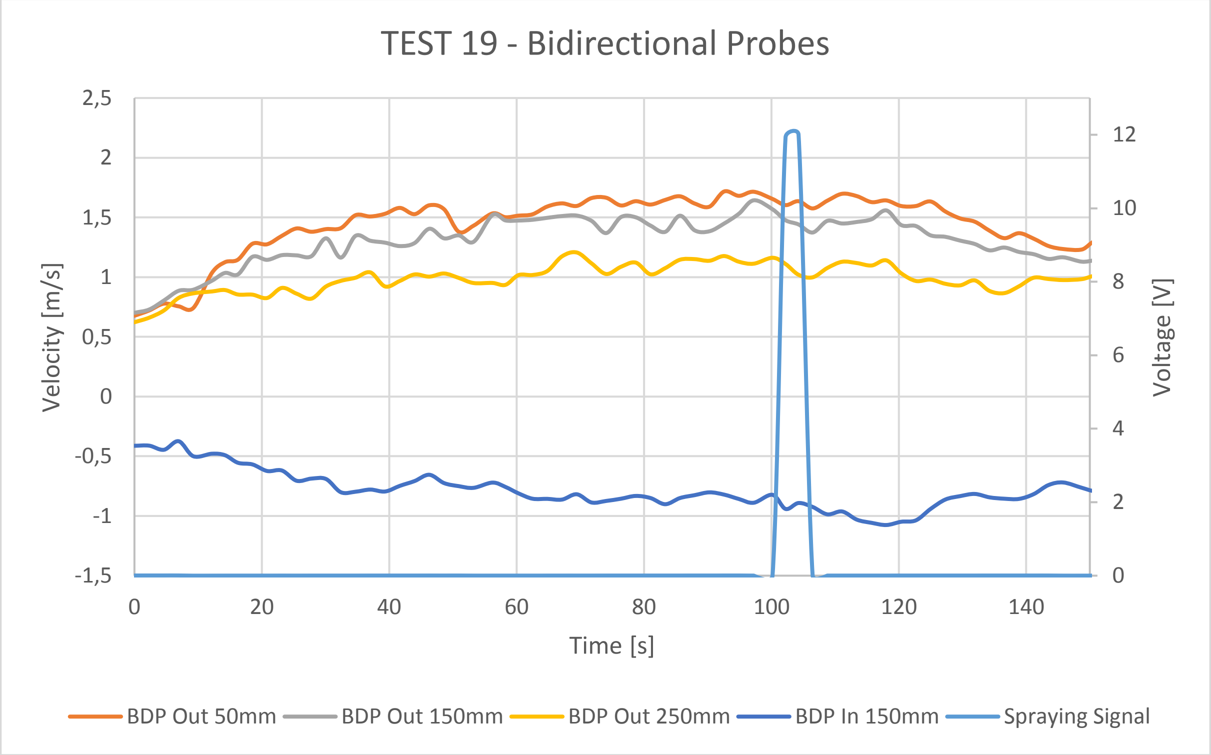

TEST 18 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

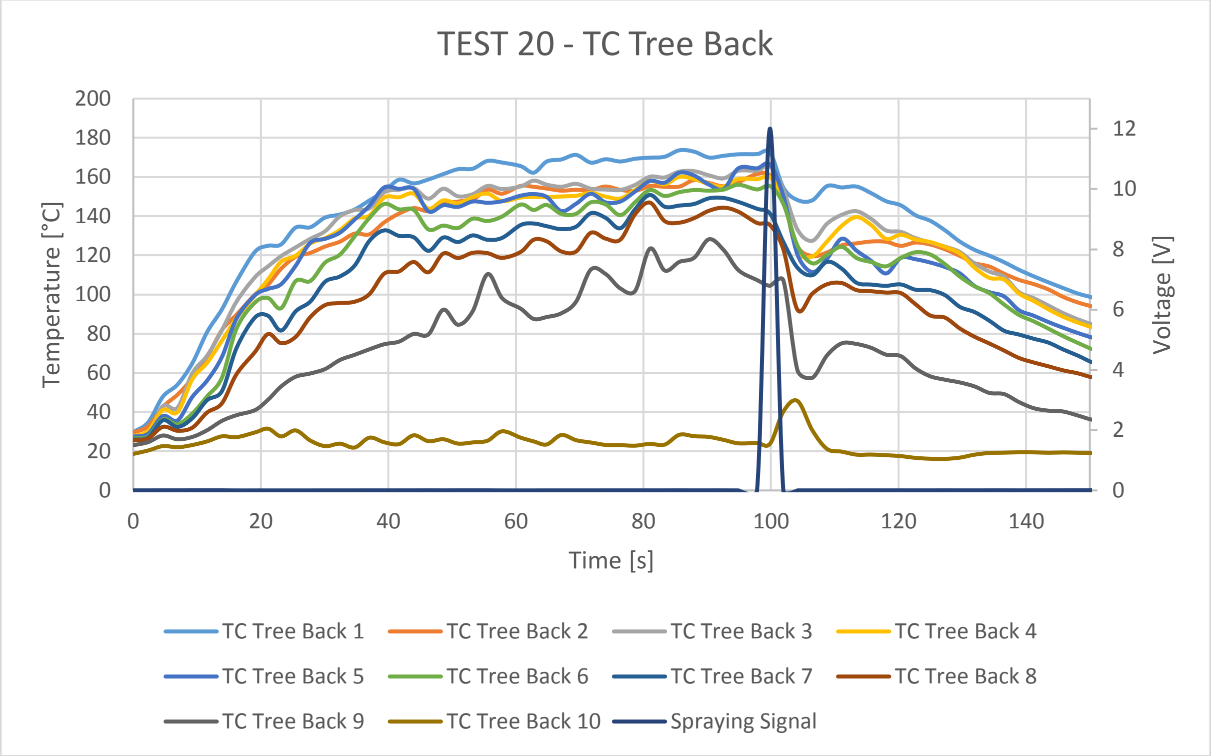

TEST 18 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

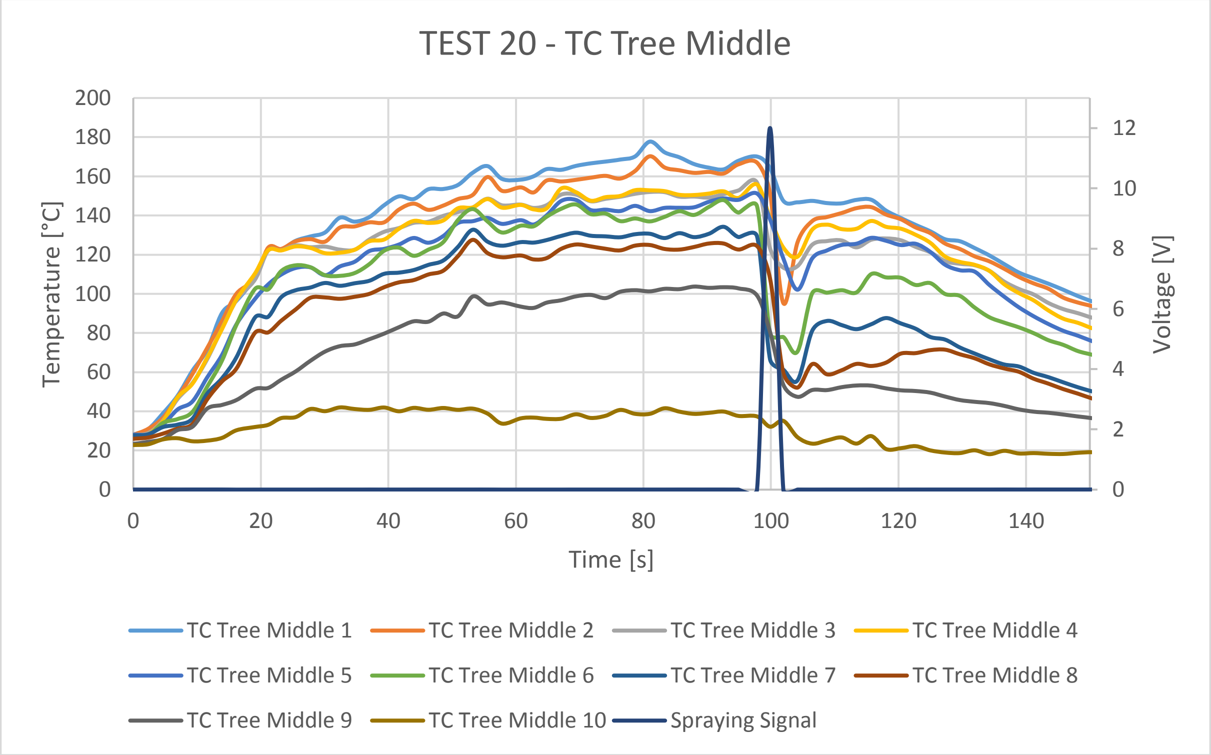

TEST 19 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

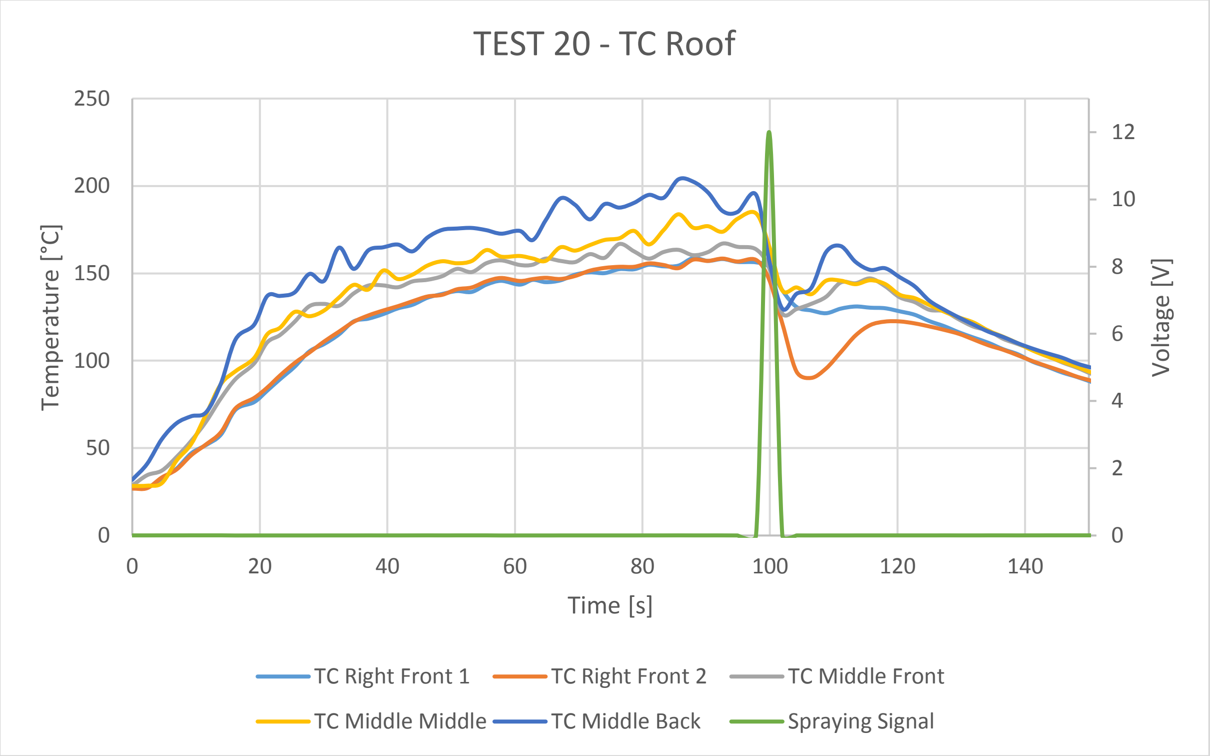

TEST 19 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

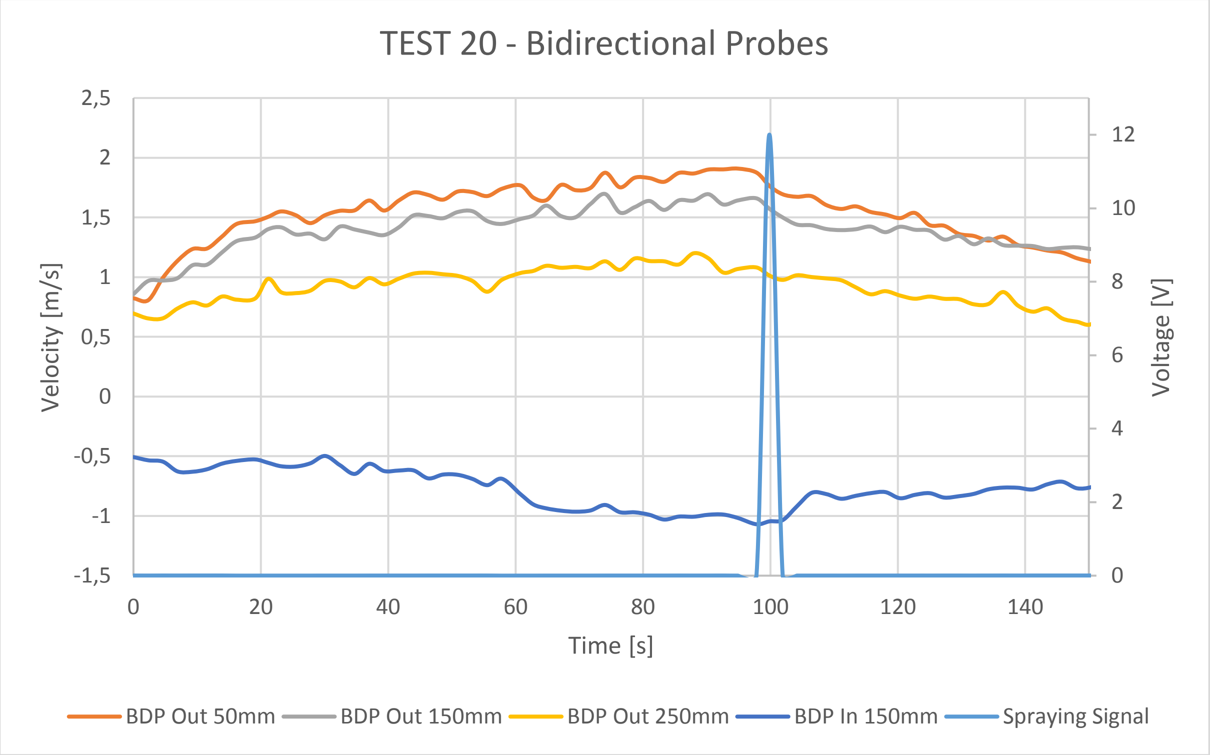

TEST 19 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

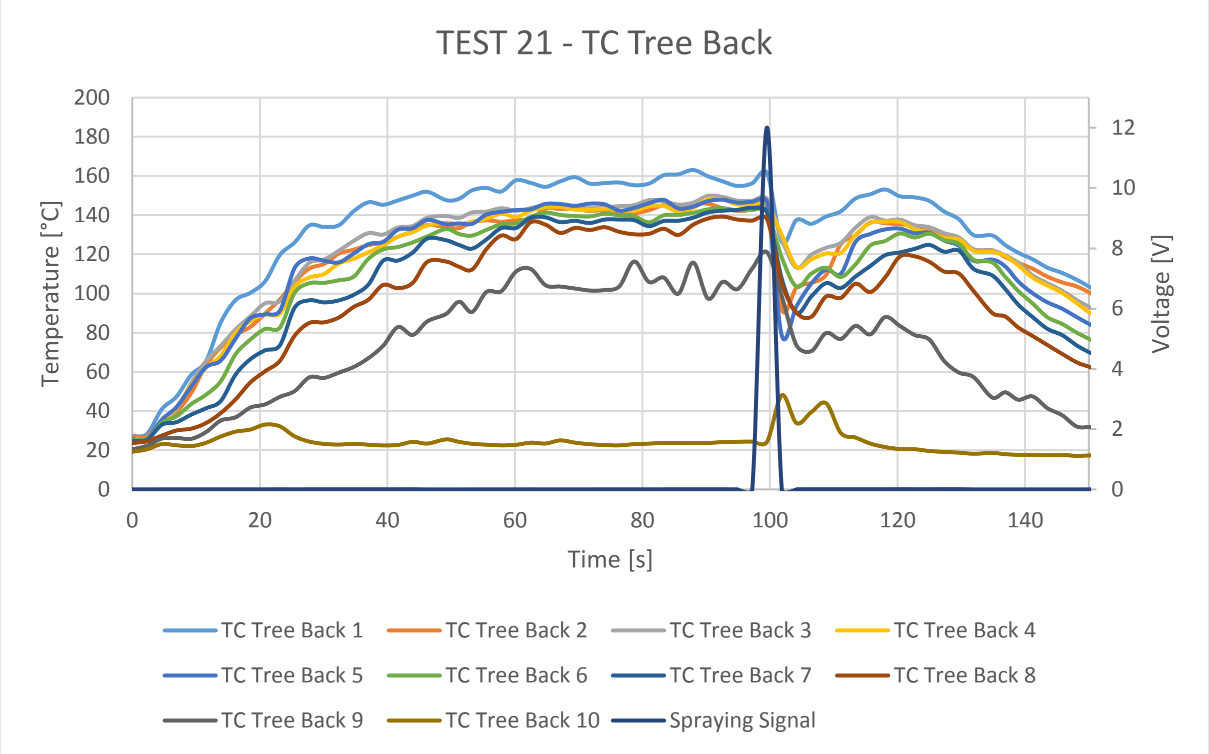

TEST 19 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

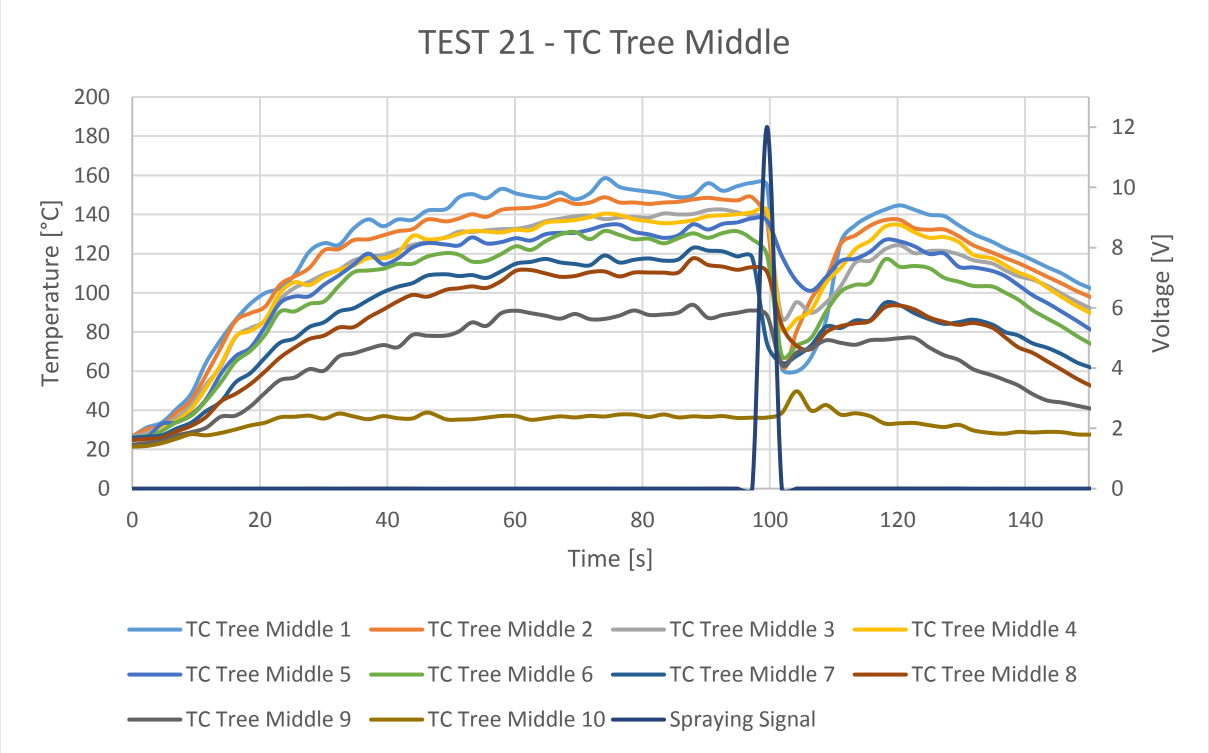

TEST 20 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

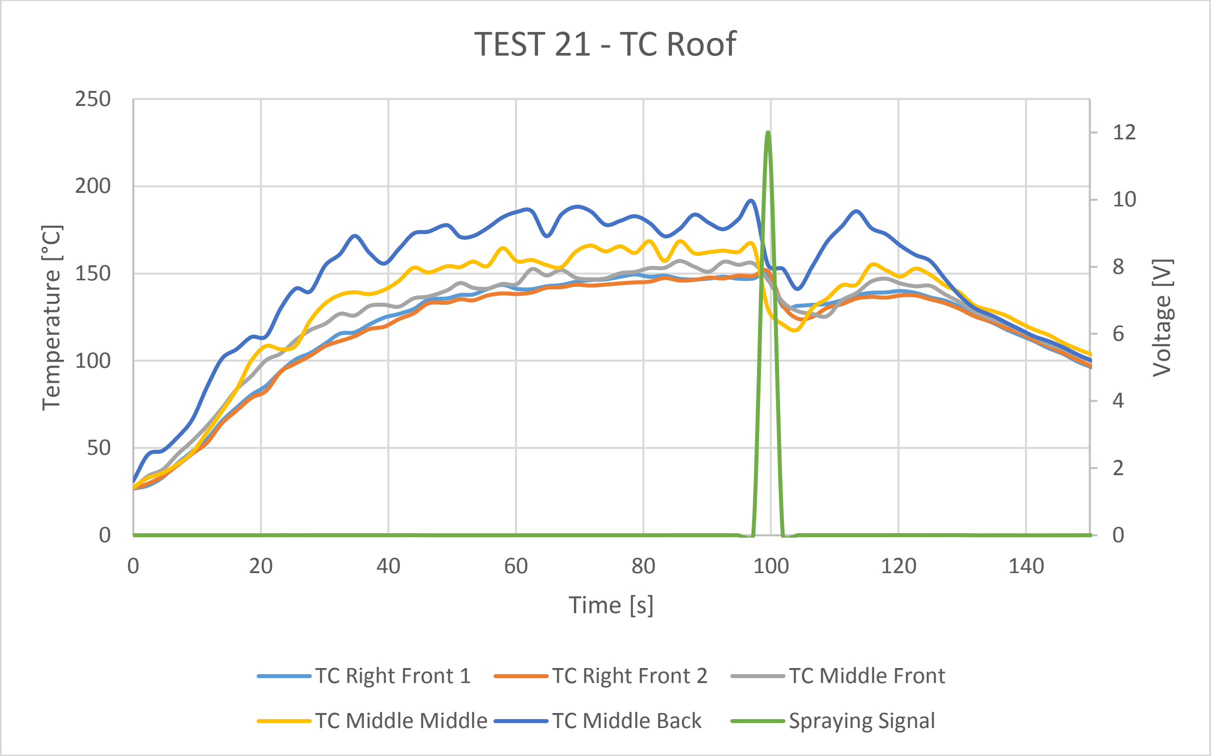

TEST 20 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

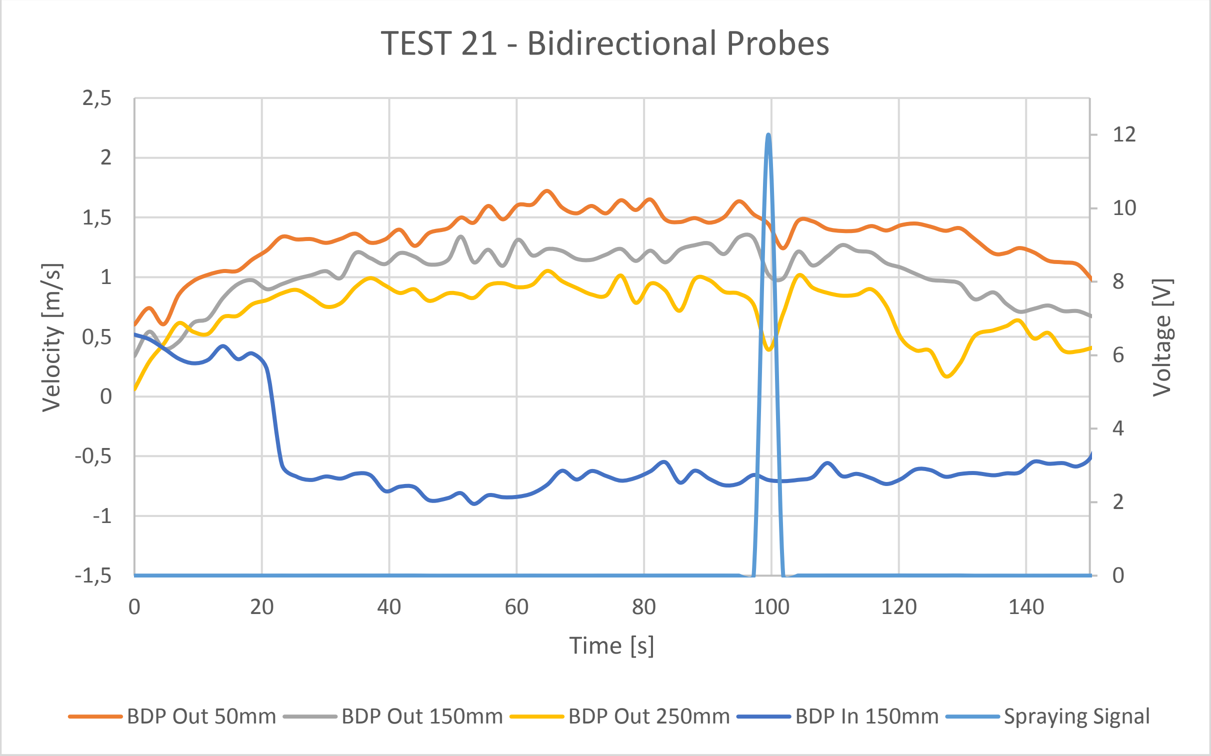

TEST 20 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

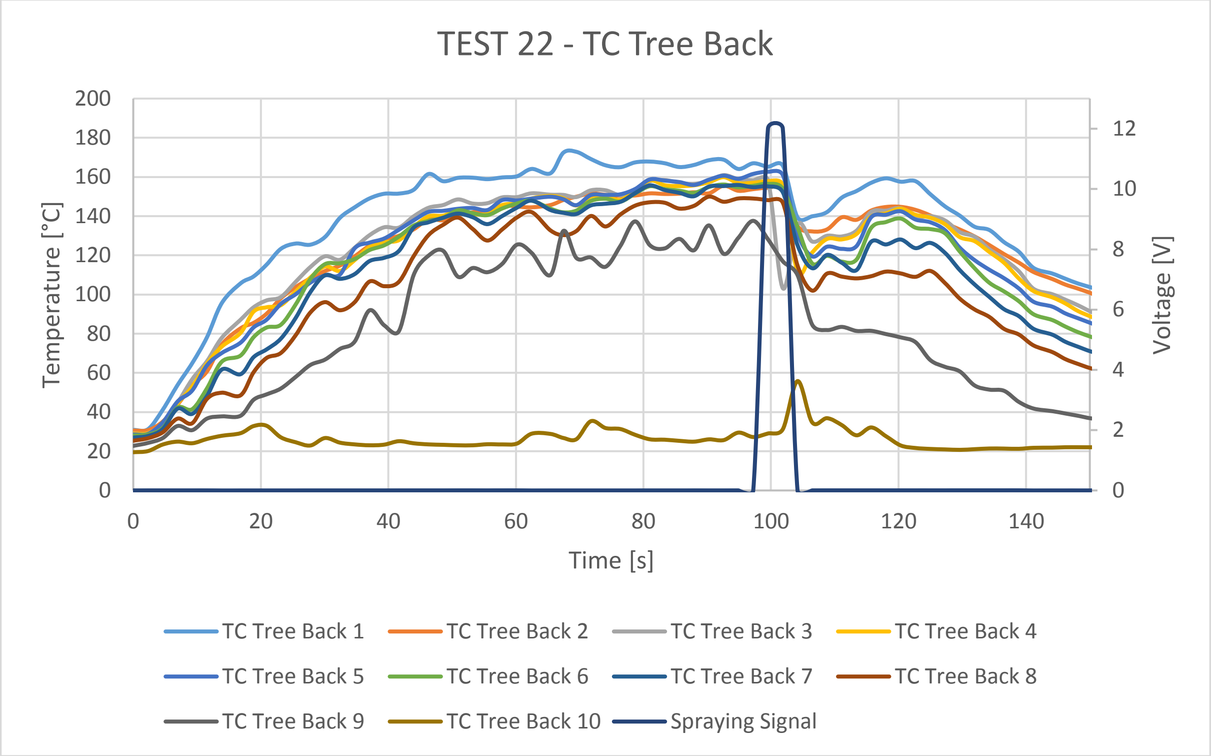

TEST 20 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

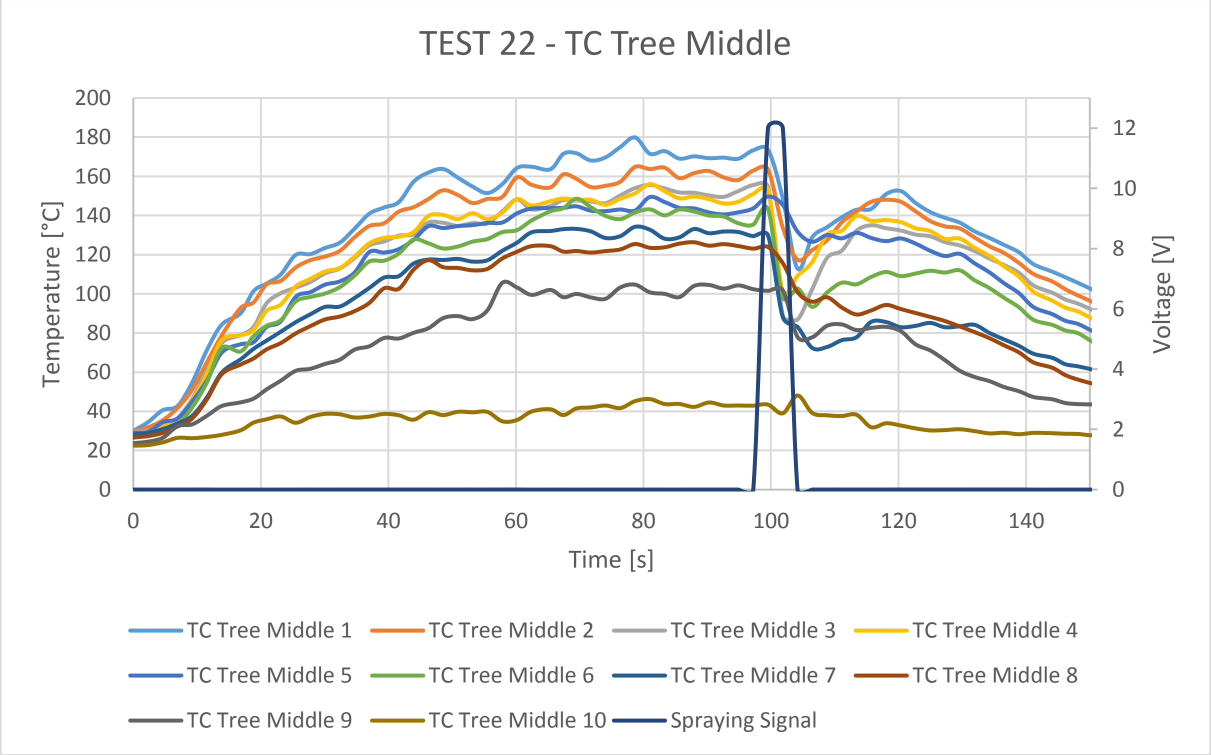

TEST 21 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

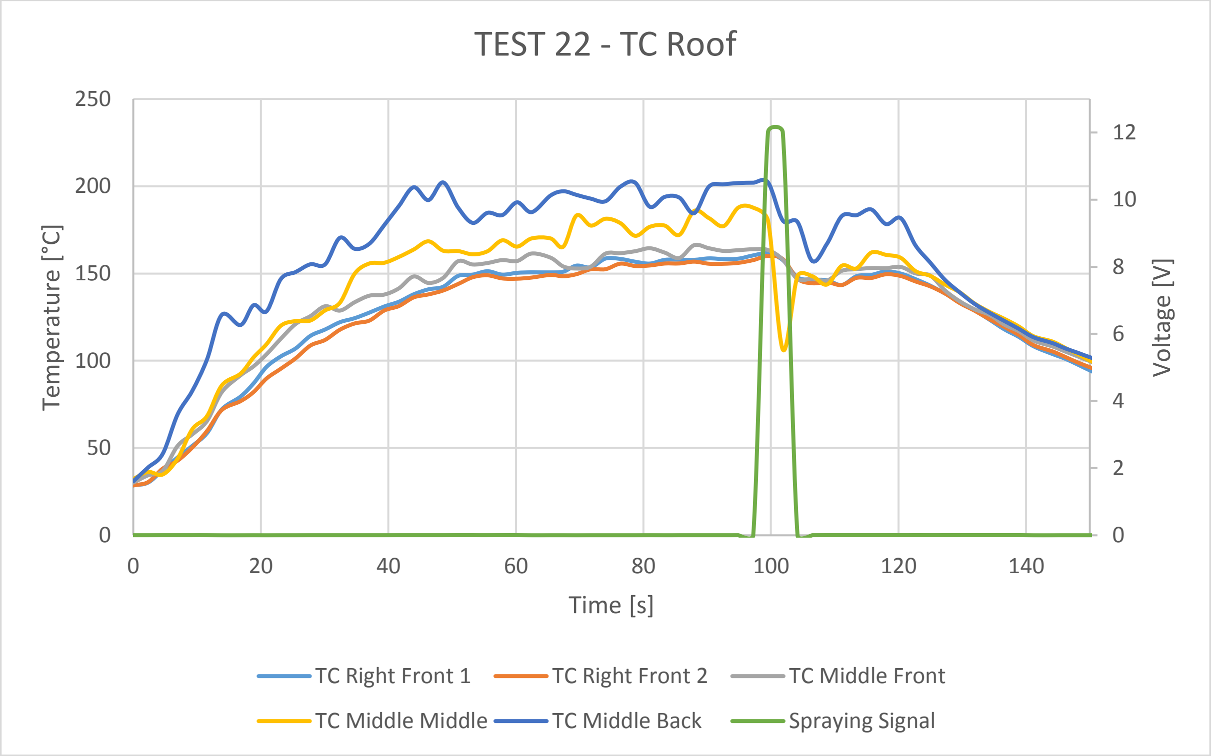

TEST 21 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

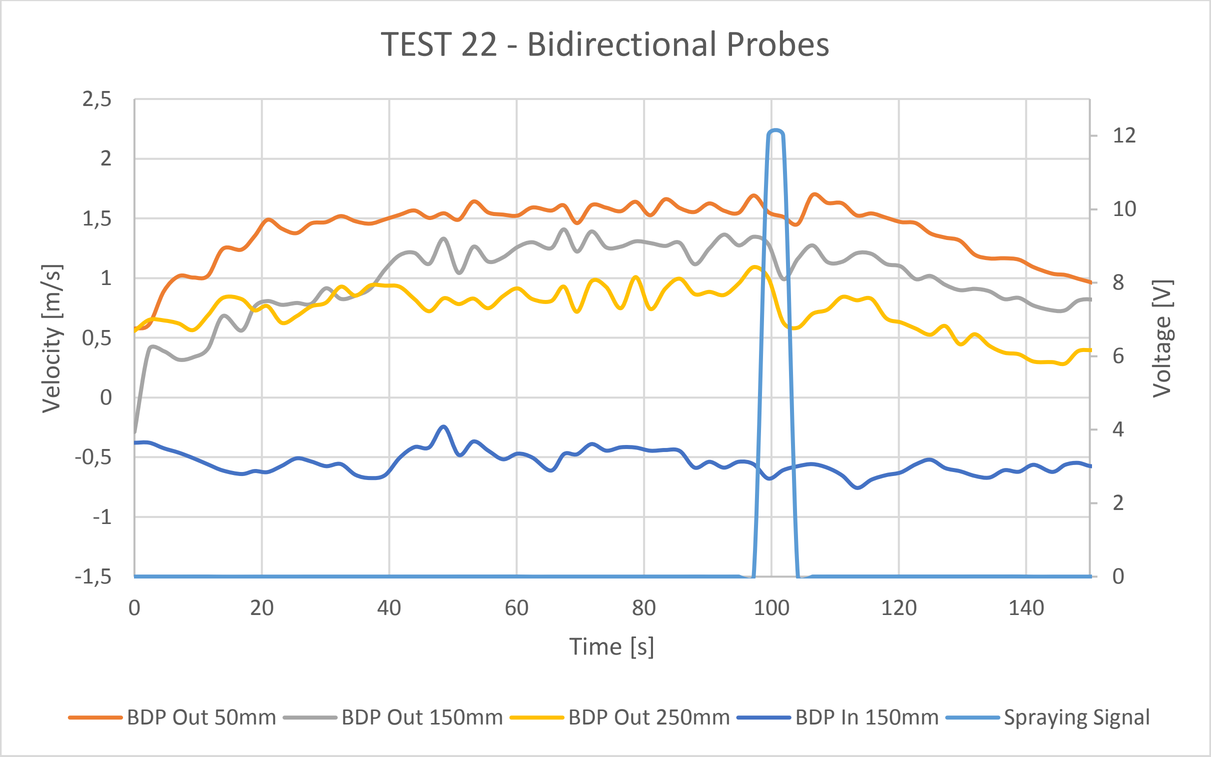

TEST 21 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

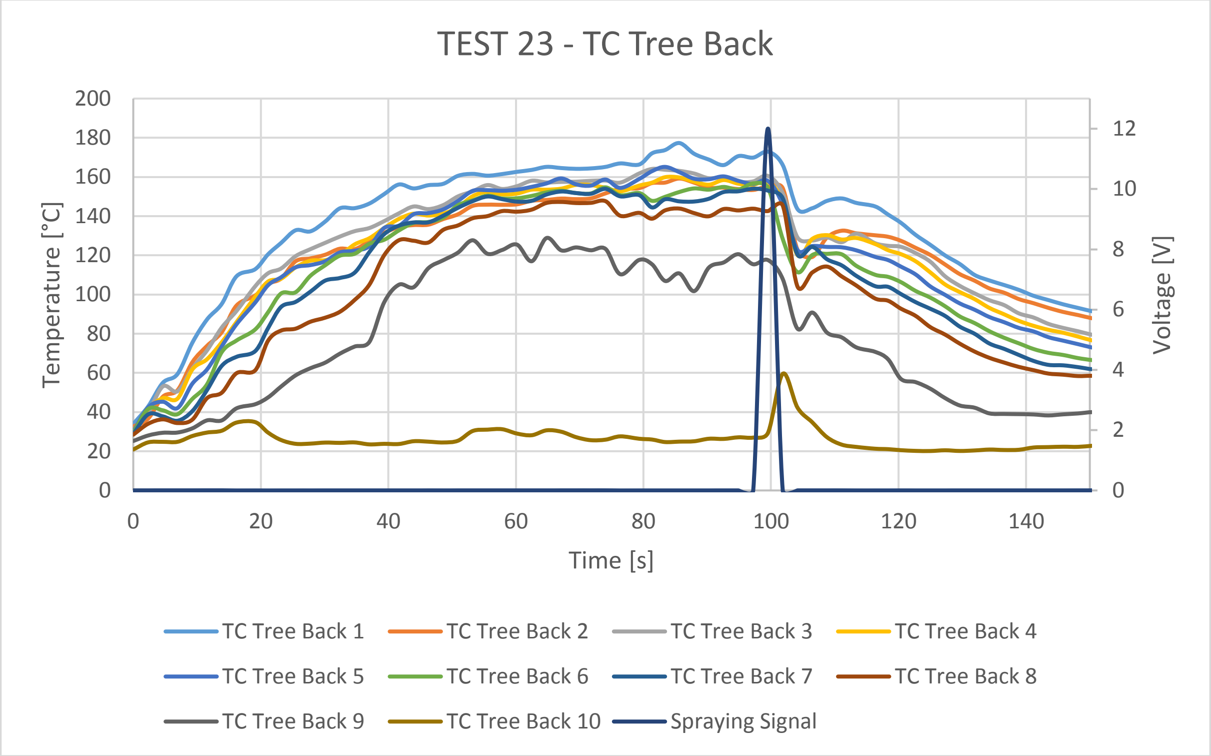

TEST 21 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

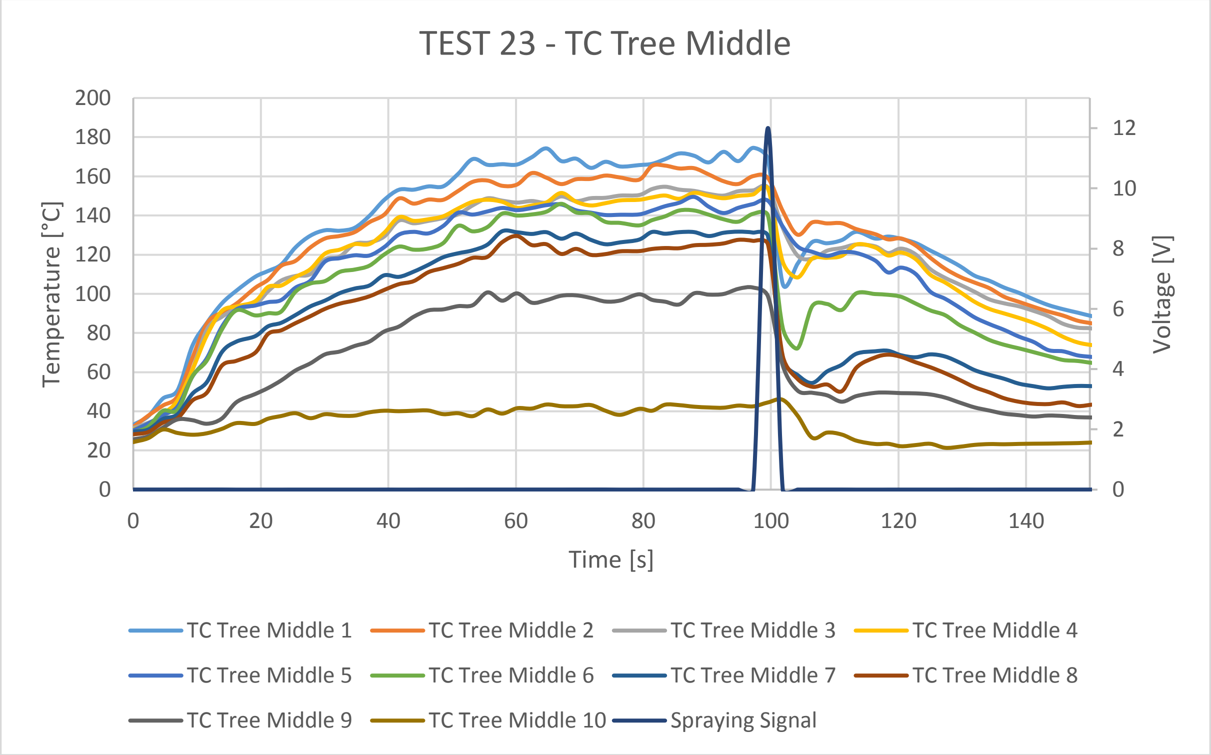

TEST 22 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

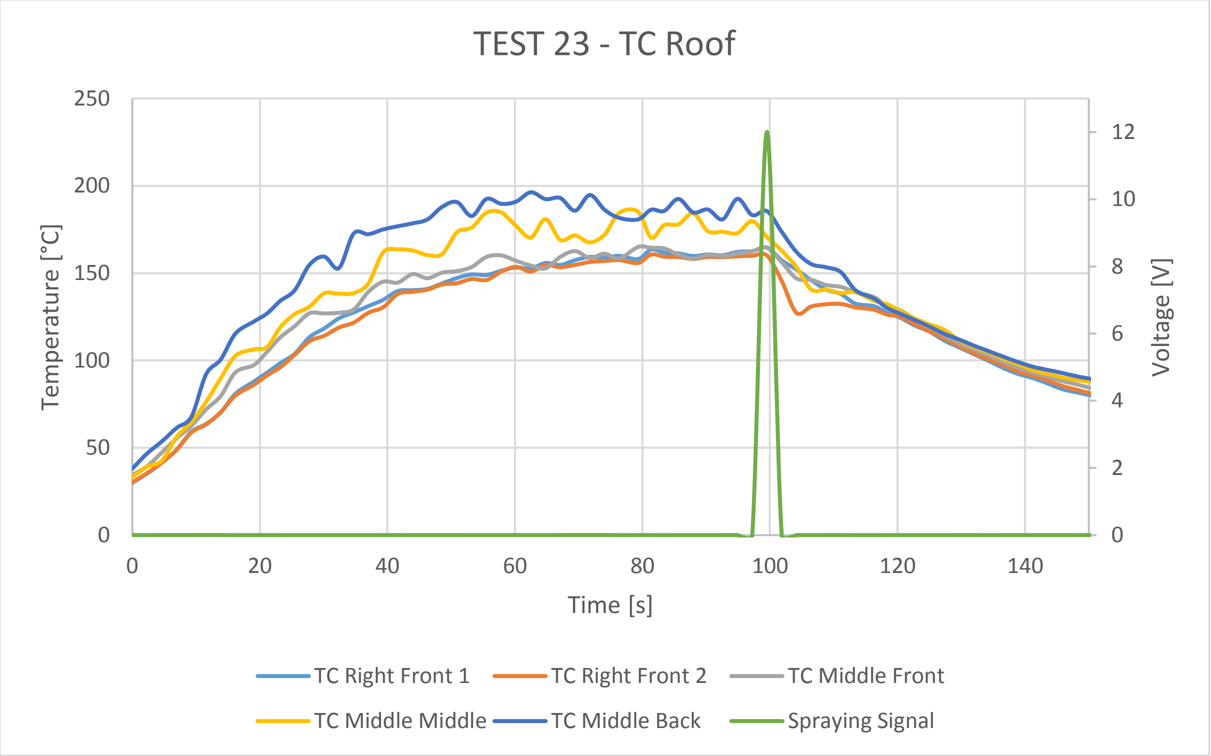

TEST 22 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

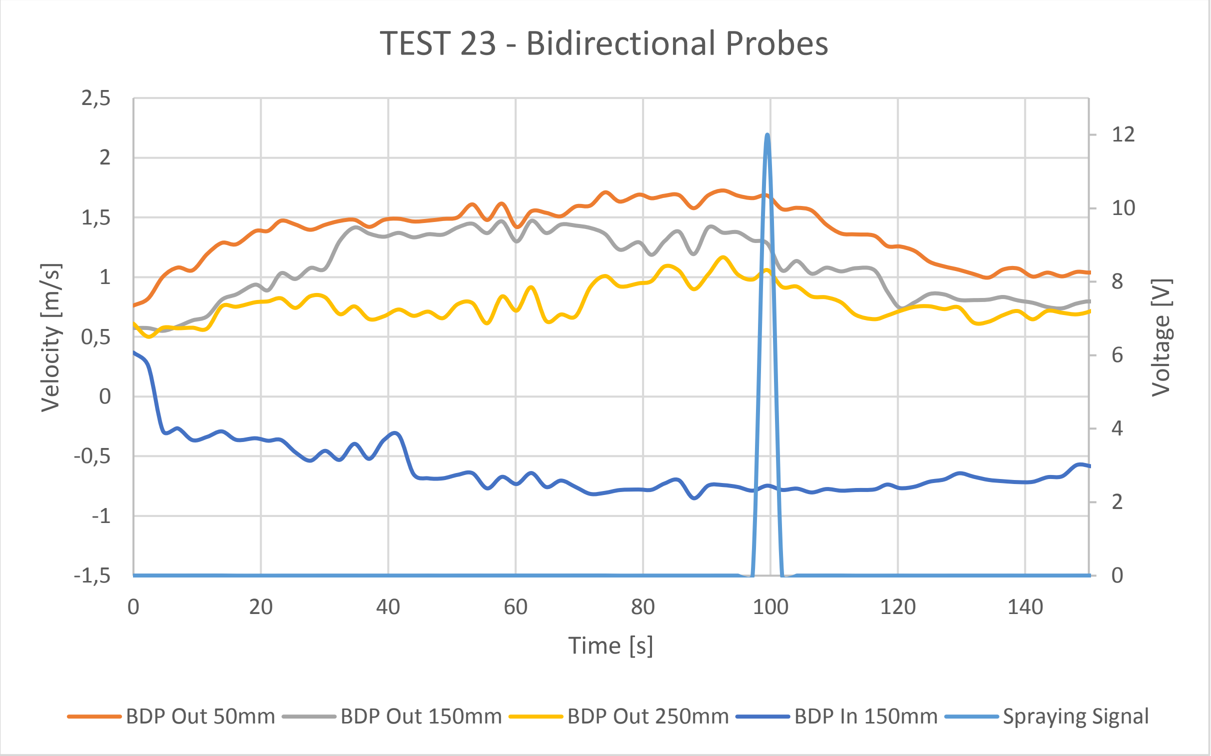

TEST 22 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

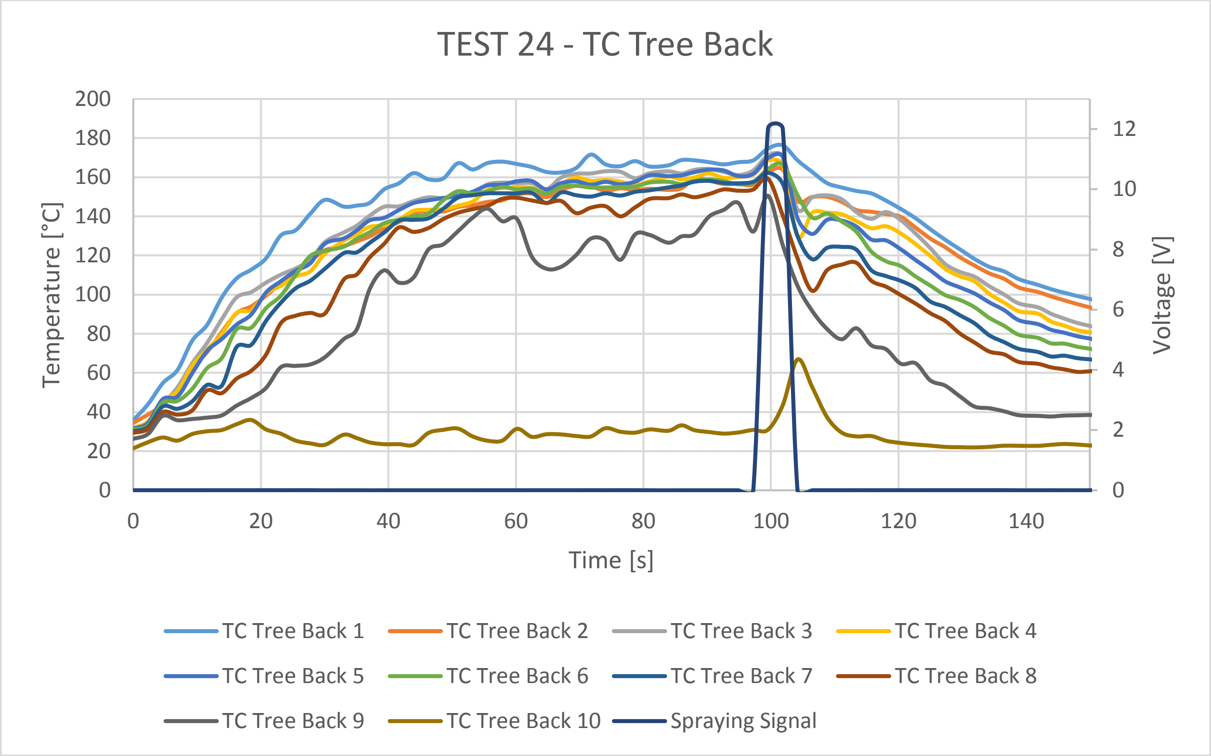

TEST 22 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

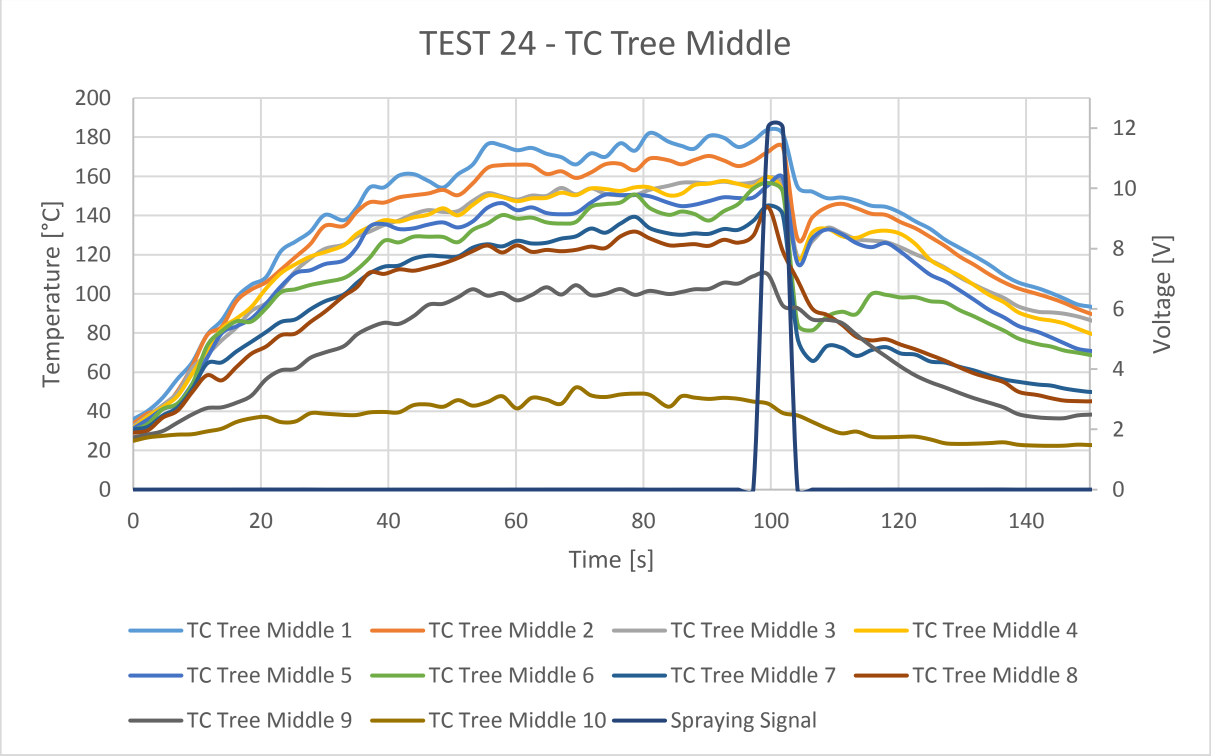

TEST 23 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

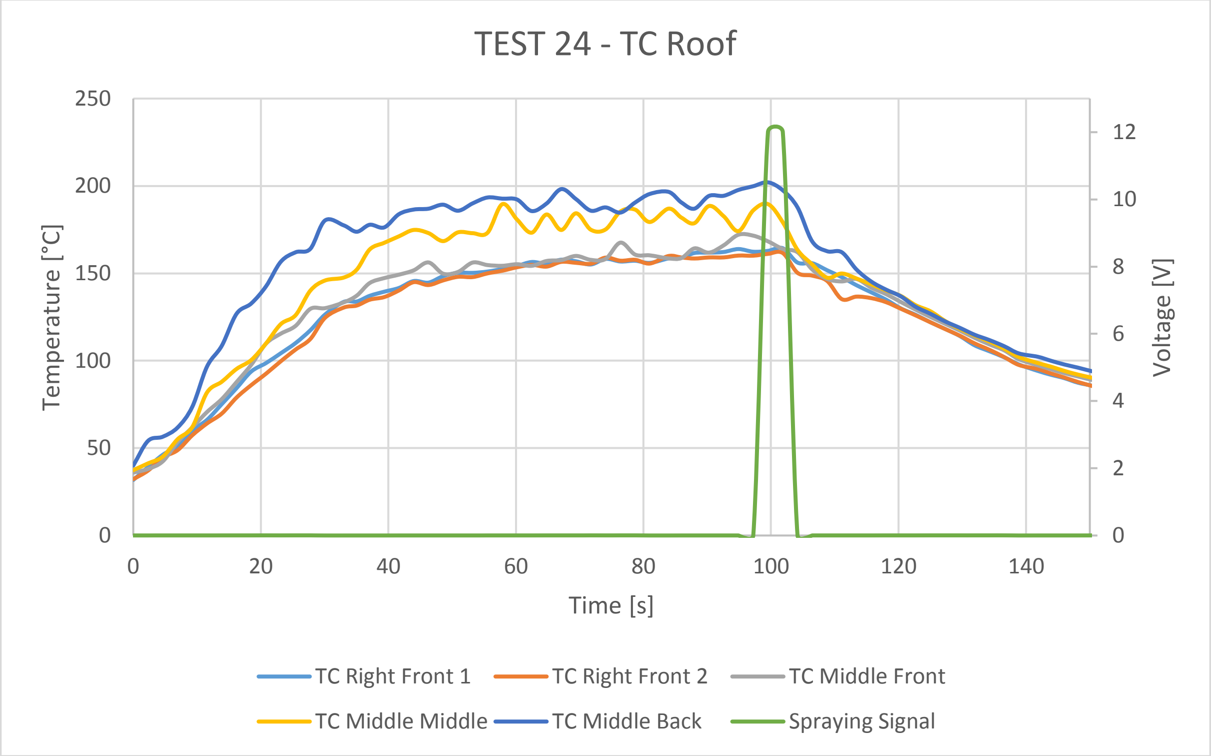

TEST 23 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

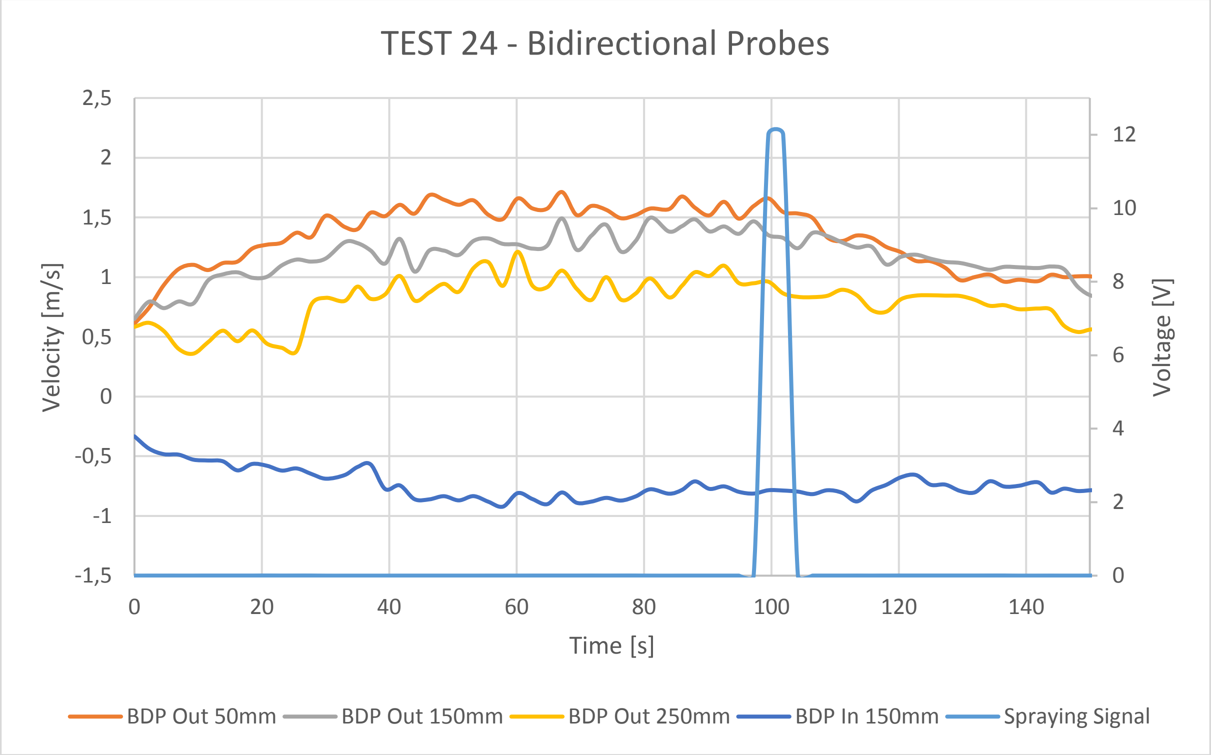

TEST 23 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

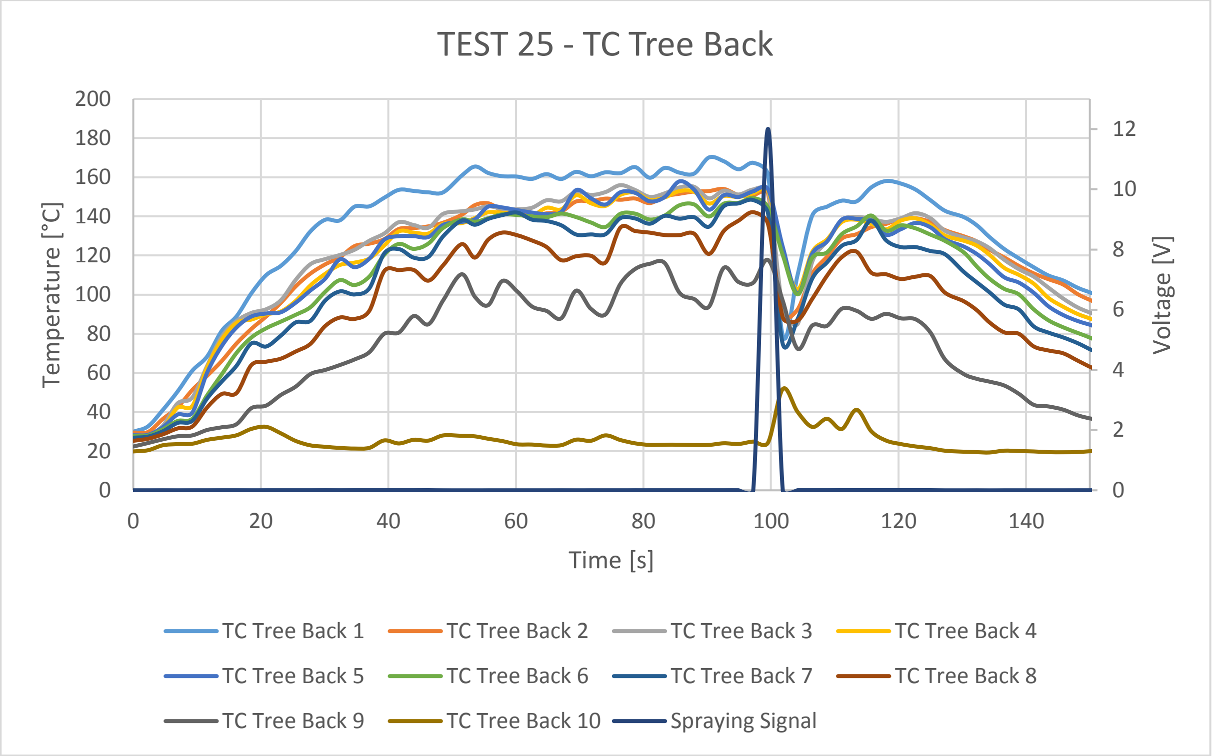

TEST 23 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

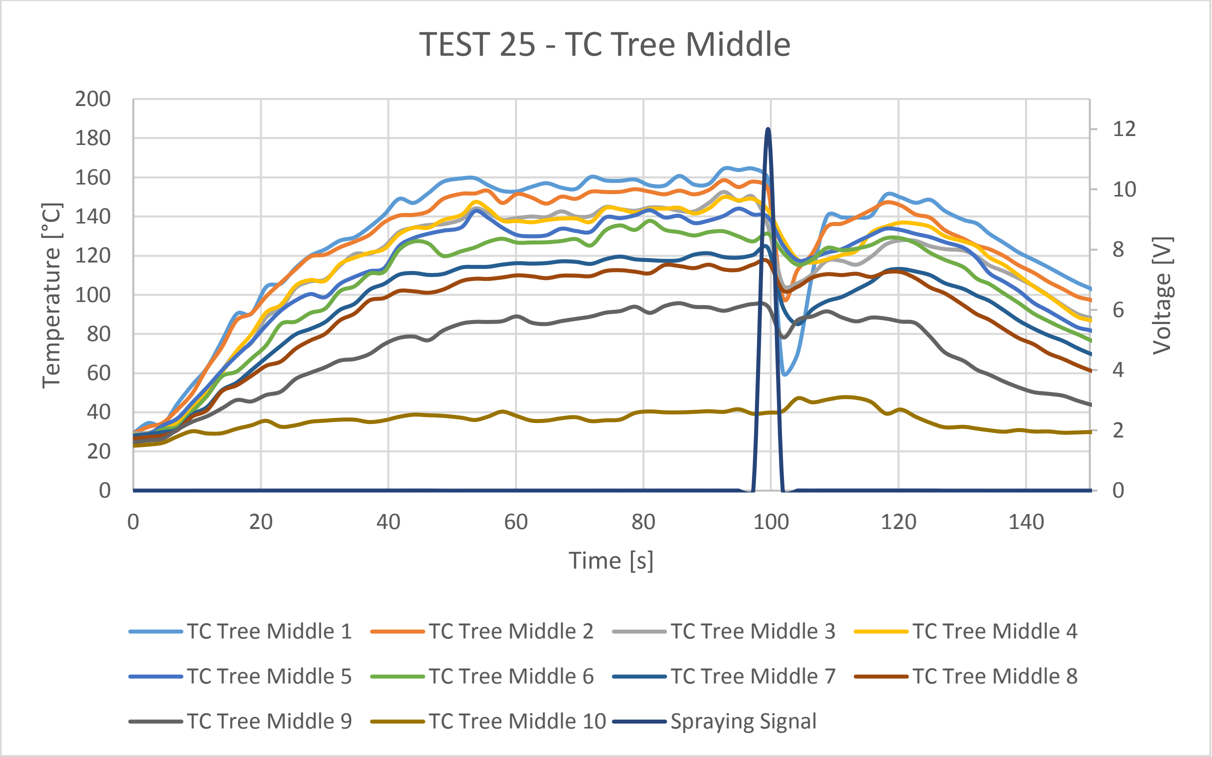

TEST 24 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

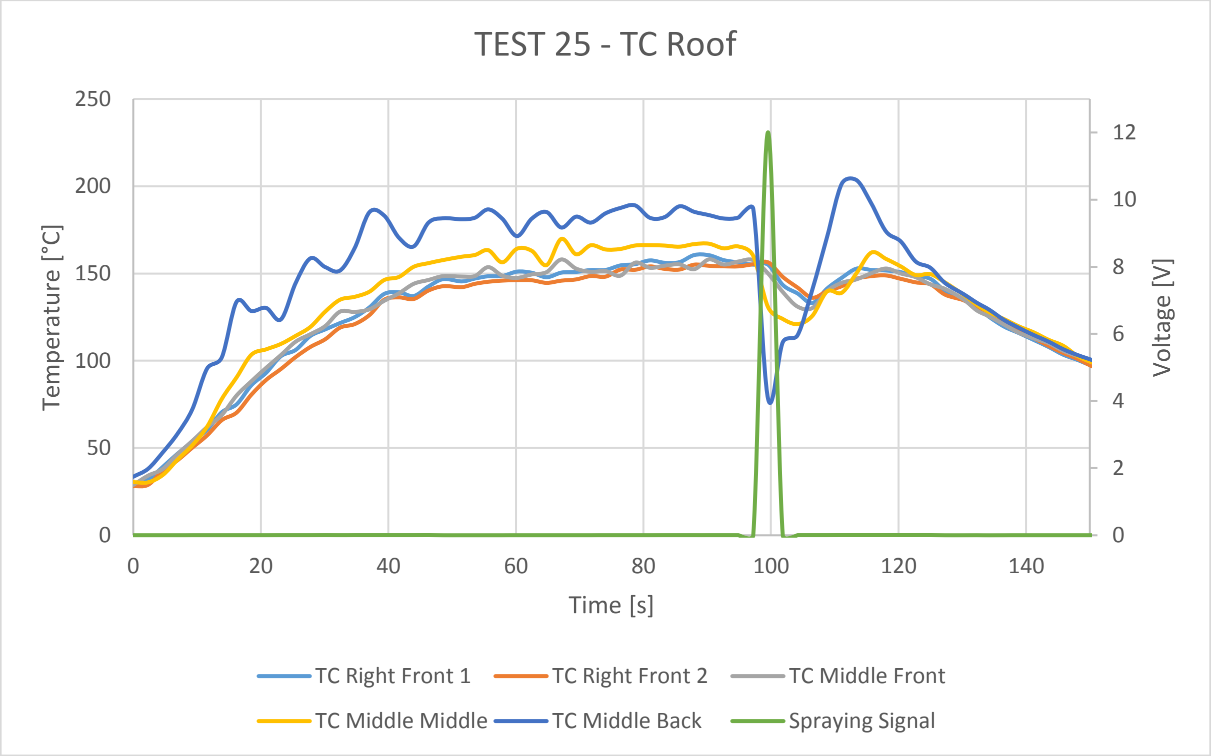

TEST 24 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

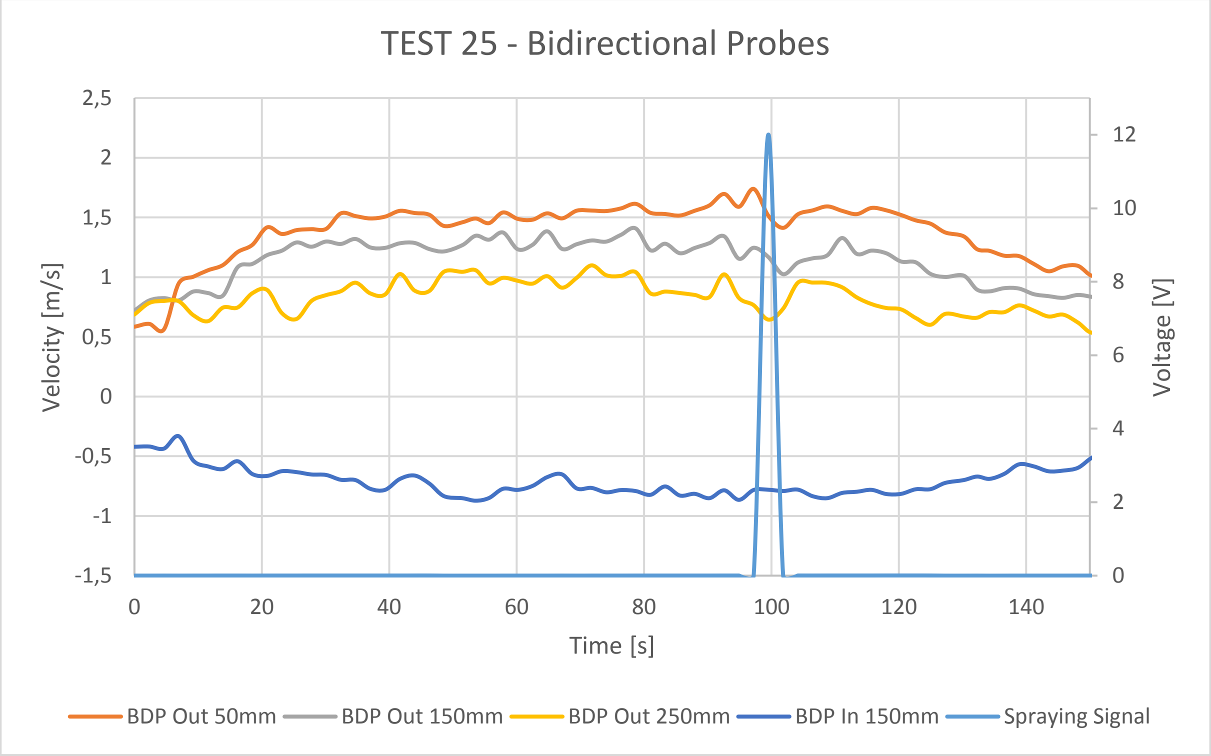

TEST 24 - TC Roof
Temperature [°C]
Voltage [V]
Time [s]
250
200
150
100
50
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

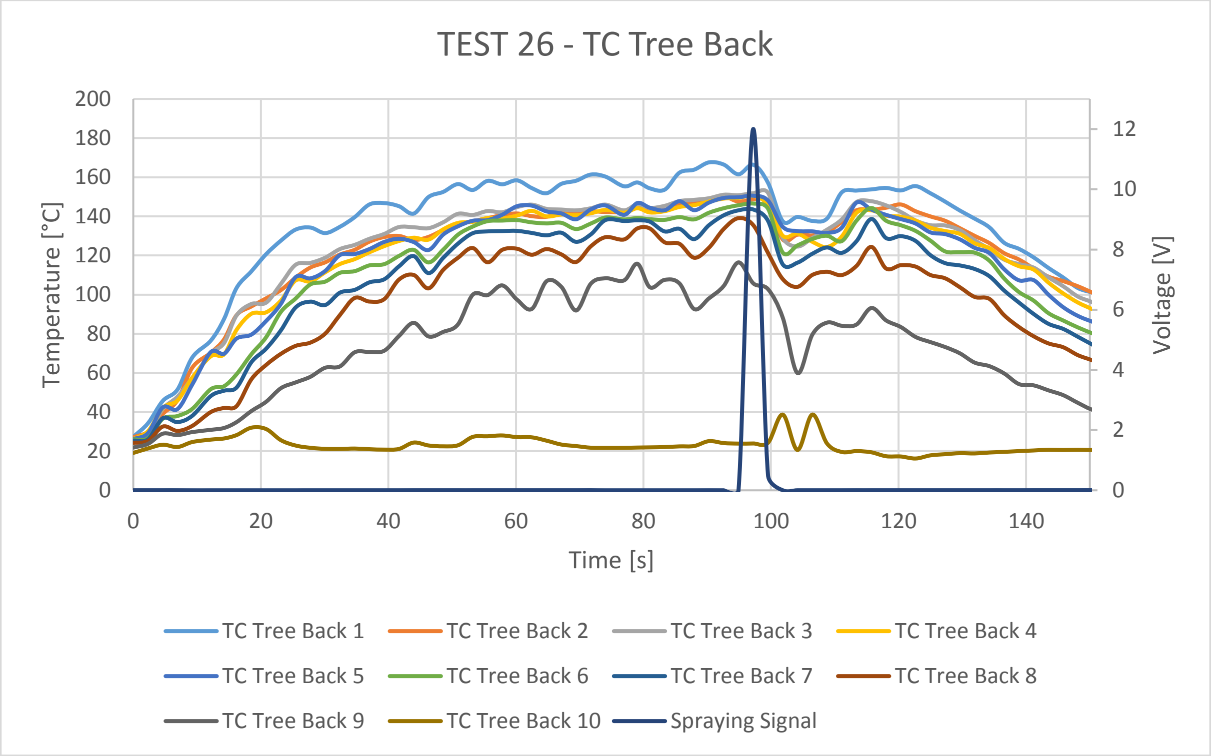

TEST 24 - Bidirectional Probes
Velocity [m/s]
Voltage [V]
Time [s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

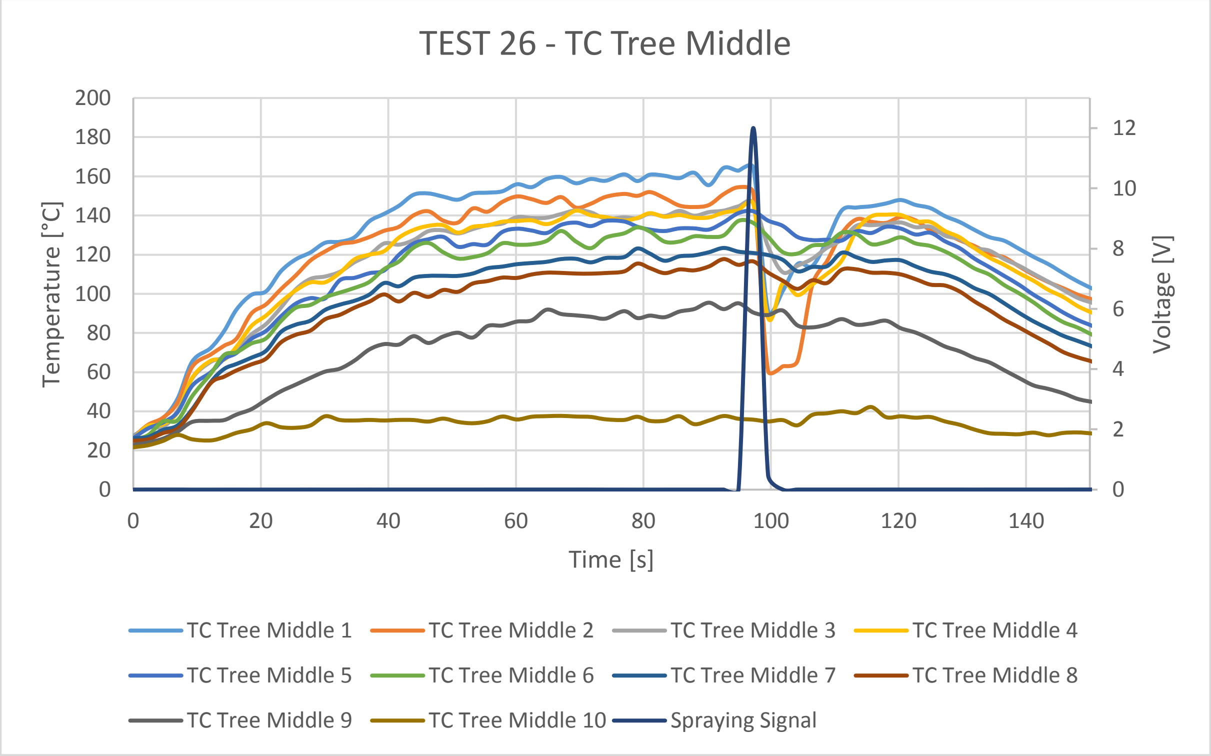

TEST 25 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Time [s]
0
20
40
60
80
100
120
140
Voltage [V]
12
10
8
6
4
2
0
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

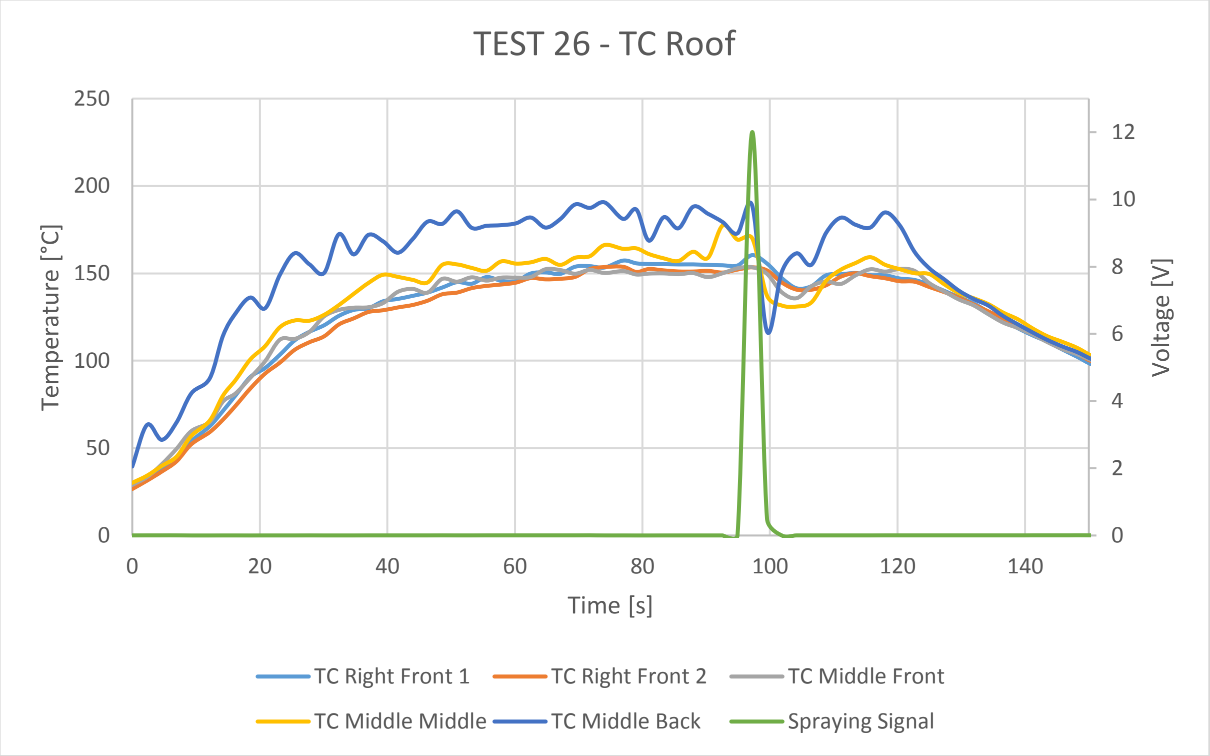

TEST 25 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Time [s]
0
20
40
60
80
100
120
140
Voltage [V]
12
10
8
6
4
2
0
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

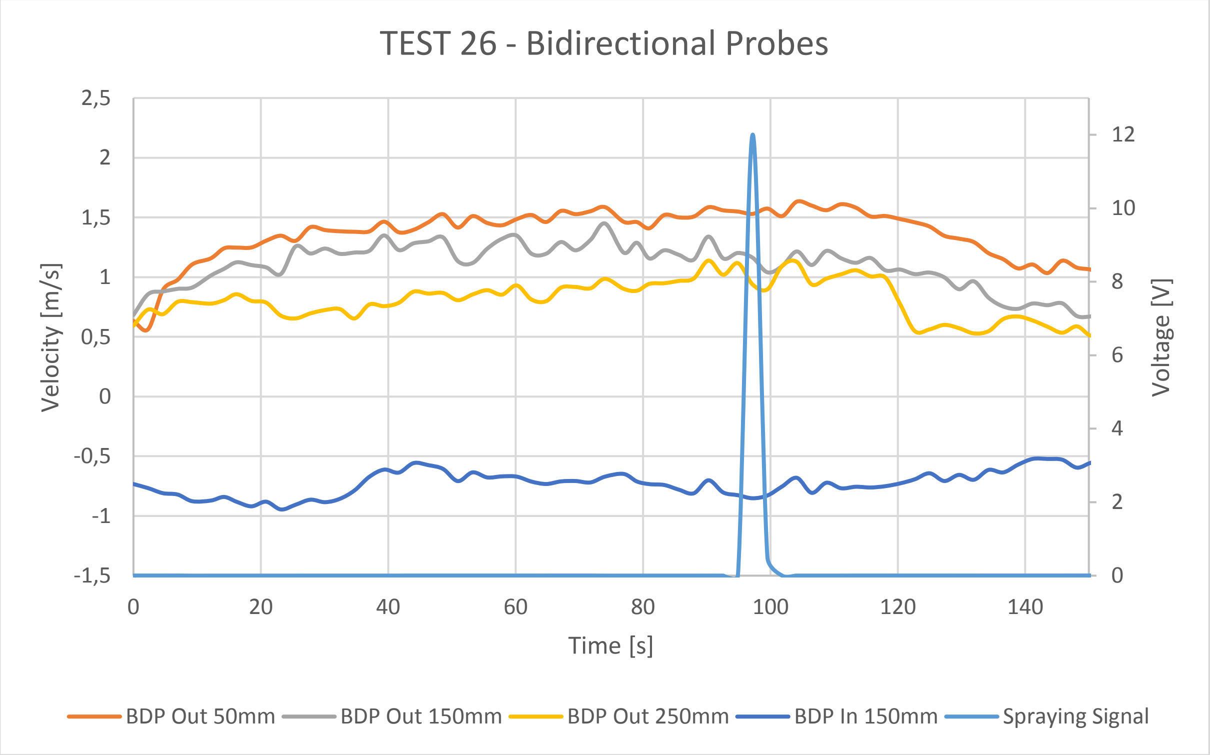

TEST 25 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

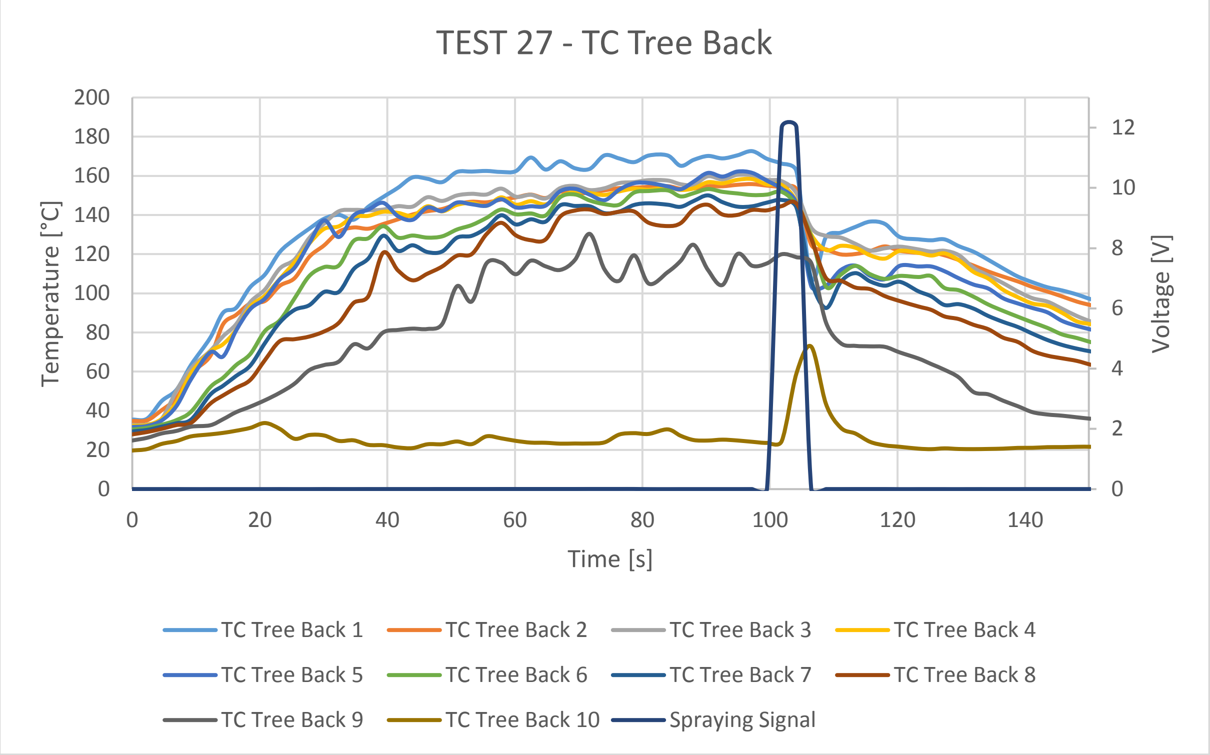

TEST 25 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

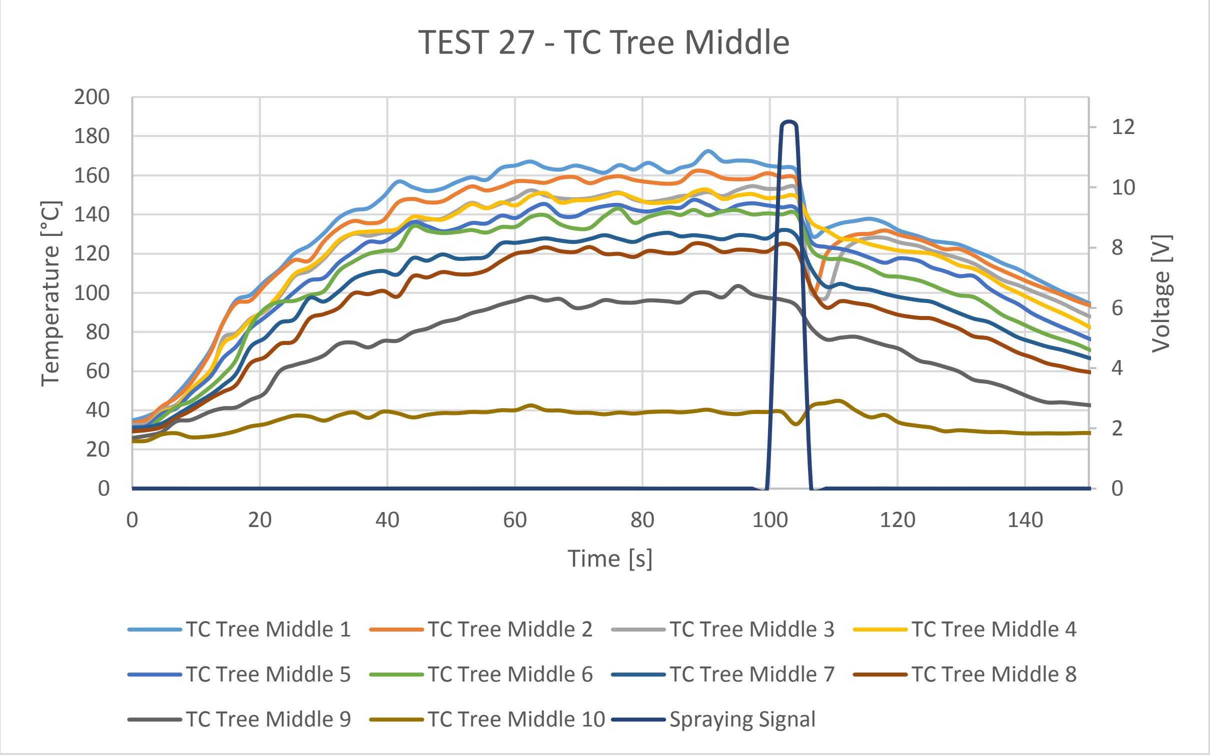

TEST 26 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

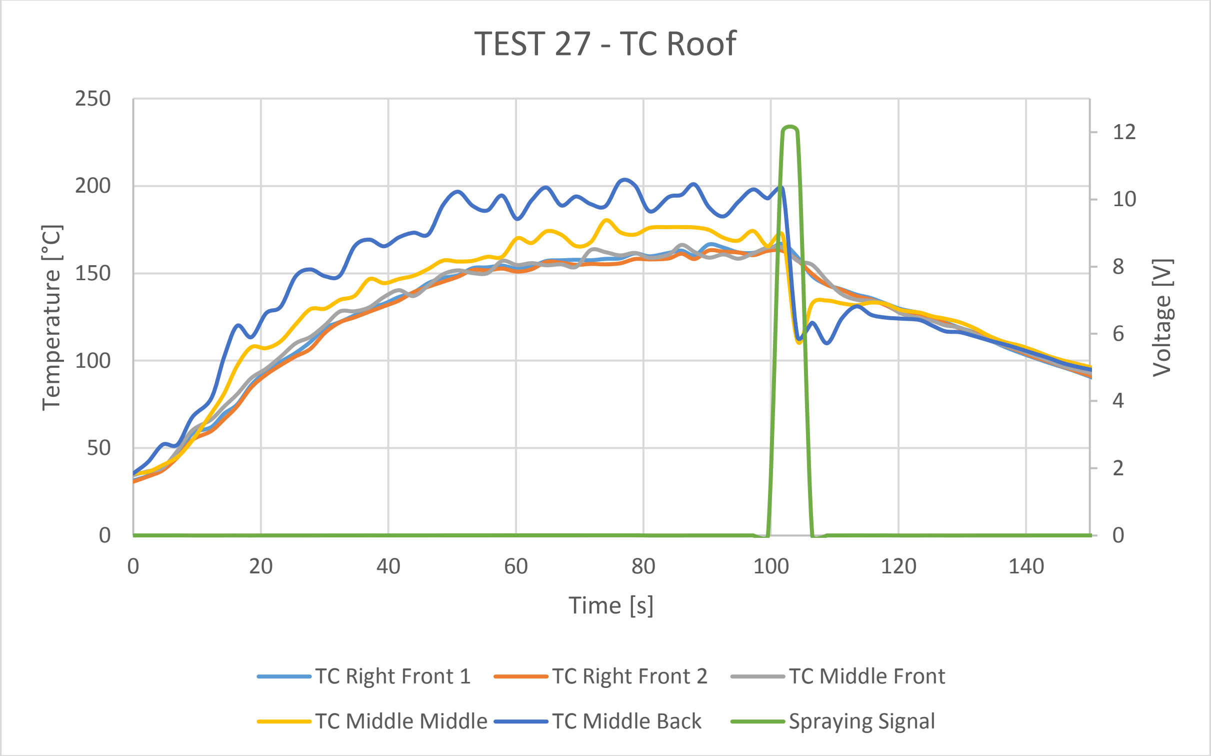

TEST 26 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

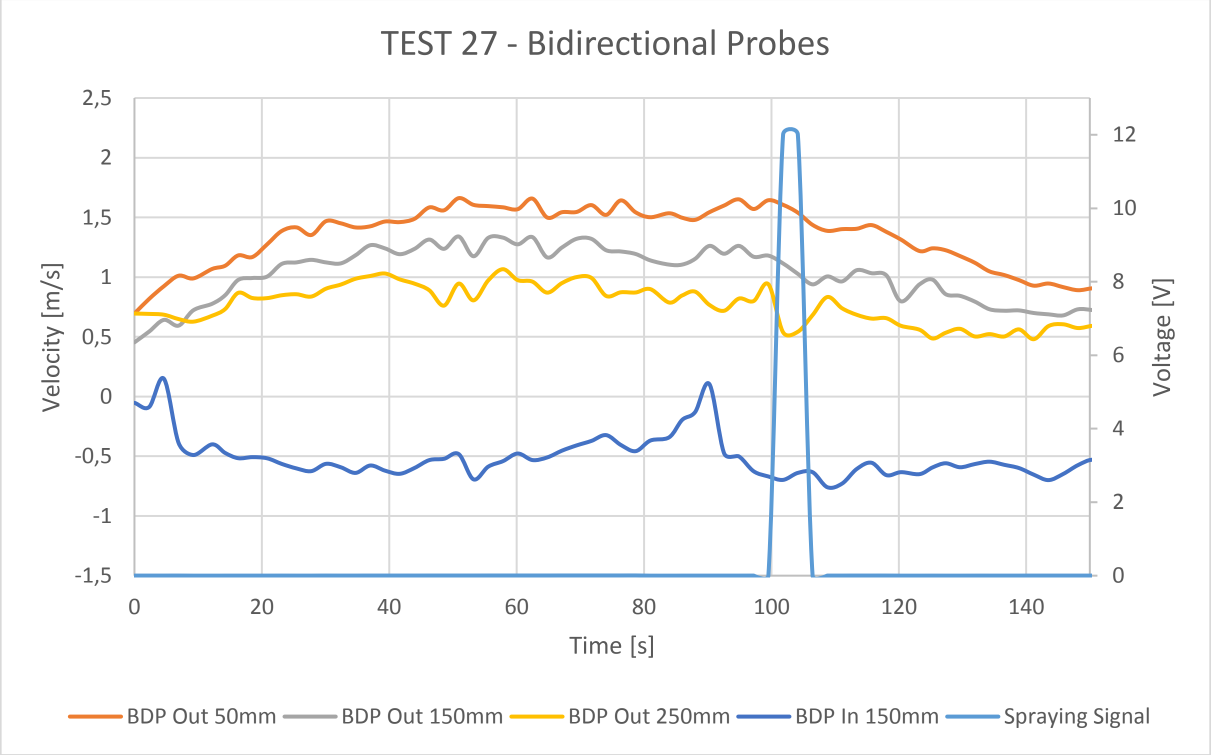

TEST 26 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

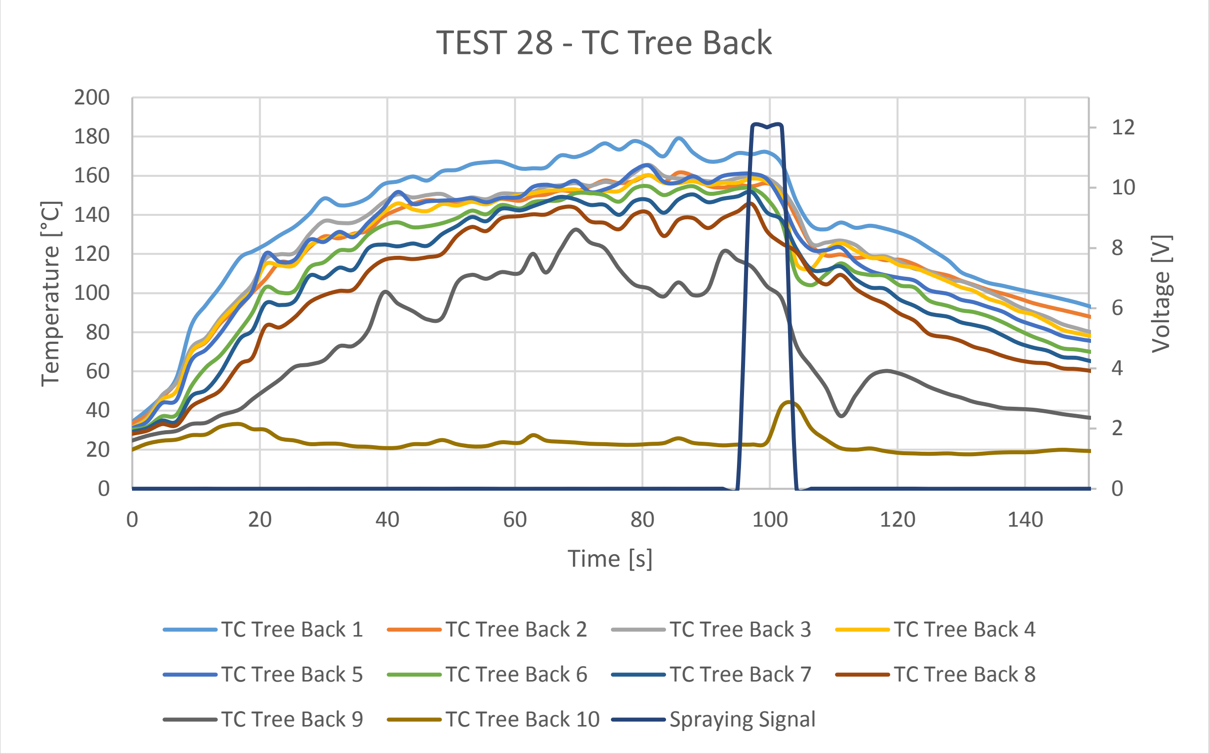

TEST 26 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

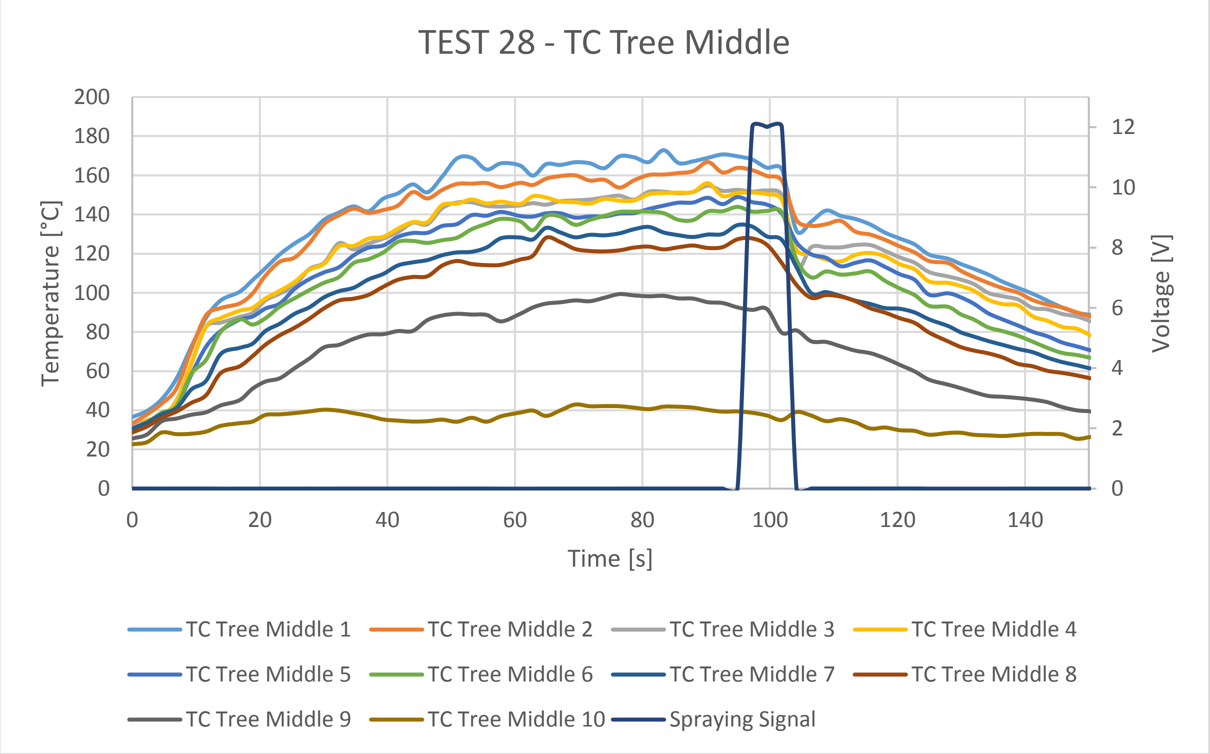

TEST 27 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

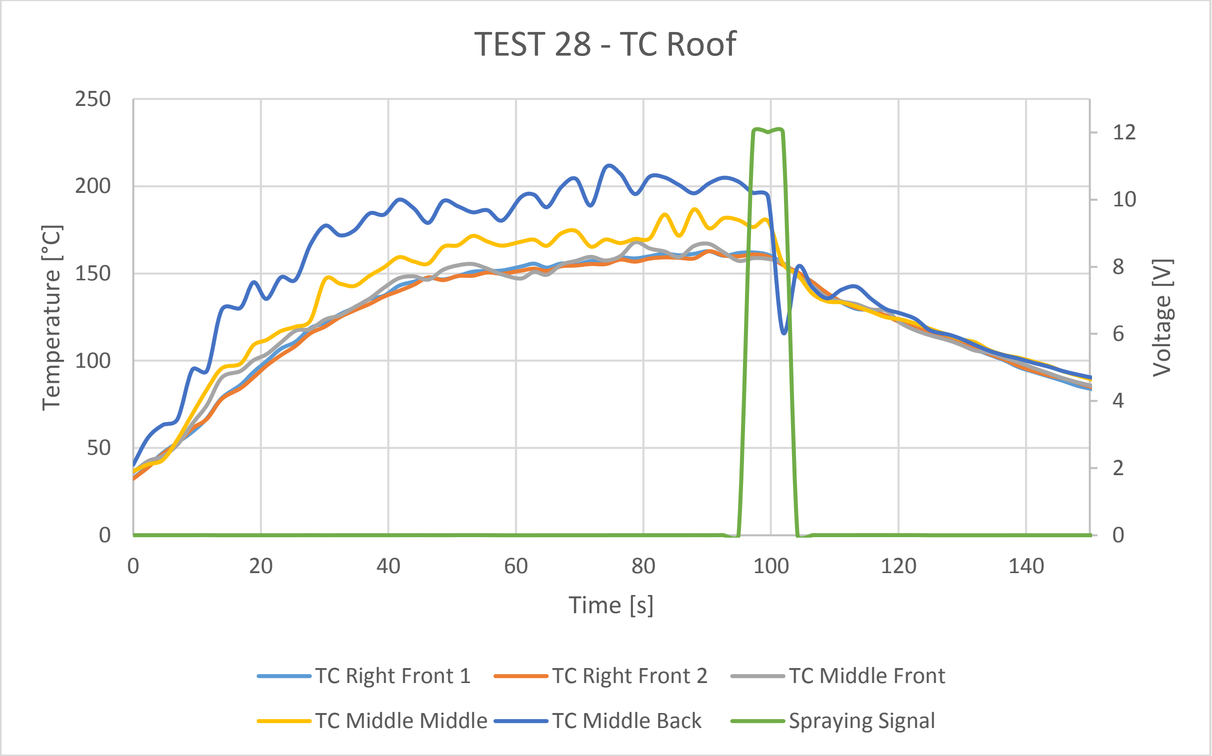

TEST 27 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

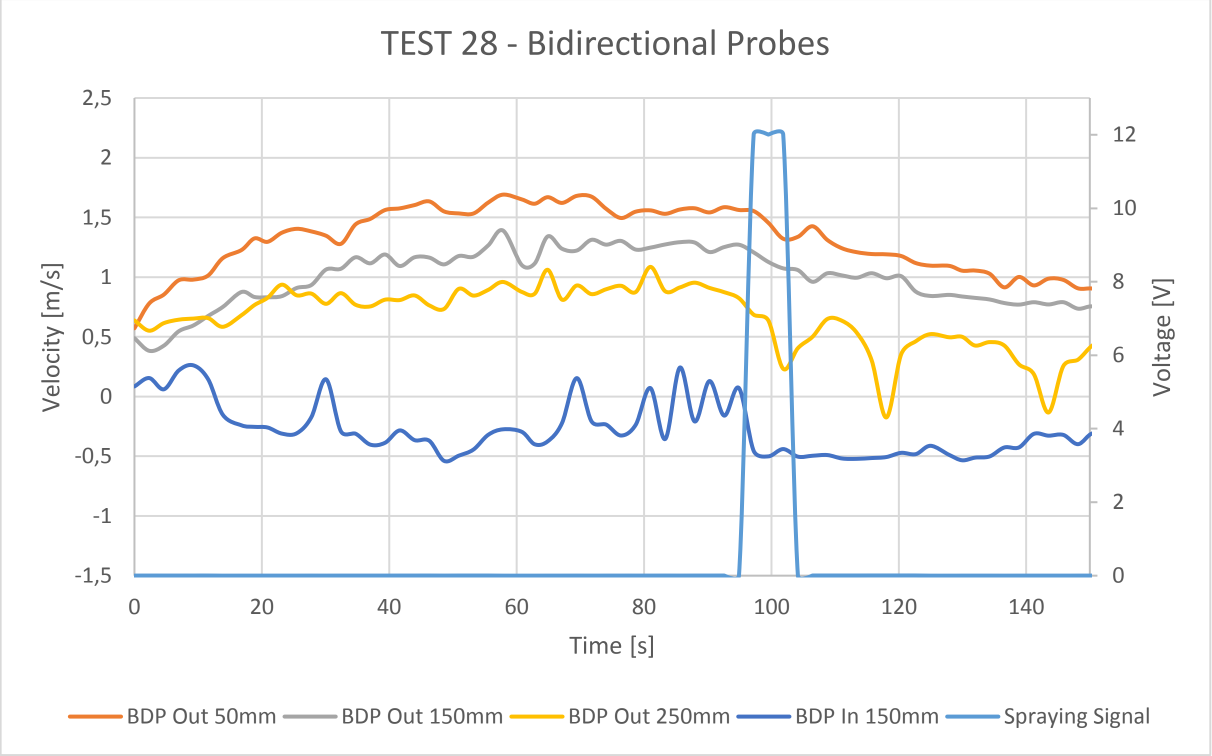

TEST 27 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

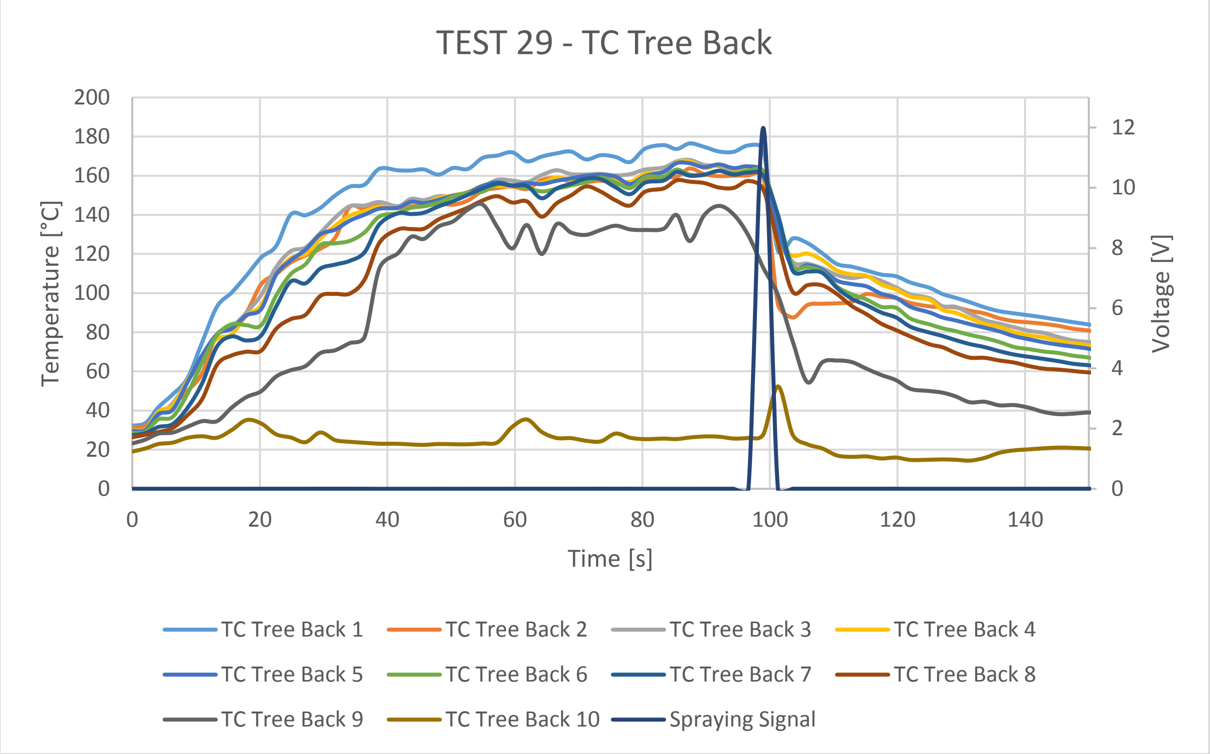

TEST 27 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

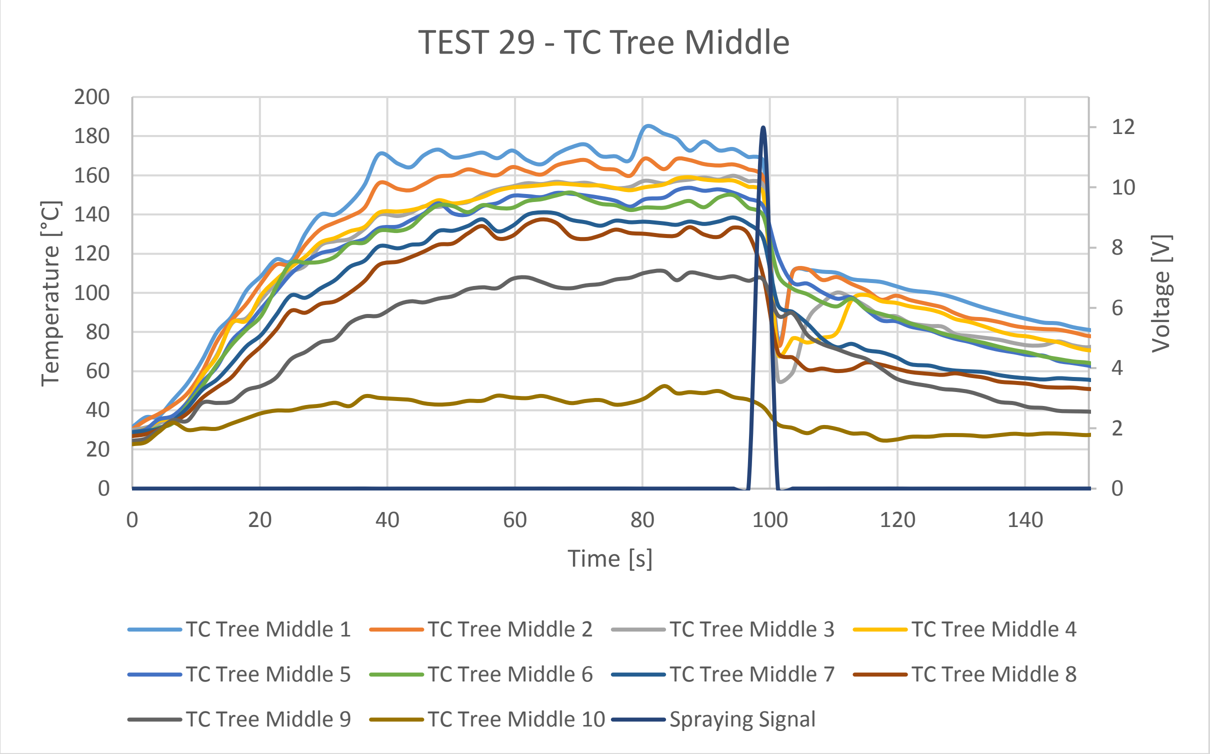

TEST 28 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

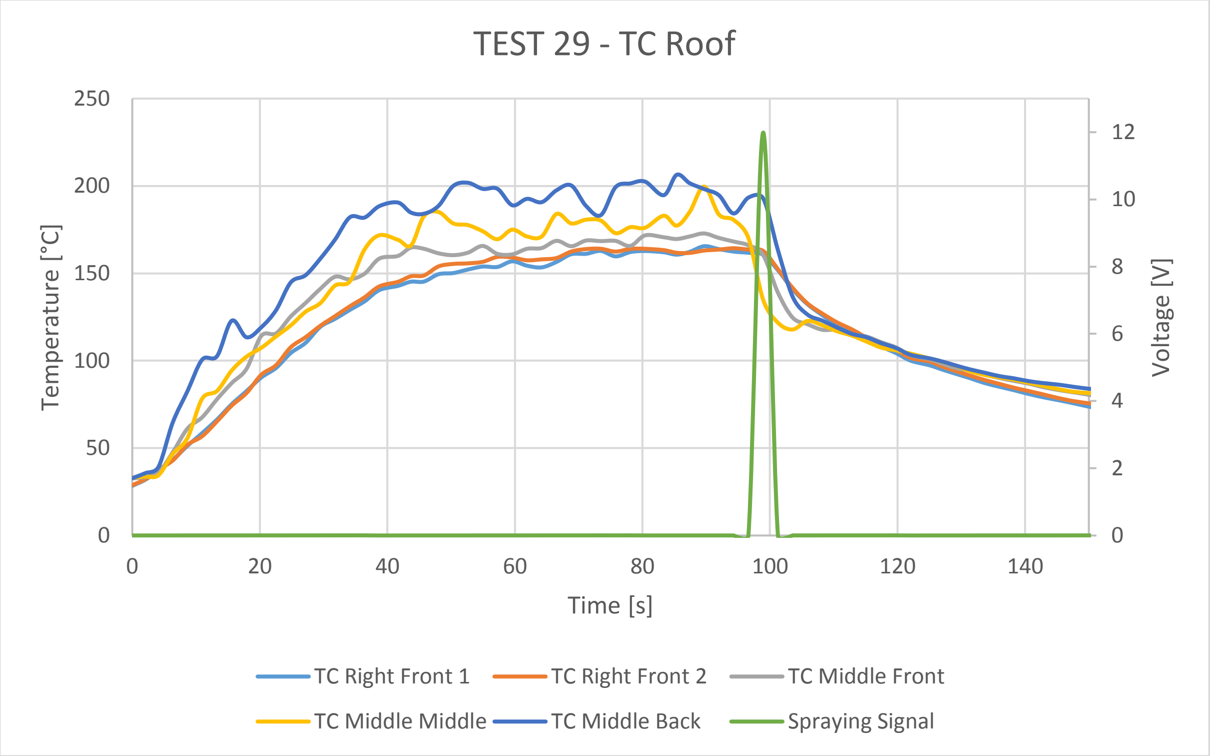

TEST 28 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

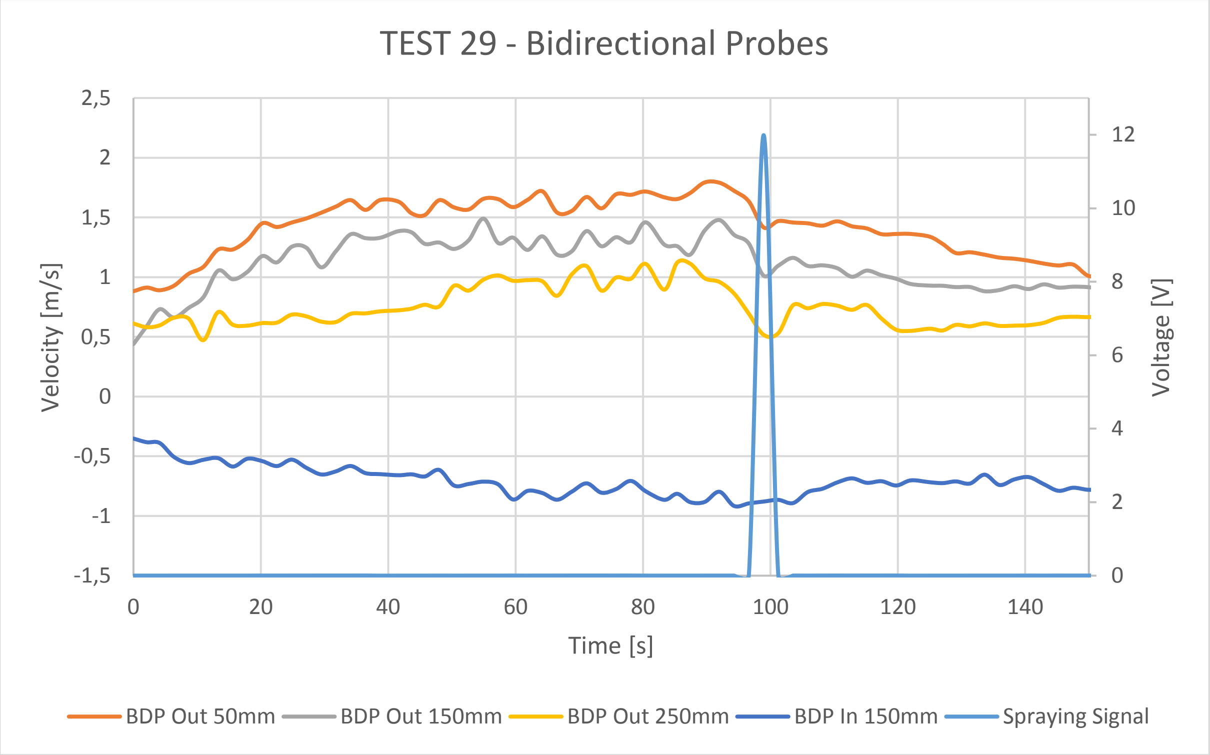

TEST 28 - TC Roof
Temperature [°C]
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Time [s]
12
10
8
6
4
2
0
Voltage [V]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

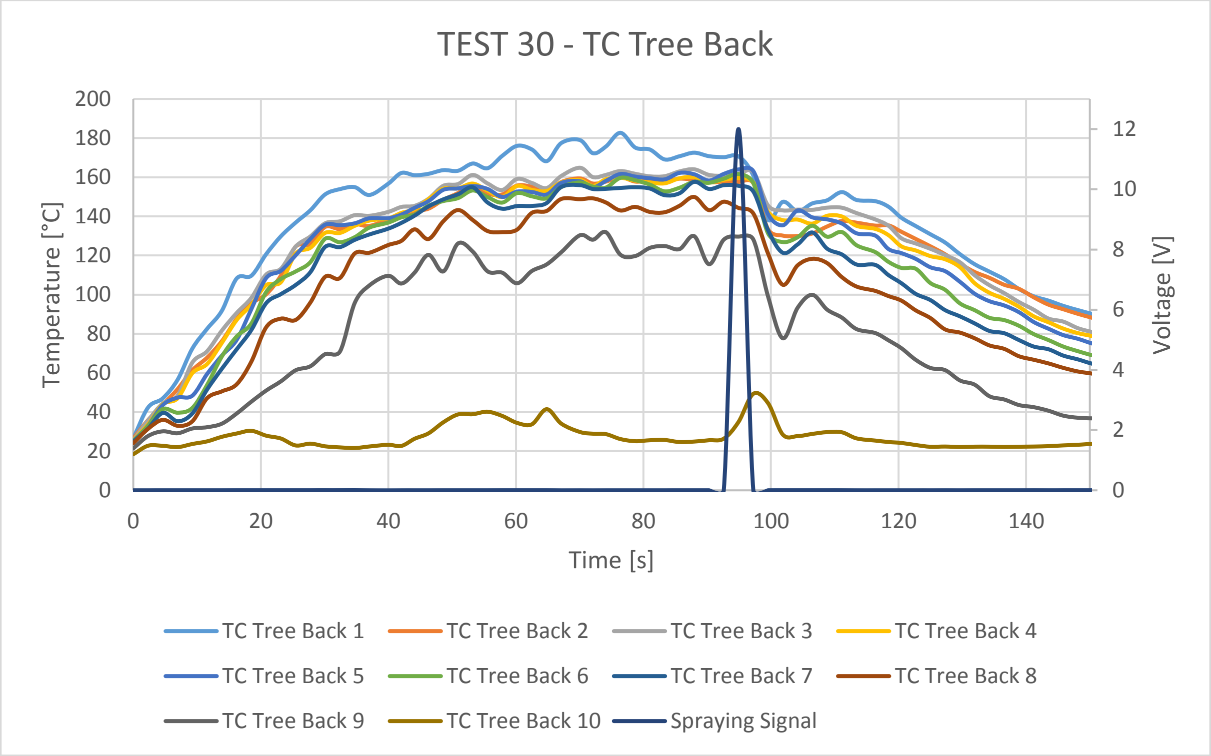

TEST 28 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
0
20
40
60
80
100
120
140
Time [s]
12
10
8
6
4
2
0
Voltage [V]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

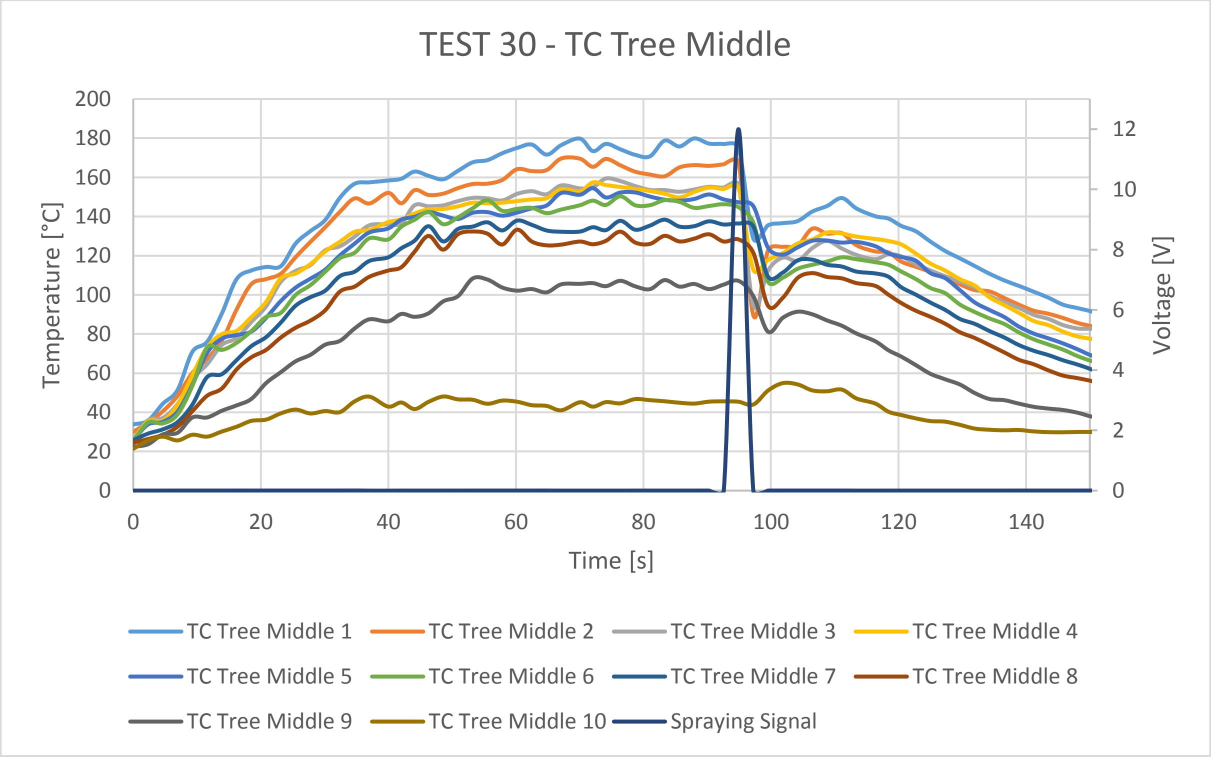

TEST 29 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

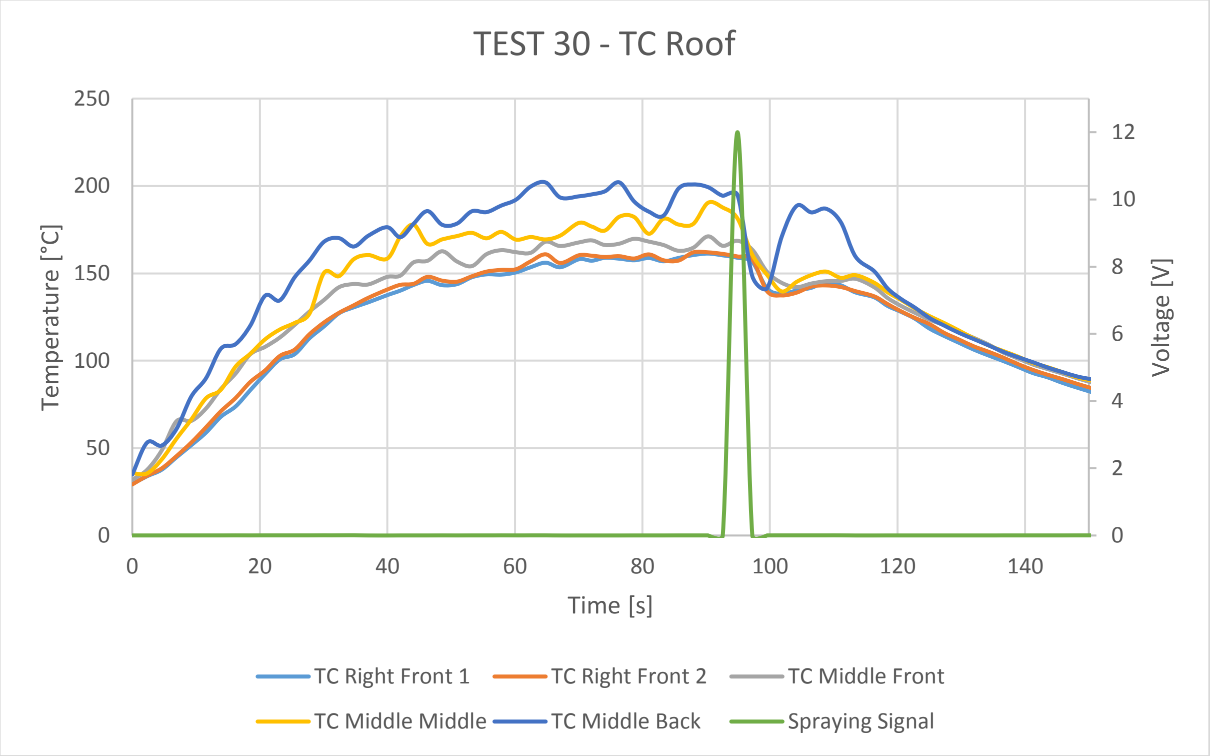

TEST 29 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

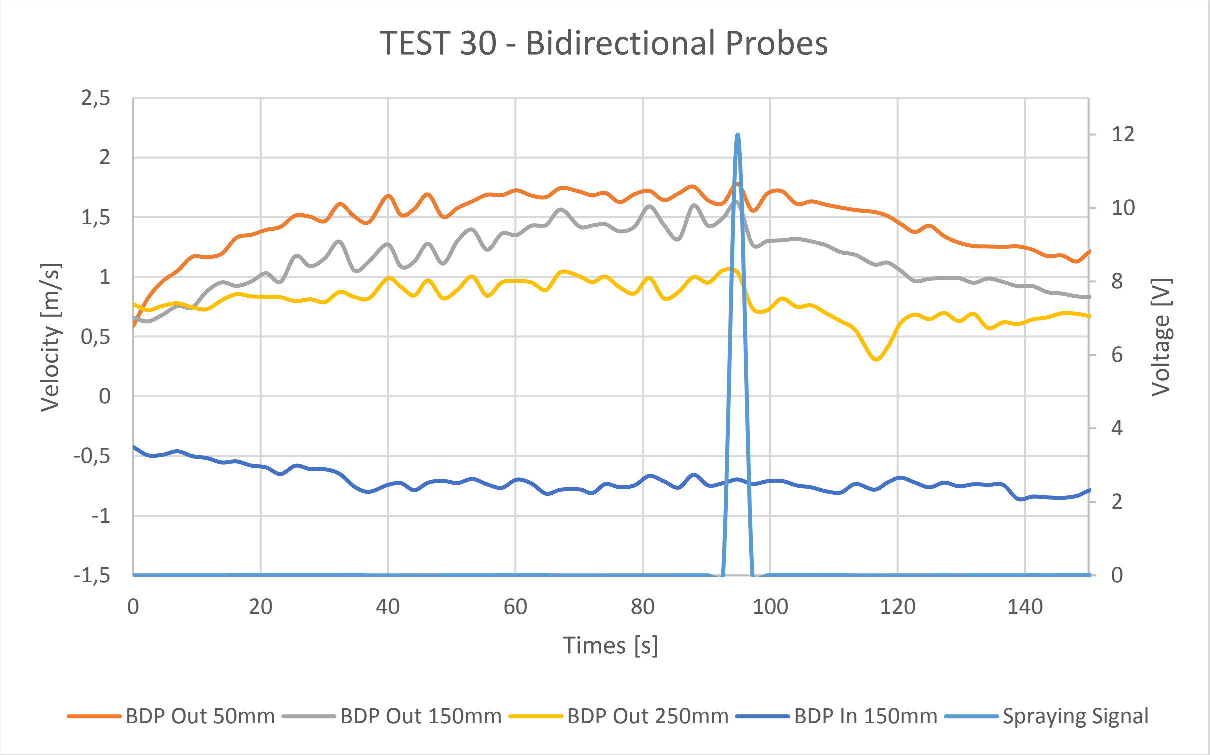

TEST 29 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

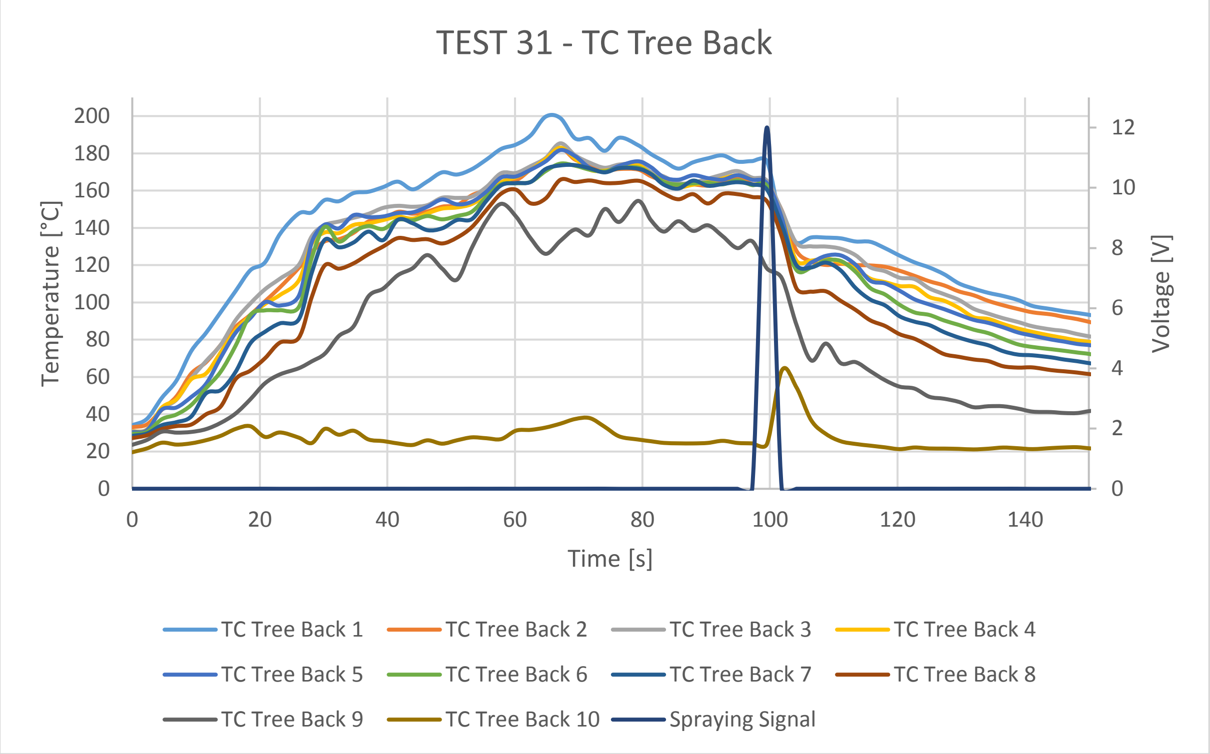

TEST 29 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

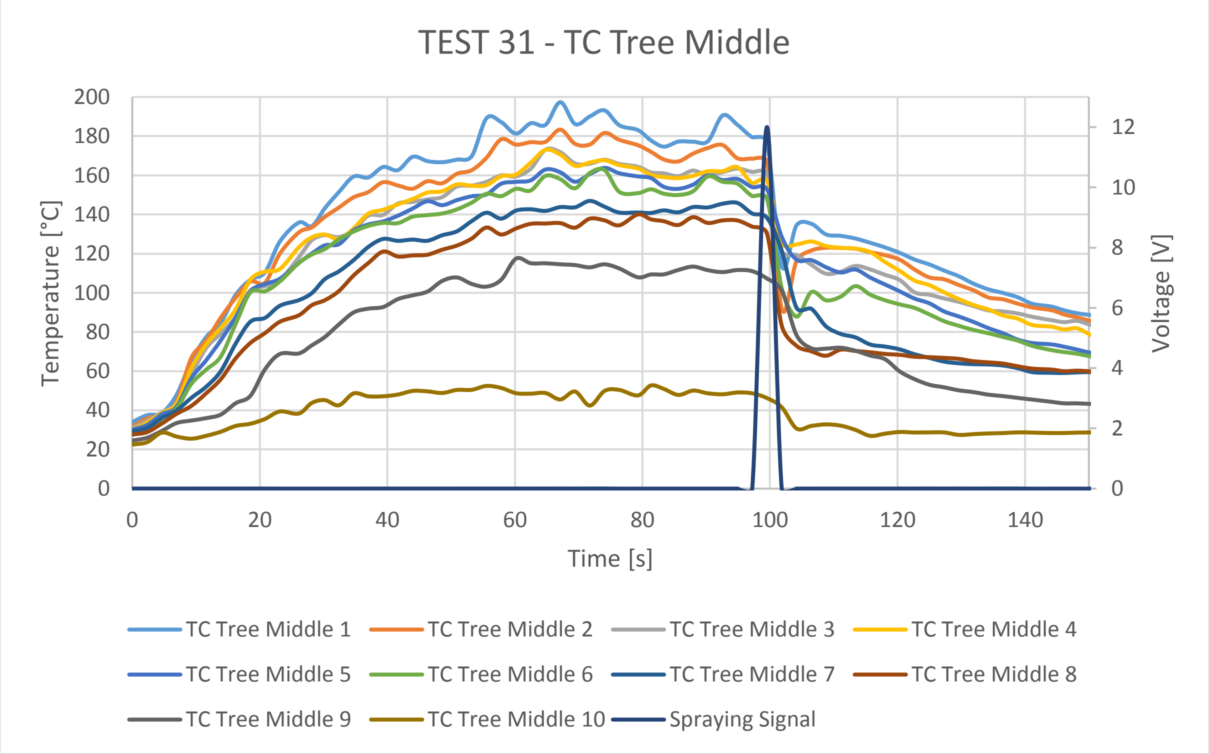

TEST 30 - TC Tree Back
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
200
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

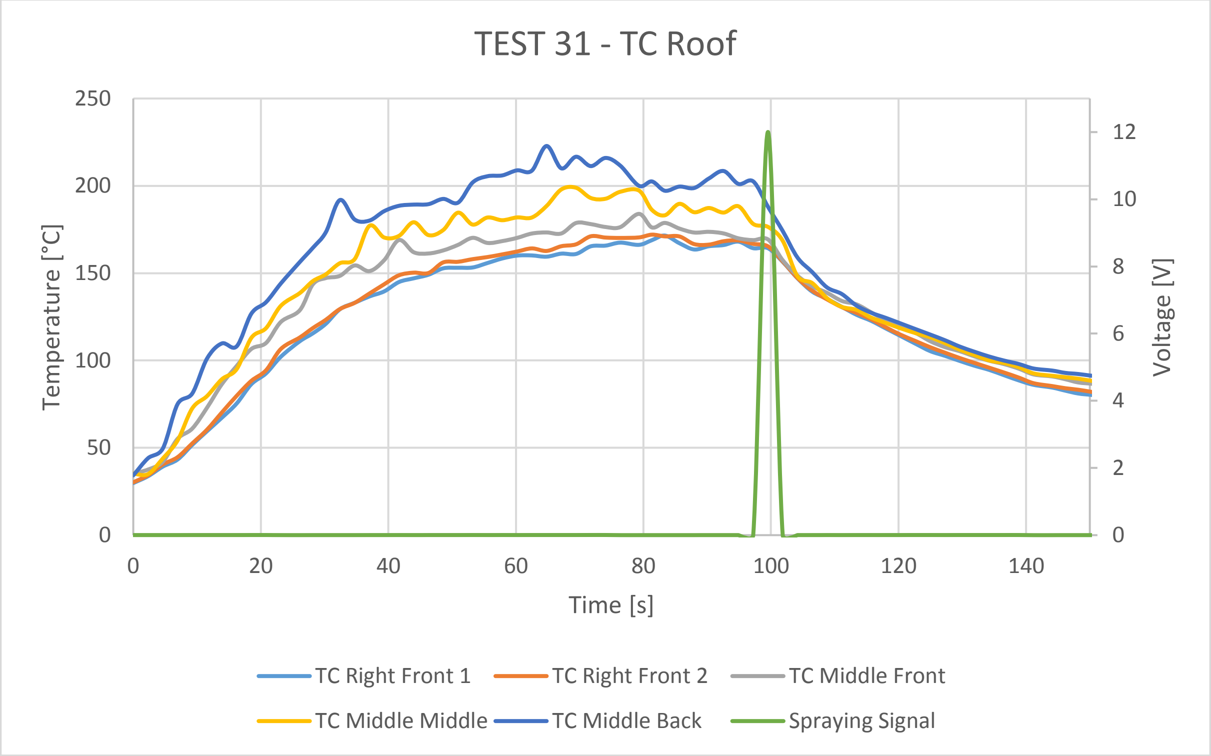

TEST 30 - TC Tree Middle
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
200
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

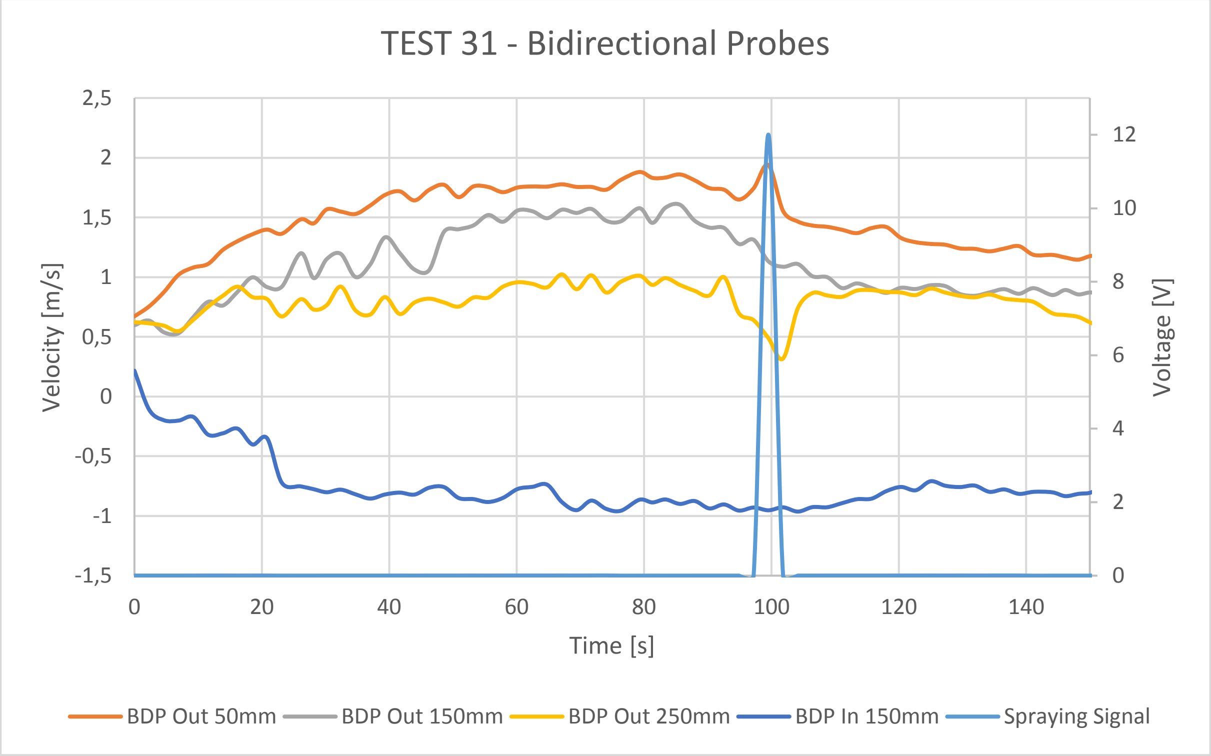

TEST 30 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

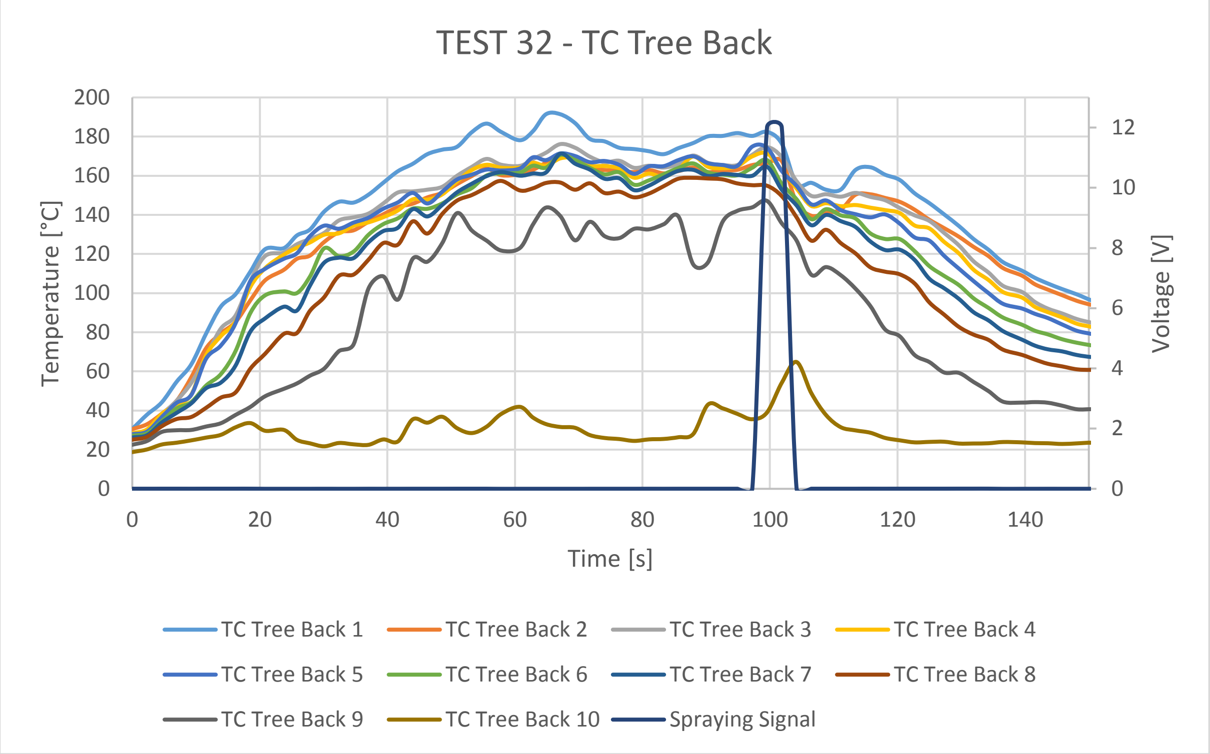

TEST 30 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Times [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

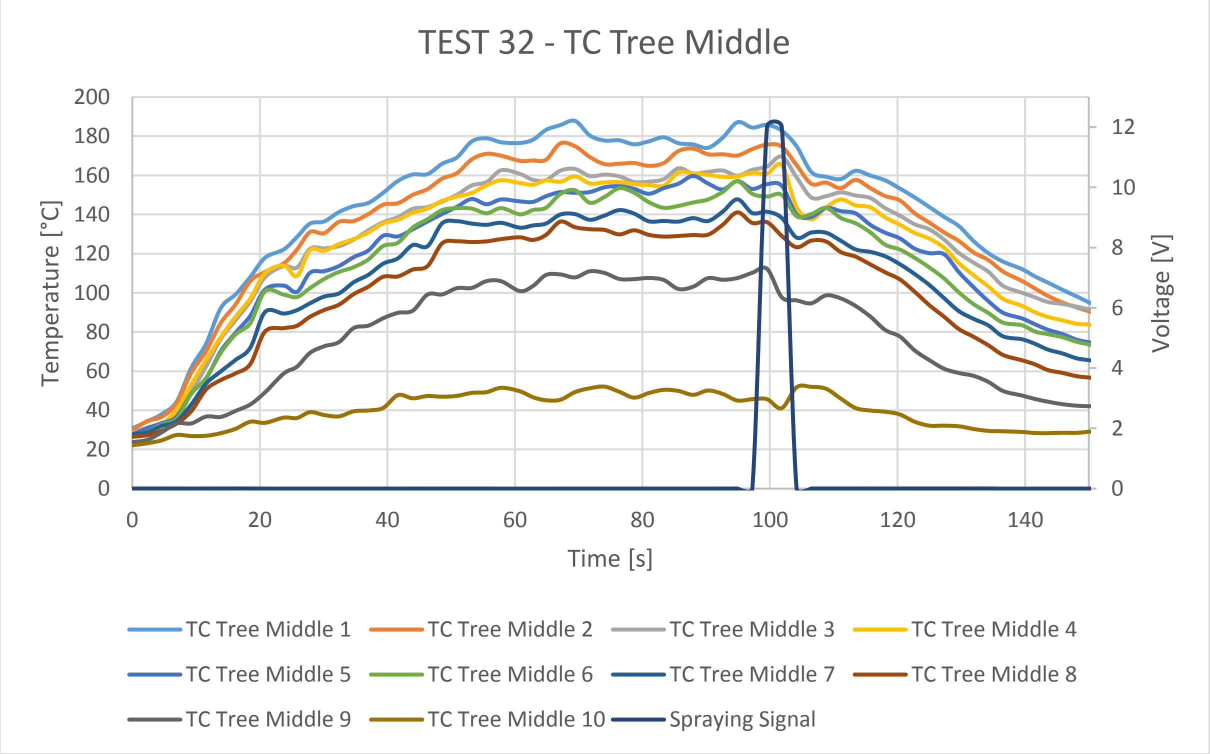

TEST 31 - TC Tree Back
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
200
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

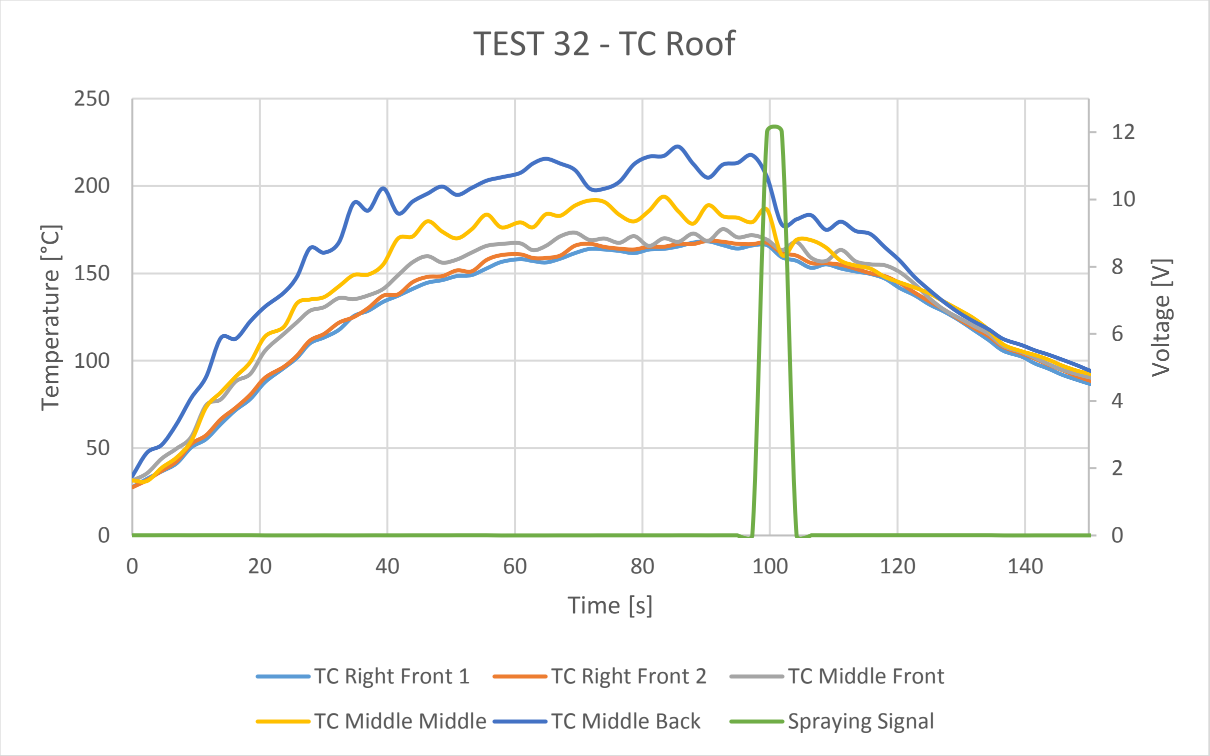

TEST 31 - TC Tree Middle
Temperature [°C]
0
20
40
60
80
100
120
140
160
180
200
Voltage [V]
0
2
4
6
8
10
12
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

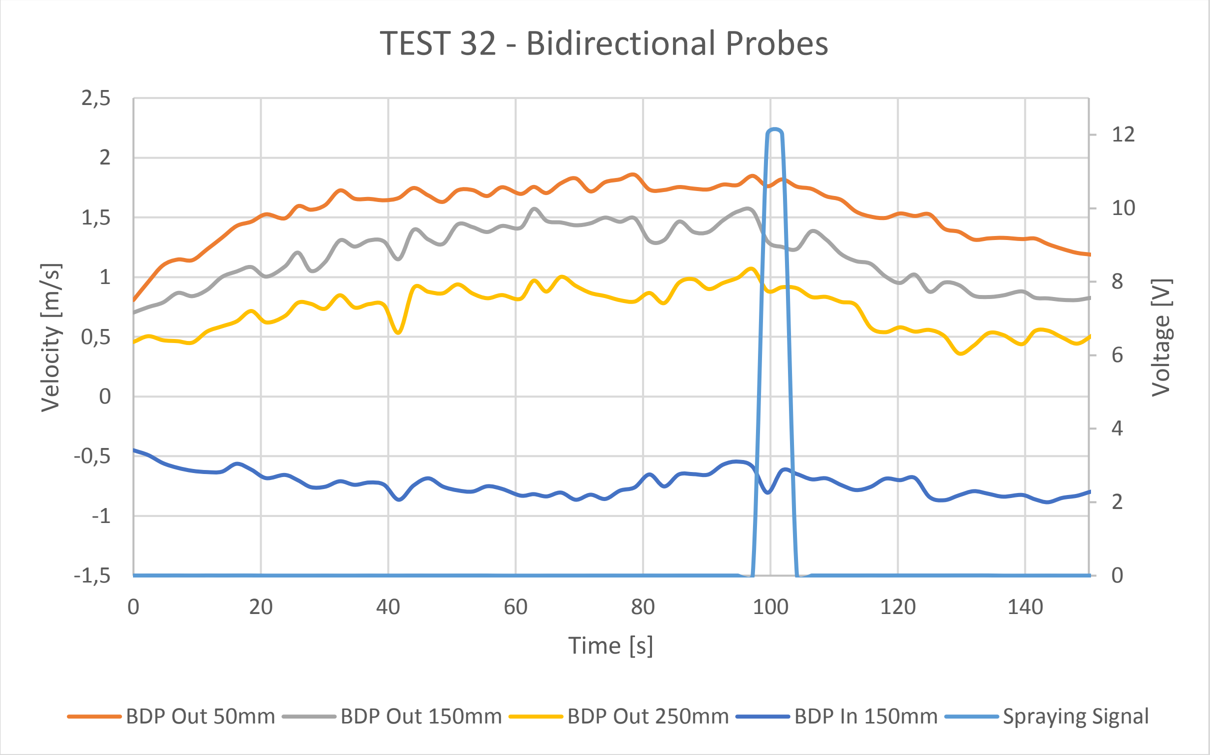

TEST 31 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

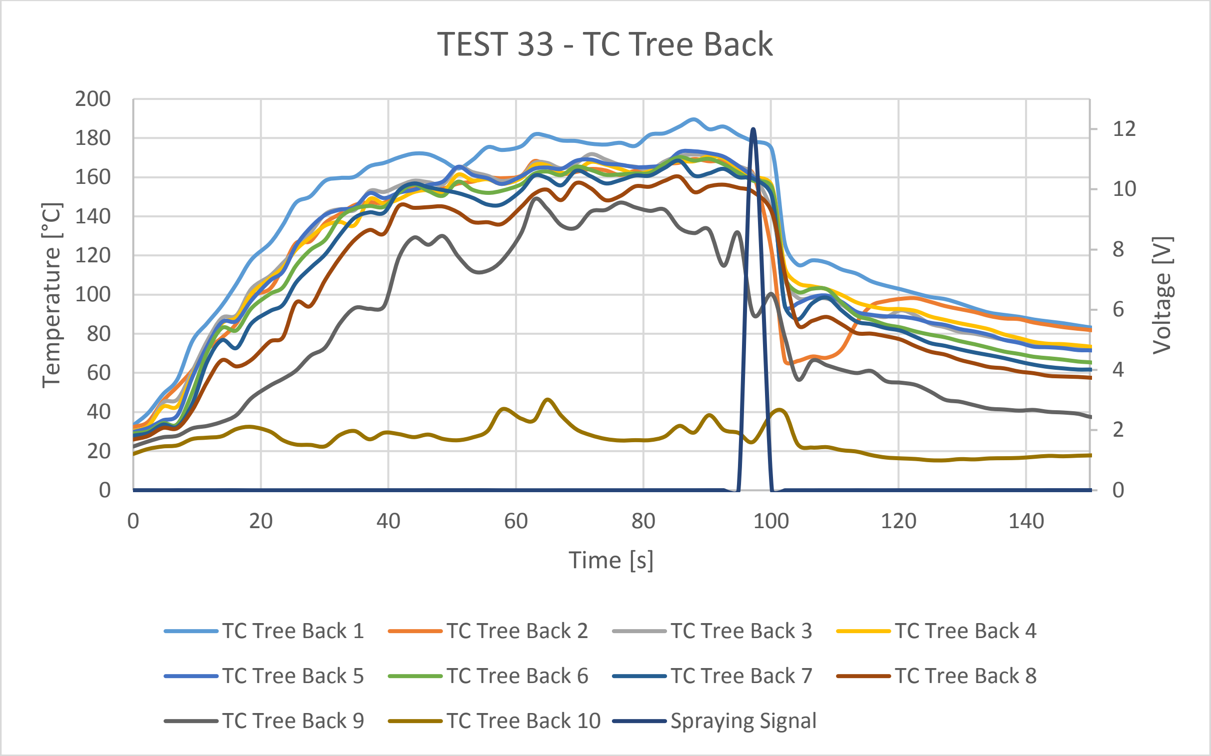

TEST 31 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

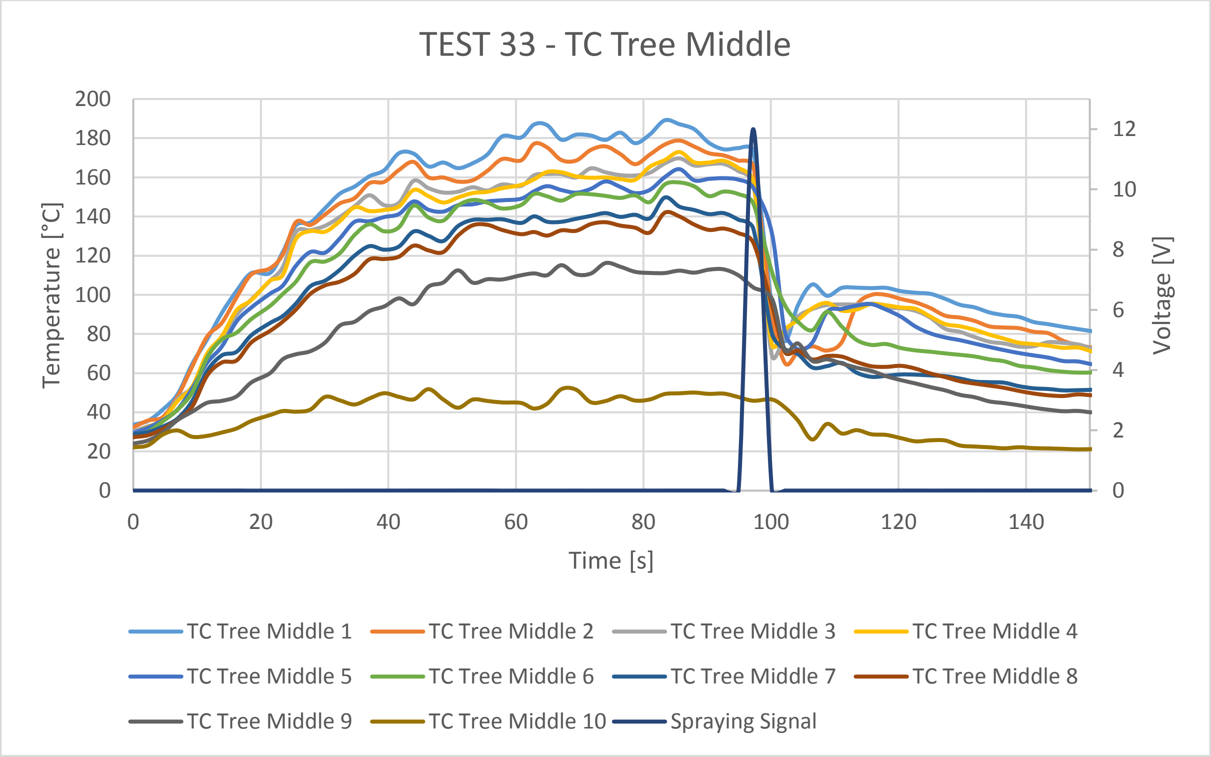

TEST 32 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

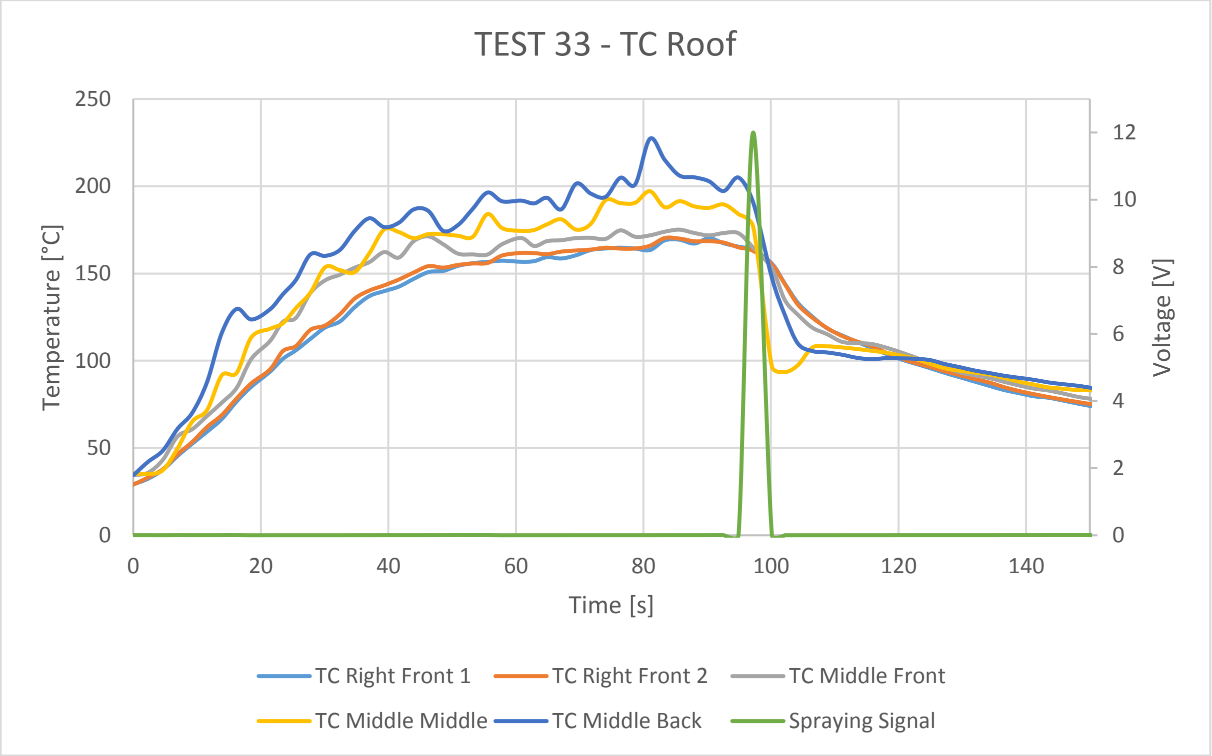

TEST 32 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

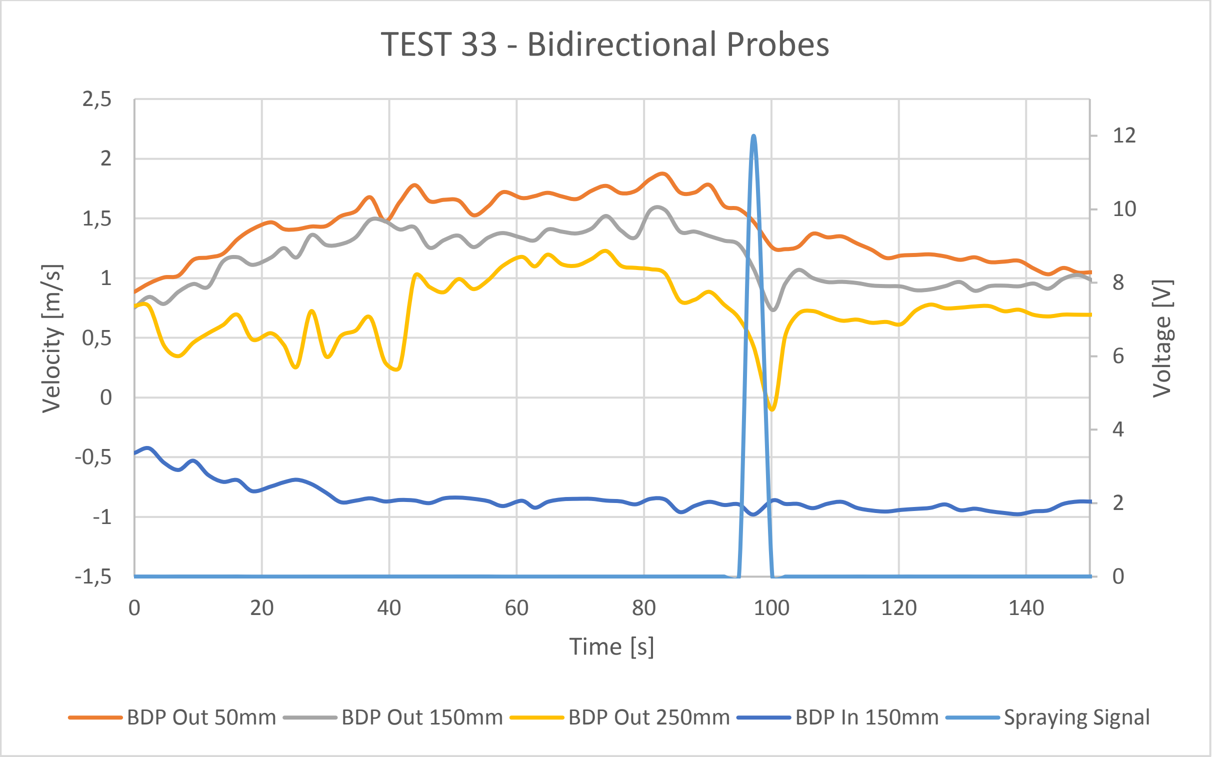

TEST 32 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

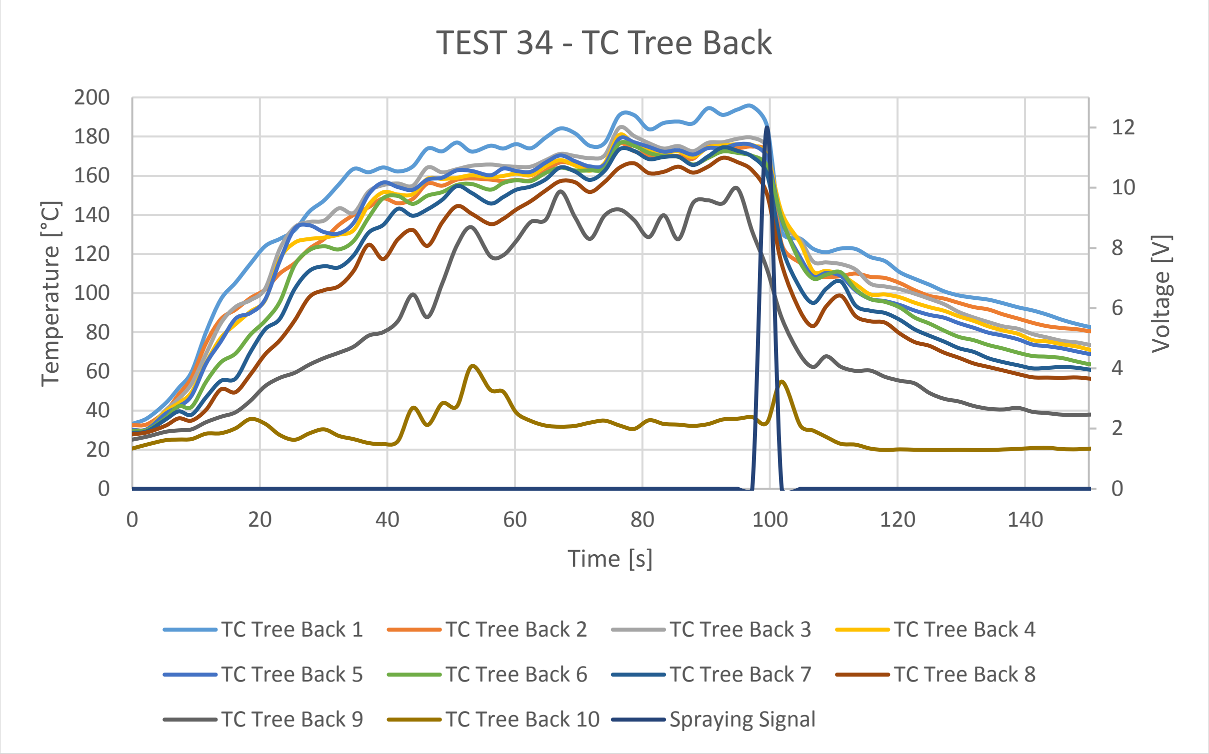

TEST 32 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

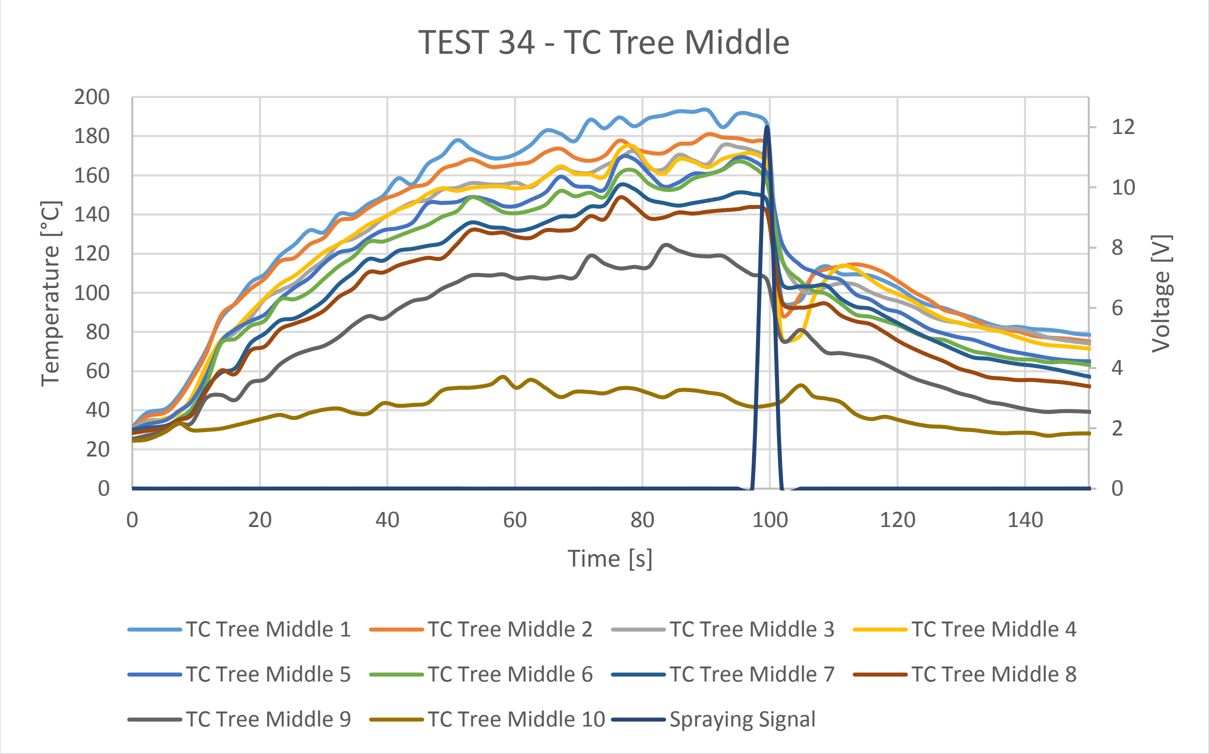

TEST 33 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

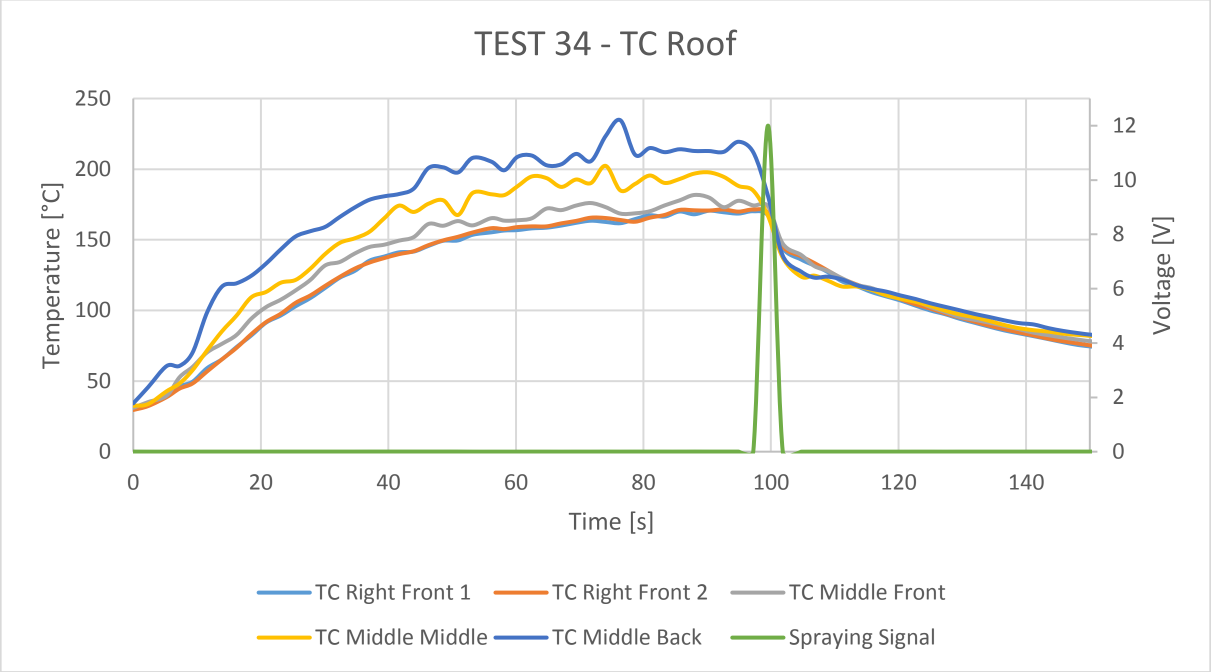

TEST 33 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

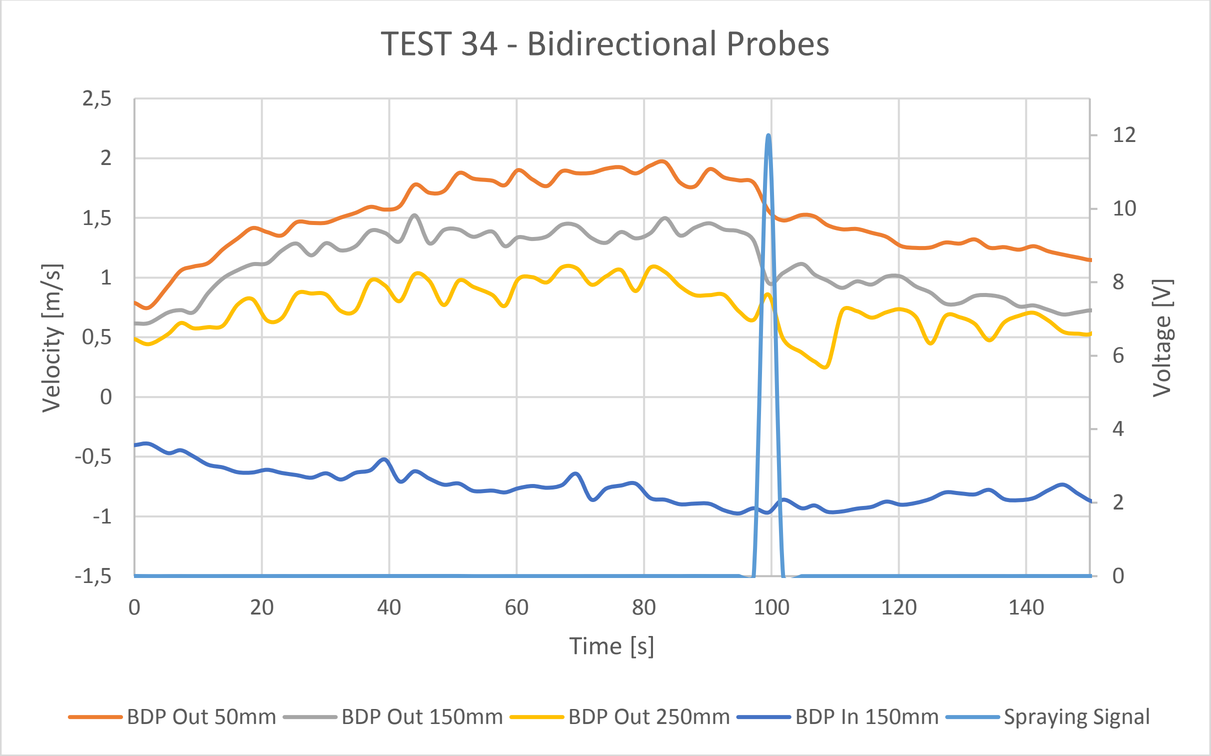

TEST 33 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

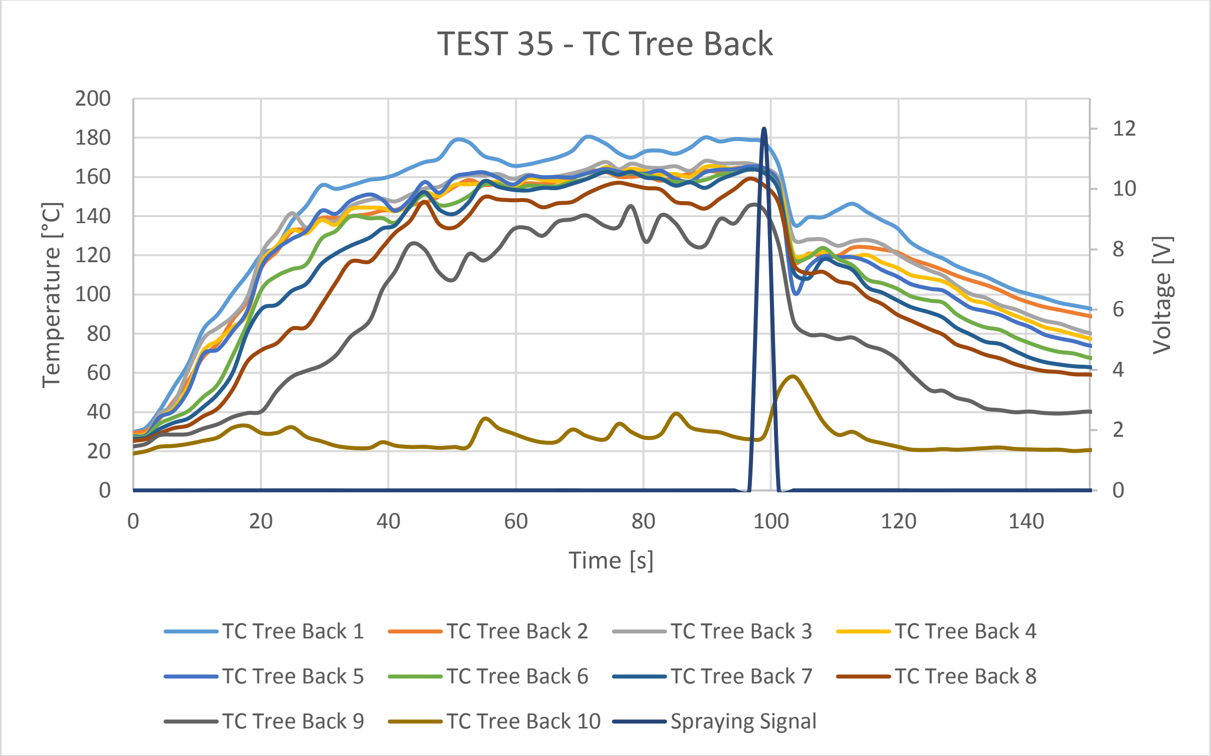

TEST 33 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

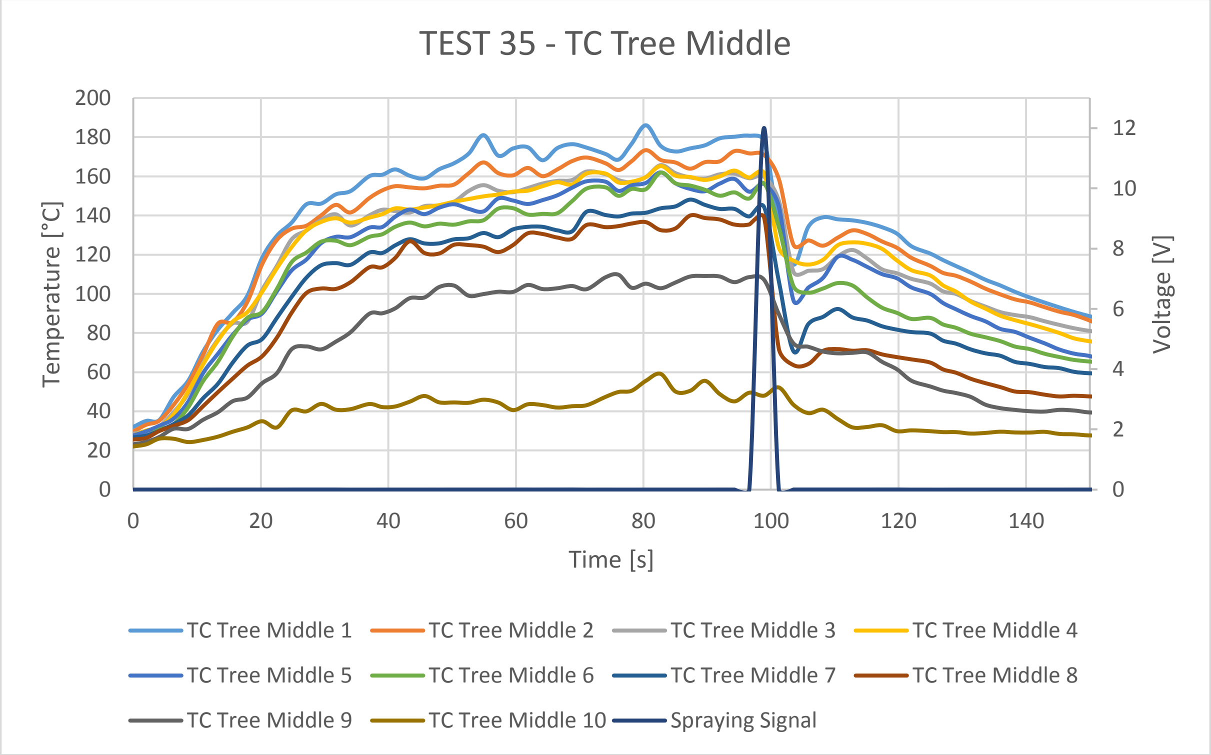

TEST 34 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

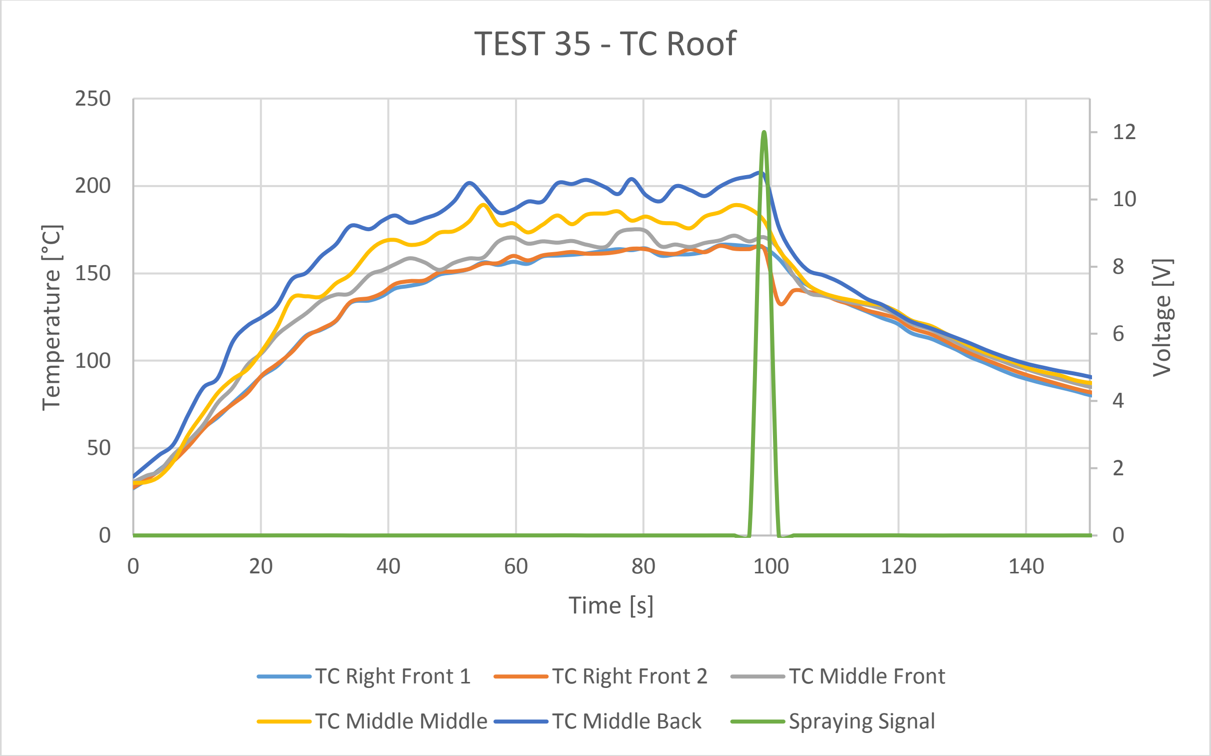

TEST 34 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

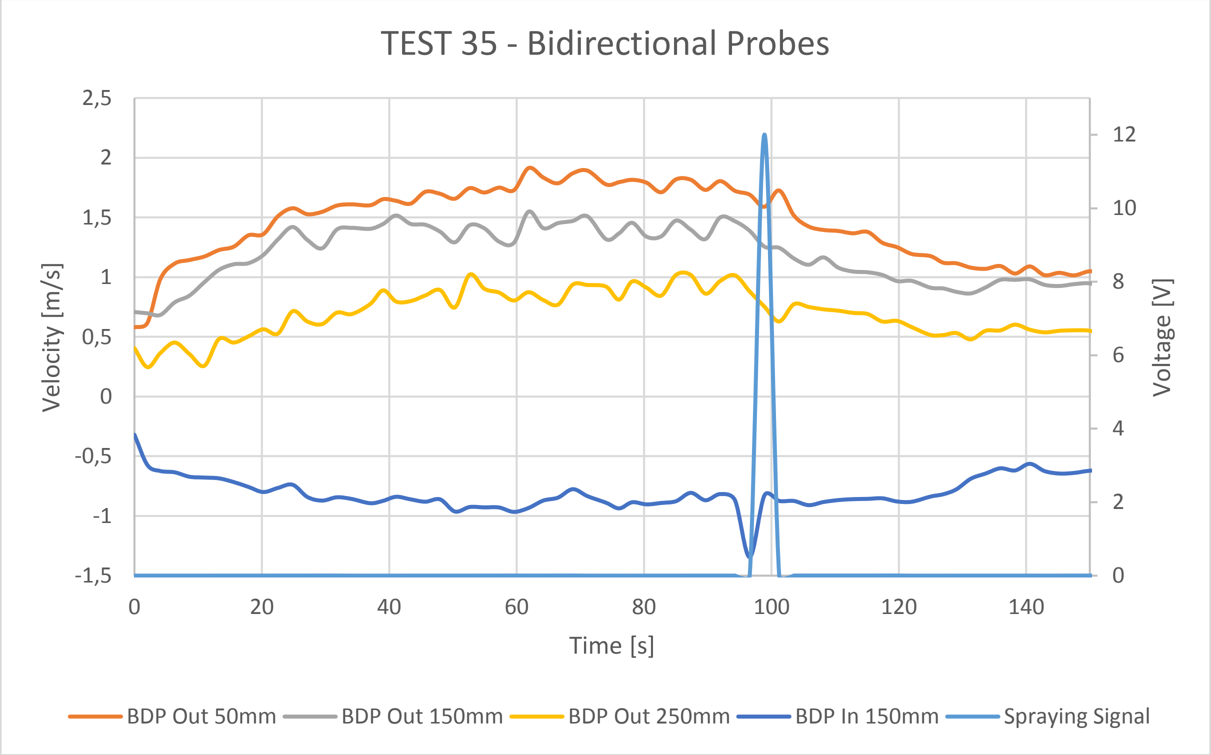

TEST 34 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

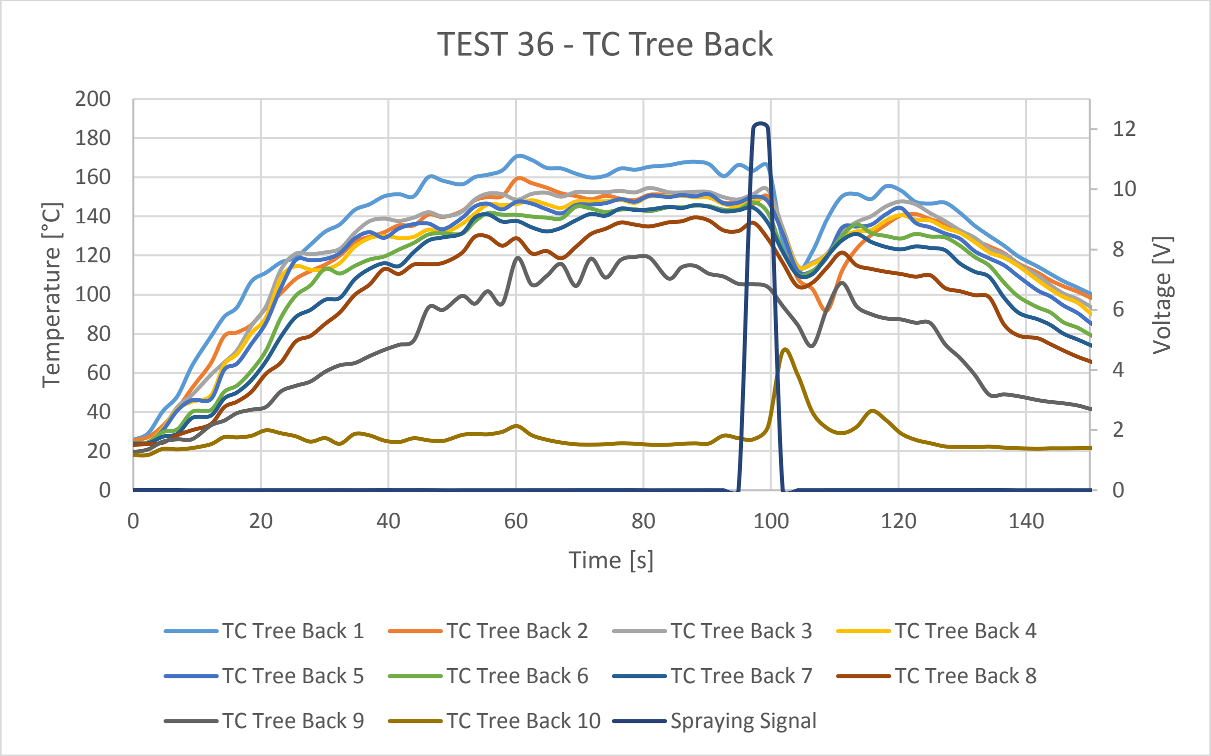

TEST 34 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

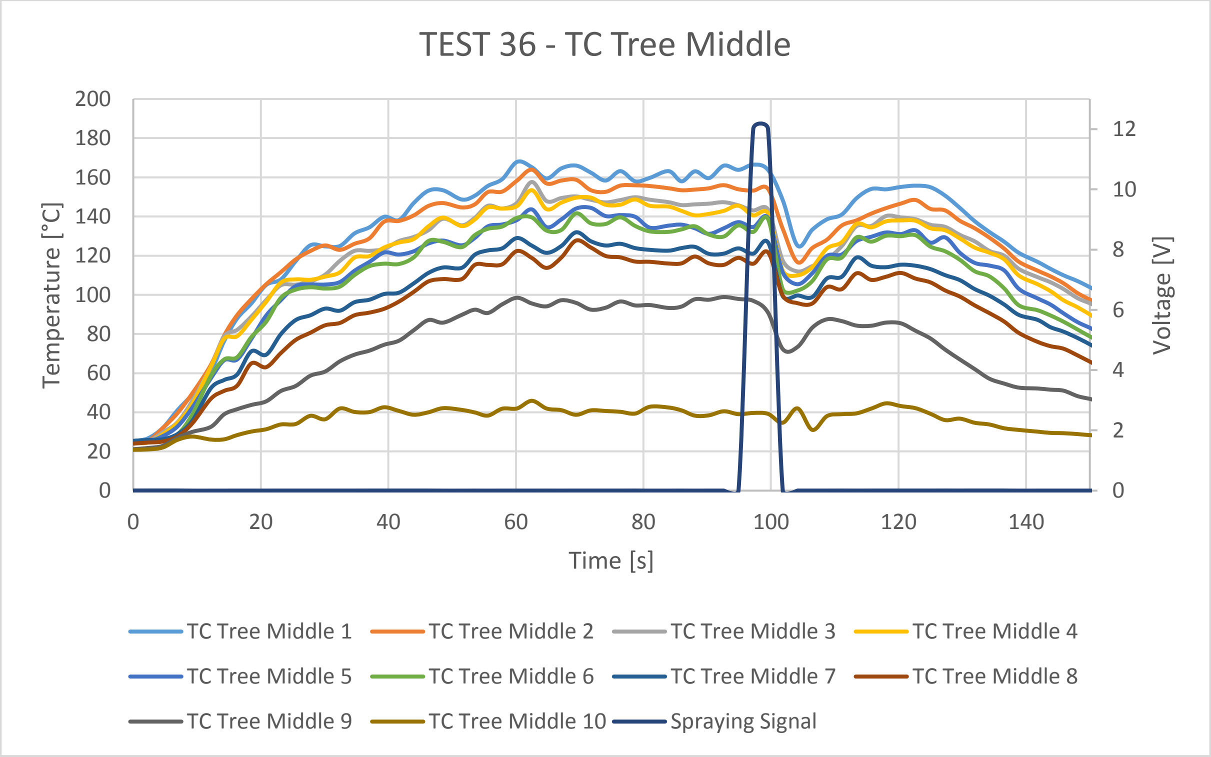

TEST 35 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

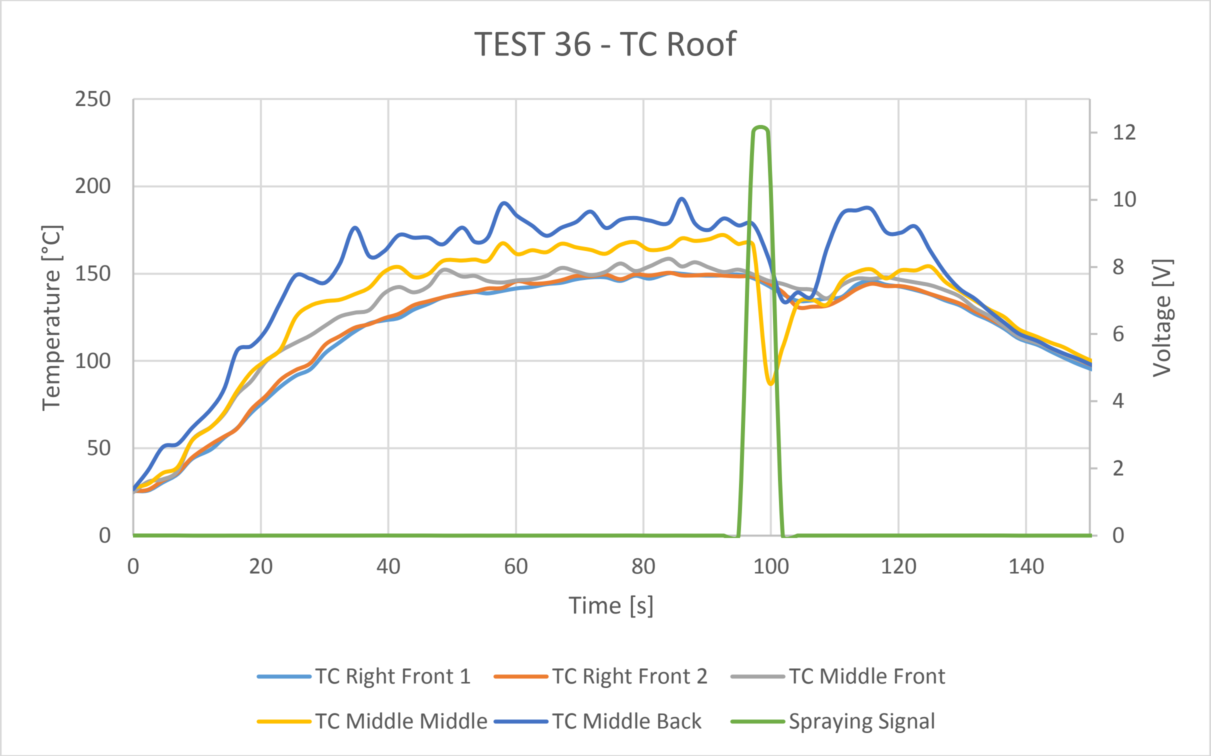

TEST 35 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

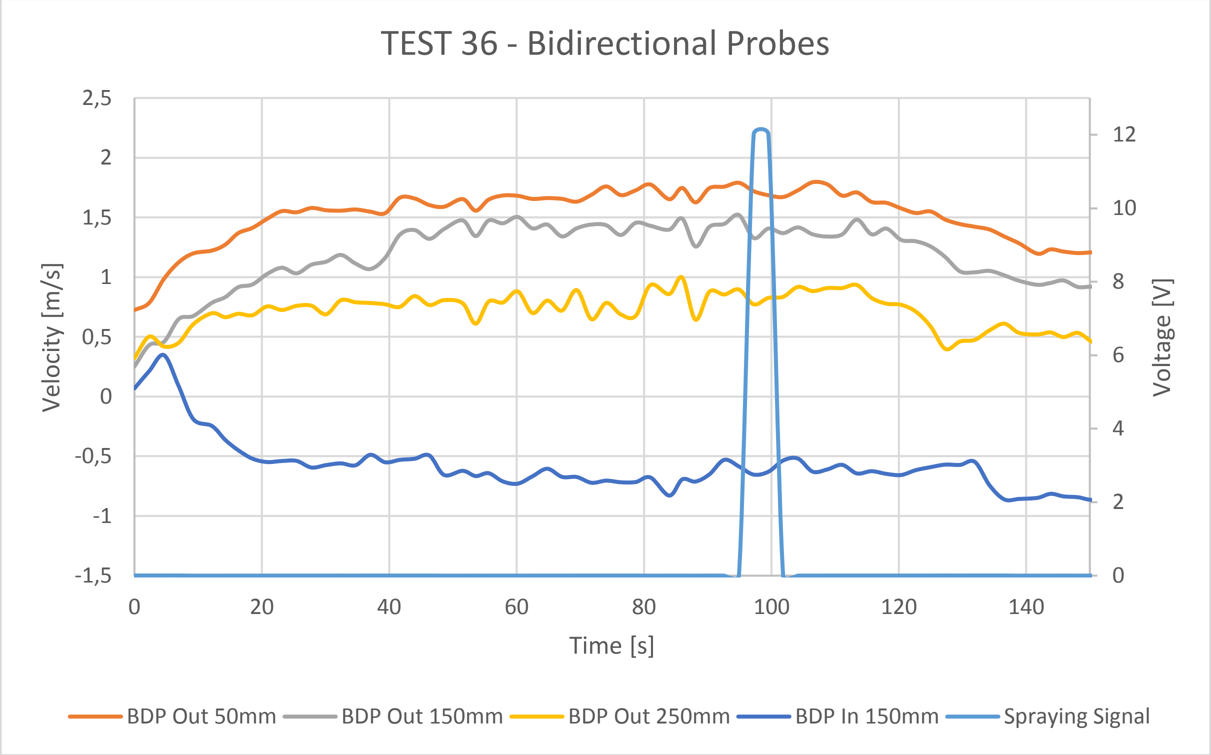

TEST 35 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

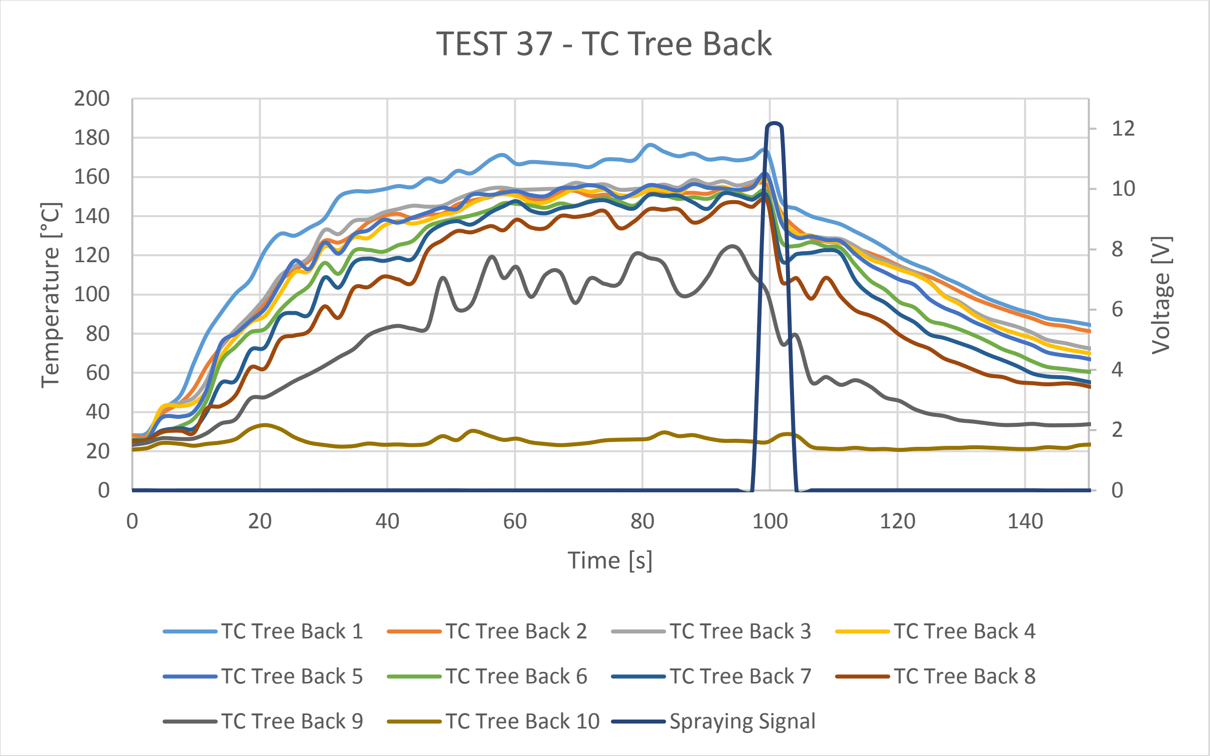

TEST 35 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

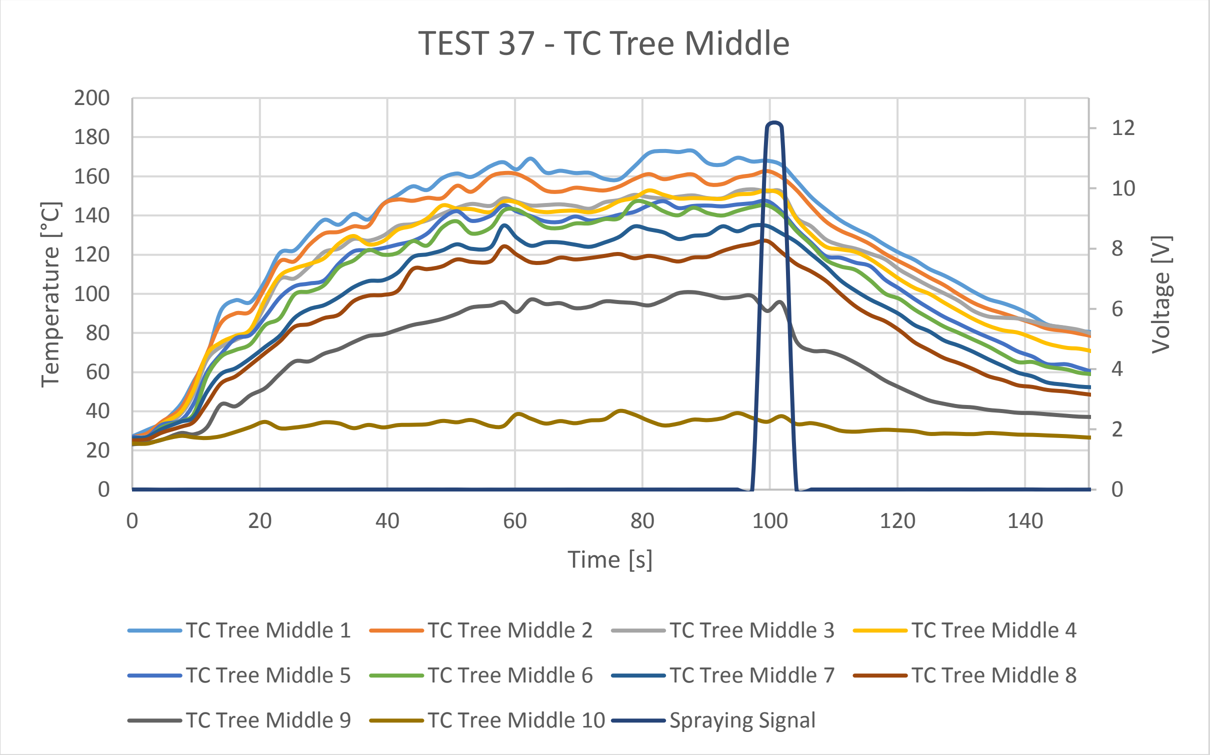

TEST 36 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

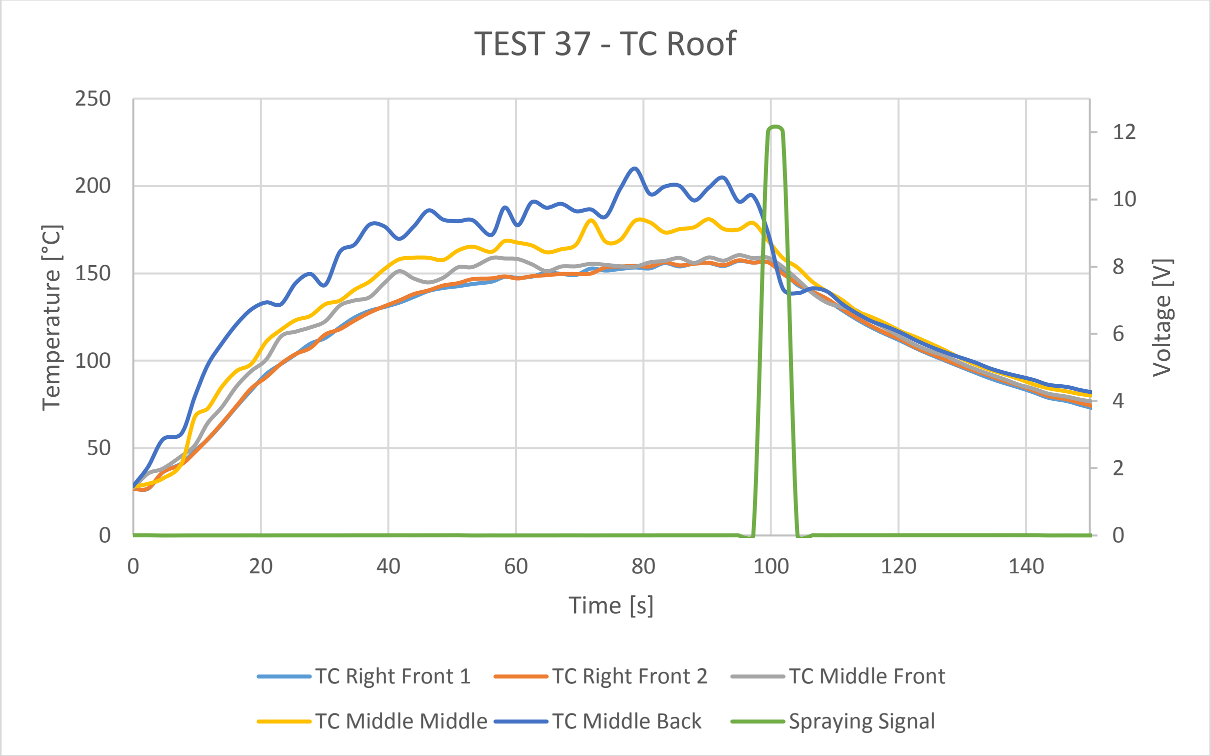

TEST 36 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

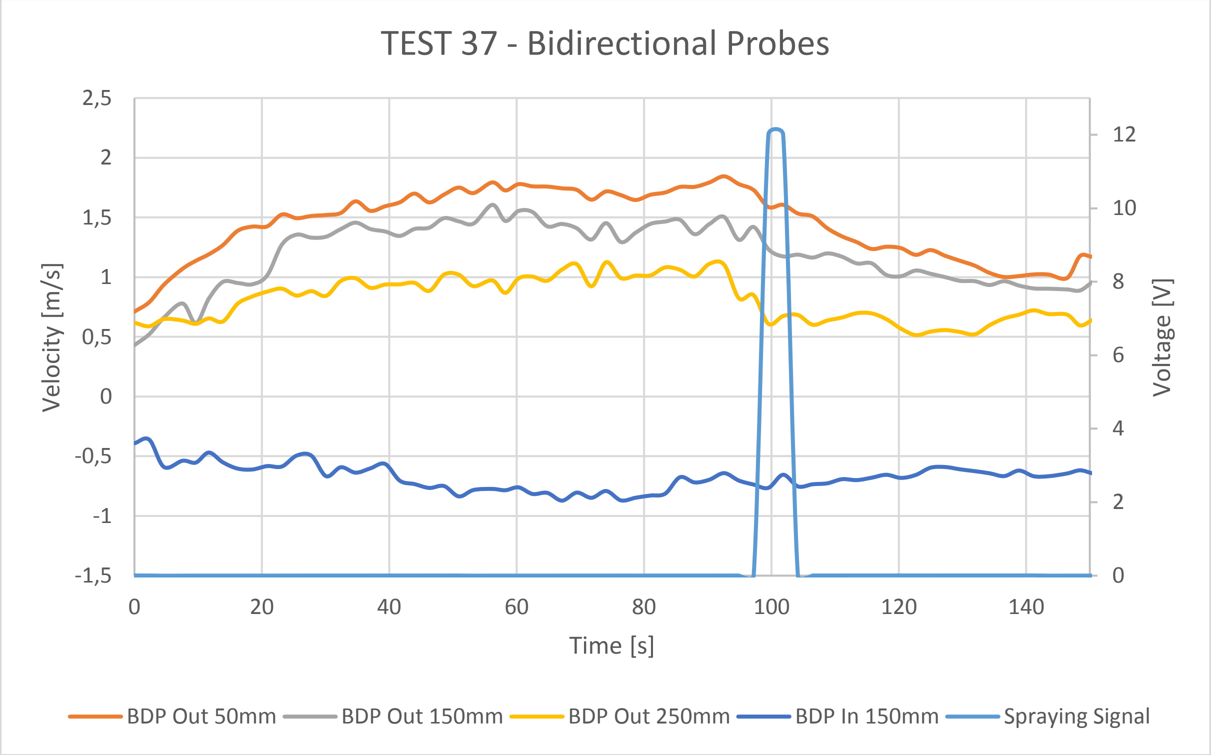

TEST 36 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

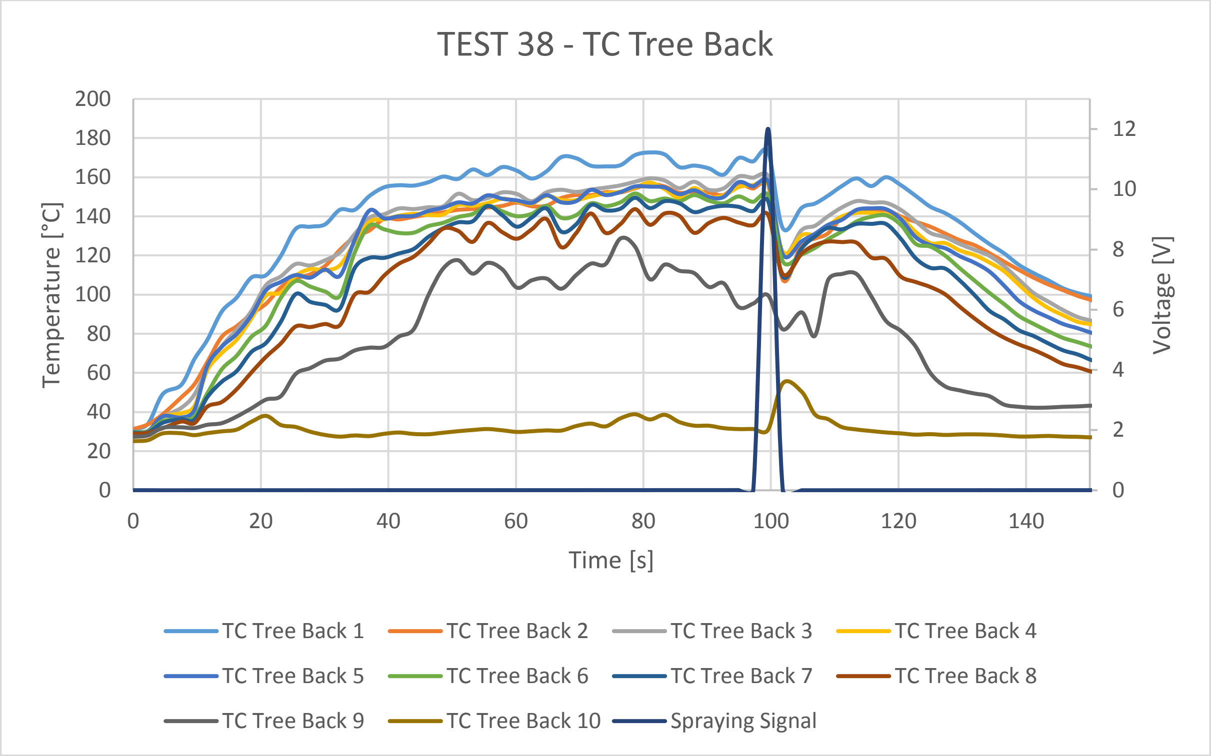

TEST 36 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

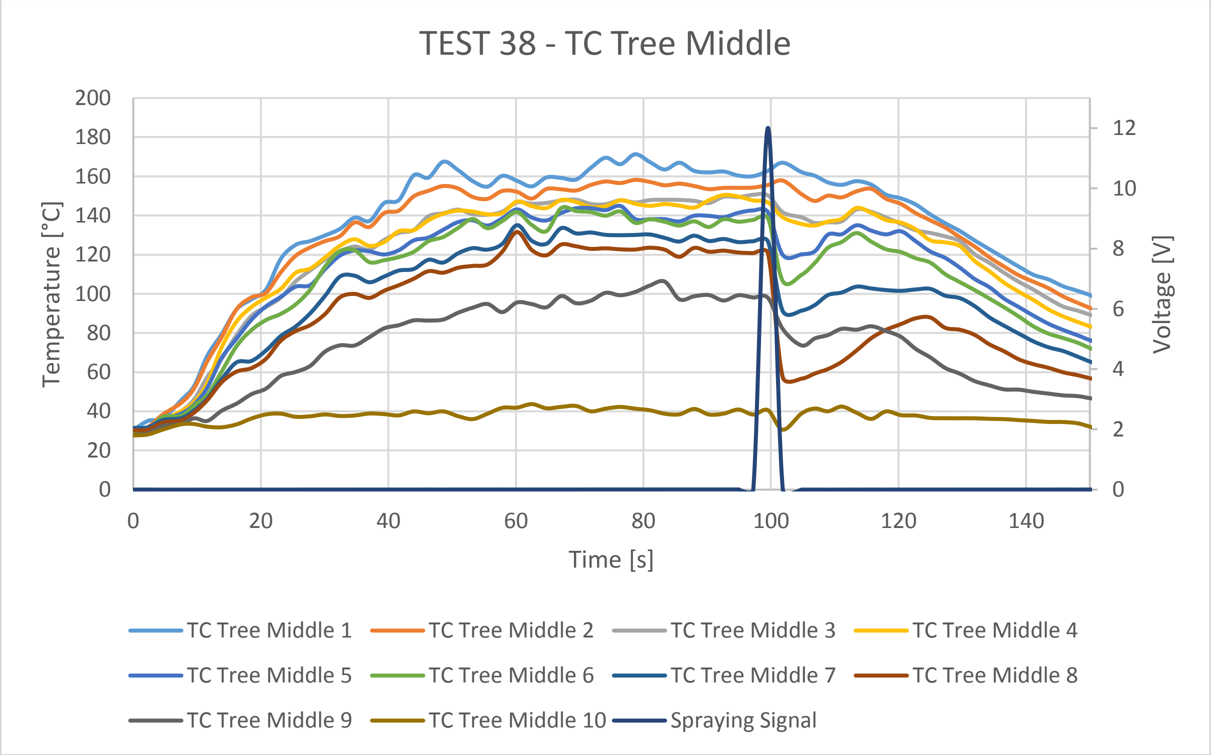

TEST 37 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

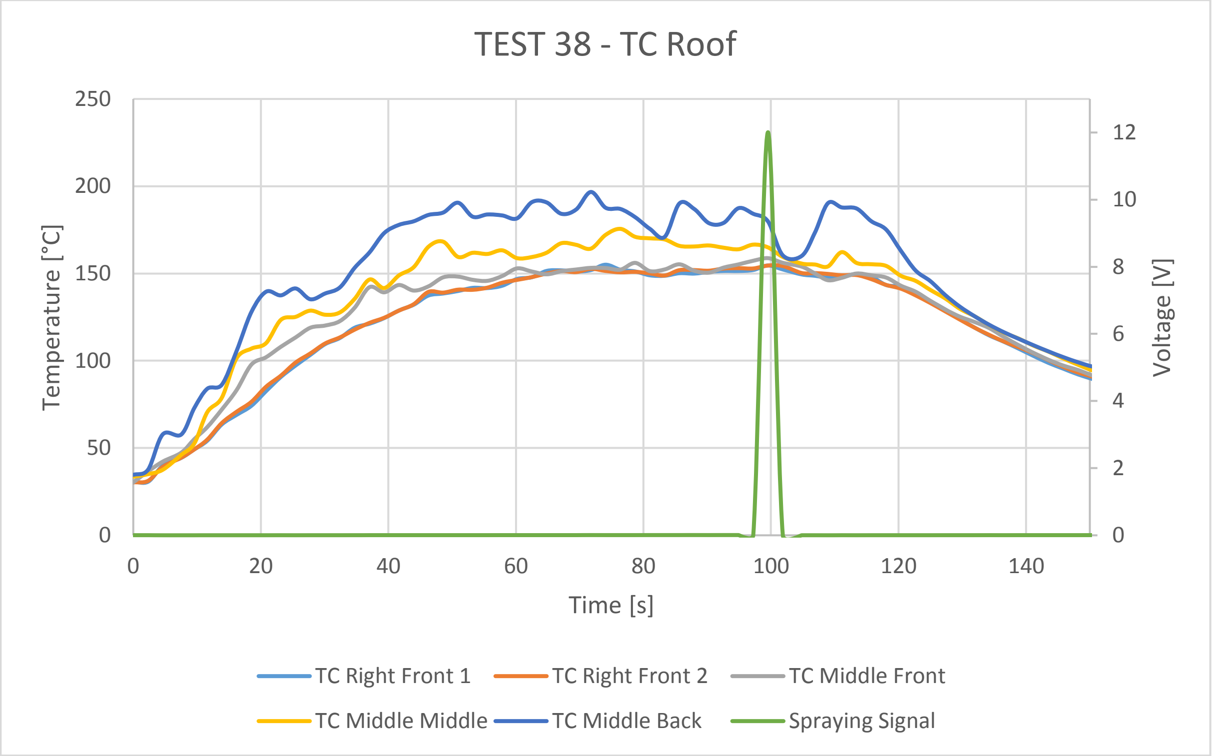

TEST 37 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

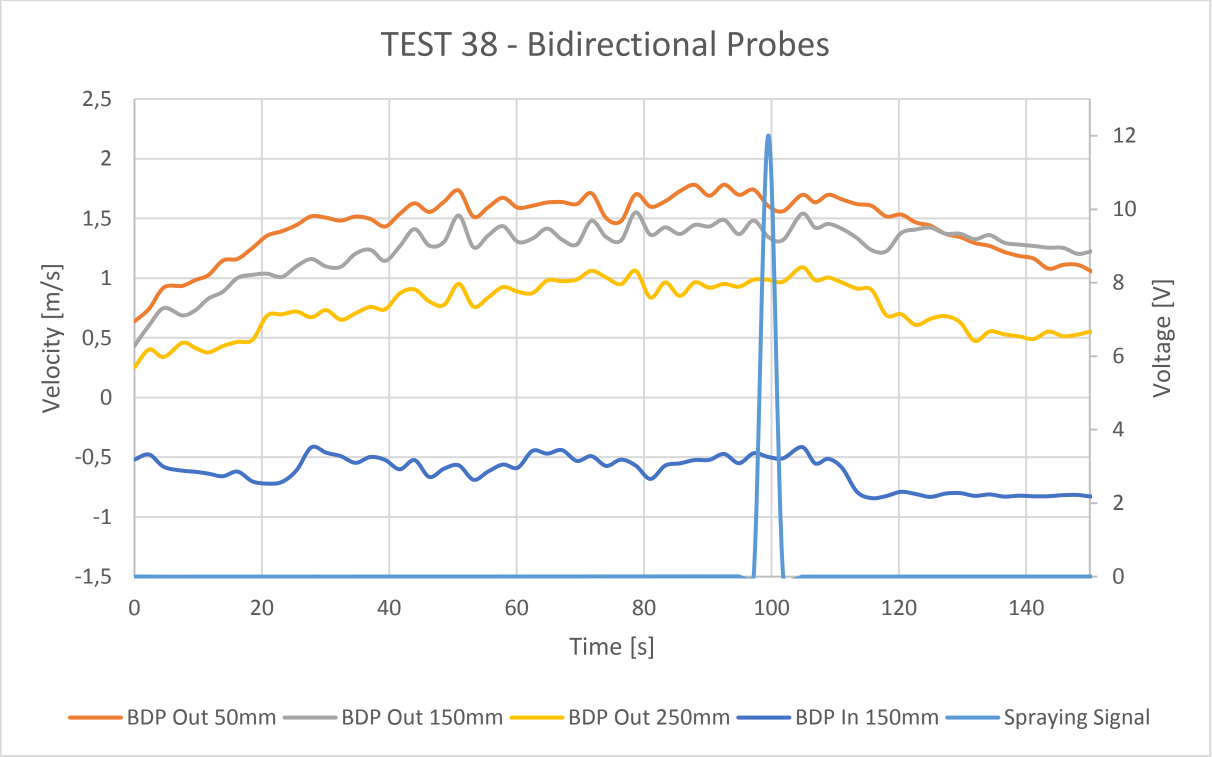

TEST 37 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

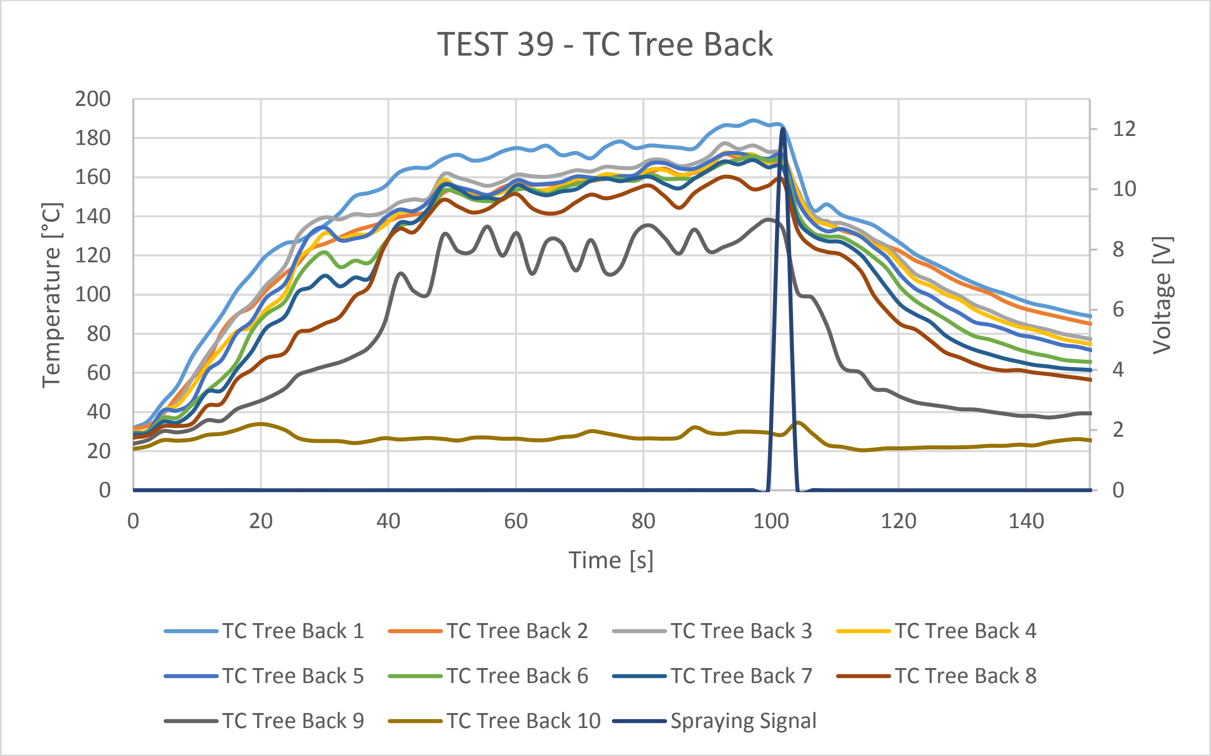

TEST 37 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

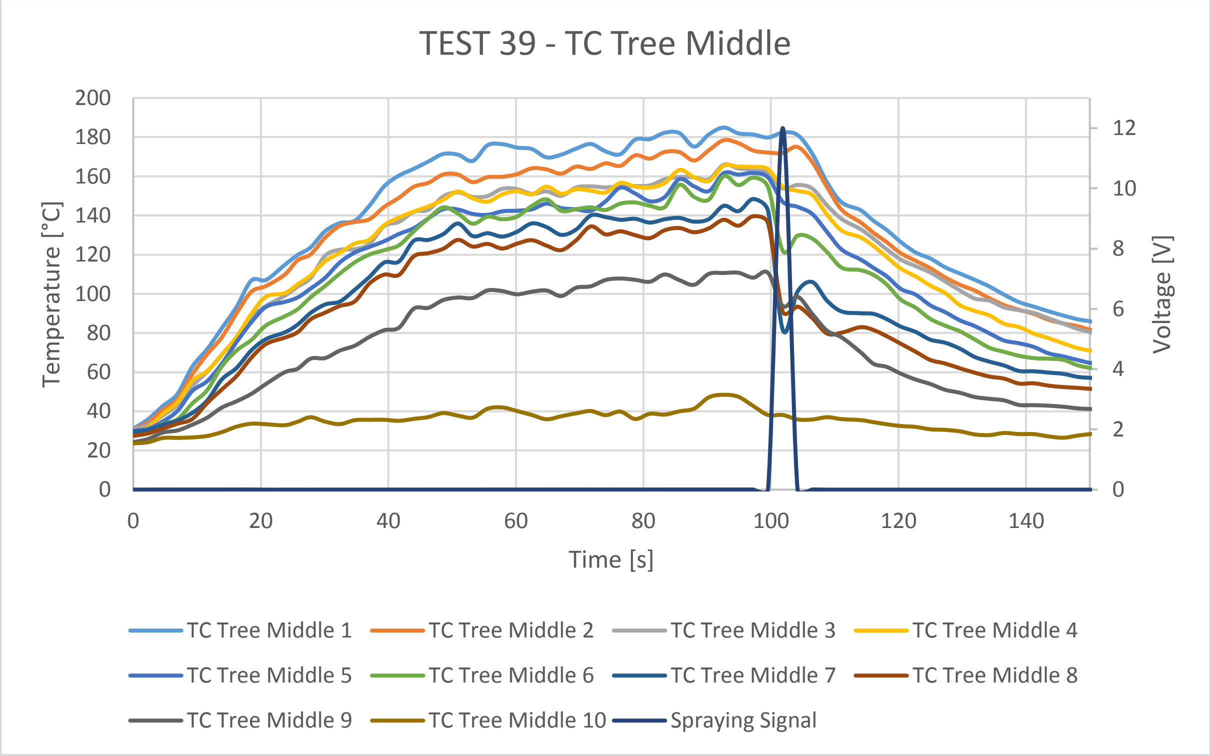

TEST 38 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

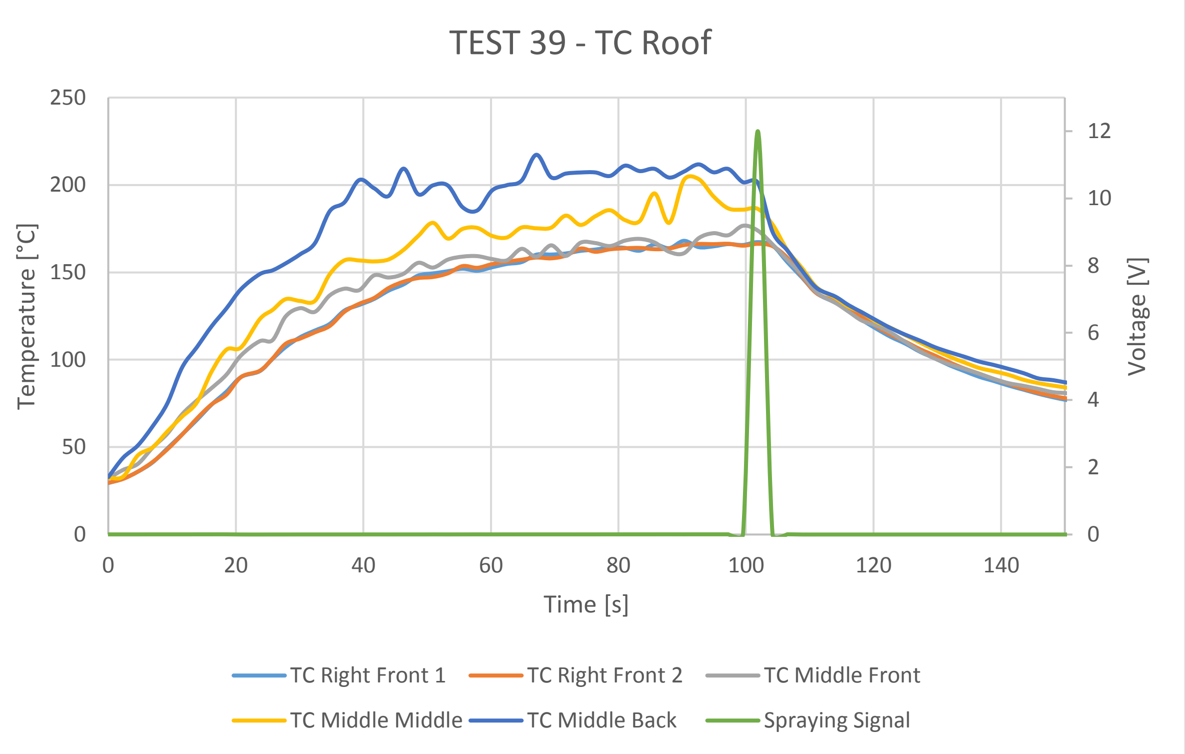

TEST 38 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

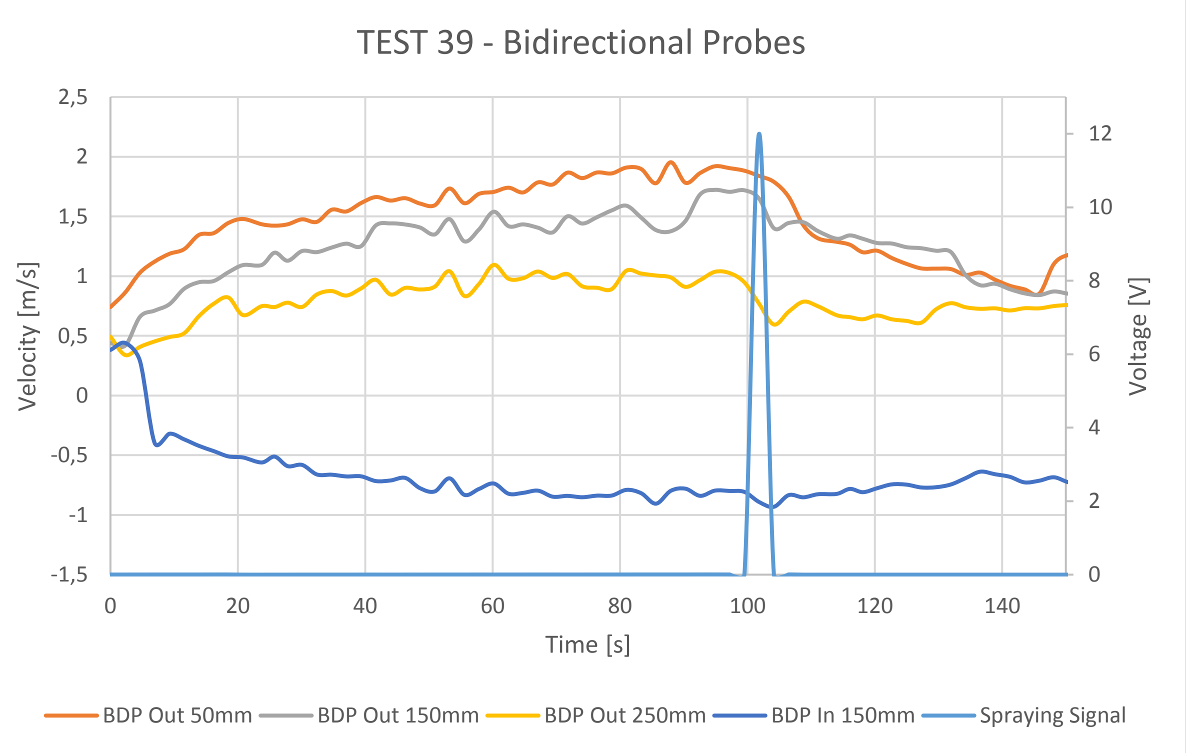

TEST 38 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

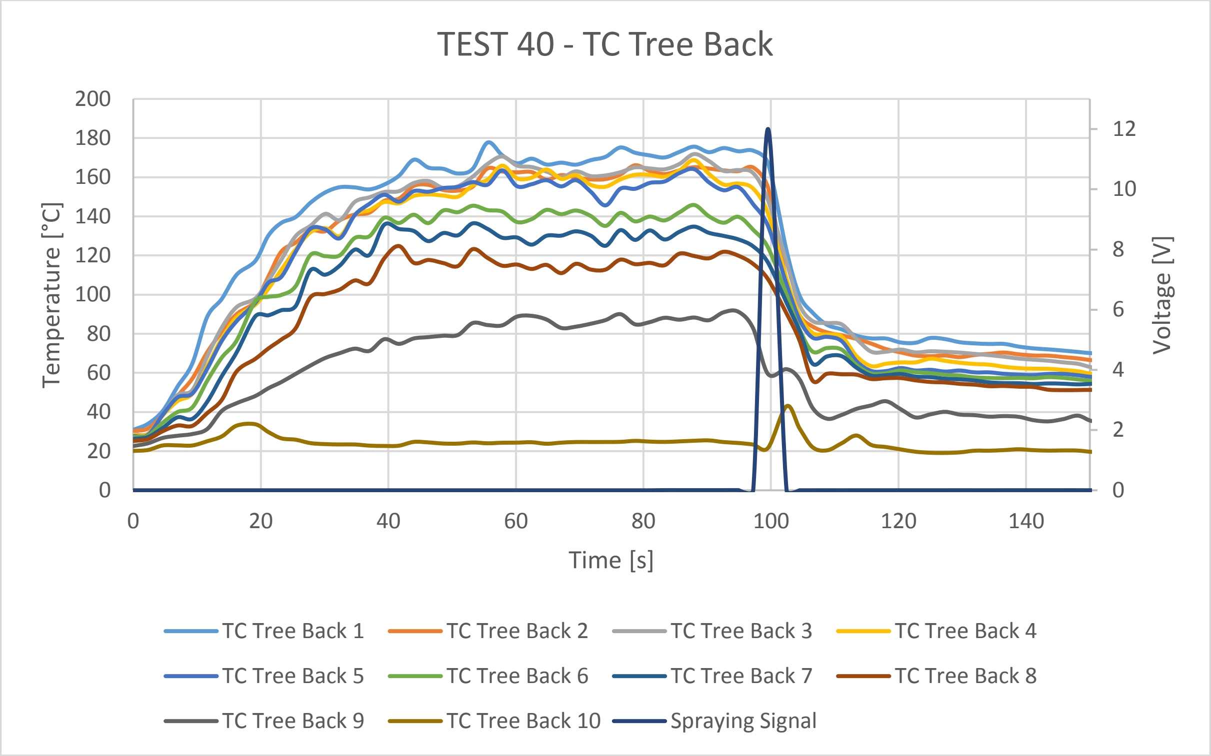

TEST 38 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

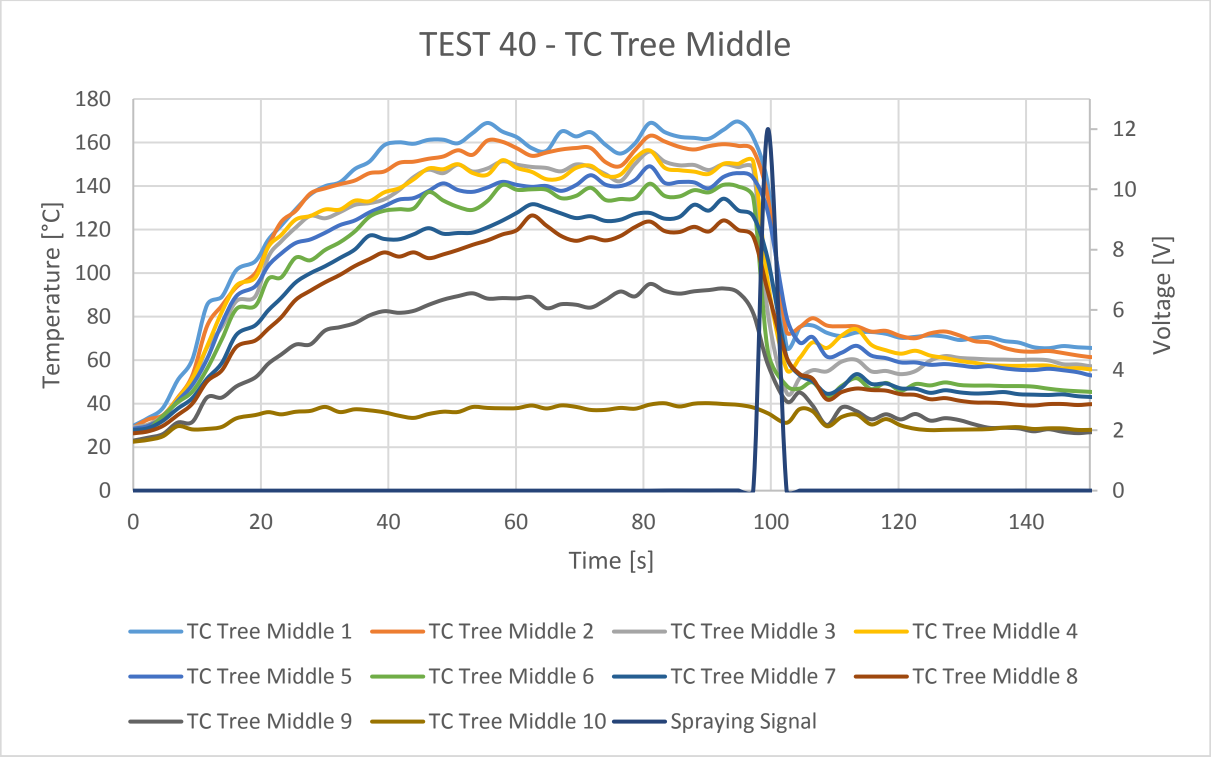

TEST 39 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

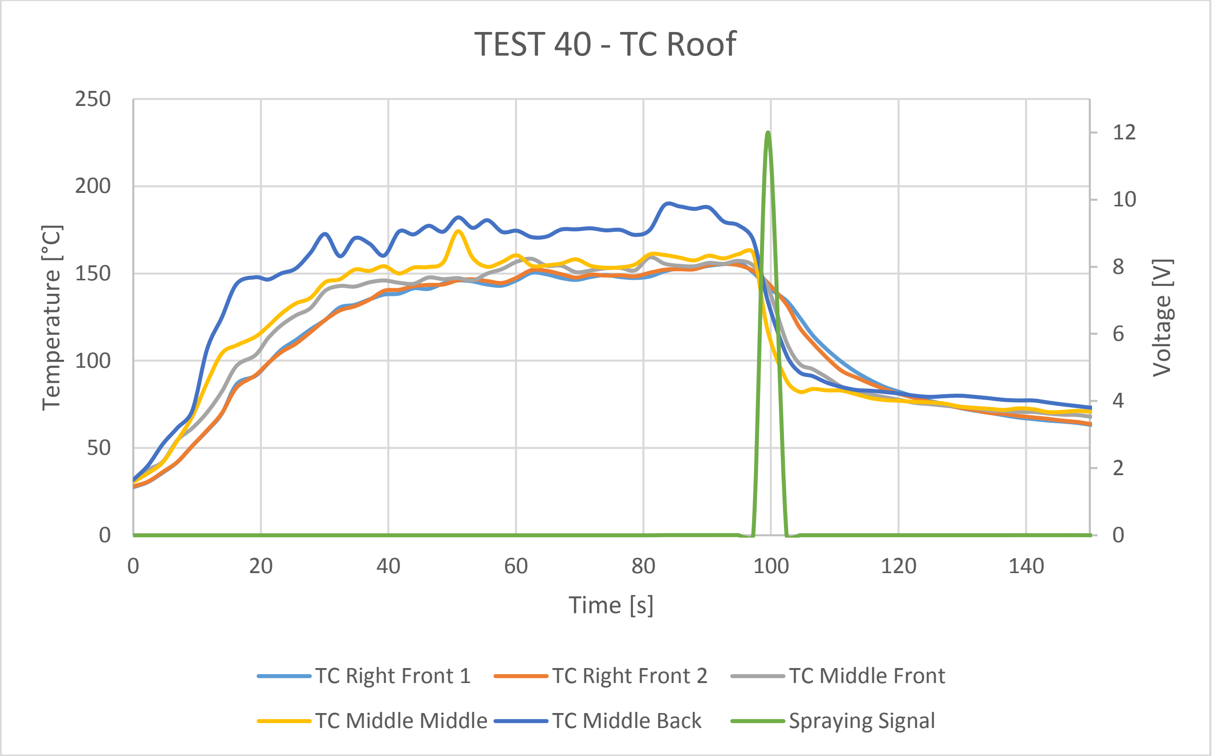

TEST 39 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

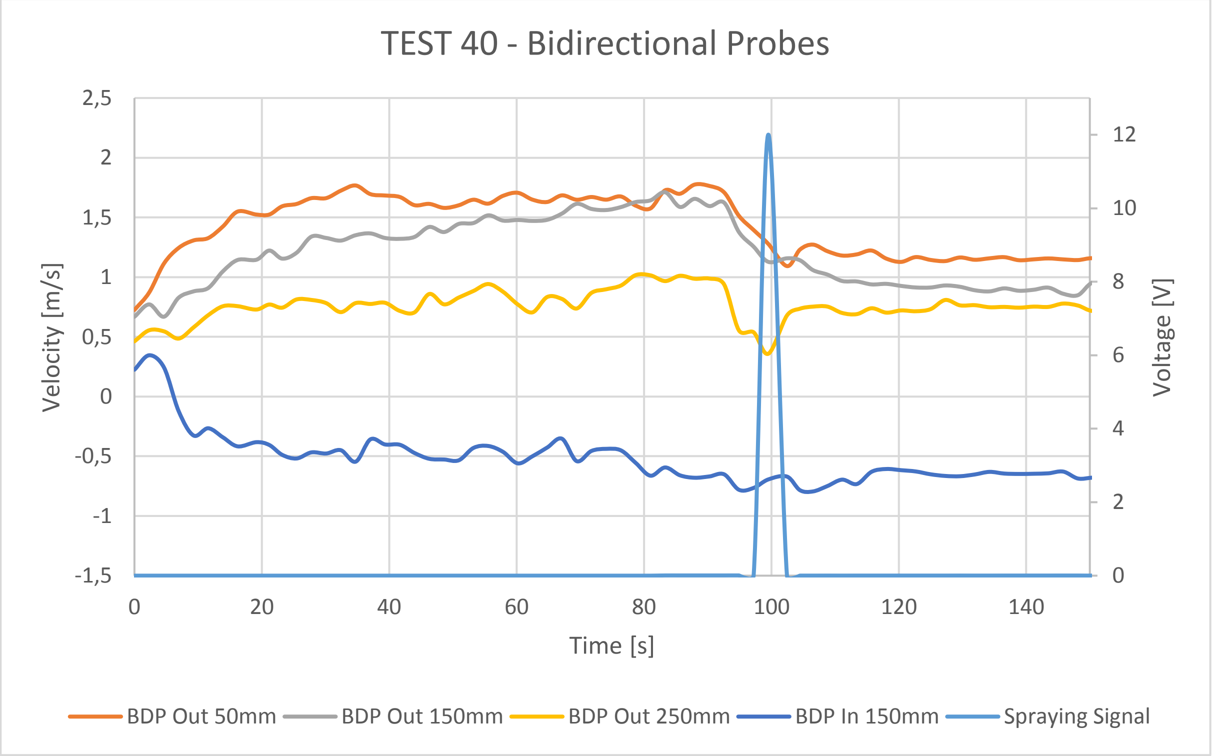

TEST 39 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

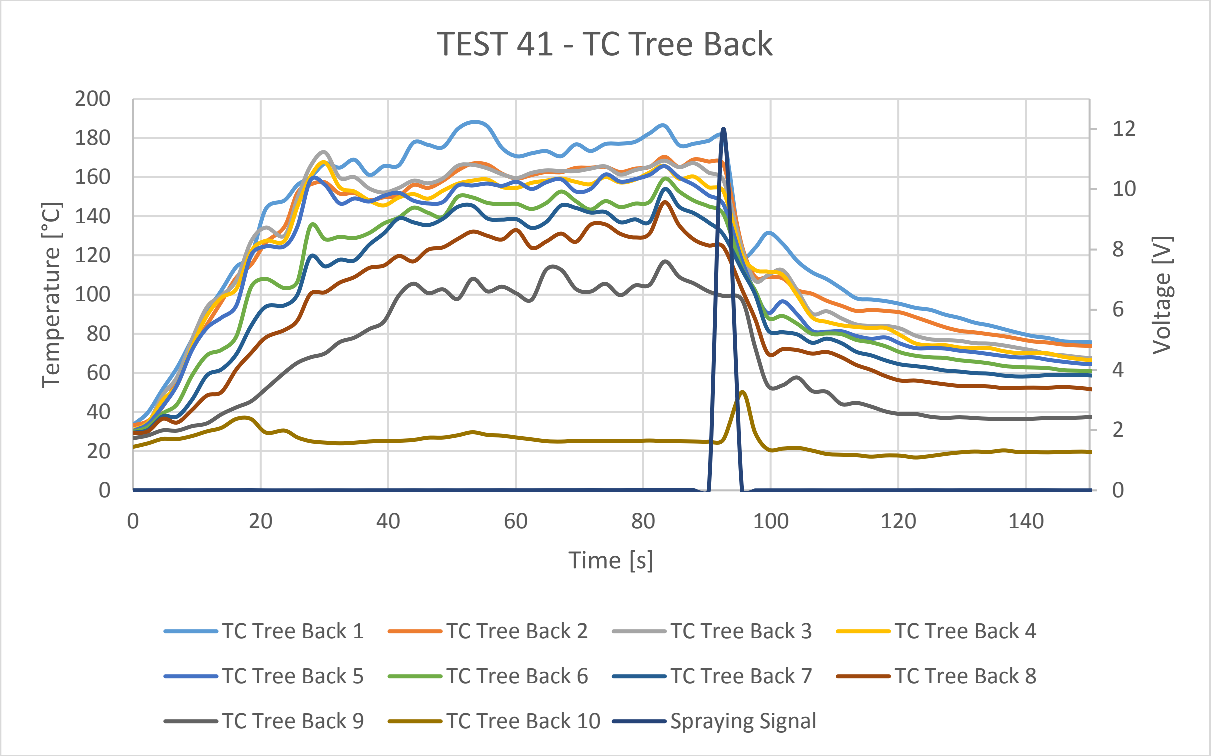

TEST 39 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

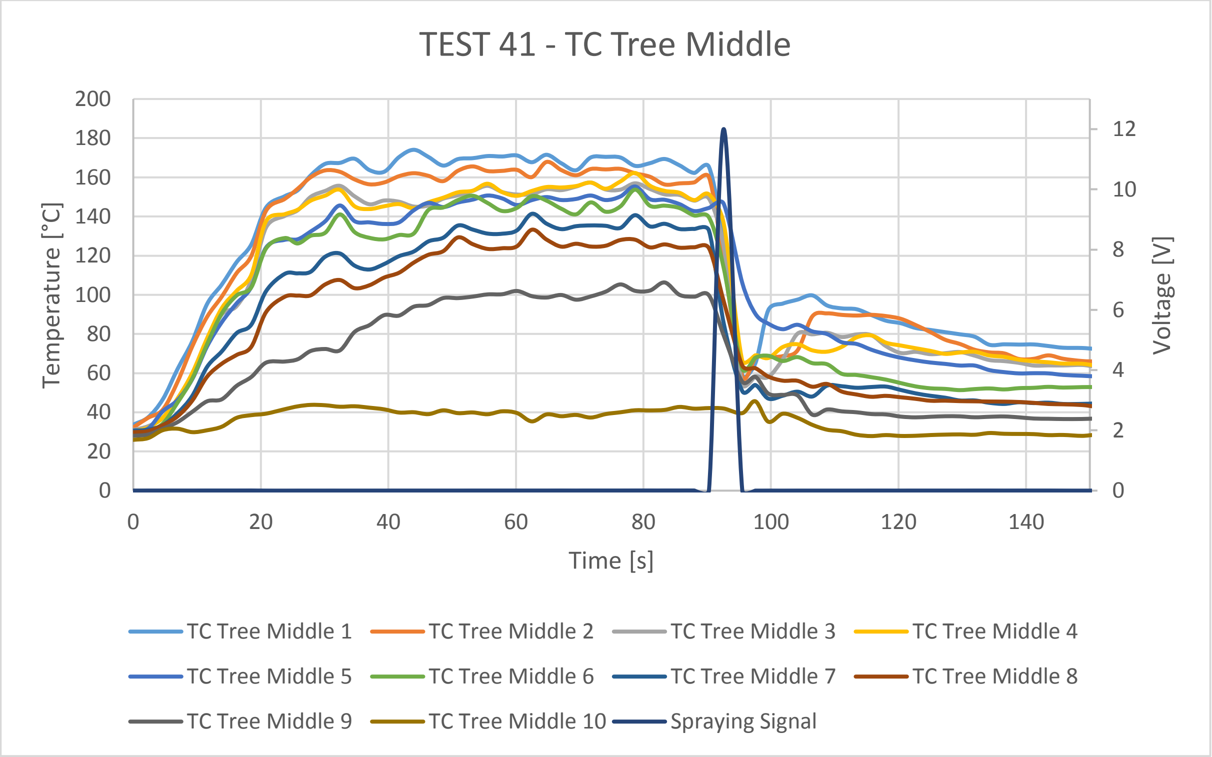

TEST 40 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

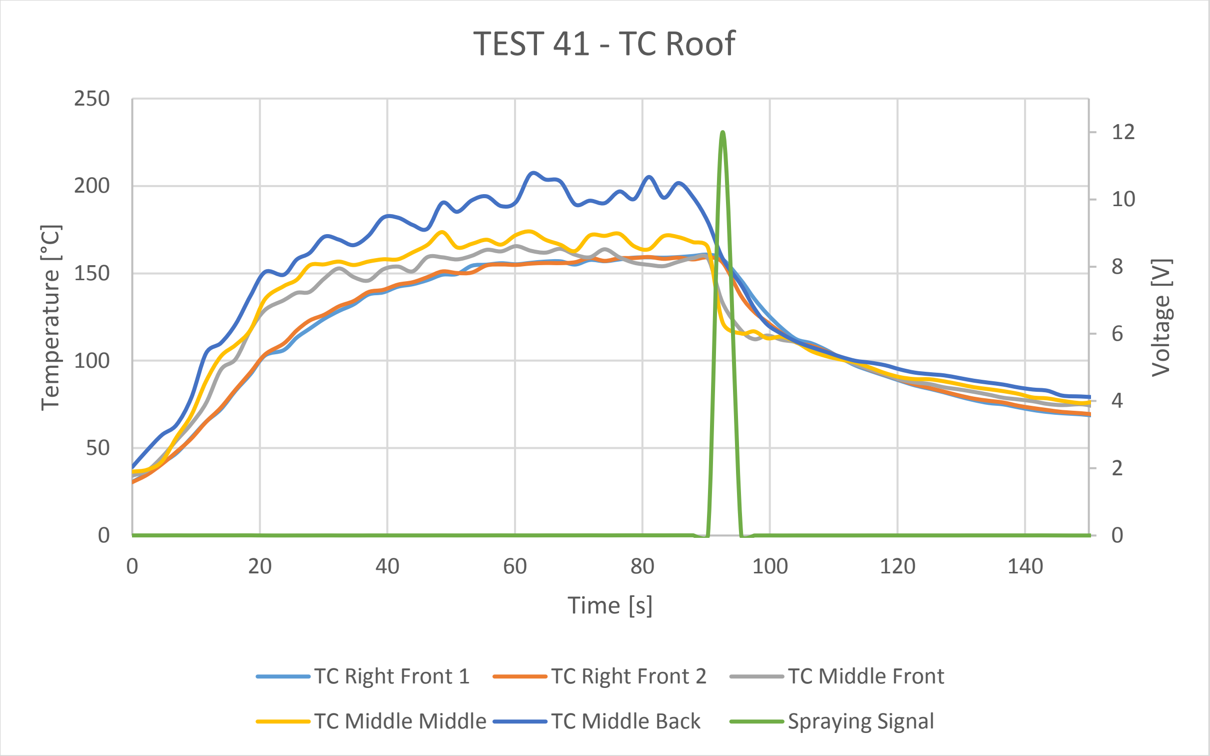

TEST 40 - TC Tree Middle
Temperature [°C]
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

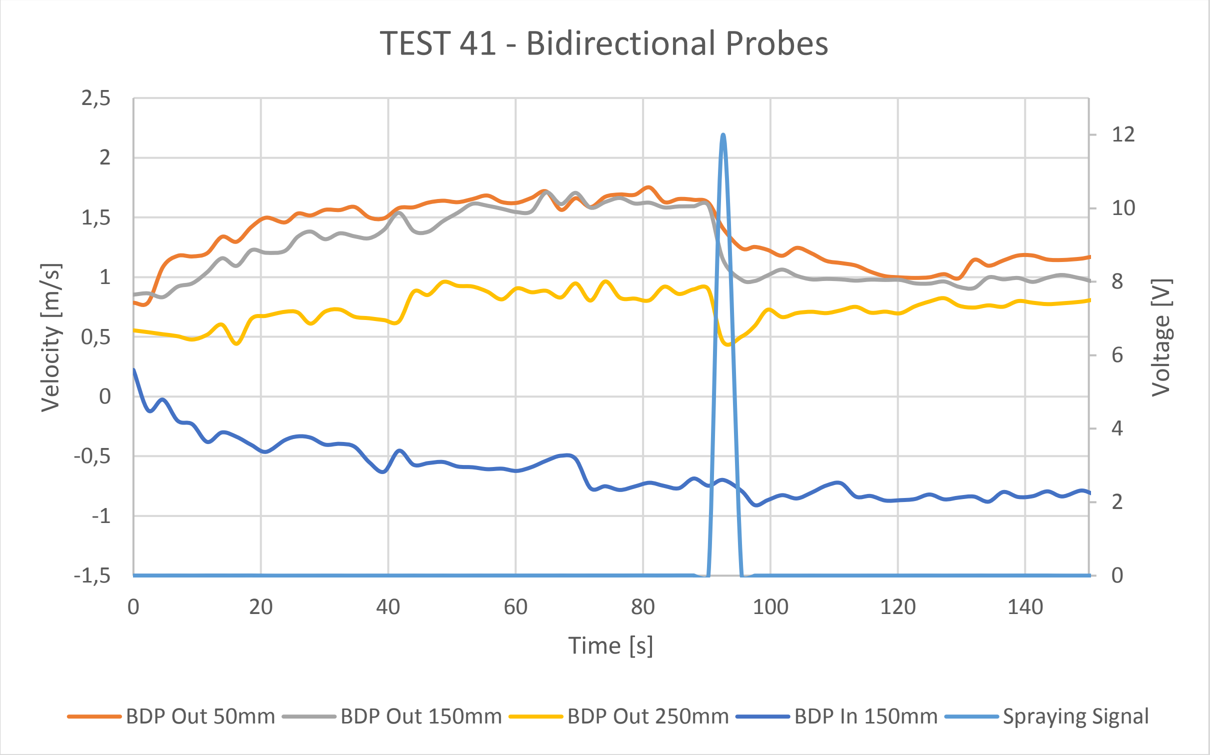

TEST 40 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal

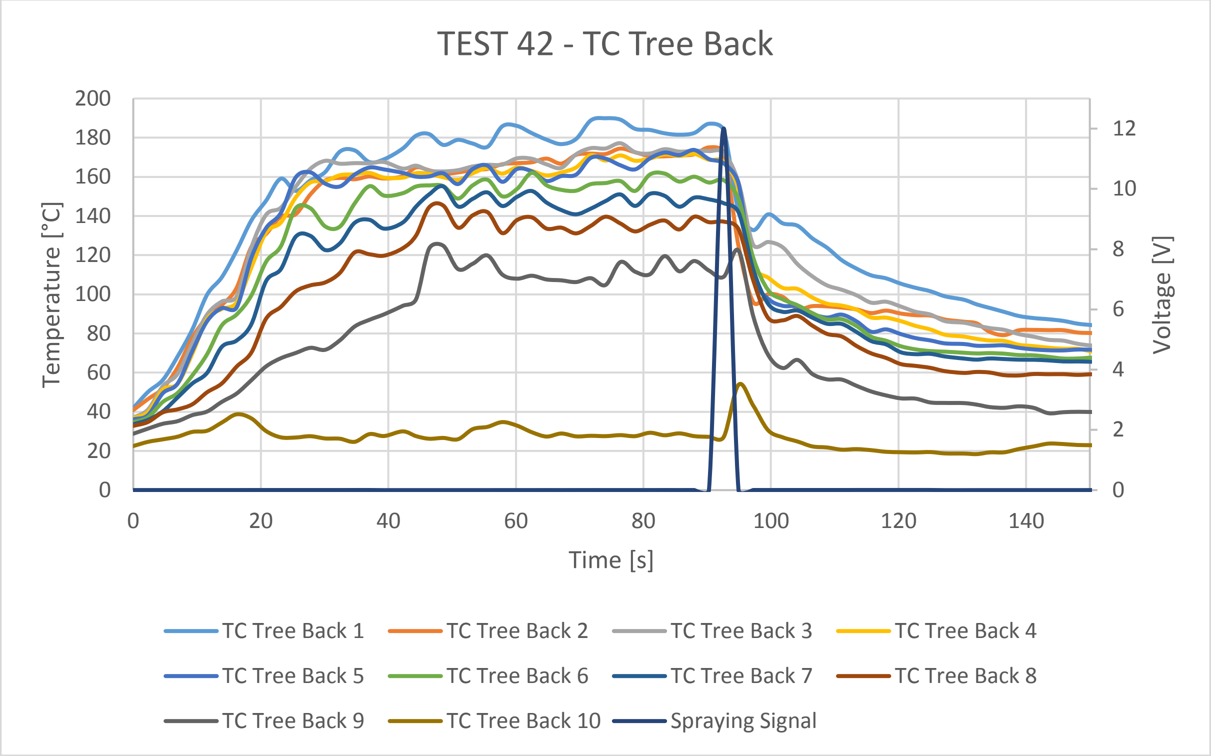

TEST 40 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal

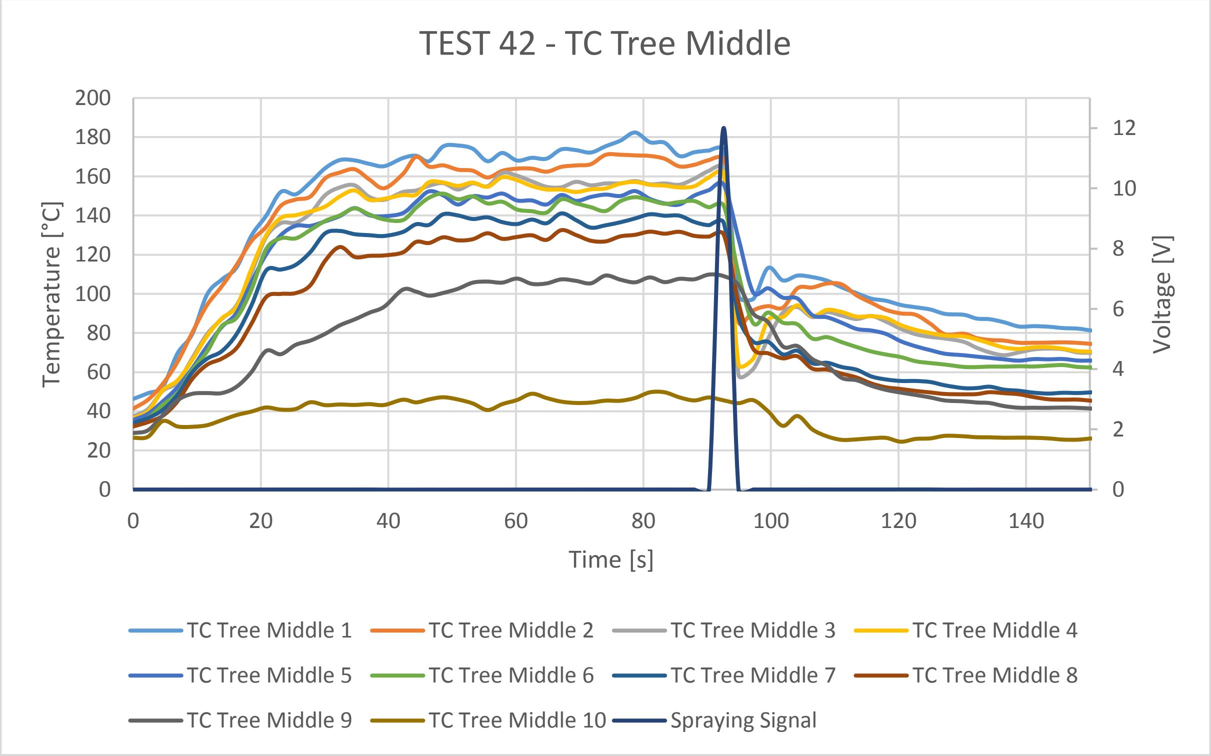

TEST 41 - TC Tree Back
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal

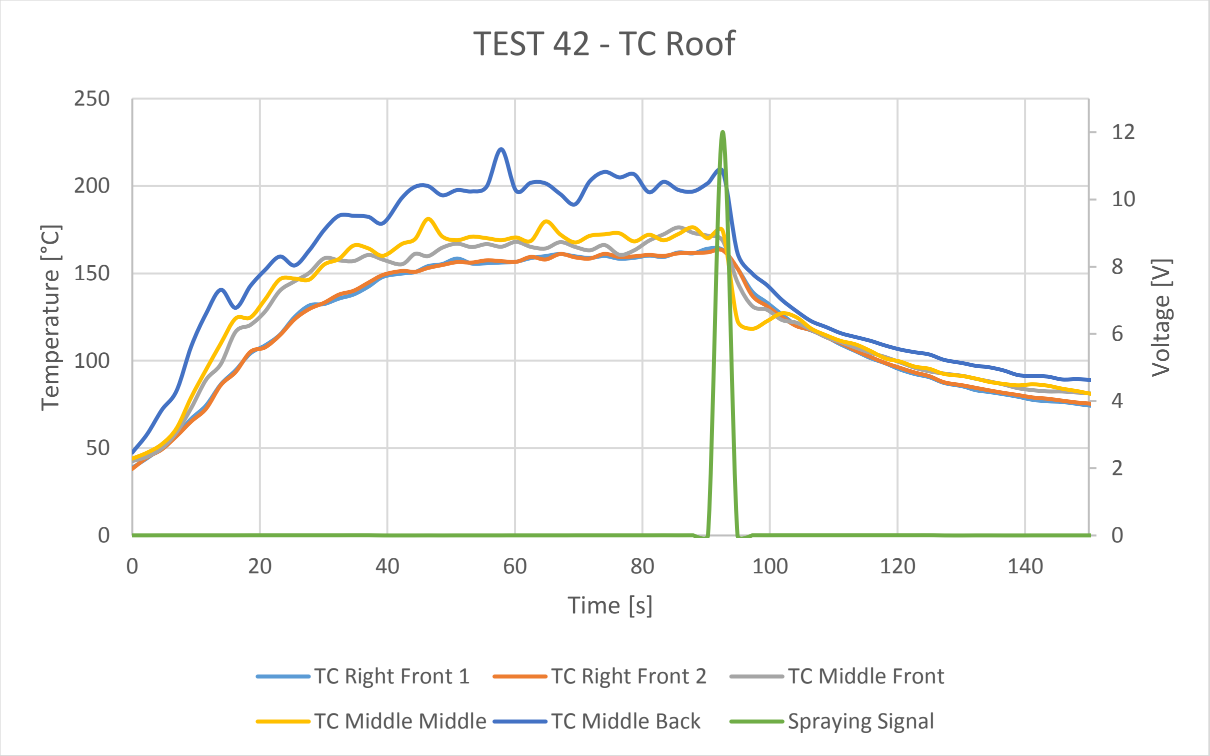

TEST 41 - TC Tree Middle
Temperature [°C]
Voltage [V]
Time [s]
200
180
160
140
120
100
80
60
40
20
0
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal

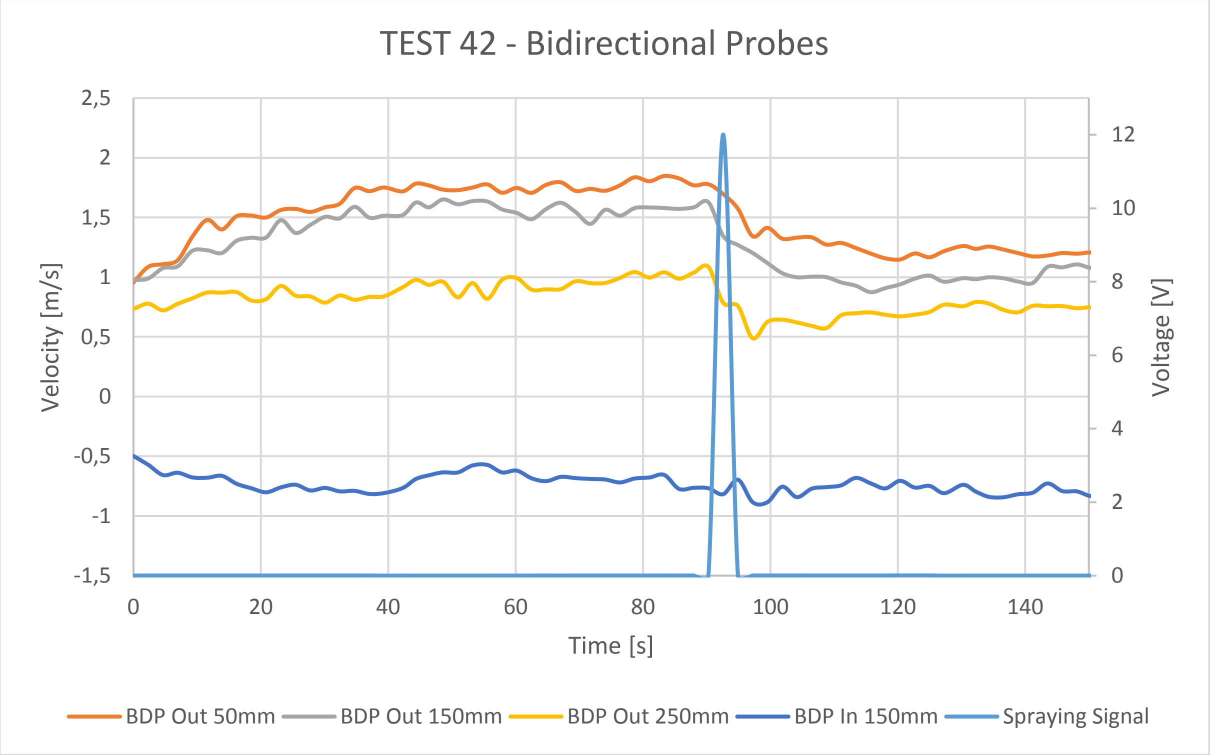

TEST 41 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal


TEST 41 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal


TEST 42 - TC Tree Back
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Back 1
TC Tree Back 2
TC Tree Back 3
TC Tree Back 4
TC Tree Back 5
TC Tree Back 6
TC Tree Back 7
TC Tree Back 8
TC Tree Back 9
TC Tree Back 10
Spraying Signal


TEST 42 - TC Tree Middle
Temperature [°C]
200
180
160
140
120
100
80
60
40
20
0
Voltage [V]
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time [s]
TC Tree Middle 1
TC Tree Middle 2
TC Tree Middle 3
TC Tree Middle 4
TC Tree Middle 5
TC Tree Middle 6
TC Tree Middle 7
TC Tree Middle 8
TC Tree Middle 9
TC Tree Middle 10
Spraying Signal


TEST 42 - TC Roof
Temperature [°C]
250
200
150
100
50
0
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
TC Right Front 1
TC Right Front 2
TC Middle Front
TC Middle Middle
TC Middle Back
Spraying Signal


TEST 42 - Bidirectional Probes
Velocity [m/s]
2,5
2
1,5
1
0,5
0
-0,5
-1
-1,5
Voltage [V]
12
10
8
6
4
2
0
Time [s]
0
20
40
60
80
100
120
140
BDP Out 50mm
BDP Out 150mm
BDP Out 250mm
BDP In 150mm
Spraying Signal