



Cavitar Welding Camera

Guide for cooling

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Cavitar Welding Camera, C300 and C400 series

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1. Introduction

This guide provides information about the cooling of Cavitar Welding Cameras (C300 and C400 series; standard models with GigE interface) and is intended to be used together with the applicable operation manual. The general principles of this guide also apply to the high-speed versions of Cavitar Welding Cameras (USB3 interface). However, since the high-speed versions typically generate more heat than the standard versions, the applicability of passive cooling is more limited with the high-speed version as compared to the standard version. All tests have been made with Cavitar Welding Camera C300, but the results and conclusions apply also to Cavitar Welding Camera C400 series. All results are indicative.

There are numerous different welding processes and welding environments. Therefore also the cooling requirements can vary substantially from case to case. Typically the following sources of heat must be dealt with:

- Internal heat load generated by the camera itself
- External heat load generated by elevated ambient temperature
- External heat load generated by the welding process

Due to the internal heat generated by the camera electronics, heat must be transferred from the camera to an external heat sink even in normal ambient temperature (25 °C). In such a situation it is usually sufficient to mount the camera from the sides with an articulated arm having a metallic clamp.

Cavitar Welding Cameras have built-in safety measures for warning about increasing camera temperature. With C300 series the camera temperature is shown in Cavitar Capture software and warnings will be displayed on the screen (see the C300 operation manual for more details). With C400 series warnings are generated by a separate temperature warning unit (see the C400 operation manual for more details). Appropriate cooling will increase the lifetime of the camera. However, at the same time it is important to keep the camera temperature above dew point to avoid condensation. Depending on the total heat load either passive cooling (Chapter 2) or active cooling (Chapter 3) is needed.

2. Passive cooling

Passive cooling is the simplest solution in situations where the external heat load is relatively small. As an example we can consider a welding process with relatively short duration and small heat output under ambient temperatures up to ~35 °C.

With passive cooling the aim is always to move the heat conductively from the camera to a separate heat sink(s). In order to achieve efficient passive cooling the thermal conductivity from the camera to the heat sink(s) must be maximized. The camera has been designed in such a way that the heat generated inside the camera can reach the outer surface of the camera housing (especially both sides) as efficiently as possible. This heat, as well as any additional external heat load, is then transferred to a heat sink(s).

Some important topics related to passive cooling are discussed in Sections 2.1 – 2.3 in more detail.

2.1 Usage of thermally conductive sheets

High thermal conductivity sheets should be applied between the camera side(s) and the mounting and/or heat sink(s) in order to maximize heat conductivity. Cavitar offers dedicated thermally conductive sheets and heat sinks for passive cooling as optional accessories.

When applying thermally conductive sheets the following guidelines should be followed:

- Use only thin (up to 0.5 mm) sheets with high thermal conductivity
 - Cavitar offers thermally conductive sheets with the following specifications:
 - Thickness 0.2 mm
 - Thermal conductivity 6 W/mK
- Ensure the sheets are clean, sufficiently large (to cover the entire interface area) and unused
- Ensure the surfaces to be joined are properly cleaned
 - Dirt in the interface can prevent proper thermal contact between the surfaces
- Always ensure that possible protective foils are removed before use
 - Protective foils typically have very poor thermal conductivity and if they are not removed, heat transfer from camera to heat sinks(s) will be severely compromised
- Remember to apply thermally conductive sheets in all interfaces between the camera and the final heat sink (e.g. welding machinery)
- Do not re-use thermally conductive sheets

In the following figures the usage of thermally conductive sheets is shown in detail in combination with Cavitar heat sinks designed for C300.

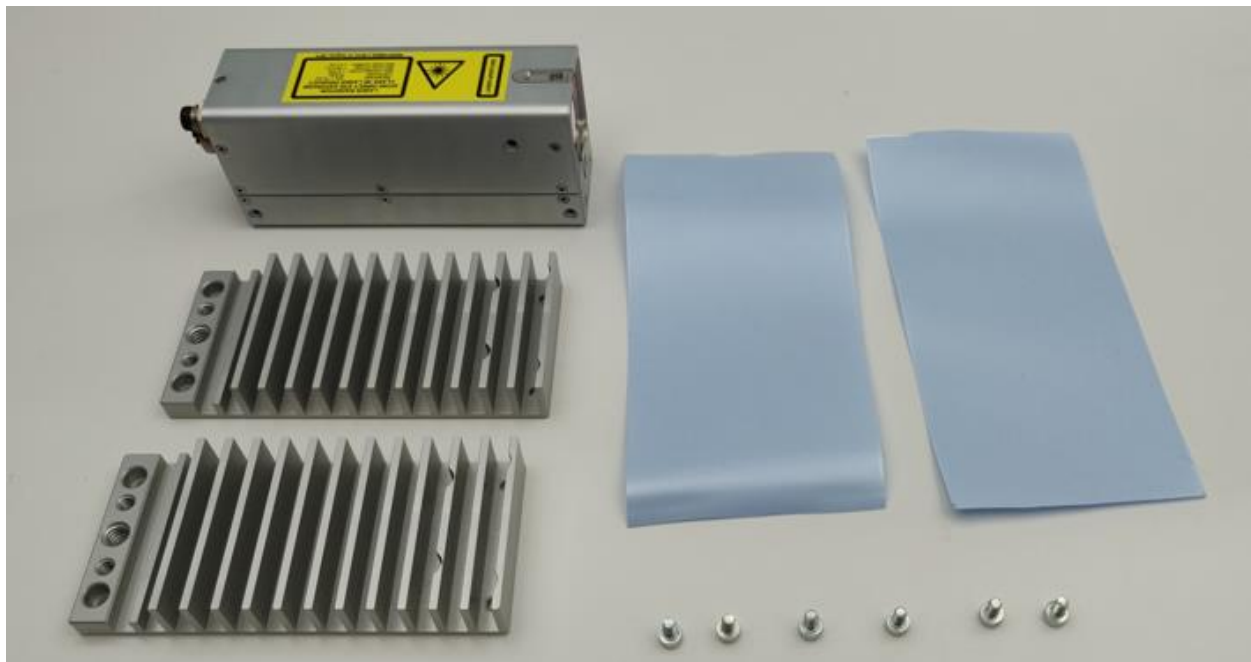


Fig. 2.1. Components for the mounting of Cavitar heat sinks (model C300).

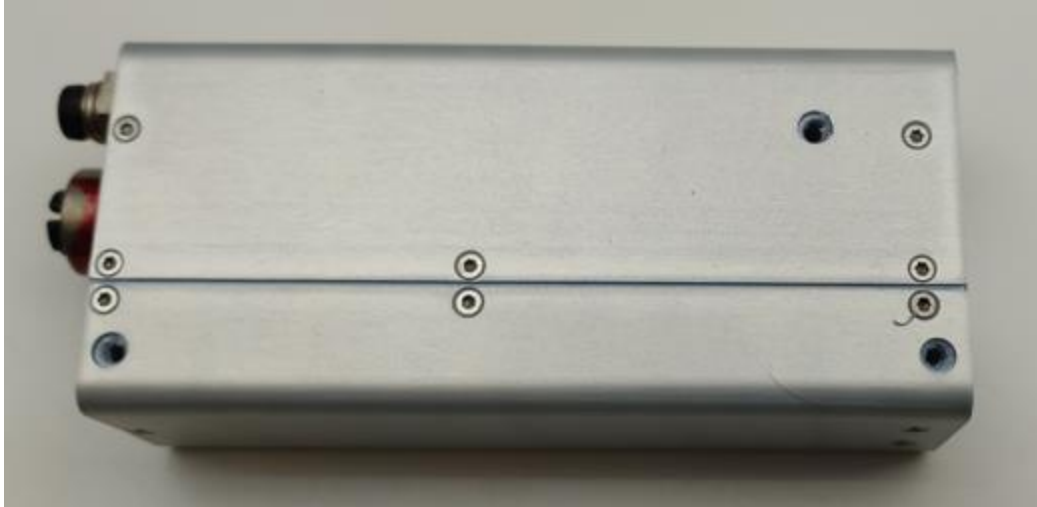


Fig. 2.2. Ensure the camera sides are clean.

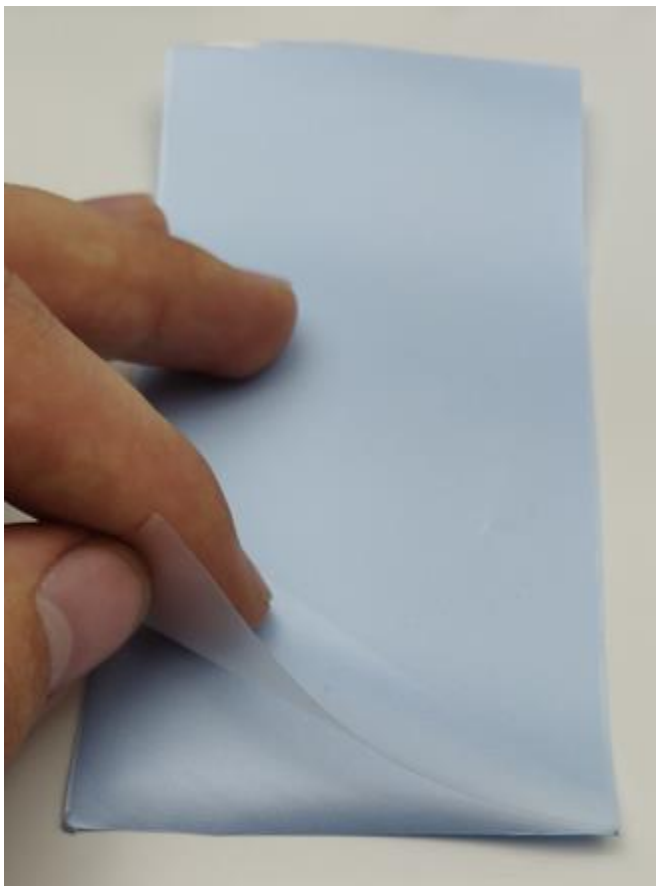


Fig. 2.3. Remove the protective foil from the thermally conductive sheet (if applicable).



Fig. 2.4. Place the thermally conductive sheet over the camera and mark the locations of the threads.

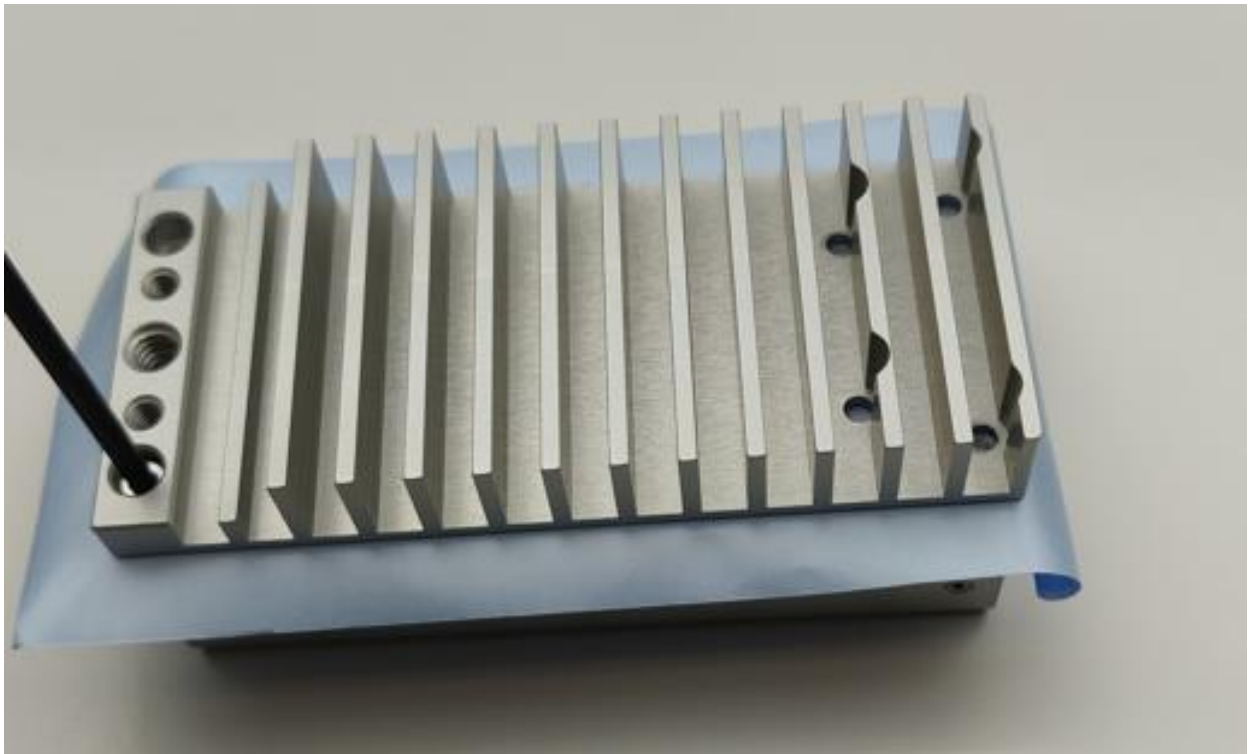


Fig. 2.5. Place the heat sink over the thermally conductive sheet and mount the heat sink with three screws (DIN912 M3x8).



Fig. 2.6. Heat sink mounted to the camera.



Fig. 2.7. Repeat the procedure for the other side.



Fig. 2.8. Remove excess sheet, if applicable.



Fig. 2.9. Heat sinks successfully mounted.

2.2 Mounting to machinery

The simplest and most compact passive cooling solution is to mount the camera to the welding machinery with a thermally conductive mount. For optimal results the following guidelines should be followed:

- The mount should be made of high thermal conductivity material such as aluminium or copper
- The mount should cover the entire side of the camera (for maximal heat transfer the camera can be mounted from both sides)
- Thermally conductive sheet should be applied between the camera side(s) and the mount(s) as well as between the mount(s) and welding machinery
- The connection point of the mount to the welding machinery should be in such a location where the temperature of the welding machinery is as low as possible (however, the temperature of the heat sink mustn't be so low that condensation could take place inside the camera). Possible mounting locations could be e.g. the metallic body of the welding machinery (roughly at the ambient temperature) or some cooled component/location of the machinery, if available
- The contact area between the mount and welding machinery should be sufficiently large (preferably at least similar contact area as between the mount and the camera)
- It is possible to reduce the effect of external heat loads by adding thermal insulation around the camera and the mount (e.g. thermally insulating sleeve)

2.3 Heat sinks

Cavitar offers dedicated heat sinks (see Section 2.2 for mounting details) that can be applied if passive cooling is sufficient but there is no suitable mounting location in the welding machinery.

In principle proper mounting to machinery can be more efficient than using separate heat sinks since the temperature of the welding machinery is typically not affected by the heat generated by the camera while the separate heat sinks get warm. Gradually thermal equilibrium will be obtained when the heat sinks receive the same heating power from the camera as what they release to the surrounding air.

Since the cooling is based on heat transfer from the heat sinks to the surrounding air, thermal insulation around the heat sinks can't be applied (unlike in Section 2.2). The efficiency of the heat sinks is improved if air can flow properly at the surfaces of the heat sinks. This is shown in Fig. 2.10.

The mechanical dimensions of the heat sinks for Cavitar Welding Camera C300 are shown in Fig. 2.11. Similar heat sinks are available for C400 series.

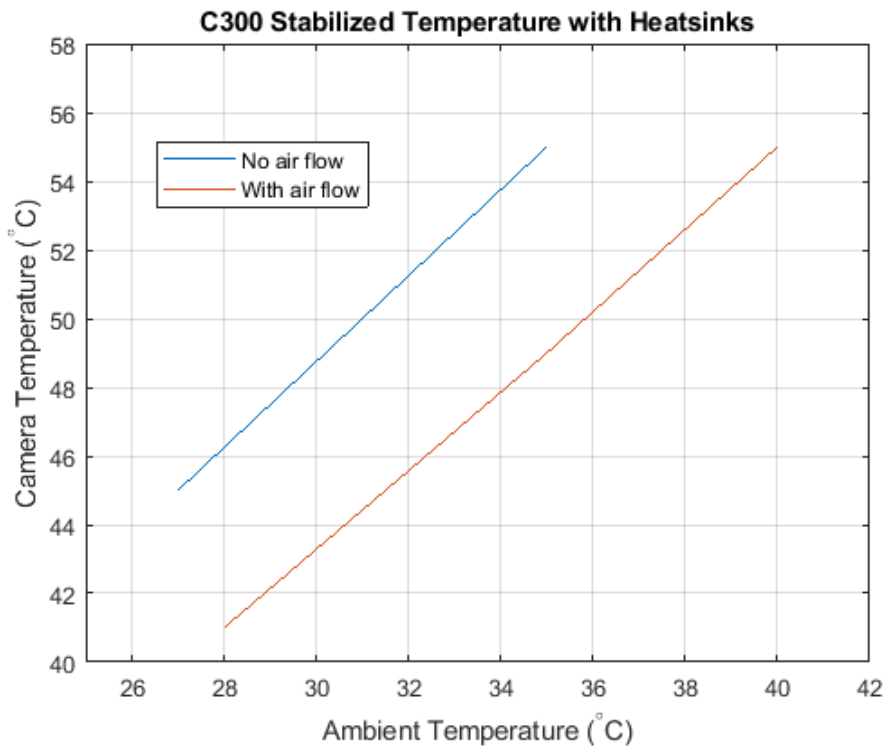


Fig. 2.10. Stabilized C300 camera temperature with heat sinks (with and without air flow).

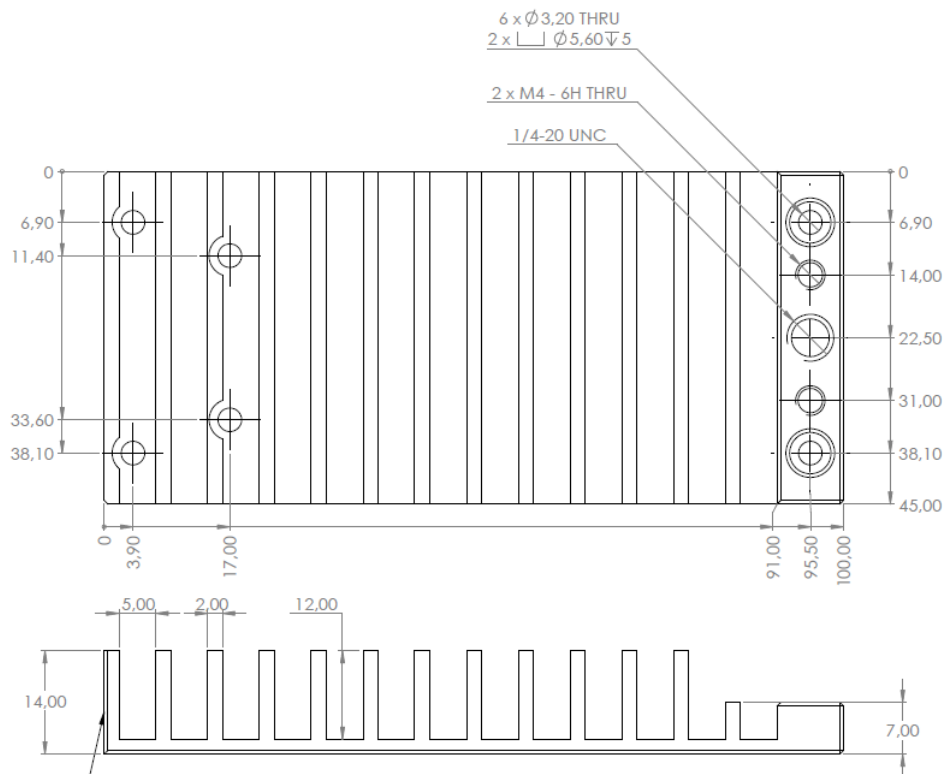


Fig. 2.11. Mechanical dimensions of the heat sink for C300.

3. Active cooling

Active cooling is the most efficient solution for challenging conditions (elevated ambient temperature, large heat load from the welding process). The most common means of active cooling include air cooling and liquid cooling. Since active cooling is typically used in challenging environments, it is crucial to ensure continuous and sufficient flow of the coolant to the camera. A dedicated warning system is strongly recommended to avoid damage to the camera in case of problems with the flow of the coolant.

Air cooling (Section 3.5) can be a practical solution for relatively challenging conditions if suitable pressurized air is available. Liquid cooling (Section 3.6) is even more efficient and for the most extreme conditions air and liquid cooling can be combined (Section 3.7).

3.1 Installation to camera

Figure 3.1 shows typical active cooling components (2x cooling connector, 2x cooling hose and 2x hose clamp) before and after installation to the camera. First the cooling connectors are connected to the threads of the camera unit (ensure O-rings are in place; maximum torque 1 Nm). Then appropriate cooling hoses (inner diameter 6 mm) are connected to the cooling connectors with appropriate hose clamps. Always ensure that the cooling connectors and cooling hoses are properly fastened and free from any leaks. Leaking cooling liquid can get in contact with the back of the camera and may in the worst case enter the camera, thus breaking the camera.

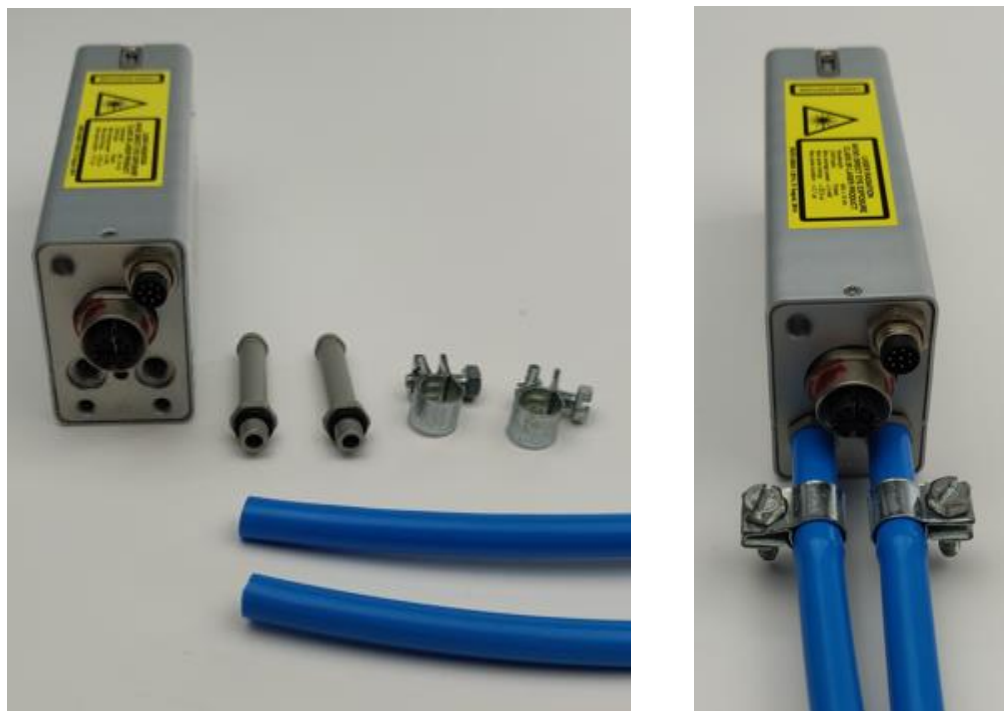


Fig. 3.1. Active cooling components before and after installation to the camera.

3.2 Thermal insulation from the environment

In high temperature environment the efficiency of cooling can be greatly improved by appropriate thermal insulation of the camera and cables from the environment. This is especially important for the cables which are not cooled as efficiently as the camera body. Various industrial thermally insulating protective sleeves are available. In the figures below the following sleeves have been applied:

- ADL Insulflex Thermosleeve B
 - Fiber glass sleeve (flexible)
 - Continuous temperature up to 540 °C
 - Suitable for inner insulation layers (three layers applied in the tests)
- ADL Insulflex Pyrojacket
 - Fiber glass sleeve with silicone rubber coating
 - Continuous temperature up to 260 °C
 - Short-term (15 min) temperature up to 1090 °C
 - Momentary (15 sec) temperature up to 1650 °C
 - Suitable for the outermost insulation layer (one layer applied in the tests)

An alternative protective sleeve for Pyrojacket for the most challenging environments:

- ADL Insulflex Pyreflect firesleeve
 - Aramid fiber blanket with aluminium coating
 - Reflects at least 90 % of radiant heat energy
 - Continuous temperature up to 340 °C
 - Short-term temperature up to 540 °C
 - Momentary (1 min) temperature up to 1650 °C

Before applying protective sleeves the proper cooling of electrical cables must be arranged. This can be done by twisting the cooling hoses around the electrical cables as shown in Fig. 3.2.



Fig. 3.2. Twisting the cooling hoses around the electrical cables.

Since the cooling hoses can't be twisted around the electrical cables right behind the camera, it is important to wrap all hoses and cables tightly inside aluminium foil behind the camera. In Fig. 3.3 four rounds of aluminium foil have been wrapped around the camera and all cables and hoses. The foil covers roughly half of the camera housing and continues to the location where the cooling hoses can be properly twisted around the electrical cables. Proper thermal contact to the camera housing is ensured by wrapping Kapton tape tightly around the aluminium foil. Since the housing of the camera is kept cool by active cooling, also the aluminium foil is kept cool and this keeps the cables cool in the region where the cooling hoses can't be properly twisted around the cables.



Fig. 3.3. Aluminium foil wrapped around camera housing, cables and hoses.

Fig 3.4 shows the effect of the aluminium foil. In this test radiator cooling (see Section 3.6.2 for more details) without camera insulation (but with cables insulated) was applied.

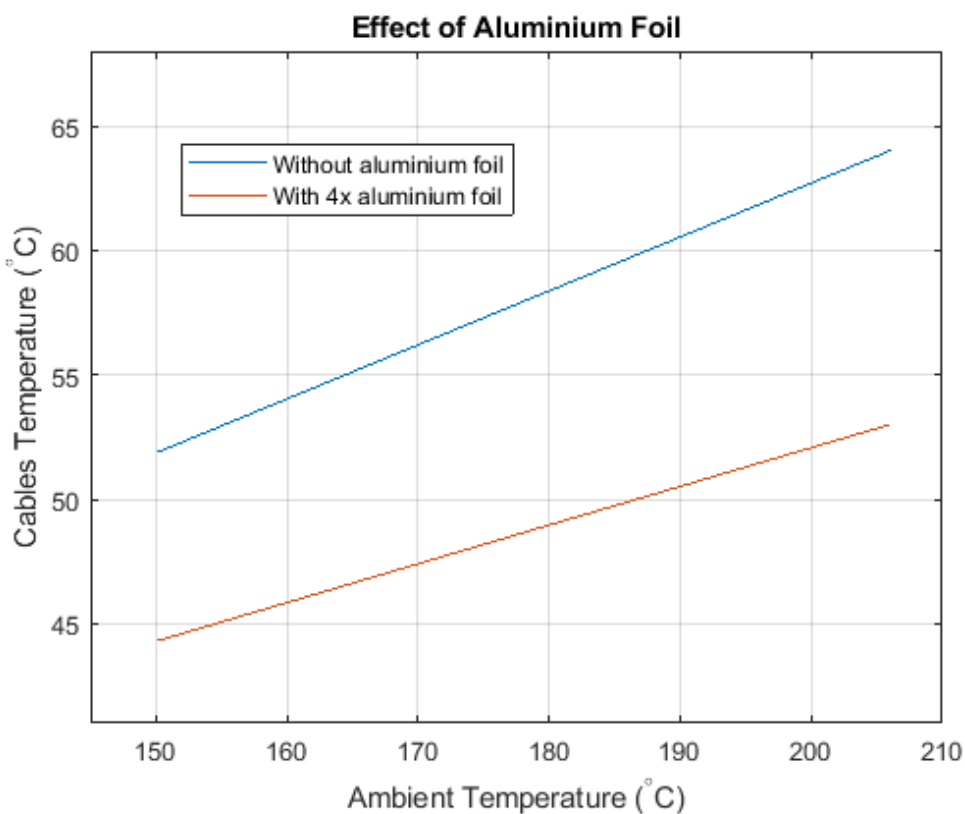


Fig. 3.4. Effect of aluminium foil on cable temperature.

The most efficient insulation arrangement is the following:

- Cooling hoses twisted around electrical cables
- Aluminium foil wrapped around camera housing as well as hoses and cables behind the camera
- Cables and camera insulated with several thermally insulating protective sleeves (with outermost sleeve being air-tight)
- Low-pressure air blown through the system (in this case air must be able to exit the system through appropriate opening between the camera housing and the outermost protective sleeve)

If low-pressure air is not applied, it is important to seal the interface between the camera housing and the outermost protective sleeve (e.g. with Kapton tape) in order to prevent hot ambient air from entering the insulation. This is shown in Fig. 3.5.



Fig. 3.5. Interface between camera housing and outermost protective sleeve sealed with Kapton tape.

In many cases also less efficient insulation arrangements may be sufficient. As an example, in moderate ambient temperatures it may not be necessary to insulate the camera housing. Therefore, if needed, space can be saved by protecting only the cables with protective sleeves. This is shown in Figs. 3.6-3.8 (please note that the steps shown in Figs 3.2 and 3.3 have been carried out beforehand). In this example effectively three layers of Thermosleeve B have been applied, but the appropriate number of layers can be smaller or larger, depending on the ambient temperature and application.



Fig. 3.6. Thermosleeve B pulled over the cables and hoses.



Fig. 3.7. Thermosleeve B wrapped around the cables and hoses (effectively two additional layers).



Fig. 3.8. Pyrojacket pulled over the cables and hoses and sealed to camera housing with Kapton tape.

Table 3.1 shows the effect of insulating the camera in addition to the cables. In this test recirculating chiller cooling (see Section 3.6.3 for more details) was applied.

Table 3.1. Measured temperatures for insulated cables without/with insulated camera.

Temperature	Only cables insulated	Cables and camera insulated
Ambient (°C)	290	290
Camera body top side (°C)	80	52
Camera body bottom side (°C)	64	43
Cables (°C)	76	67
Camera (°C)	47	39
Cooling liquid (°C)	25	25

3.3 Condensation

Condensation occurs whenever there is humidity in air and the temperature of an object falls below the dew point. Condensation must be avoided since it can damage the welding camera. Condensation can be prevented by keeping the cooling medium (air or liquid) temperature above the dew point. Usually temperatures around 25...30 °C are safe in this respect. However, in exceptionally humid and warm environments even higher cooling medium temperatures may need to be applied. Figure 3.9 shows the dependence of dew point on ambient temperature and relative humidity in normal pressure.

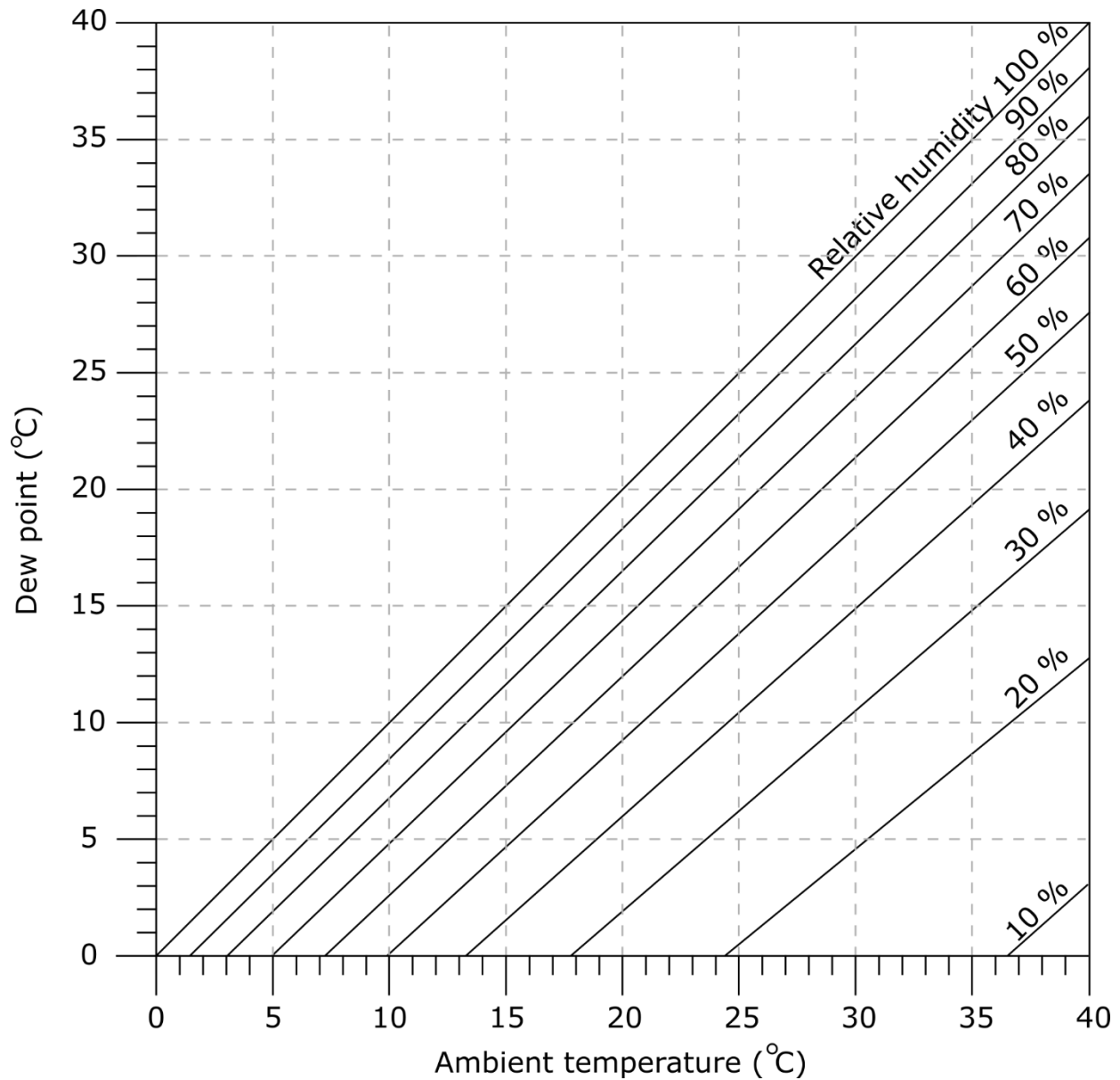


Fig. 3.9. Dependence of dew point on ambient temperature and relative humidity.

As an example, if the ambient temperature is 30 °C and relative humidity is 80 %, the temperature of the coolant must be above 27 °C in order to avoid condensation. As can be seen from Fig. 3.9, it is always safe (from the condensation point-of-view) to use coolant temperature at or above ambient temperature. In this respect the radiator solution (see Section 3.6.2) is an easy way to avoid condensation issues (provided that the radiator is located appropriately).

3.4 About the tests

The tests were carried out by putting the camera and cables inside an oven and by logging temperature values from different locations (Fig. 3.10). Also the ambient temperature inside the oven was measured.

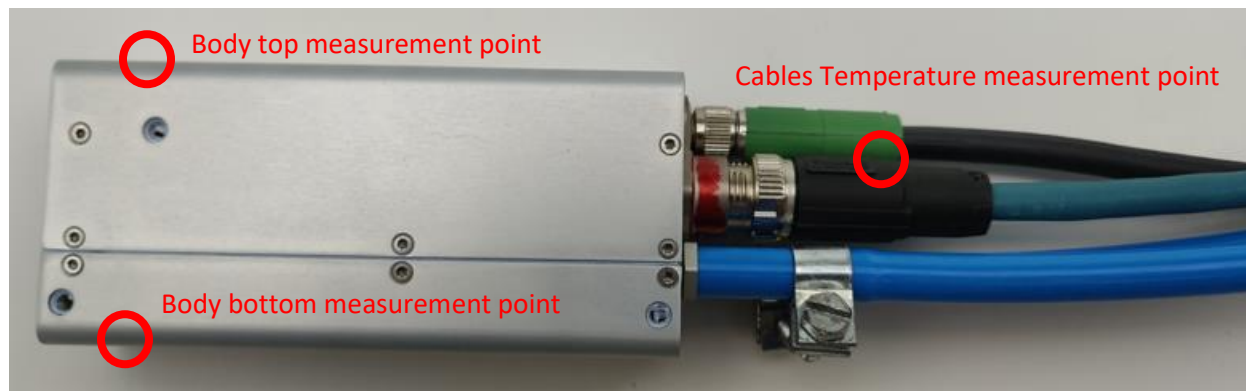


Fig. 3.10. Temperature measurement points.

All tests were realized with 25 m long inlet and outlet cooling hoses (50 m total loop length) with inner diameter of 6 mm. In the tests of Sections 3.5 and 3.6 the cables were insulated and the camera was not insulated (see Figs. 3.2, 3.3 and 3.6-3.8) except in the recirculating chiller tests, which were done also with the camera insulated (see Fig. 3.5). In the case of combined air and liquid cooling (Section 3.7) the insulation consisted of one pyrojacket (no thermosleeves applied) and the interface between camera housing and pyrojacket was not sealed (see Fig. 3.11) to let the air flow through the system. Cooling hose twisting around cables (Fig. 3.2) and aluminium foil (Fig. 3.3) were applied also in this test.



Fig. 3.11. Insulation arrangement for combined air and liquid cooling.

An example measurement is shown in Fig. 3.12, where the evolution of different temperatures as a function of time can be seen. In this test recirculating chiller (constant cooling liquid temperature 25 °C) was applied and both the cables and the camera were insulated.

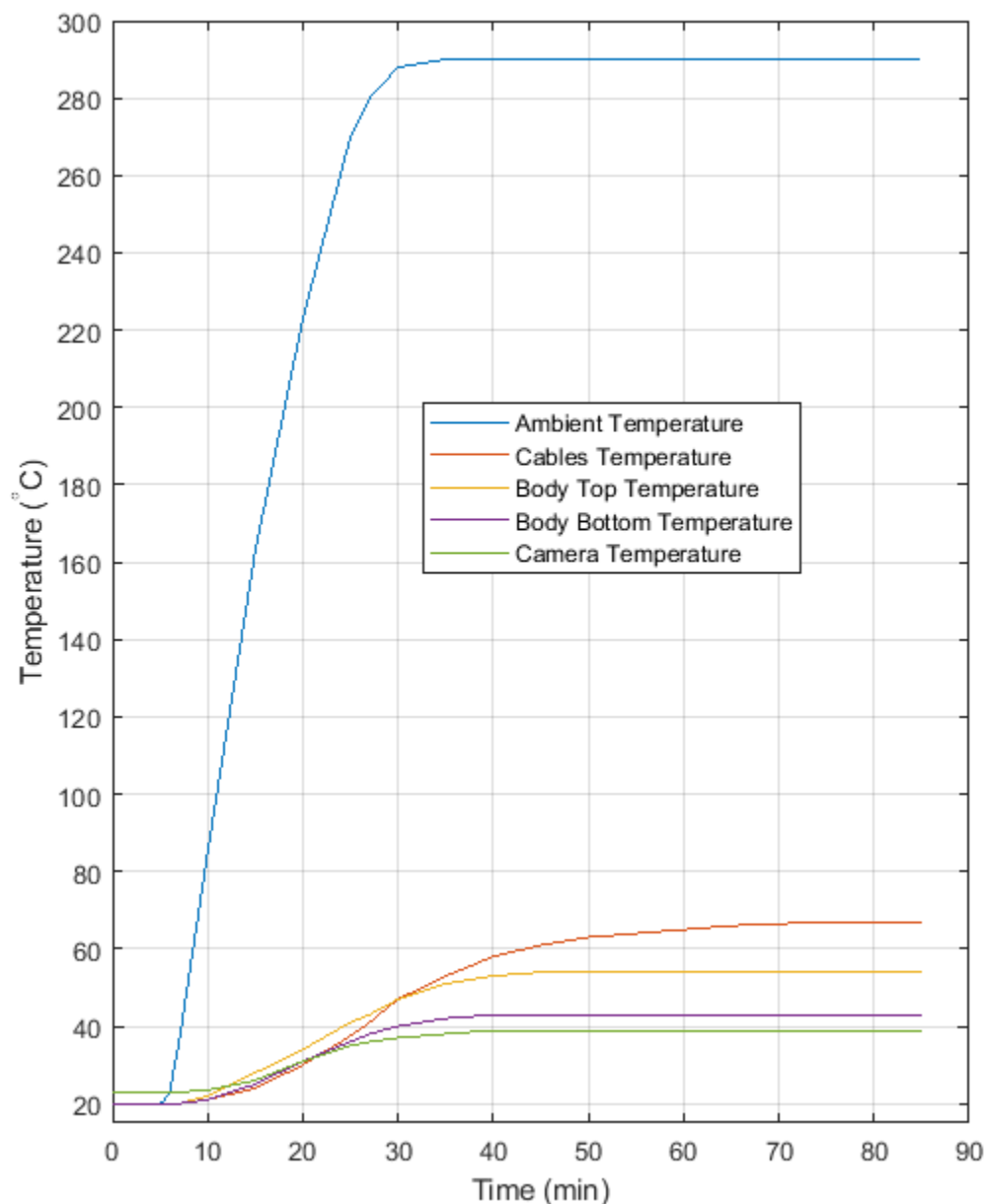


Fig. 3.12. Evolution of temperatures (recirculating chiller, cables and camera insulated).

It is important to note that the results are indicative and valid only for the described test setup. The length of insulation was less than 1 m and there was no heat load from arc process.

3.5 Air cooling

3.5.1 Pressurized air

Pressurized air can be applied simply by connecting the incoming air hose to either cooling connector of the welding camera. The air will come out from the second cooling connector of the camera. This air can be guided to desired location with a second hose (can also be utilized in air knife). If the camera and cables are insulated (e.g. inside an air-tight thermally insulating protective sleeve such as pyrojacket), the exhaust air can also be used for keeping the air inside the protective sleeve cooler. This is very useful in keeping the cables sufficiently cool. In this case there is no need to connect anything to the second cooling connector of the camera (the aluminium foil around the cables shouldn't be applied in order not to obstruct the exhaust air flow). The exhaust air can be forced to travel back inside the protective sleeve by sealing the camera end of the insulation (see Figs. 3.5 or 3.8). Pressurized air should be sufficiently pure (no water or oil) and the pressure shouldn't be excessive. Ideal temperature for the pressurized air is ~25...30 °C (to avoid condensation and enable efficient cooling). Fig. 3.13 shows the maximum ambient temperature (camera temperature reaching 55 °C) with different air pressures (cables insulated, camera not insulated, see Figs 3.2, 3.3 and 3.6-3.8; return air not cooling the air inside the protective sleeve).

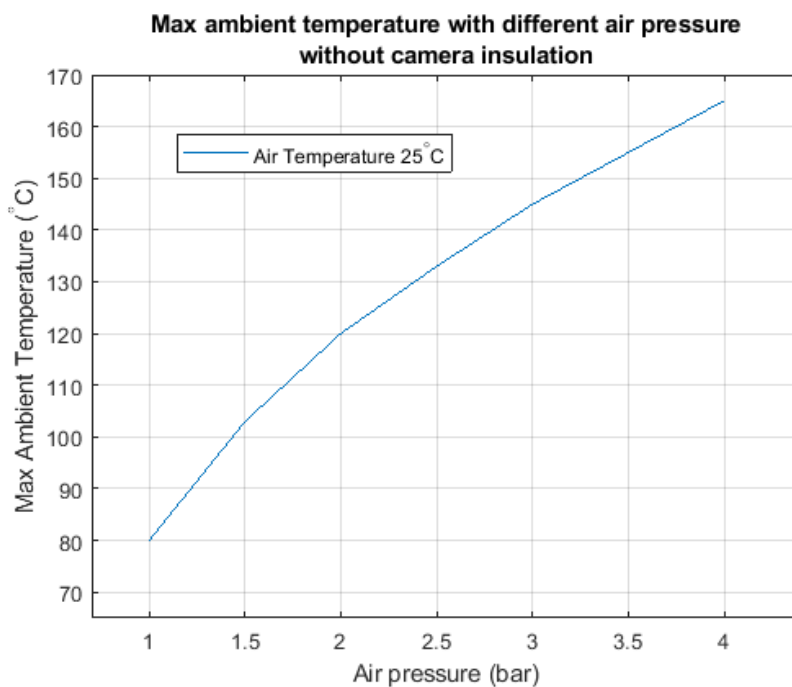


Fig 3.13. Maximum ambient temperature with different air pressures.

3.5.2 Vortex pipe

Vortex pipes can improve the efficiency of air cooling substantially. However, special attention must be paid to avoid condensation and for this reason vortex pipes can only be considered if the user is experienced with vortex pipes and can be certain that there is no risk of condensation. Otherwise same principles as with conventional pressurized air apply.

3.6 Liquid cooling

3.6.1 Requirements and recommendations

- Cooling channels inside the camera are made of aluminium. Only use cooling liquids and cooling equipment that are compatible with aluminium (to prevent corrosion). If the cooling circuitry contains more noble metals than aluminium, the usage of magnesium anodes can be considered
- Always ensure that the cooling connectors and cooling hoses are properly fastened and free from any leaks. Leaking cooling liquid can get in contact with the back of the camera and may in the worst case enter the camera, thus breaking the camera
- A mixture of pure water and inhibited glycol is recommended to avoid corrosion and algae growth
 - Pure water can be distilled, demineralised, de-ionised or reverse osmosis water
 - Never use pure water without inhibited glycol since this causes corrosion
 - Glycol must be inhibited (to avoid corrosion) and the glycol content in the mixture must be at least 20 volume % (to prevent algae growth)
 - Ethylene glycol has better cooling performance than propylene-based glycol but is more toxic
 - Modern industrial glycols contain inhibitors alongside a pH buffer and biocide to prevent corrosion, algae growth and rust
 - Never mix different glycols
- The cooling system must be properly flushed and cleaned before adding suitable inhibited glycol and pure water mixture as well as when the mixture needs to be changed
- Prevent any contamination of the cooling liquid and cooling circuitry
- Cooling solution with temperature and flow rate monitoring and alarm feature is recommended
- Regular maintenance intervals are needed to ensure proper operation (e.g. checking the condition of filters and cooling liquid)
- Never use automotive antifreeze liquids
- The cooling connectors of the welding camera are designed for a cooling hose with an inner diameter of 6 mm. Such hoses need approximately 30 ml of coolant for each meter. An additional 1 l of coolant is needed with the radiator solution (described in Section 3.6.2). If a recirculating chiller is applied (Section 3.6.3), the amount of additional coolant depends on the chiller reservoir volume

3.6.2 Radiator solution

Cavitar has made extensive empirical tests with active liquid cooling utilizing a radiator with fans and a water pump. The cooling liquid is maintained in a temperature close to the ambient temperature at the location of the radiator. Cavitar offers radiator cooling solution that is compatible with the aluminium body of the welding camera.

Fig. 3.14 shows the results for the radiator solution with cables insulated and without camera insulation (see Figs. 3.2, 3.3 and 3.6-3.8). Air temperature around the radiator was 24 °C and flow rate was 20 l/min.

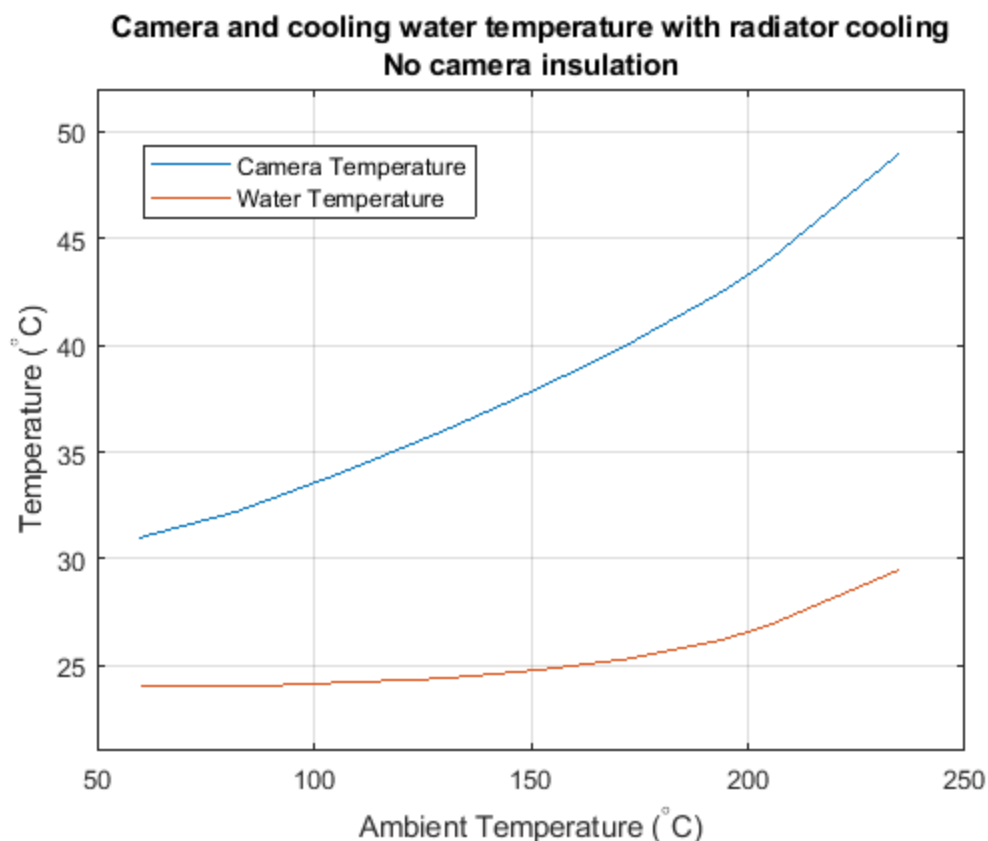


Fig. 3.13. Camera temperature as a function of ambient temperature (radiator solution).

3.6.3 Recirculating chiller

Recirculating chiller maintains the cooling liquid at the set temperature and is the most precise means of liquid cooling (provided that the chiller is sufficiently powerful). The cost of the chiller is typically higher than the cost of the radiator solution. Another important aspect with the chiller is to ensure that the chiller can be used together with the welding camera since the cooling channels inside the camera are made of aluminium (corrosion must be prevented). The results from the tests with recirculating chiller were presented in Table 3.1 (reproduced below).

Table 3.1. Results with recirculating chiller (without/with camera insulation).

Temperature	Only cables insulated	Cables and camera insulated
Ambient (°C)	290	290
Camera body top side (°C)	80	52
Camera body bottom side (°C)	64	43
Cables (°C)	76	67
Camera (°C)	47	39
Cooling liquid (°C)	25	25

3.6.4 Other possibilities

In some cases the welding machine may already have liquid cooling and it can be very straightforward to connect the welding camera to the same cooling circuitry. This method of cooling can be applied if the following conditions can be met:

- The cooling liquid temperature is always sufficiently high to prevent any risk of condensation
- The entire cooling liquid circuitry is compatible with aluminium to prevent any risk of corrosion (if this is not the case, the usage of magnesium anode can be considered)
- The continuous flow of cooling liquid through the camera is ensured (e.g. all cooled components are connected in series)

The usage of tap water is not recommended since the above conditions are usually not met.

3.7 Liquid cooling with pressurized air insulation

Liquid cooling with pressurized air insulation (combined liquid and air cooling) can be applied in extreme conditions where either method may not be sufficient separately. In this cooling method the camera and the cables are thermally insulated from the environment and the camera end of the insulation is not fully sealed. Liquid cooling is connected to the cooling connectors of the welding camera and pressurized air is blown through the insulation in such a way that the air escapes the insulation from the camera end. Liquid cooling keeps the camera cool while the flow of pressurized air inside the insulation keeps the temperature inside the insulation cool. This prevents the overheating of the cables and also improves the efficiency of liquid cooling.

Table 3.2 summarizes the results with combined liquid and air cooling. Cooling hose twisting and aluminium foil wrapping were applied around the cables (Figs. 3.2 and 3.3). The cables and the camera were inside a pyrojacket (Fig. 3.11) and the interface between camera and pyrojacket was not sealed.

Table 3.2. Results with combined liquid and air cooling.

Temperature	Pressurized air insulation 1 bar	Pressurized air insulation 2 bar
Ambient (°C)	290	290
Camera body top side (°C)	53	49
Camera body bottom side (°C)	43	40
Cables(°C)	42	37
Camera (°C)	39	37
Cooling liquid (°C)	25	25

4 Summary

Different methods of cooling for Cavitar Welding Camera C300 have been discussed and empirical results from different situations have been presented. Table 4.1 below summarizes the applicability ranges of different cooling methods under the test conditions described in earlier chapters of this guide (no heat load from the arc). It is important to keep in mind that the results are indicative and the suitability of the selected cooling solution must be confirmed separately for each application and environment.

Table 4.1. Applicability ranges of different cooling methods under the applied test conditions.

Temperature (°C)	35	40	75	100	125	150	160	250	260	300	340
Heat sink cooling (without air flow)	Green										
Heat sink cooling (with air flow)	Green	Green									
Mounting to machinery	Applicable range depends on mounting and machinery										
Cable insulation mandatory			Green	Green	Green	Green	Green	Green	Green	Green	Green
Aluminium foil mandatory			Green	Green	Green	Green	Green	Green	Green	Green	Green
Camera insulation recommended				Green	Green	Green	Green	Green	Green	Green	Green
Pressurized air cooling			1bar	2bar	3bar	4bar					
Liquid cooling with radiator								Green	Green	Green	Green
Applicability range of Pyrojacket										Green	Green
Liquid cooling with chiller										Green	Green
Applicability range of Pyreflect										Green	Green
Liquid cooling with pressurized air insulation										Green	Green