

# INFLUENCE OF HEAT TRANSFER ON THE NOZZLE OF DIFFERENT MATERIALS FOR THE E3D V6 SOLUTION

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**ABSTRACT:** The present study approaches comparative research on the thermal transfer between the components of the plasticizing part of the PLA and ABS type material respectively. It can be observed that besides the fact that the temperature difference between the heating part generated with an electric resistance placed in the heated block and the nozzle is not very large, the thermal transfer is relatively linear with small temperature losses.

**KEYWORDS:** polylactic acid (PLA), Acrylonitrile Butadiene Styrene (ABS), thermoplastic polymer, heat transfer, heat transfer simulation

## 1. INTRODUCTION

The additive manufacturing process uses various parameters of interest such as the material with mechanical and thermal properties from which the component parts are made, their dimensions, the cost of manufacturing the parts, but also the interest of the thermal study on the entire assembly using different technological parameters in order to obtain temperature gradients at different levels simulation for the nozzle of different materials as well as the rest of the component parts.

3D printing techniques with FDM (manufacturing by deposition with material), this process consists of heating a wire of thermoplastic material such as PLA, ABS or other thermoplastic polymer and extruding it through a nozzle with a preset geometry through the layer-by-layer process of the object that to be printed.

The advantages of fast printing refer to the fact that: 3D printing technology is cheap and accessible, easy to make, and the production process is very fast.

The FDM additive manufacturing device uses a stepper motor that is fed filament of plastic material, which is pulled by a toothed gear and a spring tensioning mechanism [1, 2].

The lamination of the plastic wire that is fed into the printing device for the extrusion part and for the layer deposition part is done by heating an aluminium and or steel block using a resistance of (30 W – 60 W). Based on thermal conduction, the heat is transferred through the p nozzle (print head) made of either copper or brass whose diameter is 0.4 mm.

The greatest interest lies more in studying the thermal influence on the nozzle of different materials to observe the temperature variations that occur in the hot block made of steel material or aluminium

material as well as inside the threaded steel tube but also the nozzle head. printing from different materials (nozzle). Temperature monitoring will be simulated taking into consideration that certain boundary conditions on different areas of the component parts in order to observe the behaviour of the temperature gradient that will unfold over the entire assembly [3, 4].

## 2. THERMAL SIMULATION OF THE NOZZLE MADE FROM DIFFERENT MATERIALS IN ORDER TO DETERMINE THE VARIATIONS OF THE TEMPERATURE GRADIENT.

Running the 4 simulations on the entire assembly took more time due to the resources that the Inventor CFD program imposes on the computer (RAM memory and capacity). The study of these simulations on the study assembly was started, however, without taking in consideration the support part with the cooling fan (radiator cooling device) to observe the thermal behaviour maximized on the entire surface of the parts in the work process.

2.1 Level 1 simulation of the thermal study for nozzle not bonded to hot block, made of steel material (OL).

The following input parameters were used:

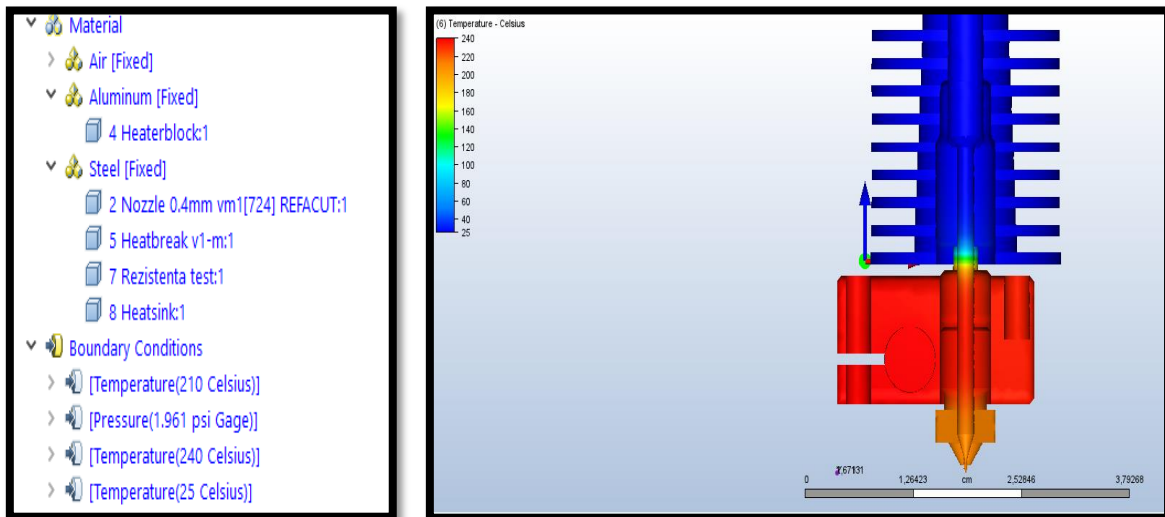
- 1961 psi wire pressure
- Temperature T=240 °C on resistance
- Temperature T=25 °C on the radiator
- Temperature T=210 °C on the nozzle

The following types of materials were used for the related parts:

- Steel nozzle

- Steel radiator
- Steel resistance
- Threaded steel tube

- Aluminium hot block, Figure 1.



**Figure 1.** Simulation results 1 of the temperature gradient for the nozzle in steel material and not sticking to the hot block

The temperature changes in the hot block are at a high level, this aspect is due more to the resistance temperature  $T=240\text{ }^{\circ}\text{C}$ .

The influence of the temperature on the nozzle remains in a temperature range between  $T=180\text{ }^{\circ}\text{C}$  and  $T=210\text{ }^{\circ}\text{C}$  and the wire withstands a melting temperature like  $T=190\text{ }^{\circ}\text{C}$

In the area of the thermal radiator, its temperature remains at a constant interval at  $T=25\text{ }^{\circ}\text{C}$ , considering the ambient temperature.

Temperature variations and differences appear more on the threaded tube of the assembly, here we are talking about temperatures between  $T=60\text{ }^{\circ}\text{C}$  and  $T=170\text{ }^{\circ}\text{C}$ , the optimum being around the temperature of  $T=130\text{ }^{\circ}\text{C}$ .

2.2 Level 2 simulation of the thermal study for the nozzle not bonded to the hot block, made of copper (Cu) material.

In this simulation another wire model with ABS material and 2 mm diameter was used, the temperatures based on the types of materials used for the parts had a different aspect on the simulation side.

The following parameters were used:

- 1961 psi wire pressure
- Temperature  $T=240\text{ }^{\circ}\text{C}$  on resistance

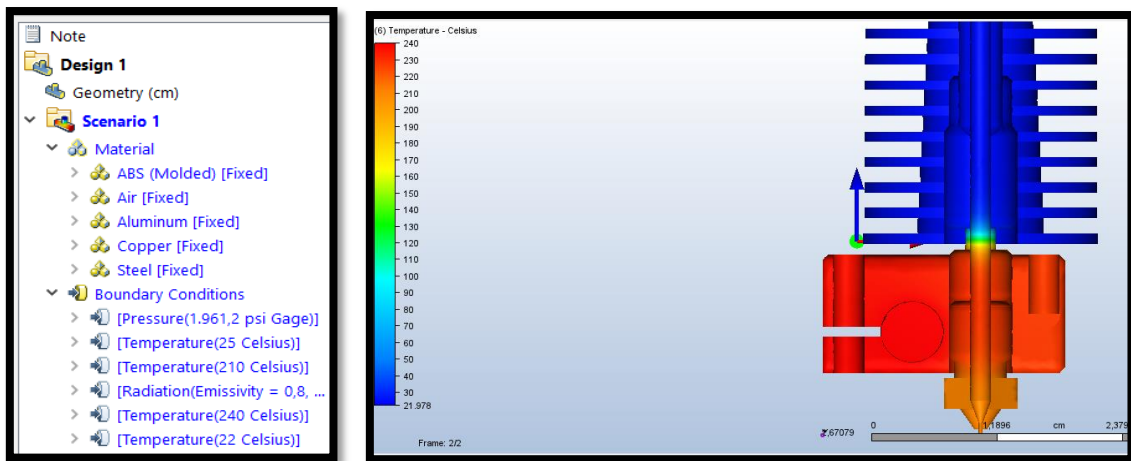
- Temperature  $T=25\text{ }^{\circ}\text{C}$  on the radiator
- Temperature  $T=210\text{ }^{\circ}\text{C}$  on the nozzle

The following types of materials were used for the related parts:

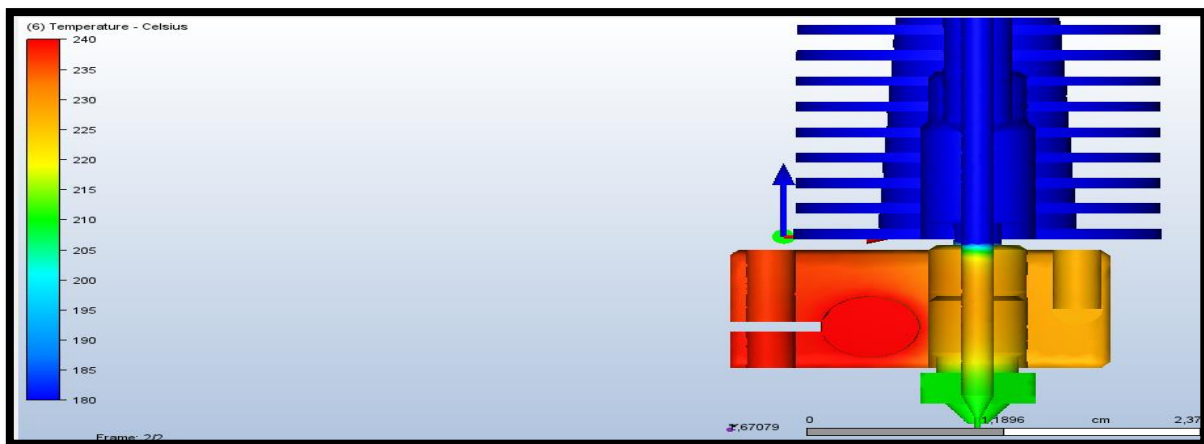
- Copper nozzle
- Aluminium radiator
- Steel resistance
- Threaded steel tube
- Aluminium hot block

Based on this simulation Figure 2, it was found that in the hot block the temperatures vary due to the resistance temperature  $T=240\text{ }^{\circ}\text{C}$  the hot block undergoing changes due to the chosen material (aluminium) and if we change the temperature of the resistance in a negative direction by  $40\text{ }^{\circ}\text{C}$  the critical temperature will affect the threaded tube touching it a maximum of  $T=160\text{ }^{\circ}\text{C}$  on the top of the threaded tube.

If we vary the temperature  $T=240\text{ }^{\circ}\text{C}$  between a minimum and a maximum, we can see that in the thermistor area the minimum temperature of  $20\text{ }^{\circ}\text{C}$  can reach, for example, if we increase it by  $160\text{ }^{\circ}\text{C}$ , the temperature in the thermistor area can even be  $220\text{ }^{\circ}\text{C}$ , Figure 3.



**Figure 2.** Result of simulation level 2 of the temperature gradient for the nozzle made from copper material and not bonded to the hot block



**Figure 3.** Temperature variation from  $T=240\text{ }^{\circ}\text{C}$  to  $T=220\text{ }^{\circ}\text{C}$

The temperature variations in the hot block are between  $180\text{ }^{\circ}\text{C}$  and  $230\text{ }^{\circ}\text{C}$ , here the wire undergoes changes on the liquid transformation side where, on the resistance side, the wire is hotter and on the opposite side the wire is colder.

At the same time, in this simulation, the radiation parameter was also considered, having a coefficient of 0.8 and being placed on 2 outer walls of the hot block, and in the entry area of the wire on the circumference of the inner tube, we added a minimum temperature of  $22\text{ }^{\circ}\text{C}$ , this aspect had a big impact on the temperature changes on the whole assembly.

### 2.3 Thermal study simulation level 3 for nozzle bonded to hot block, made of steel material (OL)

For the study of the thermal simulation on the nozzle glued to the hot block, another model of wire with a diameter of 2 mm, ABS material and entering with perfect contact inside the assembly, pushed by a force of 1961 psi equivalent to 20 kgF was used. The simulated temperatures for different types of nozzle

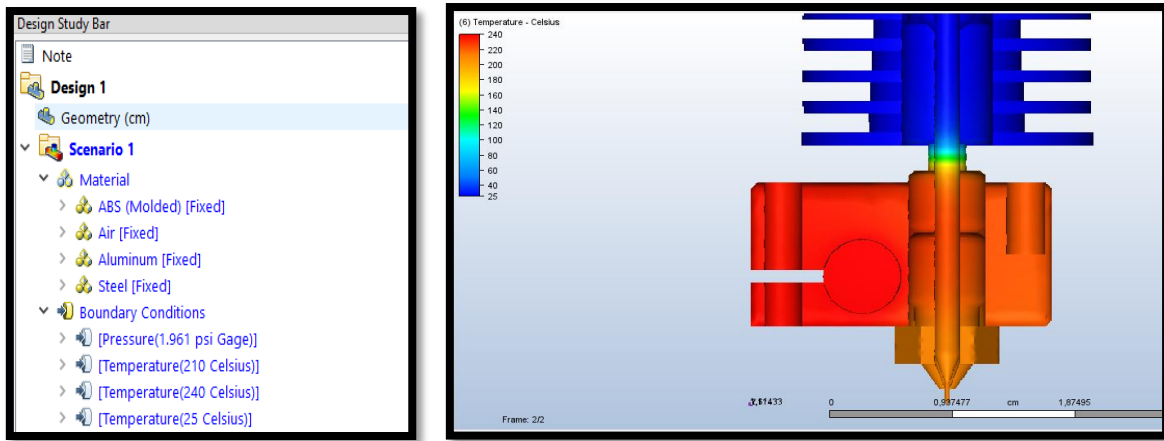
materials had a different appearance in the interior area of the hot block, but also on its exterior.

For the simulation with a glued nozzle, the following parameters were used:

- 1961 psi wire pressure
- Temperature  $T=240\text{ }^{\circ}\text{C}$  on resistance
- Temperature  $T=25\text{ }^{\circ}\text{C}$  on the radiator
- Temperature  $T=210\text{ }^{\circ}\text{C}$  on the nozzle

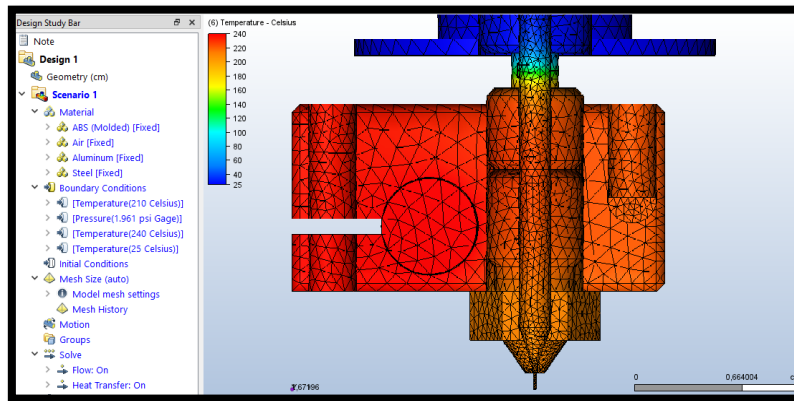
The materials used for the elements in the assembly according to the simulation were the following:

- Steel nozzle
- Steel radiator
- Steel resistance
- Threaded steel tube
- Aluminium hot block Figure 4.



**Figure 4.** Result of simulation 3 of the temperature gradient for the nozzle made of steel material and soldered to the hot block. In the hot block the temperature gradient is varied between  $T=240\text{ }^{\circ}\text{C}$  and  $T=180\text{ }^{\circ}\text{C}$ , according to the simulation it can be observed that the temperature on the bonded nozzle made from steel material has a value between  $T=180\text{ }^{\circ}\text{C}$  and  $T=200\text{ }^{\circ}\text{C}$  due to the

properties of different thermal conductivity of the steel it is made of as opposed to the solderless nozzle made of copper material Figure 5.



**Figure 5.** Maximum temperature gradient at  $T=240\text{ }^{\circ}\text{C}$  with fine mesh for the bonded nozzle made from steel material

After the simulation was processed, the nozzle being stuck to the hot block has a different thermal impact compared to the other simulations done previously.

At the level of the wire, the temperature remains on the left side (the side with the thermal resistance) around  $T=240\text{ }^{\circ}\text{C}$  and on the right side (the thermistor side) this area is completely varied around the temperatures of  $T=170\text{ }^{\circ}\text{C}$  and  $T=200\text{ }^{\circ}\text{C}$ . At the same time, at the level of the threaded tube, different temperature gradients appear with values starting from  $T=40\text{ }^{\circ}\text{C}$  and reaching values of  $T=160\text{ }^{\circ}\text{C}$  even  $T=180\text{ }^{\circ}\text{C}$ .

The critical temperature on the hot block has the value of  $T=240\text{ }^{\circ}\text{C}$  in the zone of the thermal resistance and the fastening screw of the thermal resistance, it will dissipate by losing its value over the entire surface of the hot block and the elements inserted into it. It is also mentioned that no other temperatures were considered on the outer walls of the hot block because of the future simulations, a thermal shield made of silicone material will be used to study another

temperature level and its impact on the nozzle and the rest of the component parts.

#### 2.4 Level 4 simulation of the thermal study for the nozzle bonded to the hot block, made of copper (Cu) material.

In this final simulation, which aims to study the thermal influence on the nozzle bonded from different materials, a wire with ABS type material with a diameter of 2 mm was used where the exit of the wire from the nozzle had a diameter from 0.4 to 0.2 with an extrusion of 1 mm and perfect contact inside the hot block. A compressive force equivalent to 20 kgF = 1961 psi acted on this wire. The temperature gradient being varied in these conditions due to the different thermal properties of the materials used on the bonded nozzle but also due to the boundary conditions used on the entire assembly.

The following parameters were used:

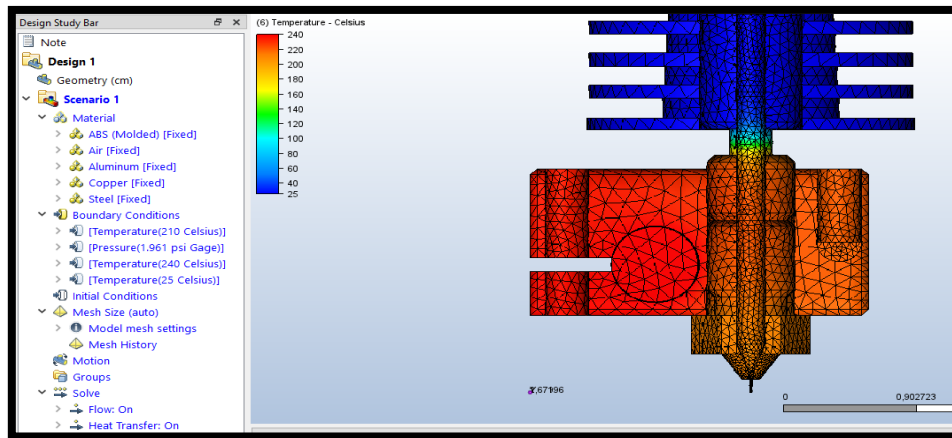
- 1961 psi wire pressure equivalent to 20 kgF

- Temperature  $T=240\text{ }^{\circ}\text{C}$  on resistance
- Temperature  $T=25\text{ }^{\circ}\text{C}$  on the radiator
- Temperature  $T=210\text{ }^{\circ}\text{C}$  on the nozzle

The following types of materials were used for the related parts:

- Copper nozzle

- Aluminium radiator
- Steel resistance
- Threaded steel tube
- Aluminium hot block Figure 6.



**Figure 6.** The maximum temperature gradient at  $T=240\text{ }^{\circ}\text{C}$  with fine mesh for the bonded nozzle made from copper material

According to this simulation it can be seen how the thermal transfer on the nozzle is different compared to the first simulations due to the fact that the material from which the nozzle is made has other thermal conductivity properties and this aspect can also be observed in the phase where the nozzle is stuck to the hot block, it has the same aluminium material and in the resistance area it can be seen how there is a critical temperature point of  $T=240\text{ }^{\circ}\text{C}$ , which will dissipate over the entire hot block and due to temperature losses and external factors (air/humidity) it can be observed how it loses its intensity on the opposite side of the resistance, a fact that will give us to think how the lamination of the wire will remain stable at a certain imposed temperature Figure 7.

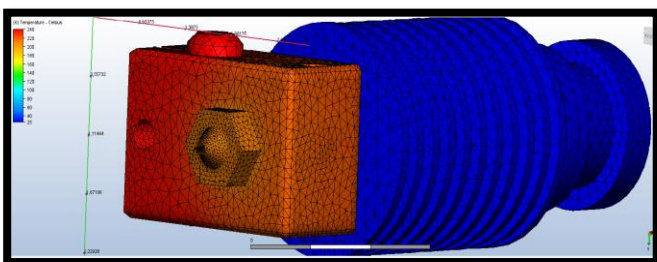
where the nozzle was not glued to the hot block, the temperature on the hot block reached the critical point of  $T=240\text{ }^{\circ}\text{C}$ .

The use of different materials of the component parts that are studied has a major impact in the sense of changing the temperature, a fact that will help us in the future and in the following much larger studies to determine which would be the most optimal material with very good thermal properties.

### 3. THE COMPARATIVE STUDY BETWEEN THE 4 SIMULATION LEVELS ANALYZED

For the comparative study between the 4 simulation levels, the following common input parameters were used, for each individual simulation, namely:

- Wire pressure of 1961 psi = 20 kgF
- Resistance temperature  $T=240\text{ }^{\circ}\text{C}$
- Radiator temperature  $T=25\text{ }^{\circ}\text{C}$
- Temperature on the nozzle of different materials  $T=210\text{ }^{\circ}\text{C}$
- Emissivity coefficient 0.8
- Temperature on 2 external walls of the hot block  $T=22\text{ }^{\circ}\text{C}$
- Nozzle materials: copper and steel
- Radiator materials: steel and aluminium
- Threaded tube materials: steel
- Materials for the hot block: steel and aluminium



**Figure 7.** Variation of the temperature gradient of the nozzle made from copper material and hot block made of aluminium material and radiator made of steel, with fine mesh.

Also in this phase it can be observed including on the lower part of the hot block where the nozzle comes bonded to it, how the temperature gradient takes a different form with variations starting from  $T=240\text{ }^{\circ}\text{C}$  to  $T=170\text{ }^{\circ}\text{C}$ , the temperature being varied in this sense unlike the other simulations where for the case

- Resistance material: steel

According to simulation 1 where copper was used as material for the non-glued nozzle, here the temperatures in the hot block are high throughout the hot block due to the resistance temperature of 240 °C. The decreasing temperature variations are mostly common to appear in the threaded tube of the assembly where the temperatures reach 60 °C and 170 °C, a fact that is not good to have these temperature differences especially around the hot block and more precisely in the area of contact between the nozzle and the threaded tube where the wire undergoes the plasticizing transformation.

In the 2nd simulation here, steel was used as material for the non-glued nozzle, in the hot block the temperatures vary due to the resistance temperature of  $T=240$  °C, the hot block reaches high temperatures due to the chosen material and aluminium and the critical temperature is more predominant in the area of the threaded tube being 160 °C. The temperature variations in the block include temperatures varying between 180 °C and 230 °C and according to the simulation it can be stated that the wire used changes on the plasticizing side where on the side with the thermal resistance the wire is much warmer and on the opposite side the wire is much colder.

In the 3rd simulation, copper was used as material for the soldered nozzle, here at the level of the wire on the left side, the temperature reaches values of 240 °C and on the opposite side, more precisely in the entrance area of the thermistor, the temperature varies from 170 °C to 200 °C. The critical temperature on the hot block appears in the zone of thermal resistance, being 240 °C. The temperature variations in the zone of the threaded tube include temperature gradients with values between 40 °C and 180 °C.

For the last simulation where steel was used as material for the soldered nozzle, the temperature gradients are varied due to the different thermal properties of the materials used for the soldered nozzle as well as the boundary conditions used differently over the entire surface. The critical temperature is 240 °C in the hot block and in the zone of the nozzle and the threaded tube, it reaches lower temperatures on the opposite side of the resistance, being in the range of 180 °C and 220 °C.

#### 4. CONCLUSIONS

The validation of the analysed data from the 4 simulations will take place on a real experimental

stand, the temperature of the thermistors will be mounted next to each other maintaining a distance with approximately 50 mm for measuring the temperatures in different points, at the same time the mesh of the 4 simulations was a fine one, more precisely 0.5 for the highest possible accuracy of temperature gradient variations.

Compared to the previous simulations taken as a study from the previous work, where both simulations include the temperature on the heating block in the area of the hole where the electric resistance is mounted, it does not show a significant temperature loss, it remains high over the entire surface, varying between a minimum of 210 °C and maximum 240 °C, in the present case of the 4 simulations it can be observed how the temperatures for both the soldered nozzle and the non-soldered nozzle made of copper and steel material reach values between 180 °C and 220 °C, a fact that represents a slight decrease in temperatures both on nozzle as well as in the hot block by approximately 20 °C respectively 40 °C, this aspect being optimal for the flow temperature of the ABS wire material.

#### 5. REFERENCES (HEADING 1)

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