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COMPARISON OF THERMAL PERFORMANCE OF 3D PRINTER LIQUEFIERS THROUGH FINITE ELEMENT MODELS

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ABSTRACT

Open source 3D printers have experienced an intense expansion during the last years, mainly because of their accessibility and the vast availability of information thanks to user communities. This fact presents researchers with a perfect context for hardware innovation, by improving the overall printing process, also in terms of durability of the printing machine.

A 3D printer liquefier must transmit heat to the thermoplastic material in order to extrude it, reaching temperatures above 200 degrees for some materials like ABS on the tip of the nozzle. The design of the heating process must comply with keeping the balance between proper heating of the material and controlling the temperature along the extruding body, so that the printer itself is not harmed for overtemperature. On the other hand, the design must guarantee that the melting front is located in an intermediate point between the nozzle tip and the entrance of the raw material, to minimize pressure drops in the system, and so decreasing the demanding energy to the feeding motors.

An alternative design of the heating system, Twist3D, is proposed in this paper.

Keywords: 3D printing, FDM, FEM, liquefier, RepRap, heat transfer

1. INTRODUCTION

The aim of this paper is to compare the thermal performance of different heat dissipation systems in the design of open source 3D printers liquefiers using FEM.

3D printing is one of the main drivers of innovation in the manufacturing technology field worldwide. This paper focuses on open source 3D printing systems specifically, and their potential to cover domestic needs. As it is an intuitive technology, ease to learn, cheap and self-reproducible, desktop 3D printers (i.e. non-industrial 3D printers) have all the characteristics required to solve possible situations that might emerge during our day-by-day life. During the next years, we will very probably witness the development of new desktop 3D-printing systems that will enable anyone to design and manufacture a certain piece, either to cover a need, or simply for inventive pleasure.

With the aim of contributing to the achievement of these visionary trends, critical parts of currently commercialized 3D-printers, such as the liquefier module, should be improved. The fact that many of these commodity 3D-printers are open source, involves the fact that they can be objective of a thorough revision and improvement, for many systems have been designed by amateurs. The advantage of this situation, is that those open-source systems suppliers give access to the design of the products they provide, and therefore, the improvement initiatives can be tackled.

In Barcelona, there is a project lead by the UPC, inspired in the Rep-Rap initiative, through which users are encouraged to develop their own 3D-printer parts or even create one from scratch [1]. Important results have been obtained, with very positive trends in terms of quality of developed systems. But in this context, the design of a fully effective and stable liquefying system has always been the main problem of the initiative, and at the same time very necessary, for controlling fluid mechanics and heat transfer of the overall process is basic for the final quality of the part [2]. With this motivation, a new extruder has been designed inside this open-source initiative, so that currently available systems may be improved.

This objective has been tackled in this study by carrying out a thermal analysis, through a FEA, of the BCNozzle model of the BCN3D+ printer, manufactured in the UPC's Centre CIM. A proposal of a new extruder geometry will be presented, so that the heat generated during the printing can be better used and distributed, thus improving the extrusion process efficiency. The result has been a new extruder called Twist3D.

2. METHODOLOGY

The geometry of BCNozzle extruder, manufactured by *Fundació CIM UPC* has the follow characteristics:

- Modular design shows great advantages in terms of versatility and favors heat dissipation. The different parts described in Figure 1 can be detached, and reattached thanks to their tapped surface.
- The heat barrier, made of stainless steel, is considered a good solution as main physical limit to prevent heat conduction towards the upper part of the liquefier.
- In line with the modular conception of the liquefier, the removable nozzle allows to change easily the extrusion precision and makes easier the maintenance of the liquefier by allowing to remove possible plastic blockages consequence of an incorrect extrusion
- Forced convection must be kept, especially for ABS printing, because of the higher temperatures needed.

Taking into account the main characteristics analyzed to BCNozzle extruder, another extruder (Xtruder), has been design and manufactured. The differences between both can be seen at figure 2. Although both models have the same general geometry, some changes have been incorporated in the new geometry of the Xtruder that make it easier to manufacture because of the larger distances separating the fins. These fins are also thicker than those at the BCNozzle model. On the other hand, the heat break, specifically the BCNozzle is composed of a tube with M6 threaded at both sides, whereas the Xtruder heat break is also a tube threaded all its way long. That contributes also to make it easier to manufacture this last model.

Another change introduced at the new model Xtruder is the shape of the nozzle. The nozzle at the BCNozzle is hexagonal, whereas in the Xtruder, that part has cylindrical geometry with two flat parts at both sides. Finally, the outlet angle is 60 degrees in the BCNNozzle and 120 degrees in the Xtruder.

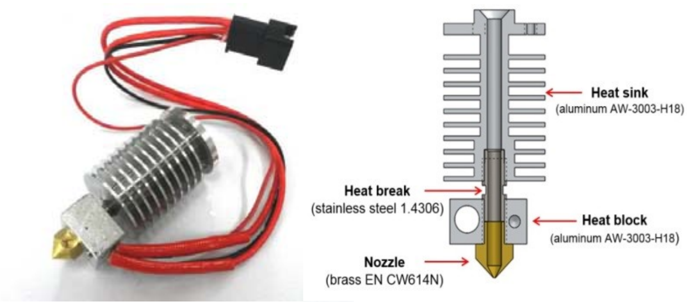

Figure 1. BCNozzle liquefier: schematic representation and parts [1]

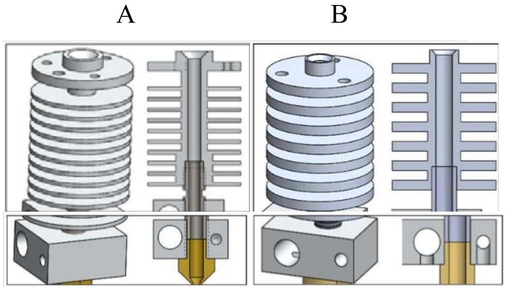

Figure 2. Differences between the analyzed extruder: A- BCNNozzle, B- Xtruder

3. FEM ANALYSIS

The geometry has been represented at the FEM software divided in 8 eight domains: the surrounding air, the heat block, the heat sink, the nozzle, the heat break, and three different air cavities. Under these assumptions, the flow behavior of the system is governed by the Navier-Stokes equations (eq. 1 and 2), while in solid domains only the equation of energy is solved (eq. 3) [3].

Continuity equation:

$$\nabla \cdot (\rho u) = 0 \tag{1}$$

Momentum conservation:

$$\rho(\mathbf{u}\nabla)\mathbf{u} = \nabla \cdot \left[-p\mathbf{I} - \mu\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T - \frac{2}{3}\mu(\nabla \cdot \mathbf{u})\mathbf{I}\right]\right. + S_M \quad (2)$$

Energy conservation:

$$\rho c_p \mathbf{u} \cdot \nabla T = \nabla \cdot (k\nabla T) + \dot{Q} \quad (3)$$

The steady-state case is solved, and therefore simulations will not be time-dependent. That being said, the initial values, meaning the values that will be the starting point of the non-linear values are: Walls: Non-slip condition. Inlet: Normal Velocity [0.3,2] m/s, Temperature 293.15 K. Symmetry: Outlet: Atmospheric Pressure, Thermal Insulation, Temperature: 483.15K (PLA melting point 210ºC). Thermal insulation, Initial values 1: Atmospheric pressure, u=(0,0,0) m/s, T=293.15 K; Initial values 2: Atmospheric pressure, u=(0.5,0,0) m/s, T=293.15 K

Analyzing the different possibilities for mesh configurations (figure 3A), and according to figure 3B, fixing a relative error of 2%, the selected mesh for the problem was the "coarse" type. In this case the number of elements is not too high and the data processing is faster and efficient.

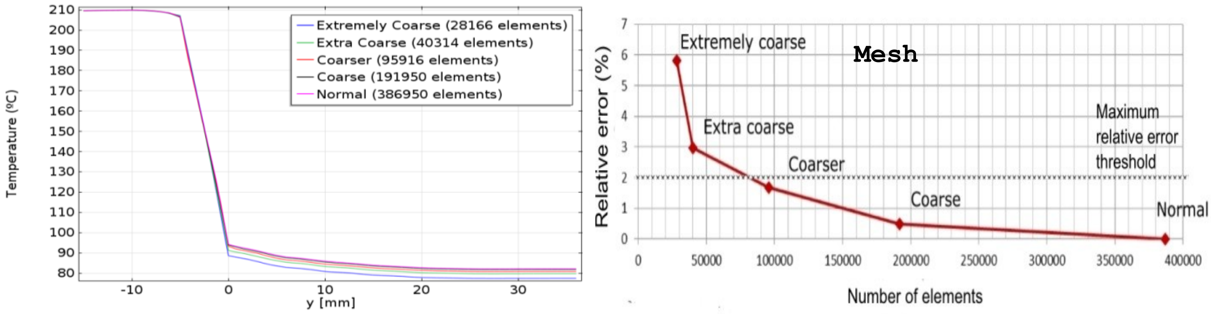

Figure 3. Mesh convergence developed for the BCNozzle extruder, considering an outer temperature of 20ºC and a fan velocity of 0.3 m/s.

4. RESULTS

The computing of the implemented model described above, gave as first result a tridimensional isothermal map. It shows the temperature achieved on the solid surfaces of the extruders when the fan is off (figure 6). The maximum temperature achieved at the extruding body is higher at the Xtruder, about 20ºC higher than that achieved in the BCNozzle liquefier. This means that the heat in the Xtruder is in a lesser amount transmitted to the heat exchanger. This provokes a better melting process of the additive material, for the temperature at the nozzle is kept higher along time. This is obviously a clear advantage of Xtruder on the BCNozzle.

On the other hand, the temperatures of the circulating cooling air evidences that the resulting air temperature is higher in the Xtruder extruding process. This fact can be explained because of the better heat transfer created by the newly defined fins.

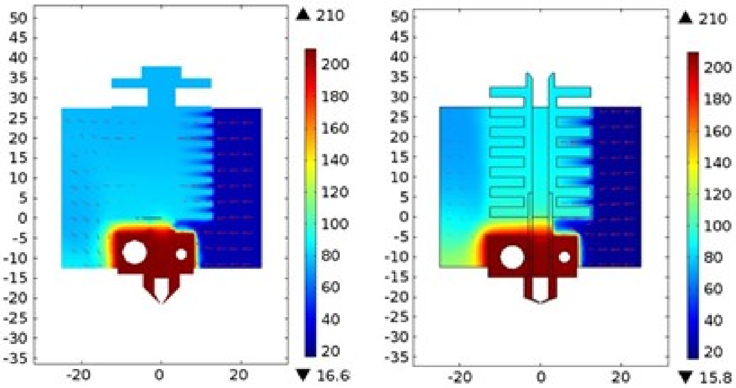

Figure 4. 3D isothermal map of extruding liquefiers. A- BCNozzle, B- Xtruder

5. EXPERIMENTAL MODEL VALIDATION

Experiments were carried out in order to test the behavior of the temperature along all the extruder under conventional conditions, and to extrapolate relevant conclusions to support the proposed computational fluid dynamics (CFD) design. The experiments were carried out using both extruders, in order to compare their behavior. Each experiment was performed with the extruder separately using the electronic system of the 3D printer at different fan speeds.

To measure the temperature gradient along the extruder, four thermocouples have been used: one located at the top of the heat sink, the other at the bottom, near the nozzle, and the other two inside the extruder body. The registered temperatures values have been taken into account to validate the model obtained through the FEM (figure 5).

On the one hand this analysis allows relate the percentages airflow that can be defined in software with the actual flow velocity air passing through the heat exchanger. On the other hand, the temperature values recorded by thermocouples placed in the body of the extruder help validate the model obtained by FEM, establishing as threshold value a 5%. Thus the model developed by FEM correctly describes the thermal problem in the extruders analyzed.

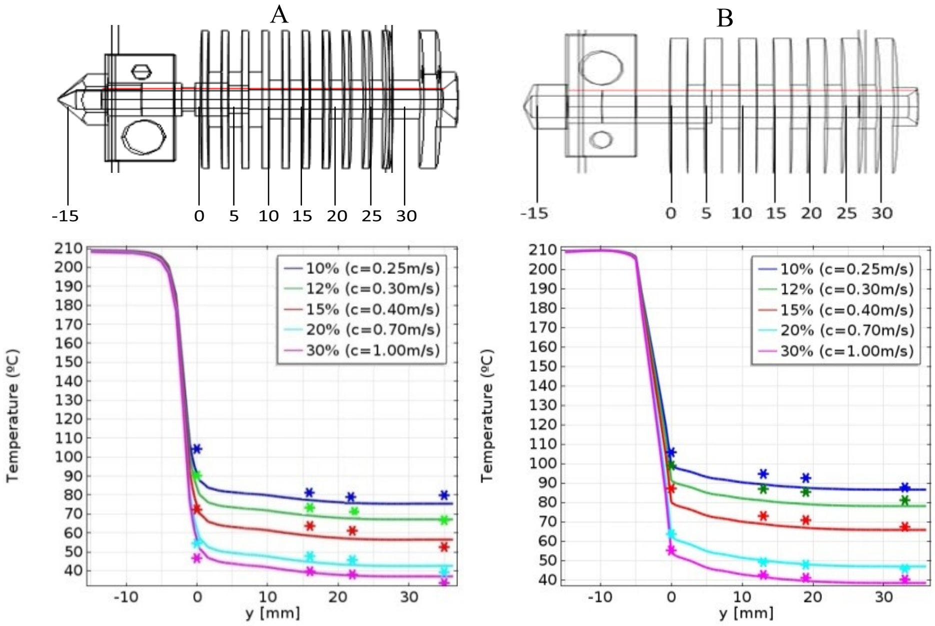

Figure 5. Temperatures comportament for different fan speed in A- BCNozzle extruder, B-Xtruder extruder

6. CONCLUSIONS

After the work done in this paper, the following conclusions can be drawn:

1. COMSOL can be used to obtain a model to analyze the heat transference problem in the extruders of 3D printing machine.
2. The newly designed Xtruder presents advantages over the already commercial one related to less manufacturing costs and time, due to its simpler geometry. On the other hand, this geometry has proved to be more efficient in keeping higher temperatures at the tip of the nozzle where the thermal process takes place.
3. The FEM was experimentally validated for the two extruders, by placing thermocouples along the liquefier bodies. The temperature profile of both extruders has been

7. REFERENCES

[1] RepRap BCN development project. Retrieved from http://www.bcn3dtechnologies.com/es/blog. Last visited on 10/05/2016

[2] Yardimci, A., Hattori, T., Guceri, S. Thermal analysis of fused deposition. Proceedings of Solid Freeform Fabrication Conference, Texas, USA, 1997.

[3] Turner B., Strong, R., Gold, S. (2014) A review of melt extrusion additive manufacturing processes: I. Process design and modelling. Rapid Prototyping Journal, 20(3), pp.192-204.

[4] Günther, D. Heymel, B., Günther, J.F., Ederer, I. (2014) Continuous 3D-printing for additive manufacturing, Rapid Prototyping Journal, 20(4), pp. 320-327.