International Journal of Mechanical Engineering and Technology (IJMET)
Volume 8, Issue 10, October 2017, pp. 750–758, Article ID: IJMET_08_10_081
Available online at http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=10
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

GAS AND REFRIGERANT ASSISTED INJECTION MOULDING PROCESS

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ABSTRACT

Assisted Injection Moulding (AIM) is part of a family of technologies that are conducted with plastic processing methods to improve product quality and significantly reduce costs. These technologies include the injection of gas or water, at high pressure, into the molten polymer within the injection mould. This process cores out sections of the part, and leaves hollow areas. The fluid-assisted injection moulding technology, which includes gas-assisted moulding and water-assisted moulding, has been used widely to manufacture plastic parts in recent years, due to the achievement of lightweight products, the relatively low resin cost per part, the fast cycle time, the uniform distribution of the packing pressure and the elimination of sink marks. Gas-assist and water-assist technology may also be combined in sequence to achieve other benefits in certain applications. The basic idea of the proposed process is that the evaporation of a small quantity of water leads to a notable decrease in the cooling time and an increase in the dimensional tolerance of the injected part. Even though several patents pertaining to the use of gas and a refrigerant to obtain a hollow component exist, there is still a lack of knowledge regarding the effectiveness of the process. The present research has evaluated the effect of a co-injection of micro quantitates of water together with nitrogen.

Keywords: gas, refrigerant, injection moulding process

Cite this Article: L. Denti, Gas and Refrigerant Assisted Injection Moulding Process, International Journal of Mechanical Engineering and Technology 8(10), 2017, pp. 750–758.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=10

1. INTRODUCTION

The fluid-assisted injection moulding technology, which includes gas-assisted moulding [1,2,3,4] and water-assisted moulding [5,6,7], has been used extensively to manufacture plastic parts in recent years. These two types of moulding have received a great deal of attention, because they offer the following advantages when compared to traditional injection moulding [8]:

- More lightweight parts;
- Faster cycle time;
- Design flexibility;
- Manufacturing flexibility;
- Low shrinkage and warpage;
- Better surface finish;
- Lower press capacity requirements.

The mould cavity in fluid-assisted injection moulding is partially filled (bubble or blow-up process), or totally filled (pushback or overflow process), with the polymer melt before the injection of gas or water into the melt core.

Despite the advantages associated with the fluid assisted injection moulding process, the moulding window and process control are more critical and problematic, since more processing parameters are involved than in conventional injection moulding: the amount of melt injection; the fluid pressure and temperature; the fluid injection delay time.

In the proposed solution, as the water and nitrogen mixture enters the hot core of the polymer part, all or a fraction of the injected water evaporates. The water phase change and the aerosol cooling effect cause a rapid decrease in the polymer temperature, and this in turn leads to a thick frozen layer.

The process is covered by three patents: US 6579489 B1 (2003), US 6896844 B2 (2005) and WO 02/078928-2002, the latter having been invented by Benedetti Luciano (Italy) for Wugim Set srl (Italy), as “a gas and refrigerant assisted injection moulding process”; but several other patents have also proposed injection assisted by gas and refrigerant solutions:

- DE3925909-1991, Bernhard Achim (Germany);
- DE40244549-1992, Gross Hermann Georg, Santelmann Karl-Heinz, Danneberg Horst (Germany) for Helphos GMBH (Germany);
- 681,932-1996 da Helmut Eckardt, Jurgen Ehritt, Alfonse Seuthe, Micheal Gosdin (Germany) for Battenfeld GmbH (Germany);

Under the hypothesis of injected polymer weight of 70 g, with a specific heat of 1900 J/kg °C [9] and all the injected water evaporated, 0.05 g of water is sufficient to decrease the polymer temperature by 1°C. The effect is localised, because polymer is a bad thermal conductor. Furthermore, the water phase change helps to increase the hollow volume pressure.

It is possible to state that only a part of the water probably evaporates during the test; in fact, the experimental process parameters used (p, T) are close to liquid-vapour transition values (220°C at 25 bar[10]). The measurement of the real pressure and temperature values in the cavity during the moulding and inside the hollow polymer melt is extremely difficult, because the system is in continuous transition.

The effect of water may be useful since, even though it does not evaporate completely, it subtracts more heat from the material than the gas used alone in a “quasi dry” process.

The aim of this paper is to evaluate the effectiveness of an easy-to-use solution that may be obtained by adopting two technologies in series.

2. MATERIALS AND EXPERIMENTAL TESTS

The experiments were carried out in two different steps; the critical aspects of the process to be evaluated and the subsequent experimental phase to be planned.

A water micro-injection unit, developed by LEAN Srl (Medolla, Italy), was used for the tests (Figure 1). The control circuit acts downstream from the gas injection circuit, and controls the servo valve group. First a chosen quantity of water is sent to lick the walls of the Venturi tube inside the unit, and the opening of a valve connects the Venturi to the circuit of Nitrogen under pressure. The water is then dragged by the gas and forms an aerosol. The biphasic fluid goes into the mould through an inlet valve. At the end of the process, both the Nitrogen and water inside the cavity of the moulded part are expelled by an exhaust valve, which is also managed by the software. The input and output of the bifasic fluid are controlled by two different valves in order to avoid the accumulation of water residues. The injection time and fluid pressure profiles are controlled. The control unit is equipped with a user interface, consisting of a display and keyboard to set the process parameters and monitor the individual activities, including any error states. The unit allows to control two different moulding conditions: with water and nitrogen or with only nitrogen.

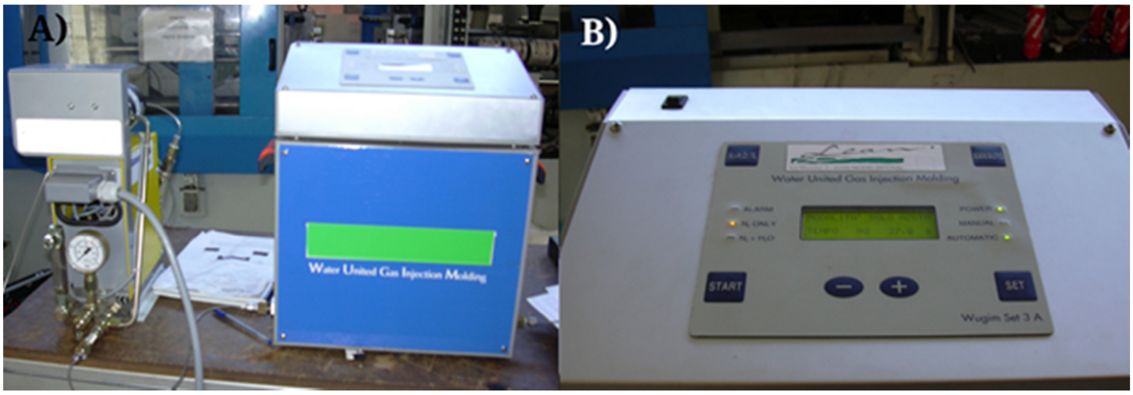

Figure 1 Water micro-injection unit: A) mixing device, which allows gases and water to be mixed prior to injection into the mould; B) Nitrogen-water controller user interface.

The first step of the investigation was performed by means of a 100-ton Battenfeld 1000-525 injection moulding machine, Volmax= 318 cm3, Qflow=167 cm3/s, while the subsequent tests were performed using a 170 ton Plastic Metal PM 170, Volmax= 270 cm3, Qflow=168 cm3/s [11].

The benchmark, which is shown in Figure 2 A), is a U shaped pipe with a constant circular section and double symmetric planes. The benchmark was an unfunctional part, and it was adopted to point out the performances of the process: the 180° curve, and a change in flow direction may cause fingering marks. The pipe shape was chosen considering that geometrical tolerances have a great importance on the assembly phase of polymer products. This shape is different from those used by other authors who have focused on the residual wall thickness [12], although it resulted in a similar geometric solution (curve of 90 or more degrees) when the authors focused on process efficacy [13, 14]. A polypropylene (PP) homopolymer was chosen for the first test; PP is one of the most widely used polymers for gas assisted moulding [15]. The first tests were started after the moulding of a massive (unhollow) component, which was then used to choose the initial process parameters. A comparative test with a PET was also performed. After an analysis of the first test results, the polypropylene homopolymer was substituted by a random polypropylene copolymer. Each moulding test was repeated in order to obtain at least 6 valid samples for each series after reaching the steady state condition. The adopted process parameters are shown in Table 1.

The massive part moulding allowed the process parameters and the weight of the unhollow component to be determined. This step was then followed by the optimization of the empting phase: the weight of the injected material decreased as the cycle time did until a complete hollow component was obtained. From an operational point of view, the optimal conditions were obtained first by controlling the amount of injected material (until complete filling of the figure), and then balancing the time delay and maintenance time of the gas (until complete absence of defects). When both of the conditions (figure filling and absence of defects) had been achieved, the reduction of the cooling time began. It should be pointed out that it may be necessary to compensate for the reduction of the cooling time with an increase in the gas retention time in the workpiece while leaving the overall cycle-time unaltered. However, a lower limit exists of the cooling time, beyond which, and in the case of a short shot, the workpiece "explodes" when the mould is opened (Figure 2 B).

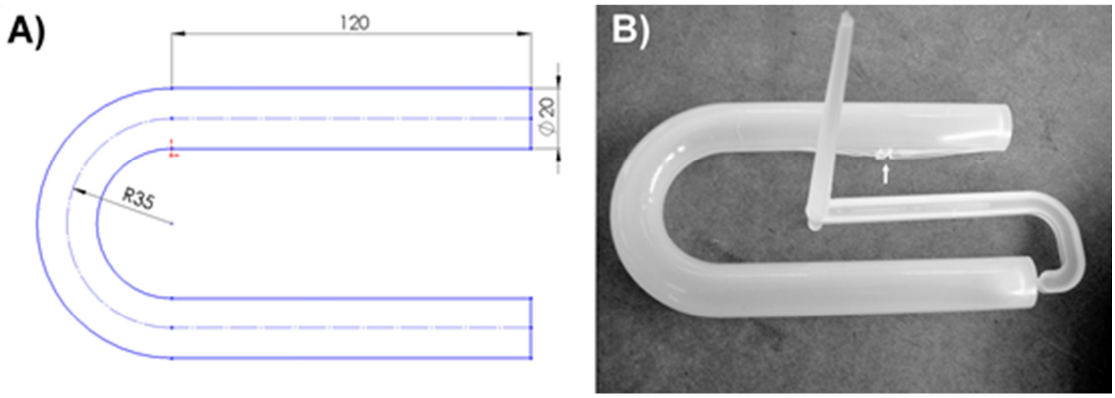

Figure 2 A) The used benchmark; B) The part “exploded” during the process parameter optimization.

Table 1 The used process parameters

<table>
<tr><th></th><th>injection moulding</th><th></th><th>Water weight [g]</th><th>T_{nozzle} [°C]</th><th>T_{mould} [°C]</th><th>$P_{injection}$ [bar]</th><th>P_{gas} [bar]</th><th>$t_{gas\ delay}$ [s]</th><th>$t_{gas\ mainten.}$ [s]</th></tr>
<tr><td rowspan="4">Preliminary test</td><td>Massive</td><td rowspan="3">polypropylene homopolymer</td><td>-</td><td rowspan="4">195</td><td rowspan="4">15</td><td rowspan="4">70</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Gas assisted</td><td>-</td><td rowspan="3">30</td><td rowspan="3">1</td><td rowspan="3">10</td></tr>
<tr><td>Gas and water micro-injection assisted</td><td rowspan="2">0.6-1.6</td></tr>
<tr><td>Gas and water micro-injection assisted</td><td>Polyethylene terephthalate</td></tr>
<tr><td rowspan="2">Final test</td><td>Gas assisted</td><td rowspan="2">random polypropylene copolymer</td><td>-</td><td rowspan="2">250</td><td rowspan="2">12</td><td rowspan="2">50</td><td rowspan="2">40</td><td rowspan="2">8-2</td><td rowspan="2">10-20</td></tr>
<tr><td>Gas and water micro-injection assisted</td><td>4-6</td></tr>
</table>

Carbonium steel was used for the mould and the extraction carriage, while the inserts were made of aluminium alloy 7075. The gate and the gas injection point were placed with the aim of verifying the effects of the fluid on the workpiece. They were in fact placed near one end of the U-shaped pipe, although at two different points, that is, the gate on the workpiece axis, while the gas injector was arranged on the mobile part of the mould (injection into the pipe, Figure 3).

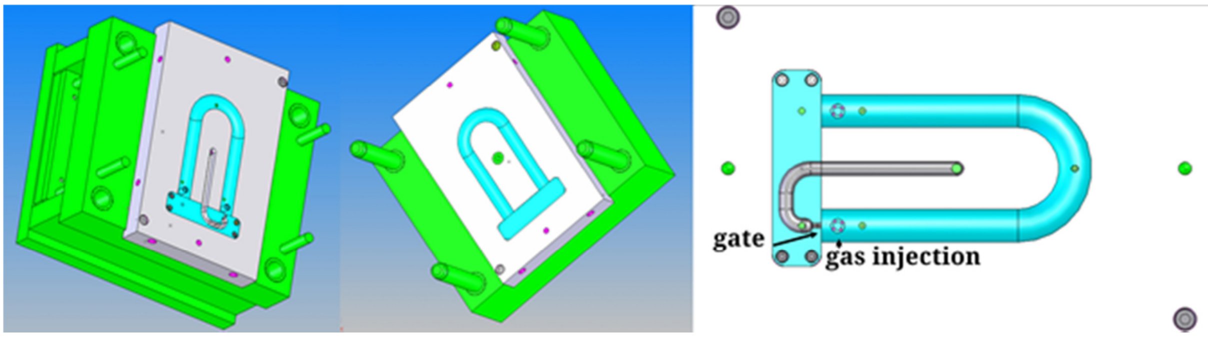

Figure 3 Mould design, injection into the pipe

Dimensional stability is the most significant parameter that can be used first to evaluate the effectiveness of the proposed technology. Figure 4A) shows the chosen control measurements: the distance D between the sides of the U-shaped pipe at the ends and the deflection angle. The weight of the samples and volume emptied inside the specimens, due to the penetration of gas, were also measured. This latter datum was obtained from the difference in weight of the samples before and after they had been filled with water. The water was mixed with blue dye to highlight the internal cavity (Figure 4 B). The presence of surface blemishes and warpage, and the incomplete contact of the two sample arms on the support surface were also investigated. In order to evaluate the effect of the water/aerosol contact on the cooling rate, the percent of crystallinity was measured at several points by means of Differential Scanning Calorimetry (DSC). The DSC Thermal Analysis was performed using a calorimeter Thermal Analysis 2010CE – TA instruments on material samples scratched from different areas of three specimens taken from the same moulding series: the sampling points on the benchmark are shown in Figure 4C).

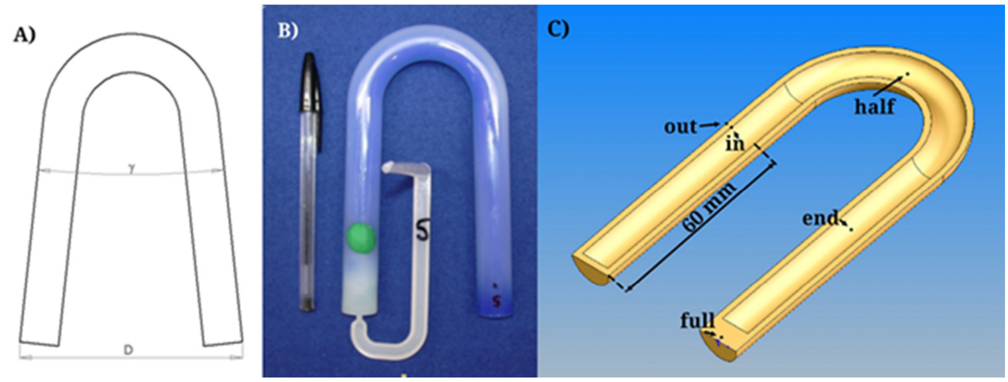

Figure 4 A) The chosen control measurements : the distance D and the deflection angle □; B) the emptying of the specimens was measured as the difference in weight before and after the specimen had been filled with coloured water; C) the arrows show the points where the material was sampled for the DSC analysis.

Homopolymer polypropylene was used for the first test: the massive part and empting optimization. Then, after an analysis of the first results, random PP copolymer was used for the subsequent test.

Homopolymer polypropylene shows resistance to deformation at elevated temperatures. With its high stiffness, tensile strength, surface hardness and good toughness at an environment temperature, random polypropylene copolymer is characterized by higher melt strengths [9]: some of the properties of the two materials are shown in Table 2. Homopolymer polypropylene can be referred to as the default state of the polypropylene material, and it is a general-purpose grade; random co-polymer polypropylene is usually selected for applications where a more malleable, clearer product is desired. It has a higher melt temperature than that of the homopolymer. In addition, it crystallizes more slowly, thus allowing the differentiated action of the cooling fluid on the different areas of the workpiece to be evaluated. Moreover, the use of higher temperatures increases the chance of water evaporation in the cavity.

Table 2 Properties of a typical polypropylene homopolymer and a random polypropylene copolymer with similar flow rates [9, 16]. *[16]

	PP homopolymer	random PP copolymer
Flow rate D 1238 Consd. L, g/10 min	4	2
Tensile strength at yield [MPa]	35,5	27,6
Izod impact resistance at 23°C [J/m]	42.7	101.4
Deflection temperature at 455 kPa [°C]	100	83
Density [g/cm^3]*	0.91÷1.2	0.9
Elongation [%]*	3.0÷80	12
Flexural Modulus [GPa]*	1.5÷7.0	1.3
Heat Deflection at 1.82 MPa [°C]*	73÷160	50
Notched Izod [J/m]*	42÷95	110÷350

3. RESULTS AND DISCUSSION

Figure 5 shows the effect of the micro-injection of water and nitrogen compared to the injection of nitrogen alone. The results point out that only a few grams of water are sufficient to increase the part hollow volume. In fact, only 2g of water were shown to increase the emptied volume by about 11%. The result raises only to 13% with the use of a triple quantity of water. Similar observations can be derived if the performances are expressed in terms of part weight VS quantity of injected water, as in Figure 6. The difference between the use of Nitrogen alone and the nitrogen/water mixture is marked. Among the tests with water micro-injection, instead, the effectiveness of the increase in water from 2 to 6 grams is negligible. This is probably due to the fact that the heat of the part is only enough to evaporate about 2 grams of water, and any additional amount remains liquid.

The thus produced parts did not show any fingering problems. This fact is in agreement with literature data, as it is known that the water assisted injection of moulded plastic parts exhibits a more severe fingering than those moulded by gas assisted injection moulding [17], and that the behaviour of a part obtained by biphasic fluid assisted injection moulding is similar to that of a component obtained by means of gas injection moulding. Therefore, the proposed solution can guarantee that the penetration in symmetrical ribs remains symmetrical, a property that is hard to obtain using just water [18].

The produced parts did not exhibit any sink marks on the surface.

The effect of the micro-injection of water on dimensional tolerances was found to be negative. In fact, the D value increased compared to the value of parts obtained using only nitrogen (Figure 7).

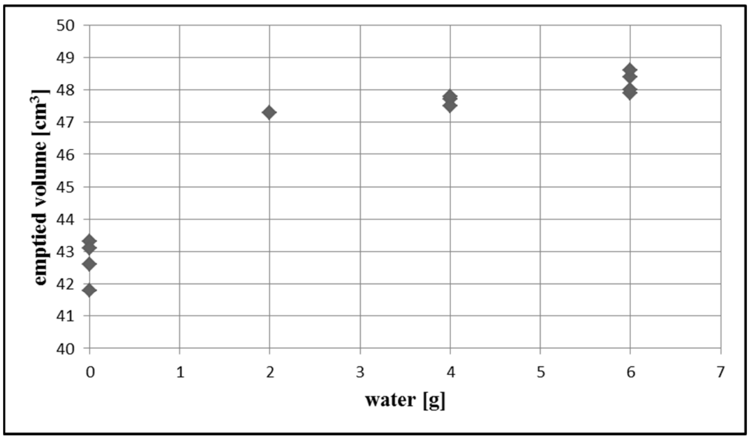

Figure 5 The volume emptied inside the specimens, due to the penetration of gas/water mixture, was obtained from the difference in weight of the samples before and after they had been filled with water that had been mixed with blue dye to highlight the internal cavity.

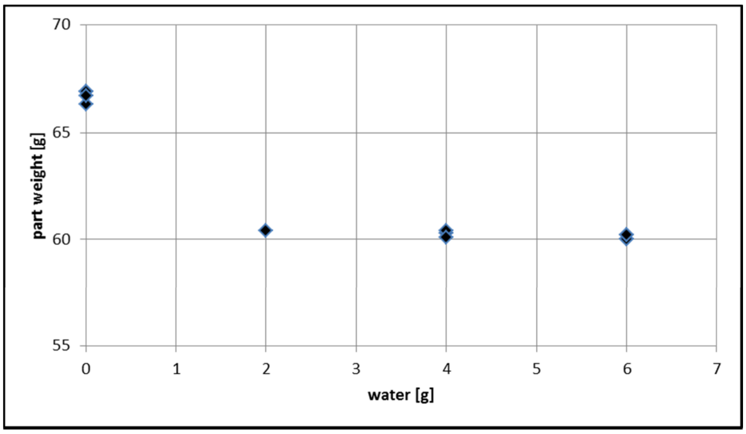

Figure 6 Effect of the water micro-injection on the part weight.

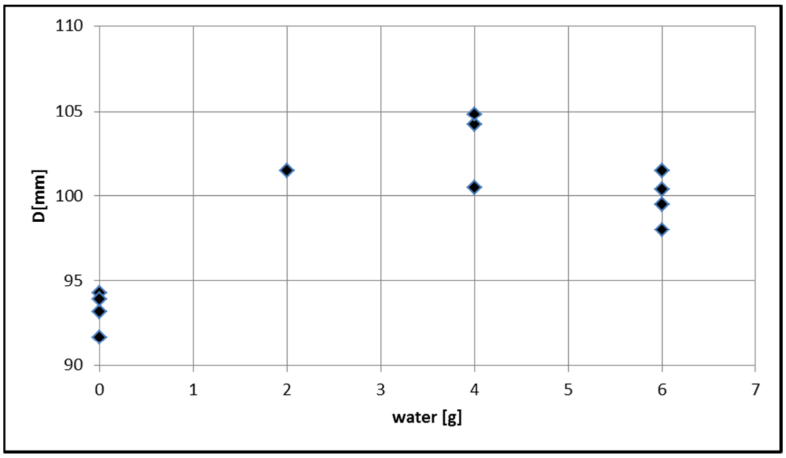

Figure 7 Effect of the injected water on the distance D between the sides of the U-shaped pipe at the ends.

Differential Scanning Calorimetry (DSC) Thermal Analysis was not useful to evaluate the results. The enthalpy values on the analysed section points are reported in Figure 8. It can be observed that the crystallinity percent is between 35 and 40%, but there are no remarkable differences between the corresponding points of the specimen with and without water, or between points of the same specimen.

4. CONCLUSION

The paper has focused on the investigation of a gas and refrigerant assisted injection moulding process.

In the proposed solution, water and nitrogen were injected inside the hot core of a polymer part during moulding, and it was observed that either all or a fraction of the injected water evaporated. The water phase change and the aerosol cooling effect caused a rapid decrease in the polymer temperature, which in turn led to a thick frozen layer.

- Even though several patents pertaining to the use of gas and refrigerant to obtain a hollow component exist, there is a lack of knowledge regarding the effectiveness of the process.
- The experimental data have shown that the co-injection of a nitrogen and water aerosol has a slightly positive effect on the hollowing of the part, as it decreases the part weight and increases the hollow volume, but it has a negative effect on the dimensional stability of the part.
- The crystallinity grade between corresponding points of parts obtained with or without water has not shown any remarkable differences.

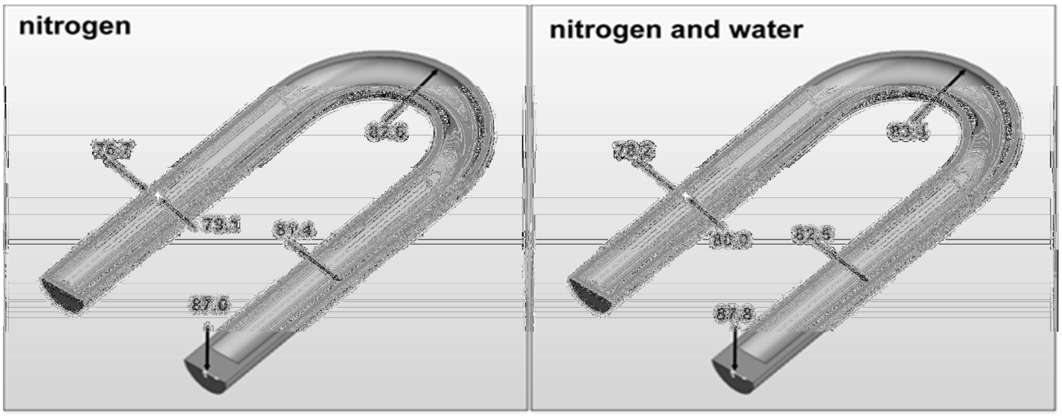

Figure 8 Enthalpy measured by means of DSC at several points

ACKNOWLEDGEMENTS

The authors are grateful to LEAN Srl, Via Marconi 2, 41036 MEDOLLA (MO) Italy, for designing and constructing the unit for the water micro-injection.

The authors also gratefully acknowledge Fortec Srl, Via Matteotti 12, 42015 Correggio (RE) Italy, for constructing the mould and supplying the press.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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