The Quandary of Making a Selection

Which Fluid Injection Technique is Appropriate? Every injection moulded part with a hollow cross-section that cannot be formed by a core or slide requires utilisation of a fluid injection technique. Selection of the most appropriate technique depends primarily on the part geometry and, sometimes, on the strategy of the company. The annual production quantity has a major influence on the manufacturing costs.

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All FIT processes (FIT: Fluid injection technique) are used to produce hollow objects. The fluid displaces the still-molten plastics melt in the interior of the solid injection moulding part, thereby forming a cavity, or void. At the same time, the fluid cools the moulded part from the inside in accordance with its heat capacity and thermal conductivity.

Of the various fluid injection techniques, which can trace their beginnings to 1938 [1], only gas-assisted injection (GIT) has found a broader market to date. It has represented the state of the art since the 1980s. Beginning with initial trials at the Institute for Plastics Processing in Aachen in 1998, the water-assisted injection technique (WIT) was developed and, in the meantime, is being employed in several high-volume applications (e.g. dipstick guide tubes, tiller heads, tricycle forks, automobile rooftop strips, cooling water pipes) [2, 3].

In spite of these successful applications, plastic processors are still some hesitant to employ WIT. Although – when prop-

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Various moulded parts produced using the water-assisted (left) and gas-assisted (right) injection techniques (Figures: TiK)

(Figures: TiK)

erly employed – it permits cycle time reductions of up to 50 %, many processors shy away from the difficult-to-handle medium of water. In addition, some end users have had disappointing experiences with parts produced via WIT, even though they were only marginally suited for the technique and could not provide the expected cost benefit.

In view of this, the processor should first check whether the intended part can be produced by means of conventional injection moulding by making some small design changes, e.g. to permit use of slides, cores, lost cores, or by using two half-shells. Table 1 evaluates different techniques for producing hollow objects using the example of cooling water pipes. A key to the success of any new processing technique is that all participants be thoroughly trained.

The Correct Injection Technique for Each Application

If use of a fluid injection technique is unavoidable or even advisable, different approaches are available:

- gas-assisted injection (GIT),
- gas-assisted injection with cool gas,
- gas-assisted injection with subsequent flushing,
- gas-assisted injection with subsequent flushing using cool gas,
- water-assisted injection (standard-WIT) and
- gas/water-assisted injection (TiK-WIT).

When selecting the injection technique, the first objective is to clarify whether and with which technique the particular part

Process / characteristics	Costs	Space required	Functional integration	Process capability	Subsequent processing	QC expenses	Burst pressure
Injection moulding	++	++	+	++	++	++	0
Injection moulding with multiple shells	++	–	+	++	0	0	–
(Suction) Blow moulding	+	+	–	+	–	+	+
Lost core technique	—	++	++	+	++	+	0
Gas-assisted injection technique (GIT)	–	++	++	0	–	0	++
Water-assisted injection technique (WIT)	+	++	++	0	–	0	++

++ very favourable + favourable o indifferent – less favourable — poor

Table 1. Comparison of methods for producing hollow parts using the example of plastic pipes

Necessary boundary conditions	GIT	Gas flushing	WIT/TiK-WIT
Material in general	Almost all possible	Almost all possible	GF content max. 25 %, with TiK-WIT > 30 % possible
Cooling water pipe material (PA66-GF30)	Special material necessary	Special material necessary	Possible only with TiK-WIT Special material necessary
Expected void cross-section in the moulded part	Up to ∅ 10 mm favourable	Up to ∅ 10 mm favourable	Favourable from ∅ 10 mm
Number of possible injection positions in the moulded part	1 or more	at least 2	1 or more
Injection directly into the part (appearance part)	Possible	Possible	Not recommended
Possible cross-section at the injection position	∅ > 2 mm	∅ > 2 mm	∅ > 6 mm
High-gloss parts with injection channel / direct injection	Possible	Possible	Possible / possible with limitations
Location of the injector	Not critical	At the channel end	Beneath the part
Minimum cooling time, determined by process	> 15 s	> 20 s	> 25 s
gas supply	Bottle, bundle, tank	Tank	—

When deciding in favour of a process, all features should be in one column

Table 2. An FIT checklist helps in selection of the appropriate FIT process by taking into account the part geometry and part requirements

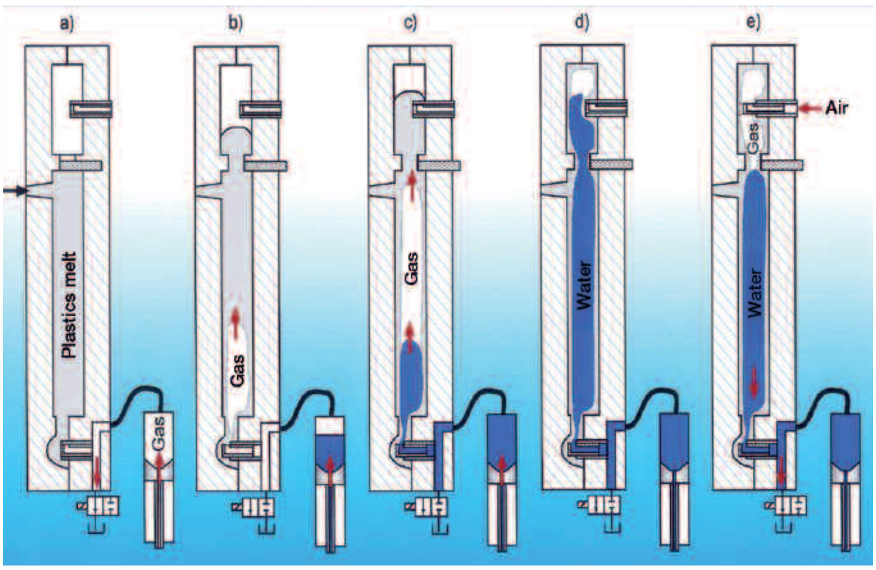

Fig. 1. Processing principle for the TiK variant of the water-assisted injection technique
a) Melt injection to fill the mould, followed by a short holding pressure phase; the TiK-WIT volume is flushed and filled with air/gas
b) The adjacent cavity is opened, likewise the injector, and the air/gas cushion pushed into the melt with the aid of water
c) The air/gas cushion forms the void, while the water pushes it through the melt and maintains it under pressure
d) The end of the water injection phase; water holding pressure phase; compression of the air/gas cushion to the final volume, which helps when draining the water
e) Water draining phase, which is aided by a flushing injector (using air)

can be produced from the technical standpoint and also from a volume production standpoint. Here, the requirements imposed on the part often limit the selection. For instance, flushing/purging techniques require two injectors, the standard approach only one. Likewise, a material specification may be the reason to choose gas-assisted injection over water-assisted injection, since not all materials can be processed in a reproducible manner when using WIT [4, 5]. Ultimately, the geometry of the moulded part plays the deciding role with regard to the technical suitability of the FIT. In this regard, opinions and assistance from experienced service providers should be sought, especially for cooling water pipes, with respect to concepts for subsequent processing of the moulded parts, as they can determine the cycle time. If that is the case, a technique that reduces the cooling time can no longer have a positive effect on the manufacturing costs if the subsequent processing is not also optimised at the same time.

Whether a part can be produced reproducibly with one of the FIT approaches under production conditions is determined by where and whether there is space on the part and in the mould to permit fluid injection, and, above all, whether the injector must inject directly into the part or may inject via a runner or auxiliary channel. Auxiliary channels are particularly beneficial for water-assisted injection, since they permit an optimal design for the area around the injector. The injector geometry also determines the space required in the mould. For water injection, inside diameters of up to 20 mm inside the injector are needed in order to have laminar flow upon entry into the moulded part [6].

Breakdown of the cycle time for WIT

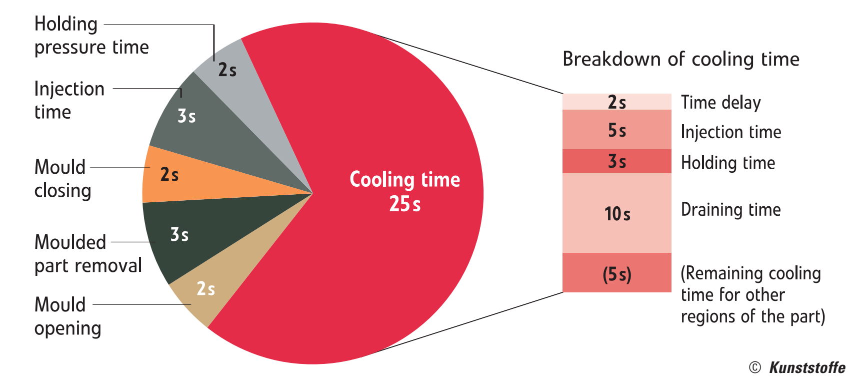

Fig. 2. The illustration shows what fraction of the overall cycle individual process steps account for. In this example of a WIT part, the overall cycle time is 37 s

Cooling medium/ Plastic	T_1 [K]	T_2 [K]	$c_{p\ average}$ [J/gK] from T_1 to T_2	m (T_1) [g]	Heat absorbed Q_{12} [J]	$Q_{12\ fluid}$ / $Q_{12\ plastic}$ [%]	Equalisation temperature T_m [K]
Plastic (280°C)	553.15	393.15	2.188	18.5	6599	100.0	—
N_2 (-20°C)	253.15	393.15	≈1.290	4.5	750	11.4	518.7
N_2 (0°C)	273.15	393.15	≈1.290	3.8	601	9.1	522.8
N_2 (+20°C)	293.15	393.15	≈1.290	3.3	455	6.9	527.3
Water (15°C)	288.15	353.15	≈4.183	15.1	4059	61.5	390.3

Table 3. The maximum heat absorbed by the fluid is calculated from Equations (1) and (2) when cooling a 30 % glass-filled PA 66 part from 280 to 120°C demoulding temperature at the inner surface of the part wall (273,15 K "corresponds to" 0°C)

Process (fluid temperature)	Cooling time [s]	Cycle time [s]	Cooling time savings [%]	Cycle time savings [%]
GIT (20°C)	40	52	0.0	0
Cool Gas (0°C)	39	51	2.6	1.9
Cool Gas (-20°C)	38	50	5.0	3.8
Water (15°C)	17	29	57.5	44.2

Table 4. The WIT process shortens the cooling time and cycle time considerably more than the standard GIT process – even when the gas is cooled

Fluid Dynamic Thinking Required

The orientation of the moulded part in the mould is an important parameter in so far as the cavity should be filled against the force of gravity if possible in order to obtain a good outside surface. With WIT the water should always flow from the bottom to the top, since this facilitates emptying of the void created. The TiK-WIT approach (Fig. 1), in which a compressed air bubble empties the moulded part, helps here [7, 8].

The part geometry should be designed to promote favourable flow, since the fluid displaces only the melt that stands directly in the way. Changes in cross-section create turbulence in the melt and thus accumulations of melt [9] that generally determine the cycle time. The designer should thus have input with regard to part design if only to increase the size of radii. FIT always requires fluid dynamic thinking. Along with the above-mentioned design principles, a few additional ones help to select the correct process (Table 2).

When its come to the cost analysis, the FIT processes differ from one another in terms of the

- achievable cycle time and
- size of the investment for the FIT system and injection mould.

The former is affected solely by the cooling time (Fig. 2). For injection of the medium and emptying of the moulded part, a minimum cooling time of 20 to 25 seconds should be assumed as a rule (above all, for WIT).

The individual FIT processes differ primarily in terms of the medium itself and in terms of the number, type and location/orientation of the injectors, since these affect the flow and thermal aspects. The medium determines the effectiveness of the cooling inside the moulded part. Thus, the achievable cooling time and possible cost savings represent the major differences between the individual processes.

Cooling Times Can be Calculated in Advance

The cooling times to be expected with the individual processes can be calculated using analytical methods based on thermodynamics and heat transfer. For this purpose, a few simplifications are made, such as assuming that all processes take place at a constant pressure of 200 bar and that the heat flow through the part wall during cooling is linear and remains unchanged at a constant mean value for each process. For a computational comparison of the processes, these assumptions are permissible, since the magnitude of the error is the same for all processes. The computations were performed for a small tube of 30 % glass-filled PA 66 with the geometry shown in Fig. 3. Starting point for the computation is a melt temperature of 280 °C and a constant mould temperature of 80 °C.

Using the material properties of nitrogen (N_2) and water, the values given in Table 3 are obtained from Equations (1) and (2).

Heat absorbed by a medium:

$$Q_{12} = H_2 - H_1 = m\,(h_2 - h_1) = m\, c_{p\,fluid}\,(T_2 - T_1) \qquad (1)$$

Equalisation temperature of two media:

$$T_m = (m_1\, c_{p1}\, T_1 + m_2\, c_{p2}\, T_2) \,/\, (m_1\, c_{p1} + m_2\, c_{p2}) \qquad (2)$$

with
p = absolute pressure = 200 bar,
m = mass,
T = absolute temperature,
Q = heat exchanged,
H = enthalpy of the fluid,
c_p = spec. heat capacity at constant pressure.

Table 3 demonstrates clearly that, regardless of temperature, nitrogen cools the plastics melt by only 7 to 12 %. Thus, after the gas has been warmed, the mould cooling must cool not only the plastics, but also – except in the case of water – also the

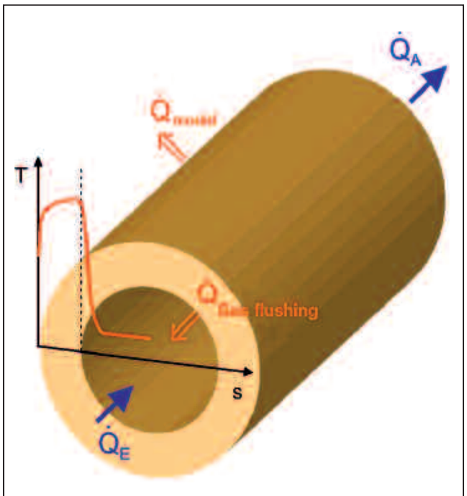

Fig. 3. This plastic pipe was taken as the basis for calculations used when evaluating the cooling time achieved with the various FIT processes: L = 200 mm, D_{void} = 10 mm, remaining wall thickness s = 2 mm, volume of the void V = 15.7 cm^3

Comparison of cooling times

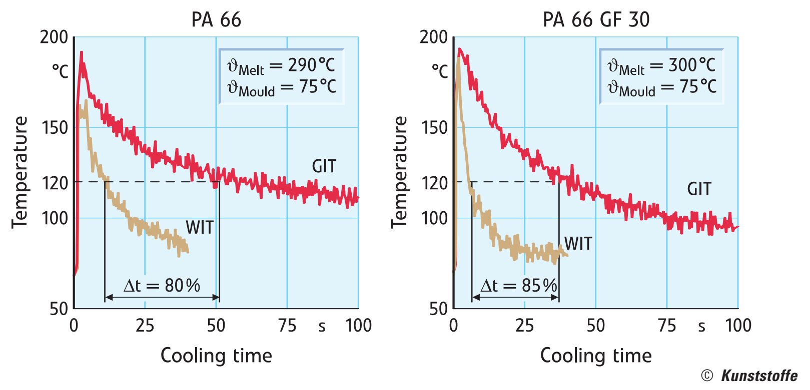

Fig. 4. The difference between WIT and GIT is obvious for a plastic pipe of 30 % glass-filled PA 66 with an outside diameter of 30 mm [8] as shown by the sharp temperature drop across the part wall (source: IKV, April 2000)

Process (fluid temperature)	T_{exit} [°C]	$\dot{Q}_{gas\ flushing}$ [J/s]	Cooling time [s]	Cycle time [s]	Cooling time savings [%]	Cycle time savings [%]
Cool gas flushing (-20°C)	119.20	70.03	29.5	41.5	26.3	20.2
Gas flushing (+20°C)	142.36	61.56	30.6	42.5	23.5	18.1

Table 5. Flushing with gas reduces the cooling time and cycle time only minimally

medium to 120 °C. In the case of water, the amount of heat absorbed is such that the water is not even warmed to 120 °C; accordingly, the water temperature is set to T_2 = 80 °C, which correspond to the value measured in actual practice. The mean temperature of the plastic is still 120 °C. The considerably greater fraction of 61 % for cooling by water versus gas is obvious. This is attributable, on the one hand, to the greater mass, and, on the other, the higher heat capacity.

Using the example of the tube, the different cooling times can be calculated by determining in advance the average heat flow through the injection mould: $\dot{Q}_{mould}$ = 154 J/s. The cooling time t_{cool} for the respective fluid is calculated using Equation 3 (see box).

Water Offers the Greater Cooling Potential

The above considerations allow the theoretical cooling times for the different processes and, after taking other time segments into account (e. g. from Fig. 2), the cycle times to be derived (Table 4). It is obvious that cool gas shortens the cycle time by only 3.8 % (versus 1.9 % for uncooled gas), while the water-assisted technique reduces it by 44.2 %.

This result is very close to what is experienced in actual practice, as can be seen from comparison of the measurements [10] obtained for a similarly sized pipe with an outside diameter of 30 mm and a part wall thickness of about 3 mm (Fig. 4).

Taking into consideration the relationship between void volume and the resin volume for different pipe diameters and wall thicknesses, the reduction in cooling time varies accordingly. If in this example the 85 % found in actual practice are applied to the calculated part, the

Equations

$$t_{cool} = (Q_{12\,plastic} - Q_{12\ Fluid}) \,/\, \dot{Q}_{mould} \qquad (3)$$

$$\dot{Q}_{gas\ flushing} = \alpha\ A\ \Delta\vartheta \qquad (4)$$

$$\dot{Q}_{gas\ flushing} = \dot{Q}_A - \dot{Q}_E \qquad (5)$$

$$\Leftrightarrow \dot{Q}_{gas\ flushing} = \dot{m}_{nitrogen}\, c_p\,(T_A - T_E) \qquad (6)$$

$$T_A - T_E = \alpha\ A \,/\, \dot{m}_{nitrogen}\ c_p \qquad (7)$$

$$\Delta\vartheta = \frac{(T_w - T_E) - (T_w - T_A)}{ln\left(\frac{T_w - T_E}{T_w - T_A}\right)} \qquad (8)$$

$$t_{cool} = Q_{12\ plastic} \,/ (\dot{Q}_{mould} + \dot{Q}_{gas\ flushing}) \qquad (9)$$

savings are 52 %, which even exceeds the calculated value of 44.2 % somewhat.

When evaluating the gas flushing process, it must be borne in mind that convective heat transfer that depends on the heat transfer coefficient α and the "mean logarithmic temperature difference" (Equation 4) occurs inside the tube as a result of fluid flow. Taking into consideration further the heat balance around the fluid (Equations 5 and 6), the difference in temperature at the gas inlet and gas outlet is obtained (Equation 7).

Equation 8 applies for the mean logarithmic temperature difference.

Under the realistic assumption that the resultant flow is turbulent, the cooling times presented in Table 5 are calculated with Equation 9.

Here, too, the calculated results agree well with practical experience, where similar results have been achieved numerous times with outside door handles [11]. It can be concluded from these calculations that for the part in this example gas flushing shortens the cycle time by more than 25 % compared to standard GIT. The temperature of the gas – as in the standard GIT process – plays only a minor role.

Take Expenses for Subsequent Processing into Account

In addition to being influenced by the cooling time, the economics are determined to a great extent by the size of the investment and the subsequent processing of the moulded part. The investment includes primarily the necessary equipment and the conditions required for production. For instance, stations for subsequent processing of cooling water pipes can account for between 30 and 50% of the overall investment. When considering the production technology, whether or not a nitrogen tank already exists or must be purchased in the near term is also a factor. The costs for nitrogen are negligible when it is supplied from a tank, while they can amount to anywhere from 0.05 to 0.10 EUR/part for large parts with nitrogen supplied from bottles. For reliable production, care must be taken to ensure that high-purity nitrogen is used and the melt is processed gently. This reduces the cleaning intervals for the injectors.

If the cycle time is determined by the subsequent processing – as already mentioned – shortening the process loops achieves little. The appropriate and, above all, a flexible concept for subsequent processing can keep these costs at a low level, especially for cooling water pipes, particularly when there is a chance for additional projects. Stations designed for subsequent processing then exploit the full cooling time potential of the WIT process. Compared to GIT, the number of parts per hour can be doubled without increasing the number of cavities.

Conclusions

When considering the number of moulded parts on the market that are produced with an FIT process, it is seen that each of the processes discussed has its own field of application. What is important for future success is that the production planners incorporate as much information as possible as early as the mould design phase. The more refined the mould concept, the fewer the problems to be faced in production later. ■

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