CMMT(MN)061

In-Process Monitoring Of The Flow Properties Of Polymer Melts Using On-Line And In-Line Methods

Summary

The quality of plastics products produced by processing techniques such as injection moulding, extrusion or compounding is dependent on the magnitude and consistency of the rheological properties of the material during processing. These properties affect how the material performs during processing. They are also a measure of the material's structure and thus provide an important indicator of the consistency of the material and its behaviour in service.

Controlling the process using in-process measurements ensures the high quality of products. Furthermore, continuous monitoring of process conditions and materials properties can lead to reduced costs and higher levels of manufacturing efficiency, thereby improving industrial competitiveness.

Collaboration between NPL, Porpoise Viscometers Ltd and converters has led to the development of an on-line technique for measuring the viscosity of materials in extrusion processes that has successfully overcome some of the issues that make off-line methods unfavourable. Similarly, further collaboration between NPL and the polymer industry has resulted in an in-line monitoring method that was developed around an instrumented nozzle for monitoring the process and material properties during injection moulding.

This note describes the on-line and in-line techniques used and presents some results of the industrial trials that were carried out.

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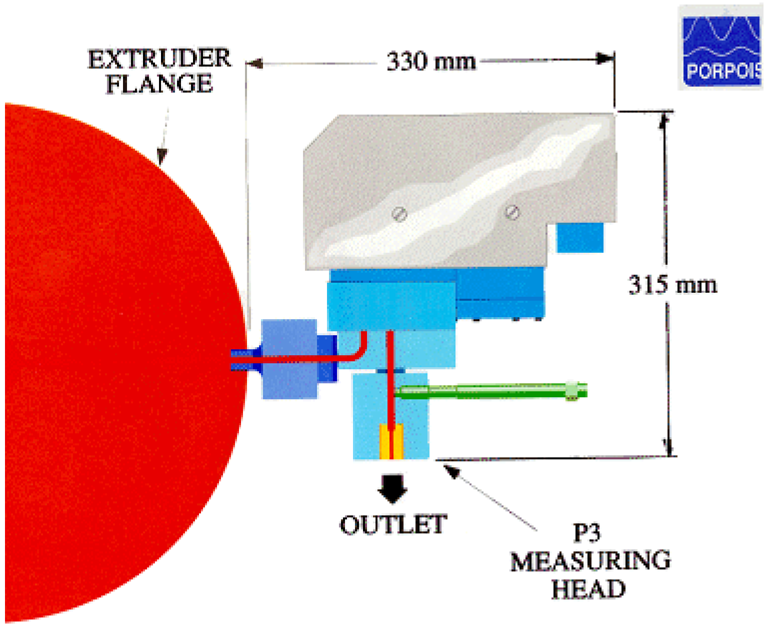
The On-Line Method



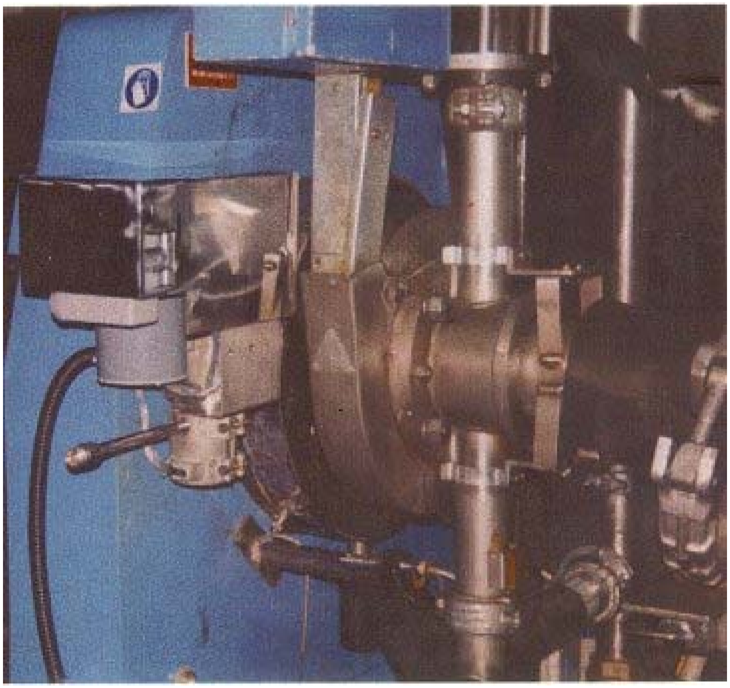


Figure 1. On-line rheometer: schematic diagram (top) and mounted on a compounding extruder (below).

A Porpoise Viscometer P3, an on-line rheometer, was attached to a commercial compounding extruder to monitor viscosity during production as shown in Figure 1. The instrument operates on the principle that a stream of melt is taken from the process at a known, controlled rate and passed through a die. From measurements of the pressure above the die and the dimensions of the die the viscosity of the material can be determined. These viscosities were then used to determine, automatically, MFI values that are more widely used by industry for quality control purposes.

These industrial trials demonstrated the ability of the instrument to monitor the consistency of compounds over extensive periods (Figure 2), to identify differences between polymers made by different reactors, (Figure 3) and to monitor the time taken to switch compounding to a different formulation. Furthermore, the technique was able to provide much more frequent and rapid monitoring than was possible using off-line methods, thus ensuring better control of the process and consequently better quality of the product. For further information see reference 1.

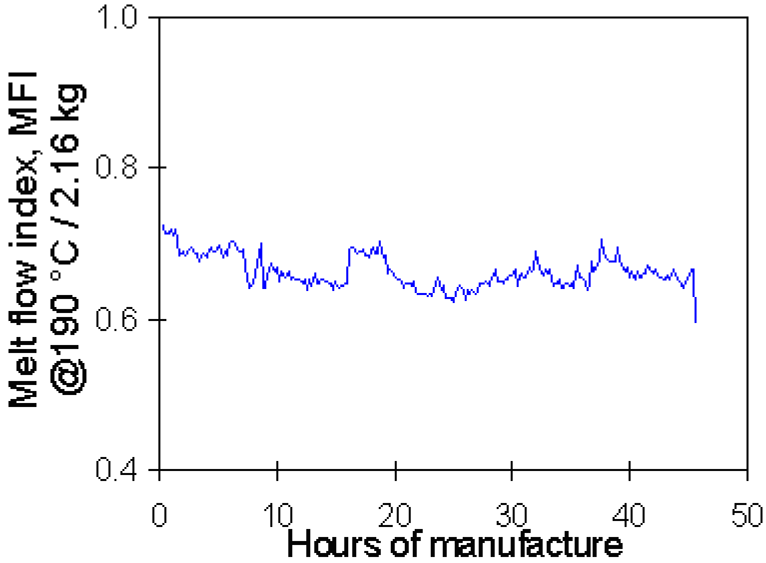


Figure 2.Variation of the MFI of a filled polyolefin measured on-line over a 2 day manufacturing run.

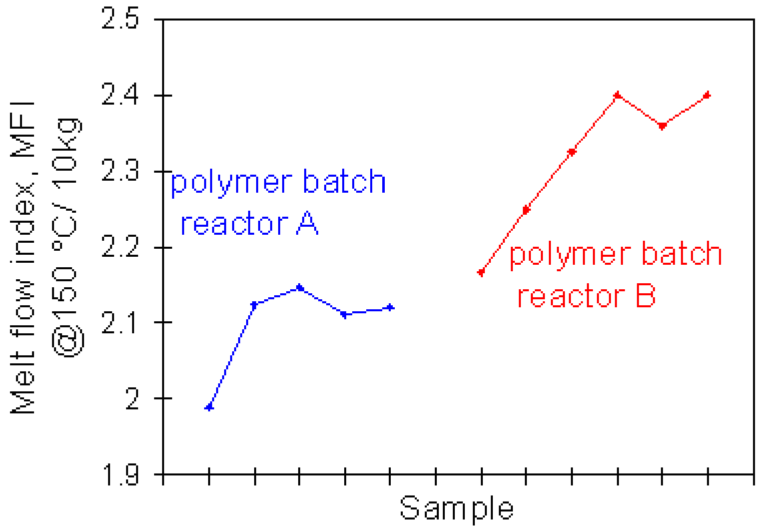
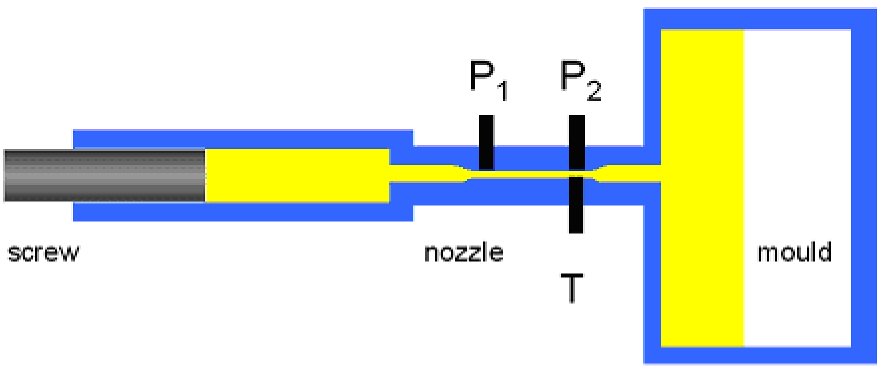


Figure 3. Batch to batch variation of a filled polyolefin (the polymer batches were supplied from different reactors).

The In-Line Method



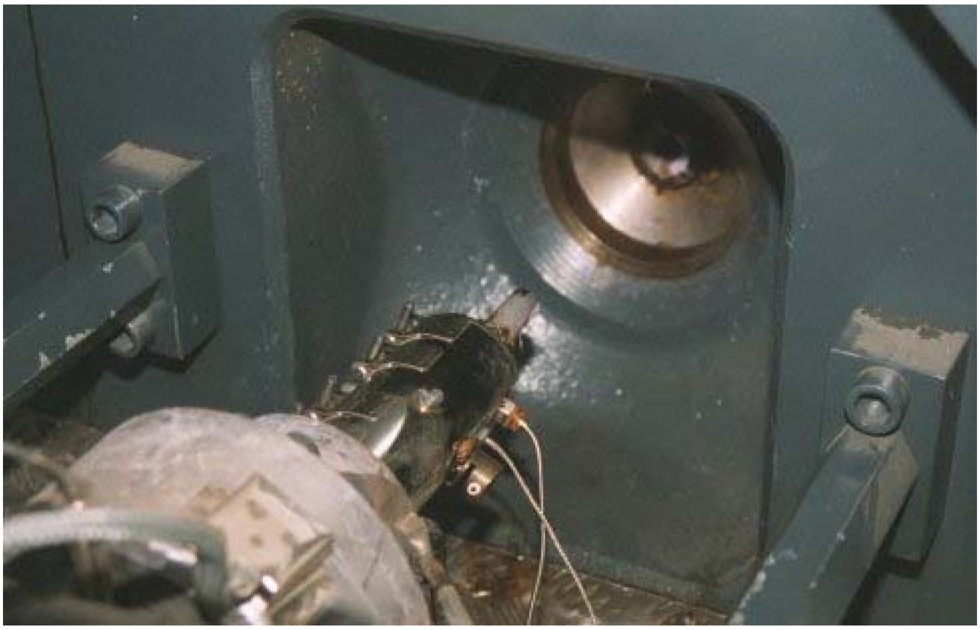


Figure 4. Schematic diagram and photograph of an instrumented nozzle on an injection moulding machine.

A standard injection moulding machine nozzle is replaced by an instrumented nozzle in this technique (see Figure 4). The flow through this nozzle generates a pressure drop that is measured by pressure transducers P1 and P2.

The software developed at NPL (see the user interface in Figure 5) calculates a viscosity value from pressure data collected. The user panel shows the pressure data on the right as obtained during a moulding cycle. The injection cycle is magnified on the left side. The bottom four graphs show the change in key parameters with time (viscosity, pressure values, temperature etc.) that can be used for quality control.

Viscosities were calculated (without applying entrance or Rabinowitsch correction factors) at a typical wall shear rate of 4 x 10^4 s^{-1}, as occurs during the injection phase. Because of shear thinning, the actual viscosities measured here are 1 - 2 orders of magnitude lower than the laboratory measurements and on-line measurements at lower shear rates. Figure 6 shows results from trials performed on a range of polypropylenes (PP) and one high density polyethylene (HDPE).

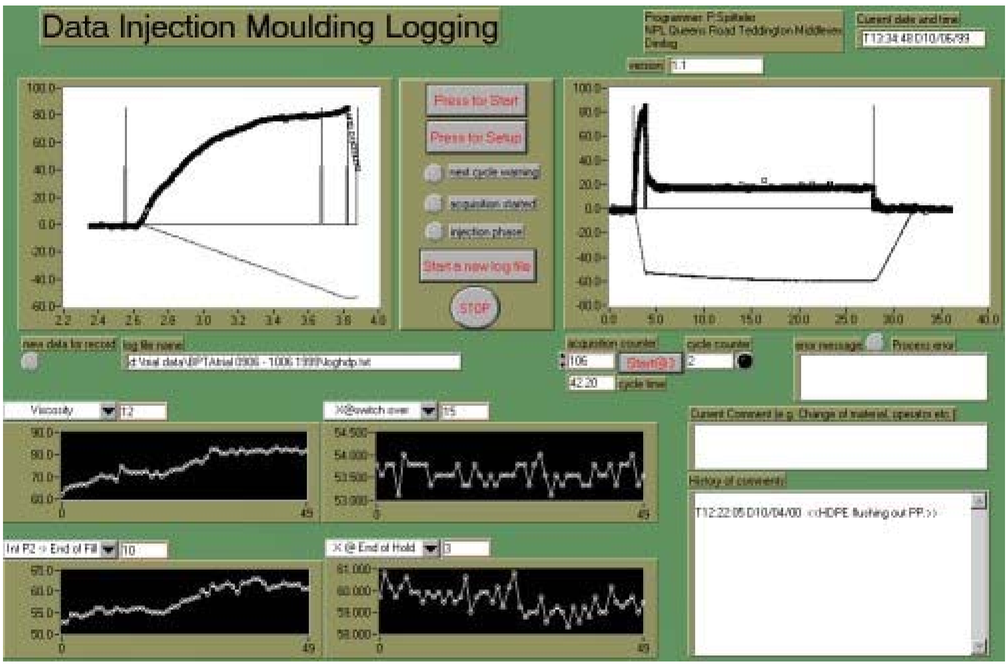


Figure 5. Data acquisition software user interface.

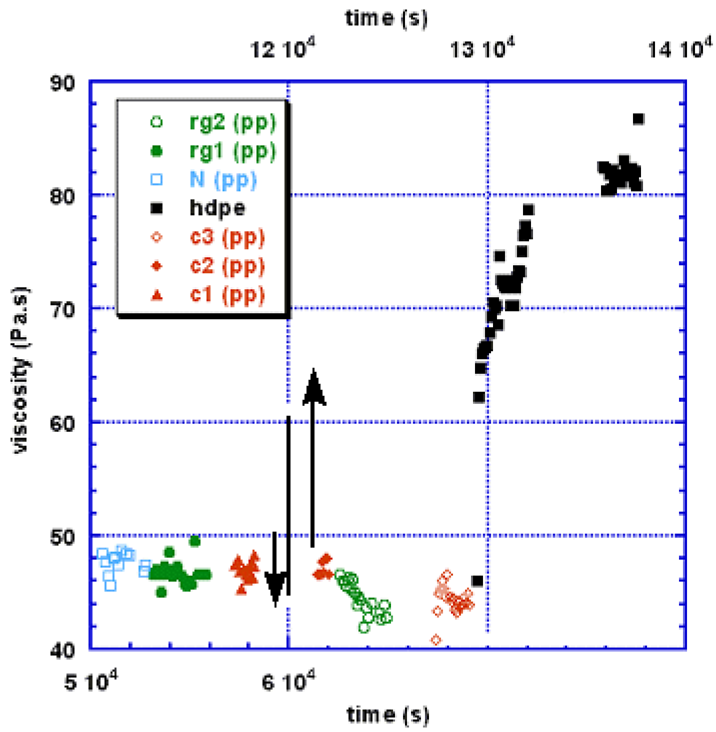


Figure 6. Viscosity results obtained during in-line trials.

PP (N) shows a viscosity value of about 47 Pa.s. A first regrind of PP (rg1) shows more or less the same value as do the coloured batches of PP (c1, c2, c3). The second regrind of PP (rg2) shows a distinct drop as the previous material is flushed out. Finally a sharp rise in viscosity can be observed as HDPE (hdpe), used in the last run, purges out the PP. For further information see reference 1.

Conclusions

The application of in-process monitoring to plastics processing can offer considerable benefits in terms of improved product quality and processing efficiency. The use of an instrument mounted on a compounding extruder and an instrumented nozzle on an injection moulding machine have been demonstrated.

On-line and in-line process monitoring provide:

- near immediate process and material consistency measures
- data that can be used for process and materials quality control
- significantly higher sampling rates than practicably possible by off-line methods,
- data acquired with relatively low levels of operator input compared with off-line methods.

These trials have illustrated some the benefits of on-line and in-line measurements under the industrial conditions of extrusion compounding and injection moulding.

Acknowledgements

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References

1. In-process monitoring of the flow properties of polymers for extrusion, compounding and injection moulding, C.S. Brown, C.R.G. Allen, M. Rides, Sharma and P. Spitteler, NPL Report CMMT(A)260, April 2000.

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