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TEMPERATURE PROFILE MEASUREMENT USING MODIFIED COOLED STAINLESS TUBE TECHNIQUE IN A SINGLE SCREW EXTRUDER COUPLED WITH A MODIFIED THERMOCOUPLE MESH – EFFECT OF SCREW SPEED

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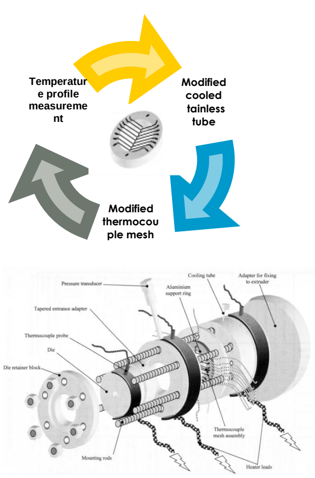
Graphical abstract



Abstract

The knowledge of the development of temperature profiles in polymer processing machinery is very useful to give a clear picture of the interrelationship between the temperature, rheological characteristics, and the behaviour of the polymer. Using the modified cooled stainless tube (CST) technique together with a modified thermocouple mesh, the temperature profiles of low-density polyethylene (LDPE) in the extruder outlet using an open channel adapter with various screw speeds were investigated. The thermocouple mesh, which was considered easy to build was shown to have outstanding performance in terms of accuracy when obtaining readings for the experiment. From the study, the results indicated that the screw speed and temperature fluctuations are directly proportional.

Keywords: Cooled stainless tube, extruder, open channel adapter, polymer, screw speed, temperature profiles, thermocouple mesh

Abstrak

Pengetahuan tentang perkembangan profil suhu dalam mesin pemprosesan polimer sangat berguna untuk memberi gambaran yang jelas tentang perkaitan antara suhu, ciri-ciri reologi, dan pencirian polimer. Menggunakan teknik *cooled stainless tube (CST)* yang diubah suai bersama-sama dengan jejaring termokopel yang diubah suai, profil suhu *low-density polyethylene (LDPE)* dalam alur keluar penyemperit menggunakan penyesuai saluran terbuka dengan pelbagai kelajuan skru telah dikaji. Jejaring termokopel, yang dianggap mudah untuk dibina, ditunjukkan mempunyai prestasi cemerlang dari segi ketepatan apabila mendapatkan bacaan untuk eksperimen. Keputusan menunjukkan bahawa kelajuan skru dan turun naik suhu adalah berkadar terus.

Kata kunci: Tiub tahan karat yang disejukkan, penyemperit, penyesuai saluran terbuka, polimer, kelajuan skru,profil suhu,jejaring termokopel

1.0 INTRODUCTION

The Cooled Stainless Tube (CST) technique was used to measure temperature and velocity profiles in an injection moulding machine [1]. This technique was chosen for use in the current work due to its reliability and accuracy as well as the capability of measuring velocity profiles dynamically as the melt was flowing in injection moulding. However, in the extrusion process, it was found that the temperature profiles changed in a complex manner, the flow rates also being lower than those found in injection moulding. Consequently, the direct application of the CST technique did not give satisfactory results.

A study by Sombatsompop *et al.* (1996) has resulted in the design of a versatile apparatus to simultaneously measure temperature and velocity profiles [2]. The apparatus was attached to the end of the barrel of an injection moulding machine. They used a temperature sensing mesh coupled with Cooled Stainless Tube (CST) technique. In the CST technique, cold water is pulsed through a stainless tube that is mounted diametrically across the flow, upstream of the temperature sensor. Pulsing water through the tube cools the melt in the vicinity of the tube to a temperature below the ambient melt temperature. As this melt flows along the duct, it eventually reaches the temperature sensor where a fall of melt temperature is recorded. A knowledge of the time interval between the pulse of water and the cooled band of melt reaching the sensor coupled with the distance between the tube and the sensor, allows the velocity of the melt, at the given radial position in the flow, to be calculated.

Extruders are one of the popular and widely used machinery in the manufacturing of various forms of polymer products, including pipes, hoses, cables, sheets, films, and insulated wires [1, 3]. There are various types of polymer processing extruders, i.e., single/multi screw extruders, disk extruders, gear pumps, and ram extruders. Significant amount of research and development has been conducted on single- and multi-screw extruders to improve the operation of polymer processing [4, 5].

Inconsistency of temperature in extruder machine needs CST to stabilize the temperature in several zone. Several research found that designing cooling system in extruder machine to obtain uniform cooling and to produce complex extruded profile is challenging [6]. This system should also be able to produce a decreased degree of residual thermal stresses by limiting the temperature gradient that develops along the profile cross section [7, 8]. The calibration and cooling system should be able to bring the profile average temperature down as quickly as possible to make it possible for high production rates, and at the same time, it should be able to bring the temperature inhomogeneity down to a level that is low enough to minimise the level of induced thermal residual stresses.

Thus, in this work, the CST technique coupled with a new thermocouple mesh, air pulsation and pulsation timer, to clear water from the cooling tube, was developed. The experimental apparatus used in this work can be divided into five sections, these being the extruder, main apparatus, water cooling system, thermocouple mesh and data collecting equipment. Moreover, an improved method of measurement was used using the modified CST technique coupled with a modified thermocouple mesh was used to measure the temperature profiles and velocity profiles across the diameter of an extruder head of a single screw extruder.

2.0 METHODOLOGY

A custom-made thermocouple mesh used in this work was node woven on the high temperature resistance electrical board as shown in Figure 1. The thermocouple mesh was from the K-type thermocouple consisting of chromel and alumel wire. The thermocouple mesh consisted of sixteen nodes that are capable of measuring sixteen points of temperature across the radial of the 50 mm extruder die head. To eliminate the deflection of the mesh resulting from the highly viscous polymer melt flow across the structure, the thermocouple wires were arranged in two planes. This was done by rearranging some wires in the circuit to act as a support leg in the other plane to retain the shape and location of the thermocouple junctions. The thermocouple mesh was then placed in between the rig in order to investigate melt temperature across the die head in the plastics extruder. The schematic diagram of the rigs specially designed and fabricated for this purpose is shown in Figure 2. The whole assembly of the rig is then mounted at the extruder head. The temperature reading at every point across the radial of the extruder die head was recorded using a data logging equipment, an autonomous data acquisition unit (ADU) (Mowlem Microsystems) that was controlled by a host computer.

Figure 1 Structure of thermocouple mesh used in this work

The extruder used was a single-screw extruder (Type 50 mm, 25/1, S+B Plastics Machinery). The heating was divided into 5 sections such as the extruder, main apparatus, water cooling system, thermocouple mesh and data collecting equipment. The data logger has the capability to read the peripheral voltages around the mesh at speeds up to 10,000 readings/sec. The data logger is equipped with a compensating junction chip that provides a reference thermocouple voltage reading equivalent to room temperature. This enables the direct conversion of readings to temperatures. However, this extra step of conversion reduces the data logging capability to 400 readings/sec. In this work, 17 channels were used for temperature and pressure measurements. This meant that the data logger could generate about 20 readings per second per channel, which was adequate for the determination of temperature profiles.

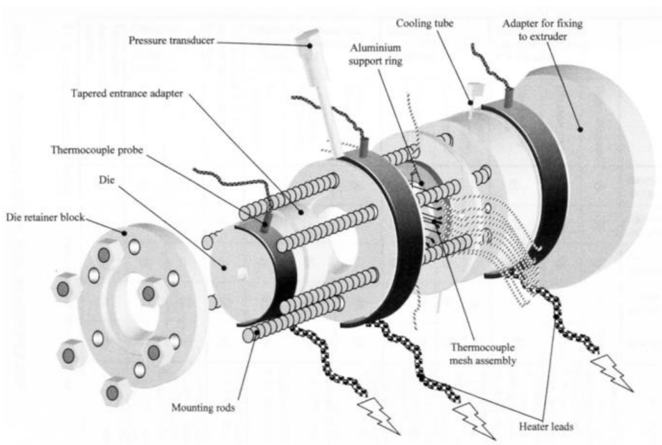


Figure 2 The experimental apparatus used

The capability of the apparatus developed in this work was evaluated. The response time was calculated theoretically. Then, the temperatures measured using the ADU were calibrated. This was followed by the evaluation of any shear heating effects on the temperature measurements at thermocouple mesh junctions with reference to the techniques used by Collins *et al*. [9].

First and foremost, the machine was set to the desired temperature. Once the desired temperature had been achieved, the material was fed into the screw and the screw speed increased to the desired value. It is important to note that the extruder used was a single screw extruder and the material used was low-density polyethylene (LDPE- Exxon Chemical). A GWBasic program called "PROFILE" was used for data logging purposes. The parameters required in the experiment were entered.

The CST technique was used to measure temperature and velocity profiles in an injection moulding machine by Sombatsompop *et. al.* [10]. This technique was chosen for use due to its reliability and accuracy as well as the capability of measuring velocity profiles dynamically while the melt is flowing.

Before the measurements were taken, the extruder was left to warm up for at least an hour. When the desired temperature setting had been reached, the screw was started and left running for at least 10 minutes to allow the temperature to stabilize before any measurements were taken. The scanning time used in all experiments was 1 minute, with reading being taken at 60 millisecond intervals. For the purpose of velocity measurements, the water pulse used was 1 second in duration.

The temperature fluctuation reported was based on the average fluctuation over a time period of 5 seconds. It was noted that in all experiments, the temperature fluctuations did not exceed 1℃. Due to the small sample size, the temperature fluctuations were taken considering the temperature difference between the minimum and maximum values [11,12]. The standard arrangement as shown in Figure 2 was used in most of the measurements carried out. Standard settings refer to the standard parameters as listed in Table 1 below. The temperature and velocity profile measurements were studied by varying the screw speed.

Table 1 Setting parameters for standard conditions

Descriptions	Standard setting
Polymer	LDPE
Temperature setting	180℃ along the equipment
Location of thermocouple mesh	103 mm away from the screw tip and 35 mm away from the die
Distance between the cooling tube and thermocouple mesh	16 mm

3.0 RESULTS AND DISCUSSION

The measurements were carried out with a constant temperature along the extruder barrel and the adapter of 180 °C, with the absence of a die. The screw speed was varied in the range of 10-50 rpm. The measurements were carried out using the standard experimental arrangement as shown in Figure 2 with various screw speeds. The stability of temperature with regards rpm/screw speed can be seen in temperature profile. The temperature and velocity profiles were measured in an open channel adapter at three screw speeds, namely, 10 rpm, 30 rpm and 50 rpm. The temperatures were set at 180 ℃ along the barrel and apparatus. The channel diameter was 35 mm and the distance of the thermocouple mesh from the screw tip was 103 mm. The experiment was carried out using an open channel adapter in the absence of a die to ensure no measurement distortions occurred due to the die. The experimental results are listed as in Table 2 below.

Table 2 Experimental results using an open channel adapter

RPM	10 rpm	30 rpm	50 rpm
Average experimental (radial) temperature profile (°C)	174.2 ± 2.2	179.1 ± 0.8	182.6 ± 1.3
Average temperature fluctuation (°C)	0.37 ± 0.11	0.38 ± 0.13	0.49 ± 0.13
Average experimental velocity profiles (mm/s)	1.6 ± 0.9	5.9 ± 3.7	9.5 ± 5.5
Average pressure (MPa)	0.11 ± 0.09	0.21 ± 0.06	0.31 ± 0.06
Average volumetric output rate, Qact (mm³/s)	1400 ± 0.21	4760 ± 0.25	8040 ± 0.32
Average volumetric output rate, Qexp (mm³/s)	1380	4640	7820
Power consumption (kJ/s)	0.35	1.55	3.28

Figure 3 shows the radial temperature profiles in the adapter at the screw speed of 30 rpm. The data shows small fluctuations of temperature and pressure with time. The fluctuations encountered are in the order 0.4 °C and ± 0.01 MPa for temperature and pressure respectively. Thermocouple measure different zone in extruder machine provides inconsistency of temperature profile. The low and constant fluctuations indicate good mixing conversely, random and large fluctuations are caused by poor mixing [13, 14, 15]. The radial temperature fluctuations at various screw speeds are as shown in Figure 4. These fluctuations are relatively small but still within the measuring range of the apparatus although when discussing them, utmost care must be taken before drawing conclusions. The results indicate that the screw speed and temperature fluctuations are directly proportional [16, 17, 18]. Whereby, as the screw speed increases, so does the fluctuation. This phenomenon could be related to the occurrence of the melting zone. The fluctuation approximately increases by 0.1 °C every 40 rpm. Hence, the results show good mixing.

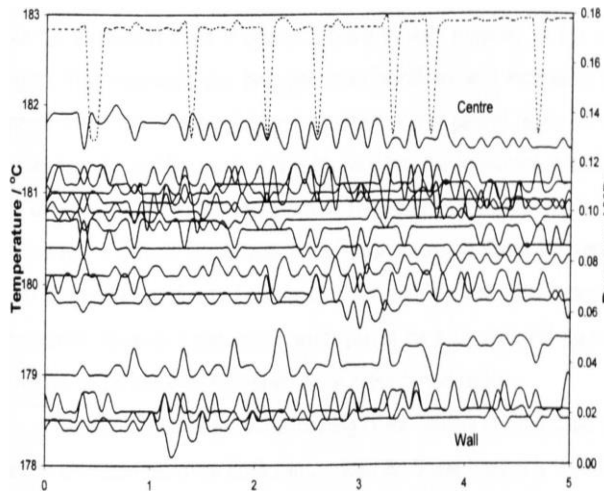


Figure 3 The temperature profiles (solid) and pressure (dashed) across the output end of the extruder at a screw speed of 30 rpm

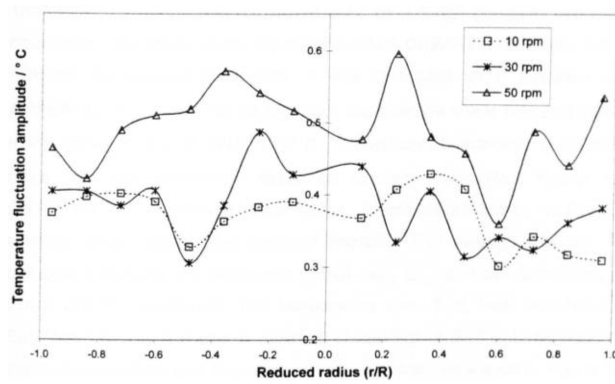


Figure 4 Temperature fluctuations at various screw speeds.

The thermocouple inhouse were created little disturbance to the flow due to the small diameter wire used and was able to provide effectively accurate temperature measurements. The results indicated that the screw speed and temperature fluctuations are directly proportional. Whereby, as the screw speed increases, so does the fluctuation. This is because as the screw speed increases, the temperature across the flow increases' as well due to the increased shear rate. The use of CST is working well in this investigation. The effect of heat treatment due to CST is not give any significant effect where slightly disturbance along the channel in the extruder machine

4.0 CONCLUSION

The thermocouple inhouse were created little disturbance to the flow due to the small diameter wire used and was able to provide effectively accurate temperature measurements. The results indicated that the screw speed and temperature fluctuations are directly proportional. Whereby, as the screw speed increases, so does the fluctuation. This is because as the screw speed increases, the temperature across the flow increases as well due to the increased shear rate. The use of CST is working well in this investigation. The effect of heat treatment due to CST is not give any significant effect where slightly disturbance along the channel in the extruder machine. Future researcher may use this thermocouple mesh in any other plastic machine 3D printing, injection molding to monitor the temperature profile.

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