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A New Approach for Modelling Residence Time Distribution in a Co-rotating Twin Screw Extruder

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Abstract: A model to determine the residence time distribution (RTD) in a co-rotating twin screw extruder is proposed. The method couples a thermomechanical approach with a chemical engineering approach and allows us to obtain the RTD without a fitting parameter. The global residence time is obtained using Ludovic© twin screw modelling software and simple chemical reactors are chosen to depict the screw profile. Experiments were carried out to validate the model. The effects of feed rate and screw speed on the residence time distribution were studied. Results are in good agreement with the predictions of the model.

Keywords: Extrusion · Modelling · Residence time distribution · Twin screw

1. Introduction

The determination of the residence time distribution (RTD) in a twin screw extruder is of interest for determining the mixing performance and controlling the quality of the product. Moreover, in reactive extrusion, the control of the residence time, as much as the control of the temperature, entails the control of the reaction along the screws.

Many authors have studied the residence time distribution either in counter-rotating [1–4] or in co-rotating twin screw extruders [5–8]. Concerning the modelling, different approaches may be considered. The most common is a chemical engineering approach, where the twin screw extruder is assimilated to a specific reactor, whose RTD can be defined using several fitting parameters. For example, Thompson *et al.* [3] used an axial dispersion model or a tank-in-series model, which requires respectively one and two fitting parameters. Another method to obtain the local residence time consists to start the calculation from the final RTD and to use a deconvolution technique in order to find the local RTD in each section of the extruder [6][10].

The aim of the present work is to model the global residence time distribution in a co-rotating twin screw extruder using an original method, without a fitting parameter. The method consists in coupling a thermomechanical approach to define the fully or partially filled areas along the extruder, and the utilisation of ideal reactors for modelling the residence time in these different sections. Experimental studies were achieved in order to compare with the simulation.

2. Theoretical Model

2.1. *Ludovic© Software*

The flow field along the extruder is obtained using Ludovic© software. This software was developed a few years ago and allows local mean residence time, pressure, temperature, filling ratio to be computed along the screw axis [11][12]. Knowing the local filling ratio inside the extruder and the local mean residence time provided by the thermomecanical approach, each filled section of the extruder is considered as a chemical reactor whose the residence time distribution is known. According to the type of elements constituting the screw profile (left- and right-handed screw elements, kneading discs), different reactors can be chosen. For example, a plate reactor is associated to a left-handed screw element and a continuously stirred tank reactor (CSTR) is associated to a block of kneading discs. The partially filled regions are modelled by a plug flow reactor.

2.2. *Procedure*

As stated before, in a first step, Ludovic© software realises a first calculation in order to obtain the filling ratio and the local residence time in each part of the extruder. In Fig. 1, a schematic description of the procedure is given. The program considers the filled and unfilled sections of the extruder, with the corresponding local residence times. τ_i and τ_j correspond to the mean residence time in the filled and unfilled section, respectively. In a second step, the different elements constituting the screw profile are assimilated to ideal chemical reactors. The calculation of the global residence time distribution is then done as follows:

- Convolution of RTD of each filled section (fs) modelled by an ideal reactor

$$E_{fs} = E_i(t) * E_{i-1}(t) * \dots * E_1(t) \quad (1)$$

- Convolution of RTD of each unfilled section (us) modelled by a plug flow reactor

$$E_{us} = E_j(t) * E_{j-1}(t) * \dots * E_1(t) \quad (2)$$

- Computation of the global residence time distribution by convolution product

$$E(t) = E_{us}(t) * E_{fs}(t) \quad (3)$$

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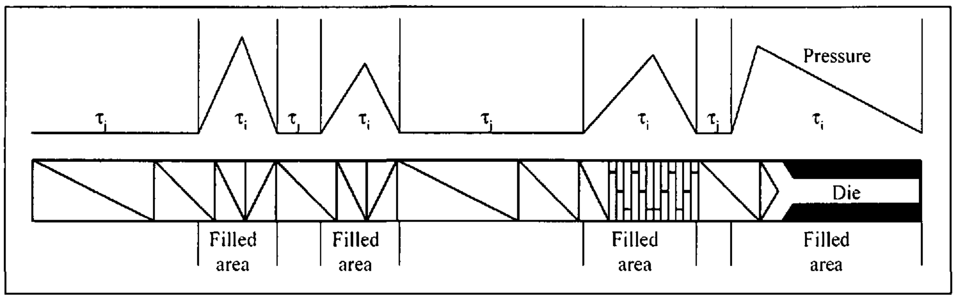

Fig. 1. Calculation procedure

3. Results and Discussion

3.1. *Experimental*

Residence time measurements are carried out in an intermeshing self-wiping co-rotating twin screw extruder (Leistritz LSM 30–34, centreline distance: C_l = 30 mm, screw diameter: D = 34 mm, barrel length: L = 1.2 m, L/D = 35). A tubular die is fixed at the end of the extruder (length L = 10 mm, diameter D = 2 mm). The screw profile is composed of right-handed screw elements, two left-handed screw elements and three blocks of kneading discs. The residence time distribution at the die exit is determined with an in-line ultra-violet fluorescence method, using anthracene methanol as tracer [13]. In this work, we use a polypropylene with a melt density of 0.75 g/cm^3. The tracer is a masterbatch of polypropylene and anthracene methanol. The tracer is introduced in the hopper and the raw residence time distribution is directly obtained on a computer at the die exit. The influence of operating conditions is studied by varying feed rate at constant screw speed and screw speed at constant feed rate.

We observe that the residence time distribution is shifted towards lower times when the feed rate increases (Fig. 2). In fact, the increase of the throughput entails a diminution of delay time, mean residence time and variance. This is a classical result largely reported in the literature [9][14][15]. The decrease of these three parameters (delay time, mean residence time and variance) is also observed when the screw speed increases. But the influence of screw speed on the shape of the residence time distribution is less pronounced than the one of the feed rate. It is also a classical result [5][7–9][15].

3.2. *Validation of the Theoretical Model*

As explained previously, to model the residence time distribution by a convolution product, a combination of reactors is necessary. Thus, we need to choose an appropriate chemical reactor to describe each type of element constituting the screw profile. For the experimental screw profile, we chose a reactor model based on the following associations: unfilled right-handed element ⇔ plug flow, left-handed element ⇔ plate reactor, blocks of kneading discs ⇔ CSTR, die ⇔ tubular reactor. In Fig. 2, a comparison between calculated and experimental residence time distributions is shown. The model gives a good description of the experimental RTD both for the influence of feed rate and the influence of screw speed. However, we can notice that for a very low throughput, the calculated RTD is less accurate. A good correlation is also observed for delay time, mean residence time and variance, whatever the operating conditions.

4. Conclusions

In the present work, a new method for determining the residence time distribution in a co-rotating twin screw extruder is presented. The method for modelling the global residence time distribution is based on the description of screw elements by means of chemical reactors, whose RTD is known. The model provides a good correlation with experimental observations, made on a type of extruder and a screw profile. The validation will obviously be made in the next future on other sizes of extruder and other screw profiles.

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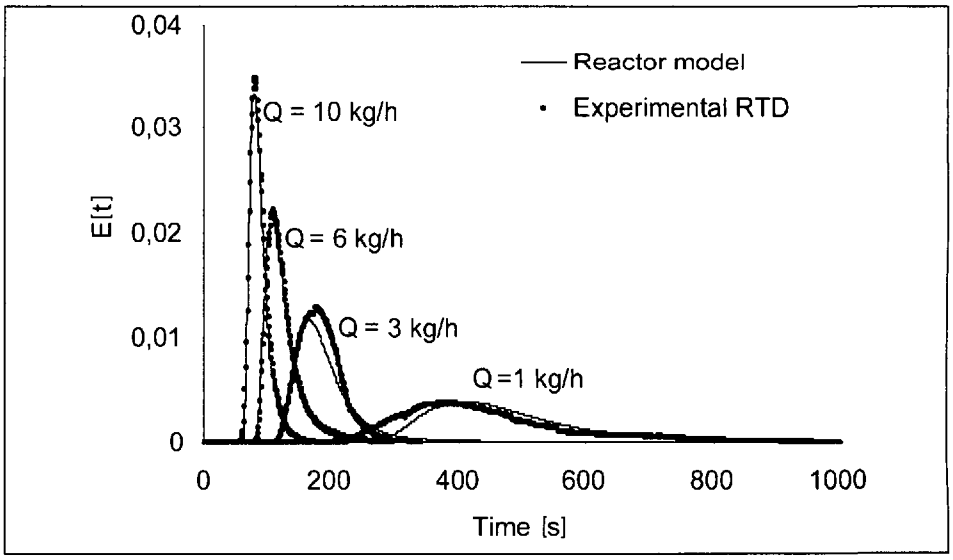

Fig. 2. Comparison between measured and calculated residence time distributions (N = 100 rpm)