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Design Methods that Work

PROBLEMS OF ENGINEERING DESIGN OF THE MODULAR PLASTICIZING SYSTEM OF CO-ROTATING TWIN-SCREW EXTRUDERS

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Abstract: *The contemporary twin-screw extruders are highly modular. The basic component of the extruder is the plasticizing system consisting of screws and barrel with the heating-cooling elements located in them. This paper reviews current practice in the application of selected elements of conceptual design when designing modular segment configurations of plasticizing systems of co-rotating twin-screw extruders. The designing process is of dynamic character regarding the subsequent working steps like determination of conditions of configuration of plasticizing system, identification of significant problems, preliminary determination of functions combining the relationships between the input and output parameters, analysis of known configurations of plasticizing systems, model research, combining several configurations of plasticizing systems. In the paper an example of plasticizing system modification of twin-screw extruder for PP powder pelletizing of high output capacity ca. 3200 kg/h has been presented.*

1. INTRODUCTION

The life cycle of a product begins with identification of a need, and extends through conceptual and preliminary design, detail design and development, production and/or construction, distribution and utilization, support, and then phase-out and disposal, [1]. The need for a new extruder comes into focus first, initiating the extruder life cycle. Conceptual and preliminary extruder design follows the need determination, with concurrent consideration for manufacturing system design (second life cycle). Product support system design, also often omitted as a design imperative, is the third life cycle.

Investigation of design processes in various disciplines shows that there is no single ideal method of design. In general, the design process is divided into the following essential stages: identification of a need and planning, conceptual design, embodiment design, detail design and verification.

The effectiveness of a plasticizing system means the ability of this system to extrude products of good quality with as high a throughput as possible, combined with a high energy efficiency [1,2,3]. Evaluation of the effectiveness of the extrusion process can be carried out according to three groups of criteria: quantitative (cover the physical magnitudes), qualitative (include the physical values, with regard to instability) and exploitational (values characterizing cost).

Conceptual design is the stage where possible ideas to fulfil the functional requirements are sought. This, being an early stage of design, requires little investment for its execution, but is crucial in its importance, as a high percentage of extruder cost is commitment at this stage. In conceptual design stage, the main functions of an extruder screw should be analysed.

The complexity of the process of extrusion, the lack of theories relating to the design of plasticizing systems, and the lack of satisfactory data concerning the properties of the material and resulting imperfections of simulation studies are the basic reasons for the development of experimental studies in this area. In practice, empirical methods predominate, supported by selected theoretical calculations both in selection of the method of carrying out the extrusion process, and during design of the geometry of the screws [4].

Model theory for twin-screw plasticizing systems establishes the geometry and operating points for extruder on the basis of an optimized model, so-called scale-up. Using model theory, it is then possible to transpose the operating and geometry date to the machine that is being designed.

2. TWIN-SCREW EXTRUDER DESIGN PROCESS

Extruder plasticizing system design

The design of the plasticizing system for the co-rotating twin-screw extruder is still considered to be more of an art than a science [4]. For the design of a twin-screw plasticizing system, one can use a combination of physical-mathematical analysis and models developed according to scale-up methods (this technique requires experimental data) and, equally important, an extensive data base of examples of successful practical experience.
As can be seen from figure 1, the type and sequence of steps that should be taken up in the concurrent plasticizing system development process, has been presented in the box scheme.

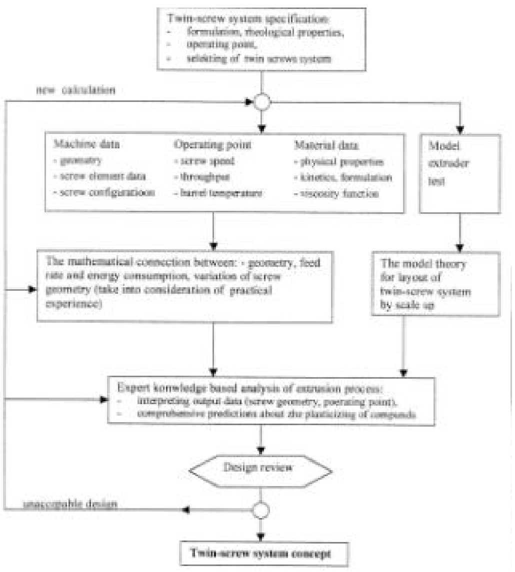

Figure 1. *Layout of the co-rotating plasticizing system.*

When working out the conception of a plasticizing system, some other tasks should be realized in parallel; namely, preliminary calculations of screw geometry (take into consideration, for example, blend conveying, pressure development) and calculations on the basis of the model theory. The results of these calculations are evaluated with the help of expert knowledge [5].

Figure 2. *Structural scheme of the expert system.*

Expert knowledge based analysis of extrusion processes should be available to make it possible for more comprehensive predictions to be made about a process.

An expert system for extrusion processing, consisting of process data collection and evaluation of effect of screw geometry and conditions of extrusion on the course of plasticization and homogenize without exceeding degradation temperatures in a twin-screw extruder, provides the designer with active assistance in design. It is based on laboratory, pilot-scale and production experience, and optimizes all production parameters. Parameters are recorded in the data bank (figure 2), evaluated and analysed regarding their influence on extrudate properties. Expert systems for a design problem to be solved use design refinement with plan selection and re-design. Expert knowledge in conjunction with calculations helps to solve extrusion problems, to support collaborative extruder development.

Depending on the analysis results, either the obtained layout of the plasticizing system may be accepted, or the decision may be taken to repeat the simplified calculations and/or the model extruder tests.

Concurrent engineering (CE) is based on parallel and collaborative actions between polymer scientists, process engineers, quality-control engineers, raw-materials suppliers, toolmakers, managers and engineering companies. The concept of CE assumes that groups of experts in different fields, covering the product life cycle, work simultaneously to meet customer needs and the market. CE has obvious shortcomings when applied to innovative product development and when existing computer-based data is not at hand. When the newer screw geometry is to be incorporated in production, then the more dynamic product and process development should be considered as an alternative to CE. The dynamic strategy begins with the development [6, 7] of a concept of plasticizing system that is then continually re-worked until the system is considered ready (figure 1).

In the layout of the plasticizing system, some requirements concerning basic components of the extruder should be determined, i.e. drive system, heating-cooling system of the barrel.

3. MODIFICATION OF THE PLASTICIZING SYSTEM FOR PELLETIZING PP POWDER

The target of above mentioned modification was decrease of the degradation of polymer when pelletizing after polimerization process.

Current designs of the first plasticizing section, often because of wrong screw configuration, may cause strong changes in the polymer structure [8, 9, 10]. It concerns PP resin of low MFR factor ($MFR_{(230;\ 2,16)}$ < 3g/10 min). It must be pointed out that PP resin because of its ease in processing becomes one of the most important thermoplastics in European market. The low thermal conductivity of PP precludes the high increase of its temperature, so the longer time of heating up the polymer in the plasticizing zone is needed.

A thorough understanding of plasticizing phenomena in screw extruders requires a description of the plasticizing geometry. Plasticizing experimental studies that highlight the design features of intermeshing, co-rotating twin screws are presented here.

Experimental

The experiments for checking influence of screw configuration degree of degradation were carried out on Leistritz extruder type Micro 27/GL36D. Ten experimental configurations were used in this study. These contained different quantities of right-handed screw elements and right- and left-handed and neutral kneading elements. For the experiments also following screws with degassing provided with two blocks of kneading elements were used for this purpose.

In the designing process of co-rotating twin-screw plasticizing systems following requirements must be taken into consideration:

a) the following division of plasticizing zone into three sub-zones is purpose full: preliminary compressing and heating up zone, preliminary plasticizing zone and intensive plasticizing zone.
b) reaching the required polymer temperature transported to the intensive plasticizing zone by the appropriate elongation of the preliminary compressing and heating up zone. Excessive temperature gradients generated in the preliminary plasticizing zone can be avoided by separating the shearing elements with forward-conveying screw elements. The total shear input is then distributed in a sequence of the shear zones.

The Industrial experiments were carried out on the pelletizing lines for PP powder (PKN ORLEN S.A. Poland). The conveying system of powder is done in a closed nitrogen atmosphere loop. The lines are based on:

a) non-intermeshing, counter-rotating twin-screw system in a two-stage design with a down-stream single screw melt (Japan Steel Works LTD Mixer type CIM-320 and extruder P305-18 SW)
b) an intermeshing, co-rotating, twin-screw extruder with degassing (extruder Berstorff, type ZE130Ax28D) as a single stage.

In the modification of screw configuration of co-rotating twin-screw extruders the special attention should be paid for the conclusions drawn from lab and industrial experiments concerning the suitable mixing of the additives with PP powder before the intensive plasticizing zone.

The range of standard screw modification concerned:

a) decrease of the energy dissipation in the intensive plasticizing zone before degassing through zone elongation,
b) achieving higher PP mixture temperature by the elongation of the preliminary heating up zone,
c) simultaneous enhancing the mixing effectiveness of the additives with PP powder in the preliminary compressing and heating up zone.

In fig. 3 the modifications of screw configuration have been presented.

4. SUMMARY

Twin-screw extruder development is a complex process that entails both the mechanistic (the actual engineering of hardware and software) and the humanistic views (interaction between people, and interaction between extruder and users).

In this paper, a concept for the design of plasticizing systems of intermeshing co-rotating twin-screw extruders have been presented. The main features of adopting concurrent engineering design have been described. When a dynamic strategy is employed, design operations should not be done sequentially, but should be paralleled whenever it is possible. This type of strategy begins with the development of a concept that is then continually re-worked until the plasticizing system is considered ready.

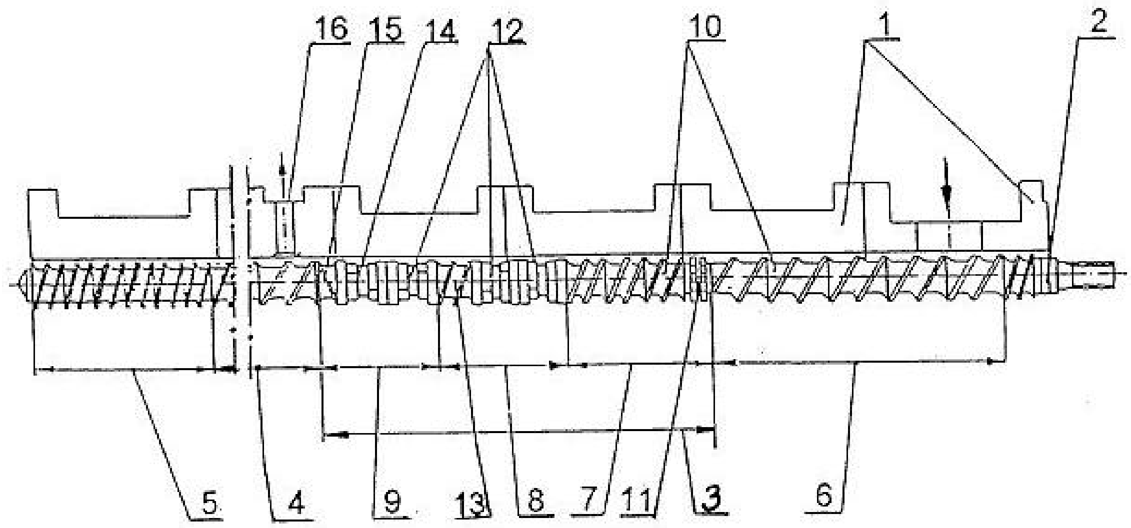

Figure 3. *The outline of plasticizing system of the co-rotating twin-screw system: 1-cylinder, 2 – screw, 3 – plasticizing zone, 4 – degassing zone, 5 – metering zone, 6 – feeding zone, 7 – preliminary compressing and heating up zone, 8 – preliminary plasticizing zone, 9 – intensive plasticizing zone, 10,13 – conveying screw elements, 11 – mixing elements, 12 – kneading elements, 14 – reverse conveying kneading elements, 15 – reverse conveying screw elements, 16 – degassing hole.*

In the designing process of co-rotating twin-screw plasticizing systems for processing PP, following requirements must be taken into consideration:

a) reaching the required temperature of polymer transported to the intensive plasticizing zone by the appropriate elongation of the preliminary heating up zone,
b) intensification of mixing efficiency of PP resin with additives at the beginning of the preliminary compressing and heating up zone,
c) decreasing the energy dissipation in the preliminary plasticizing zone,
d) minimization of the energy dissipation of the mechanical drive in the pumping zone by using the suitable screw geometric profile or gear pump.

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