AIP Conference Proceedings

RESEARCH ARTICLE | FEBRUARY 05 2019

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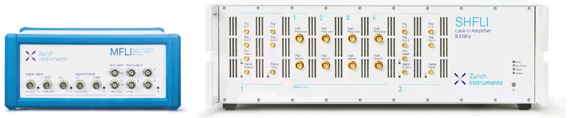
AIP Conf. Proc. 2065, 030010 (2019)
https://doi.org/10.1063/1.5088268



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Self-Optimizing Barrel Temperature Setting Control of Single Screw Extruders for Improving the Melt Quality

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Abstract. Since extrusion is one of the most important manufacturing processes due to the increasing demand of polymer products, the melt quality of the polymer plays a crucial role. Indeed, the melt quality depends on the condition of preparing and processing the polymer. In fact, the resulting melt quality is highly reliant on the parameter settings of the extruder. A thermal homogeneous polymer melt as well as an increase of the throughput is conceivable. Moreover, an improper barrel temperature setting can lead to a deterioration of the material. Nowadays, the temperature of the barrel is either set with the help of an experienced process engineer or by seeking for advice from the resin manufacturer. If neither option is possible the barrel temperature can be set by applying trial and error experiments. Rather than assuming the "correct" barrel temperature setting, it is more efficient to identify the correct barrel temperature setting by means of measured quality criterions. In the 21st century, digitization permeates all areas of our lives and presents the industry with new challenges. The affected industry operators have to react promptly to the changes in the process of digitalization supposing to ensure long-term competitiveness. However, extrusion is one of the most important production processes in the polymer industry and is also facing new challenges. One of these challenges is the regulation of the barrel temperature control which influences the melt quality and thus the product quality. Certainly, the expert knowledge of the experienced machine operators represents a transitional solution which needs to be implemented by a digital and more intelligent solution. In this manner, an extruder that self-corrects the barrel temperature with the objective to meet an optimal barrel temperature setting regardless of the screw geometry and the resin is highly preferable. This is why the aim of this work concentrates on the development of a suitable control algorithm that independently detects the optimum process and controls the optimum barrel temperature setting. For this reason, rules of behavior are derived from the process behavior of the extruder in terms of its use as a basis for intelligent barrel temperature control.

Keywords: Single Screw Extrusion, Barrel Temperature Setting, Pressure Fluctuation, Fuzzy Logic, Control Algorithm
PACS: 83.80Sg, 66.70Hk

INTRODUCTION

The focal point of many researches is the optimization of extrusion processes regarding different parameter settings. Taking into account that suitable barrel temperature settings need to be found, in practice so-called "trial and error" tests are carried out, whereby the melting process is not always sufficiently favored. However, since polymers have a distinct temperature-time dependent behavior, specifically the barrel temperature setting exerts a great influence on the extruder performance. Thus, finding an optimal setting of the barrel heaters is beneficial for the resulting polymer melt quality. To be precise, the barrel temperature influences criteria such as the distribution of the melt temperature over the cross-section, material homogeneity, wear, melt temperature, etc. [1, 2].

In the 21st century, digitization permeates all areas of our lives and the polymer industry has to face new challenges. The affected industry operators have to react promptly to the changes in the process of digitalization with the purpose to ensure long-term competitiveness. Extrusion is one of the most important production processes in the polymer industry and already has to meet new challenges. In fact, one of these challenges is the regulation of the barrel temperature control which influences the melt quality and thus the product quality. Therefore, the aim of this project is to develop a suitable control algorithm that independently detects the optimum process and sets the optimum barrel temperature setting independently. The expert knowledge of the experienced machine operators represents a transitional solution which needs to be implemented by a digital and more intelligent solution. The challenge is to optimize the axial barrel temperature in the extrusion process and at the same time to maintain the optimum barrel temperature despite disturbances. Self-learning and self-regulating systems are promising for a successful response to this challenge.

Proceedings of PPS-34
AIP Conf. Proc. 2065, 030010-1–030010-5; https://doi.org/10.1063/1.5088268
Published by AIP Publishing. 978-0-7354-1793-9/$30.00

EXPERIMENTAL SETUP AND IMPLEMENTATION OF A KNOWLEDGE BASE

The demands on products in the polymer processing industry are constantly increasing. On the one hand, the products must be able to operate efficiently in terms of resources and costs. On the other hand, the products have to be user-friendly and reliable. This incident requires a robust and predictive approach. Unexpected operating situations need to be managed without problems and future effects of influences need to be anticipated on the basis of experience. The solution for such the requirements can be accomplished using self-optimizing systems. Self-optimization offers the decisive advantage over simple optimization strategies in ensuring that capable systems with inherent partial intelligence can react autonomously and with a degree of flexibility to changing operating conditions [3]. Intelligence in this context means that the system possesses knowledge of correlations between the target value and the control parameters, independently determines the optimum and performs the necessary behavioral adjustments.

With the intention to develop a self-optimizing system, target values were defined in advance [4] which provide information about the melt quality. The target variables are (up to now) the melt temperature and melt pressure fluctuation, both measured at the screw tip. The pressure fluctuation represents the material homogeneity, whereas the temperature fluctuation indicates the thermal melt homogeneity.

The main components of an expert system consist of the control system (knowledge processing) and the expert database (knowledge base). Both are functionally separated from one another and can be developed with one another. The expert knowledge can be provided to the machine operator in the form of a database without a control-based problem strategy. To obtain expert knowledge about the correlation between barrel temperature setting of the individual barrel temperature zones and the resulting target variables, extensive experimental investigations were carried out. The aim of these experimental studies was to extract behavior rules for the development of a knowledge database. Therefore, the data of the experimental investigations serve as raw data for the compilation of the knowledge database and respectively rules of behavior which can be conducted onto the barrel temperature setting.

In [4] the barrel temperature was examined with the aim of determining correlations between the set barrel temperature and the extruder performance. The experimental examinations were carried out on a 45 mm diameter single screw extruder with a length of 32 L/D. A three sectional and a barrier screw with no mixing or shearing elements were used. The extruder had a smooth bushing and was equipped with six separate temperature zones and the set temperature can be set individually. In zone 6 (throttle die), a strain gauge pressure transducer (Gneuß, DA-250, type J) as well as a bridge with multiple probes (customized, type J) were mounted to measure the radial temperature across the channel. The installed measurement techniques, the power of the barrel heater bands and the throttle die are depicted in FIGURE 1. A data acquisition program (testCommander; Gantner Instruments and LabView; National Instruments) was used to communicate between the experimental instruments and the computer device.

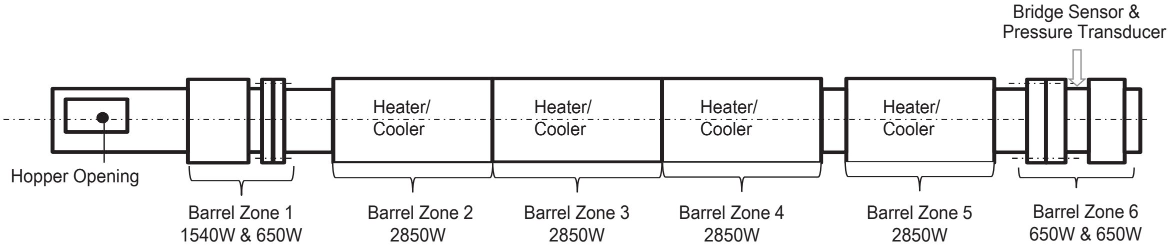

FIGURE 1. Overview of the Extruder with Information on Performance and Location of Equipment

The results of the experiments [4] clearly showed effects of the barrel temperature control on the extruder performance. However, the examination of the material behavior demonstrated that materials like PP and PS can be generalized referring to the barrel temperature setting. This means that for those materials it is possible to develop recommended actions regarding the barrel temperature. Consequently, the virtual signs of the extruder like the pressure and temperature fluctuations over time to derive basic rules for the barrel temperature setting control. FIGURE 2 demonstrates exemplarily the results of PP with a three-zone screw and an rpm of 100 for the barrel temperature in the feed and transit zone. As shown in FIGURE 2, the pressure (blue) and the temporal temperature (red) fluctuations increase with an increasing barrel temperature. Hence, for the development of the basic rule, it was stated that a cooler temperature in the feed zone (A) was favored since the experimental results showed that it leads to a higher friction coefficient and thus stabilizes the conveying process which can be observed by the decreasing fluctuations. Therefore as a rule of behavior (for PP, three-zone screw) a barrel temperature of about 160 °C is recommended. Regarding the barrel temperature in the transit area (B) it can be observed that a higher temperature leads to increasing pressure fluctuations whereas a lower temperature leads to a decrease in the temporal temperature fluctuations. In this manner a temperature in between is desirable. This location will be near the point of intersection of the curves. In this case, the barrel temperature should be set to approximately about 240 °C. Additionally, throughput measurements proved that the melting process will be improved when applying higher temperatures in the transition area [4].

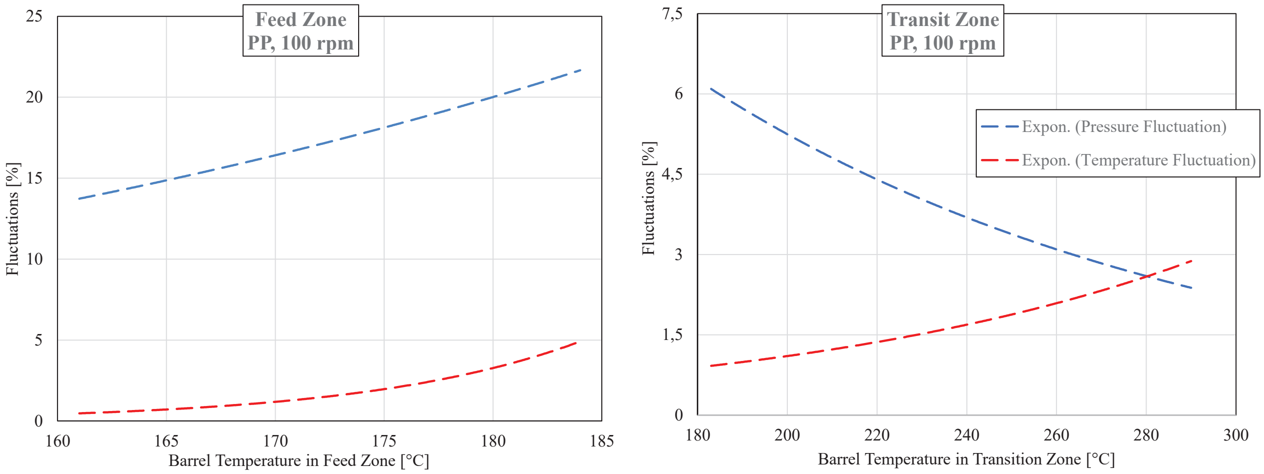

FIGURE 2. Correlations between the Barrel Temperature in the Feed and Transit Zone and the Target Fluctuations

FUZZY CONTROL

The fact that mathematics is seen as synonymous with precision has inspired many scientists to express considerable concern about its lack of application to real problems. This concern increases in the field of natural science since there is always a gap between theory and the interpretation of the results in comparison to the inaccurate real world. Many important theorists have contributed to the discussion about indeterminacy, occasionally citing human subjectivity as the perpetrator [6]. In the real world, a great deal of information is provided by experts who usually do not think in precise terms, but describe complicated systems through a series of vague terms. In this case an experienced process engineer might propose to set the extruder ends "cold" and the middle "hot". Fuzzy logic, in this event, is very beneficial because it allows to express vague statements ("hot" and "cold") by using an expert system. Fuzzy systems refer to special graphical methods with fuzzy linguistic terms of human thinking in connection with simple logical equations (If-Then rule basis) to form one or more control variables from several fuzzy variables. Signal flow diagrams in block diagrams (see FIGURE 3) are required to understand the mode of operation. A fuzzy system can be understood as a static non-linear transmission system.

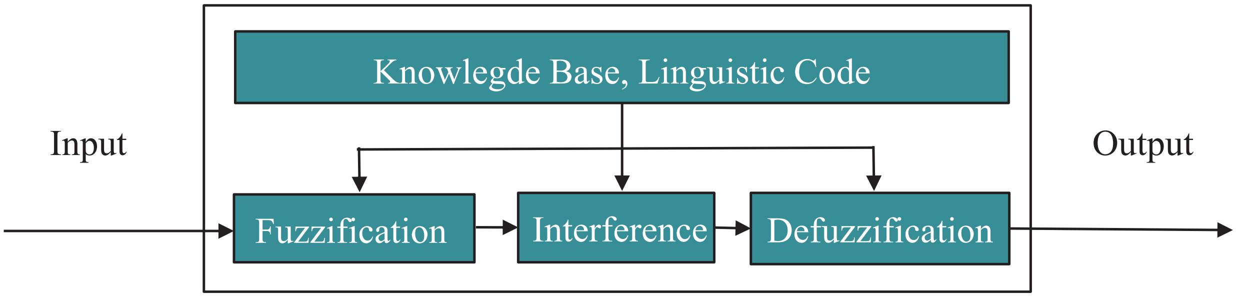

FIGURE 3. Structure of a Fuzzy Controller

A control circuit is required to influence the physical target variables in the technical process. The fuzzy controller, presented in FIGURE 3, essentially consists of three function blocks: fuzzification, interference and defuzzification. Whereas the basic structure of a fuzzy controller is presented in FIGURE 3, FIGURE 4 represents the transmission to a barrel temperature fuzzy controller. During fuzzification, the precise input values are matched to fuzzy linguistic terms. In this case, the precise temperature and pressure fluctuation values are concatenated to fuzzy domains, as in this example to "regular" and "high" fluctuations by using trapezium shapes. In the next function block (the interference) the actual states are linked to the knowledge base by defining rules by applying If-Then rules. I.e. regarding the crisp pressure and temperature fluctuations, for the feed zone it was concluded that both target criterions increase the higher the barrel temperature gets. Therefore, the If-Then rule is: “IF the temperature and the pressure fluctuation is recorded as “high” THEN increase the barrel temperature in zone 1”. When creating the interference, it is particularly important to ensure that no undefined states are created.

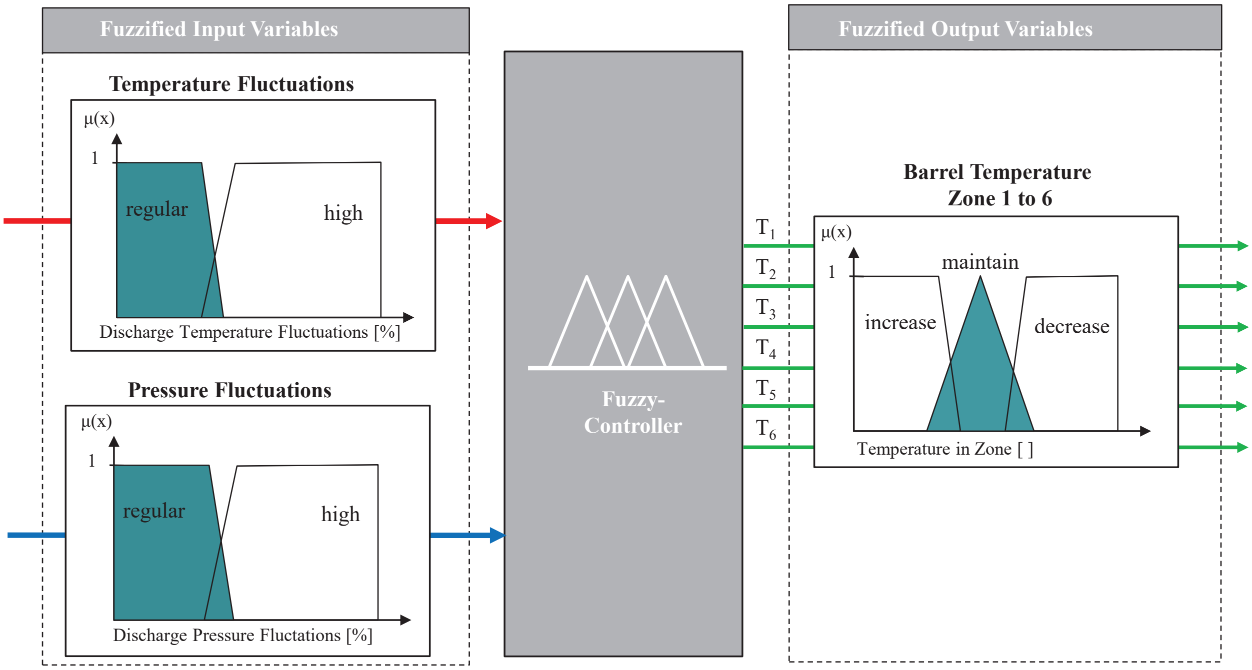

FIGURE 4. Overview of Input and Output Values for the Extruder

The basic idea of the data base is divided into two aspects. On the one side, the fuzzy controller needs information to accomplish the fuzzification step. On the other side, it is possible to set a basic temperature recommendation before the actual optimization process starts. In this manner less optimization loops need to be performed.

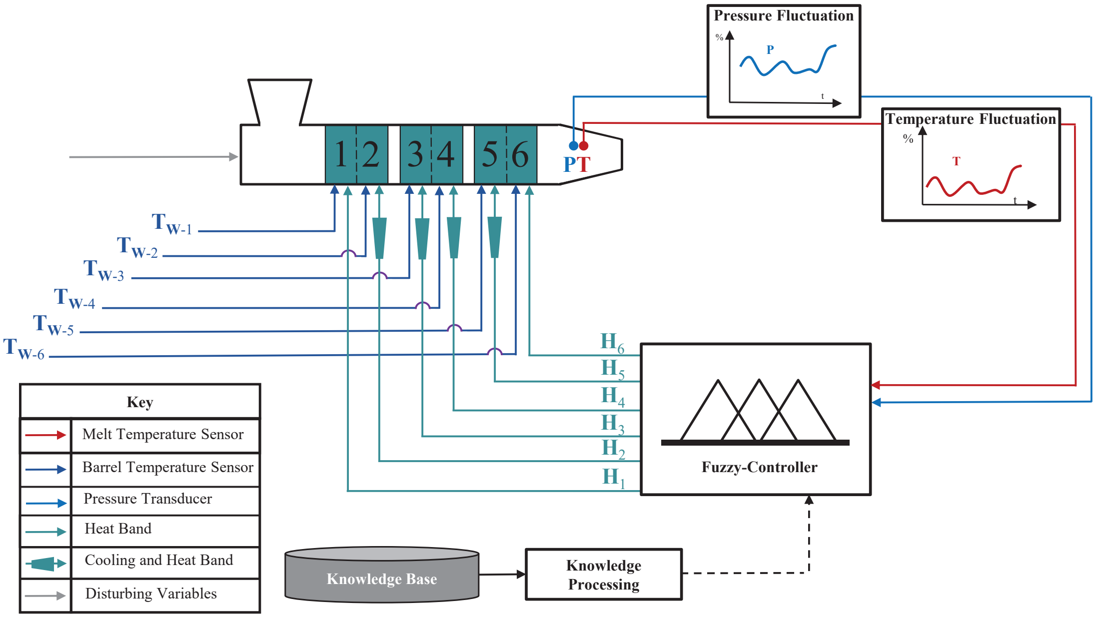

FIGURE 5. Structure of the Circuit Diagram with Depiction of the Interfaces and Processing of the Measurement Signals

In general, the fuzzy controller works chronologically. First of all, a basic barrel temperature profile is set. After a defined period of time, the pressure and temperature fluctuations are determined. The crisp values are forwarded to the fuzzy controller. The controller is responsible for adjusting the barrel temperature. Here, the fluctuation values are processed further. For example, the request for zone one could be “decrease the barrel temperature by 10 °C”. This signal is transmitted to the heating control system that adjusts the barrel temperature in zone one accordingly. Furthermore, after a defined period of time, the fluctuations are determined once again to evaluate the optimization step. If the barrel temperature adjustment in zone one leads to a decrease of the fluctuation and the fluctuation are now in an area of “regular”, the next barrel zone will be optimized. Otherwise, if a deterioration has occurred, the barrel temperature change will be canceled and a different barrel temperature will be checked out until the fluctuations are regular. The same procedure is applied for the remaining barrel zones. The optimization is finished when the last zone is reached and the fluctuations are classified “regular”. Figure 5 demonstrates a synopsis of the fuzzy system and the described operational sequence.

CONCLUSIONS & FUTURE WORK

The extruder barrel temperature was examined in order to find correlations between the set barrel temperature and the extruder performance. The carried out experiments clearly showed effects of the barrel temperature control on the extrusion performance. As shown from the experimental results, the effects on the discharge pressure variation, temporal temperature variation and throughput behavior are highly significant. For the purpose of producing a good melt quality, the barrel temperature setting needs to be set correctly.

In this paper, a self-optimizing approach for adjusting the axial barrel temperature for a single-screw extruder with six barrel zones is outlined and presented. For this purpose, a fuzzy system was chosen. The examination of the material behavior of the PP and the PS resin in combination with a three-zone scree and a barrier screw demonstrated a similar barrel temperature setting. If-Then rules were applied in order to improve the barrel temperature for each barrel zone. The rules were realized by using the virtual signs of the extruder like the pressure and temperature fluctuations over time. Although this method has been proposed and performed already [5], there is no opportunity yet to set the barrel temperature control on the foundation of basic settings in conjunction with a regulation algorithm that ensures a focused process control.

Future work will concentrate on more target values e.g. the discharge temperature, distribution temperature over the cross-section and the power consumption taking account more materials and a different screw size.

ACKNOWLEDGMENTS

We are grateful for the support of the project by the Deutsche Forschungsgemeinschaft under grant number DFG-Project SCHO 551/29-1.

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