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Application of fuzzy inference system to polypropylene business policy in a petrochemical plant in India

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ABSTRACT

Polypropylene is a versatile thermoplastic resin available in a wide range of formulations for engineering applications. This paper presents a new approach to predict the quality of polypropylene in petrochemical plants. A model is constructed based on a large number of data collected from a renowned petrochemical plant in India and used to predict the polypropylene quality through the proposed approach. The quality of polypropylene depends on the indices like melt flow index and the xylene solubility of the product. The parameters controlling these two indices are hydrogen flow, donor flow, pressure and temperature of polymerization reactors. Using these four input and two output parameters, four Mamdani fuzzy inference systems are formed depending on the different membership functions of the variables. The model outcomes are then compared with the collected plant data and a sequence of statistical data analyses selects the most suitable model among them. Some sensitivity analyses with respect to some parameters are also performed to validate the proposed models. The raw materials for producing polypropylene are very much costly specially the catalyst teal. So if the desired grade of PP is not achieved by the trial and error run then the production cost becomes uncontrollable. With the help of our proposed approach by controlling some parameters during the production phase, the quality of polypropylene can be improved. Thus it will save both time and cost by reducing the yield of non-prime, off-grade products obtained by the conventional procedure.

1. Introduction

Polypropylene (commonly called just PP) is a type of thermoplastic polymer resin. The chemical designation is $(-C_3H_6-)_n$. It is used both in industry and in consumer goods; it can be used both as a structural plastic and as a fiber as well. The structural plastic is often used for food containers, particularly those that need to be microwave safe and dishwasher safe. The melting point of polypropylene is very high compared to many other plastics, at 320 °F (160 °C). Polypropylene is also very easy to add dyes to and it is often used as a fiber in carpet manufacturing that needs to be rugged and durable. Other benefits of polypropylene are that it does not absorb water like other plastics, it does not deteriorate in the presence of bacteria, mold or other elements, it is lightweight and very flexible. Rapid growth of polypropylene as a novel material, touching all conceivable application areas and excelling in most of them, has helped industries in most sectors (including petrochemicals, electrical and electronics, consumer durables, packaging, storage, gasket and sealants, material handling and conveying, transportation and communication, furniture, footwear, personal care and health care, sports and entertainment etc.) grow at a rapid pace. The global demand for polypropylene jumped from 6.4 million metric tons in 1983 to 38.6 million metric tons in 2004, with a growing rate as high as 5.8% from 2004 to 2009 (Alberta, 2004). Recently the world annual polypropylene production has increased from 52 million metric tons in 2008 to 69.1 million metric tons in 2013 and forecast an annual increase on polypropylene global demand by 3.7% in the 2010–2014 time frame (Alshaiban, 2011). One can therefore expect a very booming market and bright future market for polypropylene.

The history of polypropylene began in 1954 when a German chemist named Karl Rehn and an Italian chemist named Giulio Natta first polymerized it (Martin, 1954). This led to a large commercial production of the product that began just three years later (Sailors and Hogan, 1981). In last 60 years, the uses of polypropylene have expanded rapidly in every aspect of life because of its versatility and affordability. The mean consumption rate of

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polypropylene was about 10% per year in the recent past, in application field this value is however way higher (Karger and Kocsis, 1995). Depending on the end-users demand 3 types of polypropylene are produced (*i*) homopolymer (*ii*) impact copolymer and (*iii*) random copolymer. Each type of polymer are produced in 4 different grades of Melt flow index (MFI) such as 3.5, 7, 10 and 36 and these grades determine the quality of a polymer.

Application of polypropylene is based on its quality, which is controlled by its properties, like melt flow index (MFI) and xylene solubility. To determine the quality of polypropylene we, in this paper, have tried to form a mathematical model. The quality of the polymer depends on the products that is used to synthesize it (considered to be the input variables) and the characteristics of the final polymer (considered as the output variables). In classical logic approach an exact definition of mathematical model equations are needed to formulate a physical model and this approach requires an exact definition of the mathematical model equations to describe the phenomenon (Naderloo et al., 2012). But in practical field where the polymer is produced no such exact definitions have been followed and the variables take only linguistic values rather than some crisp values. One of the best method to make a mathematical model from it, is to apply fuzzy logic approach just like how Zhou et al., 2014 applied fuzzy programming to create an integrated model for sustainable municipal energy system planning and management in Shenzhen, China. The fuzzy logic generally allows a simple knowledge representation of the production process in terms of if-then rules (Naderloo et al., 2012). Fuzzy inference systems (FIS) can properly describe the complex and non-linear phenomena with the precise rules. The rules are typically in if-then format with different matching degrees for a given operational situation (Amiryousefi et al., 2011). Fuzzy inference is able to handle vague situations and build model with words in the term of linguistic variables. This is especially valuable where models are developed based on experts knowledge and individuals without a mathematical background are involved (Cornelissen et al., 2003).

Fuzzy inference system is one of the most efficient computational method rather than other analytical and statistical techniques. Since polypropylene production system and technologies are quite intricate and uncertain, they can widely be applied for modeling of different components in this sector, because they can study new patterns which were not previously available in the trained data sets and they can also apprise knowledge over time as long as more training data sets are provided (Khoshnevisan et al., 2014b). In the context of environmental management, the use of the fuzzy logic method is strongly suggested. Khoshnevisan et al. (2014b) estimated the yield of greenhouse strawberry with the help of adaptive neuro-fuzzy inference system (ANFIS). Ana et al. (2014) suggested an integrated recycling approach for GFRP pultrusion wastes using fuzzy logic. Sami et al. (2014) had done a case study in cane farms in Iran using fuzzy logic. Khoshnevisan et al. (2014c) predicted the potato yield based on energy inputs by means of ANFIS. Alavi (2013) had determined the quality of Mozafati dates using Mamdani fuzzy inference system. Abghari and Sadi (2013) applied ANFIS for predicting the yield distribution of the main products in the steam cracking of atmospheric gasoil. Hosoz et al. (2011) predicted the performance of a refrigeration system with the help of ANFIS. Wua et al. (2015) introduces a technique of measuring performance of thermal power firms in China via fuzzy Enhanced Russell measure model. Similarly, Afrinaldi and Zhang (2014) proposed an alternative methods for normalization and aggregation in life cycle assessment (LCA) using a fuzzy logic based aggregation method; Khoshnevisan et al. (2014a) appraised the environmental impact on tomato and cucumber cultivation in greenhouses using life cycle assessment and ANFIS. Khoshnevisan et al. (2013) projected an environmental indices in potato production using artificial neural network; Pishgar-Komleh et al. (2012) analysed energy consumption and carbon-di-oxide emissions analysis of potato production in Iran. Nevertheless, uses of fuzzy inference system are still in its very early stages and there is the lack of applicable models.

In spite of the above mentioned development, lacunas still exist in the formulation and solution of models as:

- A new model for polypropylene production policy has been developed for first time.
- Effective parameters controlling the quality of polypropylene have been identified.
- Mamdani fuzzy inference system has been introduced.
- Predicted and observed data are compared through some sensitivity analyses.

In this paper, a complete fuzzy model is constructed based on the data available from the petrochemical plant in India. In this formulation, we have concentrated on 3.5 MFI polypropylene – powder because of its versatile and enormous application in polymer industry. For this model, the essential parameters for the production system of PP are identified and appropriate fuzzy inferences, implications, aggregation and defuzzification methods are selected to give the better output i.e, the better quality of PP. The main purpose of this study is to develop few FIS models and then select the best model out of these four in order to predict the better quality of 3.5 MFI polypropylene. Here, we have made a primary investigation on the parameters controlling the production and choose the most appropriate input and output variables. A Mamdani fuzzy inference system (MFIS) is then developed using these inputs and outputs. Through this approach, the models are formulated and solved. Using some statistical tests, the best model is selected. Finally, the result from the proposed model and the actual industry model are compared and thus the presented approach and model are validated.

The paper has been presented section wise as follows:

- Section 1 gives introduction.
- Notations and abbreviations are presented in Section 2.
- The plant setup is described in Section 2.
- Formulation of fuzzy model is given in Section 3.
- Section 4 illustrates the solution procedure.
- Sensitivity analyses are presented in Section 5.
- Section 6 concludes the paper.

2. Plant setup

Production process of polypropylene is a very complex, intricate and an elongated continuous process. The raw materials like propylene, ethylene, and any other desired comonomers are fed into the reactor. Hydrogen is then added to control the molecular weight. Teal is blended to activate the catalyst. At that point of time donor is mixed to the precontacting pot. Polymerization conditions (pressure, temperature and reactant concentrations) are set by the polymer grade being made. The reaction itself is exothermic and the cooling of the reactor is achieved by plate heat exchange, where liquefied reactor gas (mainly propylene) is mixed with fresh feed and injected into the reactor. Flash evaporation of the liquid in the polymer bed ensures maximum heat exchange. The polymer powder is then discharged from the reactor and separated from the unreacted monomer in a discharge vessel at an atmospheric pressure. The production of polypropylene is a very complex and as well as an elongated process. The plant set-up of a polypropylene unit is presented in Fig. 1.

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