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Mamdani Fuzzy Modeling of Flash Vaporization Using a New Concept: Fuzzy Composition Variable

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Abstract

In this paper, a novel modeling method is presented using Mamdani fuzzy approach by introducing a new fuzzy concept, named Fuzzy Composition Variable. Fuzzy Composition Variable tries to combine the mole (or mass) fraction variables of the model in one variable. This variable tackles the problem of a high number of fuzzy rules when using Mamdani approach. The proposed method is capable of modeling complex systems with a large number of variables (including molar composition) with an acceptable performance, by passing solving various types of mathematical equations governing the system and calculating several parameters. To demonstrate the capabilities of the proposed approach, it was implemented to modeling the equilibrium flash separation of crude oil. The overall prediction accuracy of the model (with a manageable number of rules) was obtained more than 85%, without using an optimization procedure.

Keywords: Mamdani Fuzzy Modeling, Equilibrium Separation of Crude Oil, Fuzzy Composition Variable, Fuzzy Rules, Fuzzy Logic.

Introduction

Generally, there are three main approaches to dynamic modeling, namely white-box (mechanistic), black box and gray box. Mechanistic approach needs a detailed knowledge of the governing phenomena, and difficulties can be arise from the poor knowledge [1]. Intelligent based techniques like fuzzy logic known as gray-box approach and Artificial Neural Network (ANN) known as black-box approach [2–5], for developing which a detailed knowledge of the process is of less concern may overcome the complexities and drawbacks of the mechanistic approach. In the fuzzy modeling approach that the two types of which are Mamdani [6] and Takagi-Sugeno (TS) [7], all the uncertainties and model complications are treated in linguistic expressions in the form of If –Then rules based on the theory of fuzzy logic. In the Mamdani approach, qualitative experience and knowledge of the experts who are dealing with the process are incorporated in the development of the model [8].

In this paper, a novel Mamdani approach is proposed by using which, the large number of rules of the model is drastically reduced. It is worth underlying that the large number of rules is the main shortcoming of the Mamdani fuzzy approach.. A new fuzzy concept, named "Fuzzy Composition Variable - FCV" is introduced, which tries to present all the molar fractions of each phase in one variable. The performance of the obtained model has been evaluated to predict the behavior of a flash separator of crude oil.

Fuzzy Composition Variable – FCV

Using FCV, the molar fractions of all components in a material stream are represented by one fuzzy variable. The maximum number of fuzzy sets of an FCV is the number of components involved in the material stream. The degree of membership of the fuzzy sets is the fuzzy representation of molar fraction value. The crisp molar fraction values of each component when using FCV is the normalized membership value of the corresponding fuzzy set for the component, so that various elements of the defuzzified members sum up to one. In addition, the similar approach that is used in lumping oil cuts or defining water-free compositions in the mechanistic modeling approach can be used for FCV in cases where the number of the components is large, called lumping mapping. Moreover Lumping mapping may be exploited to merge different pure components with similar behaviors, representing as one lumped component to reduce the number of the fuzzy sets, and in turn the number of rules. Using lumping mapping for a fuzzy stream, n components are mapped into 'm' lumped components (where m<n). The degree of the membership function of each lumped fuzzy set is the normalized summation of the degree of membership of all fuzzy sets corresponding to pure components involved in the lumped components.

Case Study: Flash Separator of Crude Oil

The flash separator of crude oil with a typical feed stream condition is selected as the case study. It is aimed to predict the liquid fraction and outlet streams mole fractions versus feed condition.

In addition, it seems a relatively good assumption to lump components in the gas phase of the feed in such a way that first lumped fuzzy set includes light gas components and the other includes heavy gas components. In addition, each oil cut is inherently a fraction of components in the crude oil. Therefore, six lumped fuzzy sets are considered for FCV, labeled as "Rich in light gas", "Rich in heavy gas", "Rich in light oil", "Rich in relatively heavy oil", "Rich in heavy oil" and "Rich in very heavy oil" as shown in Figure 1.

Result and discussion

The performance of the developed model is evaluated for different feed conditions against their corresponding counterparts obtained through a PetroSim simulator (Table 1). Using the FCV in the obtained model, a reduction of more than 95% for the number of rules is achieved.

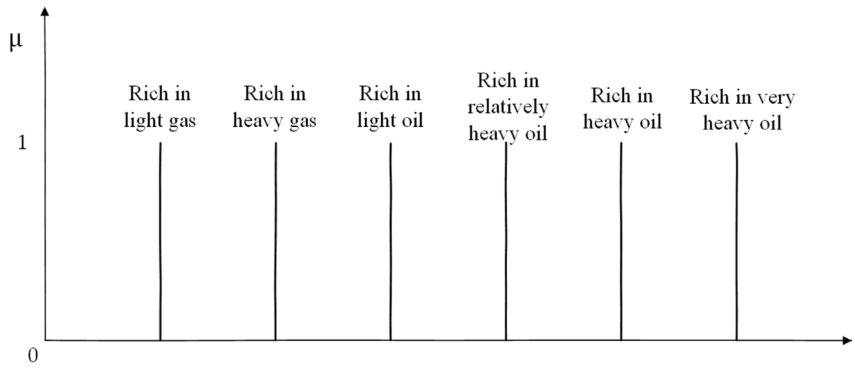

Figure 1: Defined LCV for the fuzzy streams in the model.

Table 1: Comparison of developed model results against PetroSim.

Feed condition – 1

T	P	z_1	z_2	z_3	z_4	z_5	z_6
40	700	0.24	0.09	0.43	0.13	0.08	0.03

Model outputs

	y_1	y_2	y_3	y_4	y_5	y_6	x_1	x_2	x_3	x_4	x_5	x_6	L/F
Petro-SIM	0.87	0.13	0	0	0	0	0	0.07	0.57	0.17	0.11	0.05	0.76
Mod-el	0.84	0.17	0	0	0	0	0	0.06	0.58	0.17	0.11	0.05	0.68
Error	3%	30%	-	-	-	-	-	14%	2%	0	0	0	10%

Feed condition – 2

T	P	z_1	z_2	z_3	z_4	z_5	z_6
30	250	0.29	0.11	0.38	0.12	0.07	0.03

Model outputs

	y_1	y_2	y_3	y_4	y_5	y_6	x_1	x_2	x_3	x_4	x_5	x_6	L/F
Petro-SIM	0.82	0.18	0	0	0	0	0	0.06	0.58	0.18	0.11	0.04	0.66
Mod-el	0.74	0.15	0	0	0	0	0	0.08	0.56	0.17	0.11	0.04	0.65
Error	8%	17%	-	-	-	-	-	33%	3%	5%	0	0	1%

Conclusions

This work dealt with a new approach to design Mamdani fuzzy dynamic model for a flash separator for any mixture of the components at any operating temperature and pressure, regardless of the complexity of the model. The concept of FCV is introduced for reducing the number of rules as well as simplifying the rule definition in the development of Mamdani fuzzy model.

The proposed approach has been used to develop a Mamdani fuzzy model to present the behavior of the typical flash separation process of crude oil. Using the proposed approach, a fuzzy Mamdani model with a manageable and significantly lower number of rules has been obtained. The main objective was to predict the outlet stream molar fractions and liquid fraction of the separator. In the developed model, lumping mapping has been used for FCV, so that six lumped components have been defined.

The performance of the proposed model was evaluated by comparing its results against their corresponding counterparts obtained from the simulation of the process using a full-fledged commercial simulator. The overall accuracy of the proposed fuzzy model is more than 85%, showing the capability of the proposed model.

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