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FUZZY INFORMATION AND POSSIBILISTIC UNCERTAINTY IN CHEMICAL ENGINEERING

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Abstract: Applications of the fuzzy theory in the various fields of the chemical engineering are summarized. Various forms of the fuzzy information associated with the solution of chemical engineering problems are analysed. Fuzzy structures and fuzzy valuated structures for the representation of engineer's knowledge are discussed more detailed.

Keywords: Chemical engineering, fuzzy variables, fuzzy constraints, fuzzy ranking, fuzzy structures, fuzzy valuation

1. INTRODUCTION

There is a great difference between the impact of the fuzzy paradigm on the mathematics and on the engineering. Since the fuzzy theory was founded in 1965 almost the whole apparatus of the mathematics has been generalized. In the engineering applications the concept of the fuzzy membership appeared rather as a supplementary tool than a general reconstruction. From the engineer's pragmatic point of view the fuzzy theory provided

- an opportunity for the solution of the previously unsolved problems,
- a better human interface, and
- a new tool for the management of the inherently possibilistic uncertainty.

Since 1965 the fuzzy sets have entered into the chemical engineers' thought gradually. In the *mathematical modelling* of the process units and technological systems the fuzzy methods are used for the formalization of verbal models characterizing the expert's knowledge [1]. In the *process control* the fuzzy algorithms are applied for the description of the skilled operator's experience [2]. Recently new adaptive and learning fuzzy controllers have also been elaborated. In the *process synthesis* the fuzzy theory made possible the interpretation of the subjective constraints, the formalization of the heuristic algorithms [3], and the treatment of the inherently possibilistic uncertainty accompanying the information feedback in the evolutionary synthesis [4]. In the *production control* the consideration of the flexible constraints and the realisation of the multicriteria evaluation are promoted by the fussy principle [5].

The main forms of the fussy information in the chemical engineering applications are variables, constraints, ranking of objects, rules, models, structures and valuation of structures.

2. FUZZY VARIABLES

The *fuzzy variables* are more or less arbitrarily defined fussy subsets of the universe of discourse. The reason for the use of fussy characteristics in the chemical engineering is that the specialists are not able and/or do not want to be restricted to a well defined crisp value of the given property.

In the first case the *ill-defined* or *unmeasurable* features are defined by subjective, verbal variables instead or crisp values. For example in a hydrometallurgical technology the density of a slurry can not be measured exactly, however, the terms of "very thick", "thick". "normal", "thin" and "very thin" have an inaccurate but characteristic meaning in the specialists' communication - even without any previous agreement. It is to be noted that the meaning of the fussy variables is *relative* to the given problem and even to the given place and time of the use. For example the fuzzy variables in Fig. 1 are associated with the opinion of certain specialists about a certain pulp.

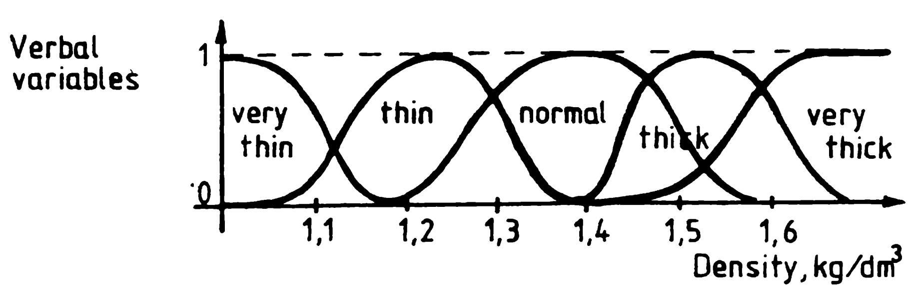

Fig. 1. Fussy variables expressing the specialists' opinion about a given slurry

On the contrary, in the second case the use of a fuzzy variable is not constrained, but the *main feature of a quantitatively known expression is emphasized* with it. As an example the analysis of the numerical results can be mentioned, where the essence of the detailed data set can be summarised by fuzzy statements.

3. FUZZY CONSTRAINTS

The *fuzzy constraints* can adaquately be used for the description of the *flexible decisions*. In the majority of the engineering tasks the properties can be varied within a certain interval without any significant consequence, while beyond these limits considerable effects emerge. For example in the flexible production control of a multiproduct batch plant the decision maker's opinion about the prescribed storage levels can be expressed by trapesoidal membership functions. As it can be seen from Fig. 2.

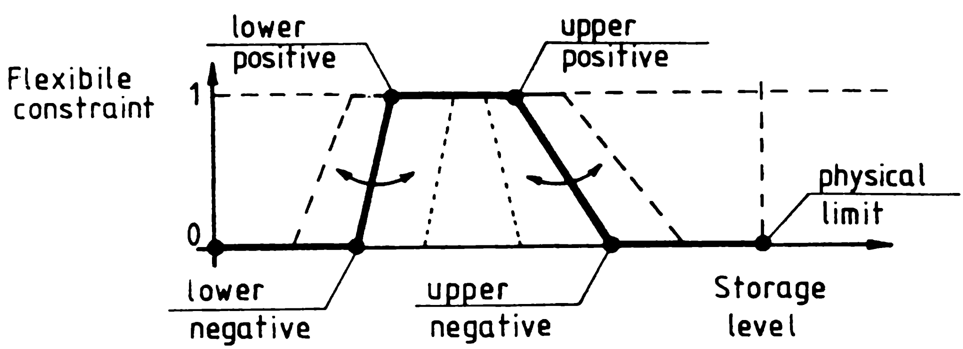

Fig. 2. Fussy constraints for the storage level in a multiproduct plant

4. FUZZY RANKING OF OBJECTS

Fuzzy membership functions interpreted above the universe of discrete objects can be used for the representation of the *uncertain ranking* of the objects in question. In this case the fuzziness should not be associated with inaccuracy. For example in Fig. 3 the acceptability values of various chemical reactors for the realization of a given reaction are shown. As it can be seen from the Figure the correct ranking can be described by ambiguous and fuzzy information, and inversely, the unambiguous and crisp ranking may be inaccurate.

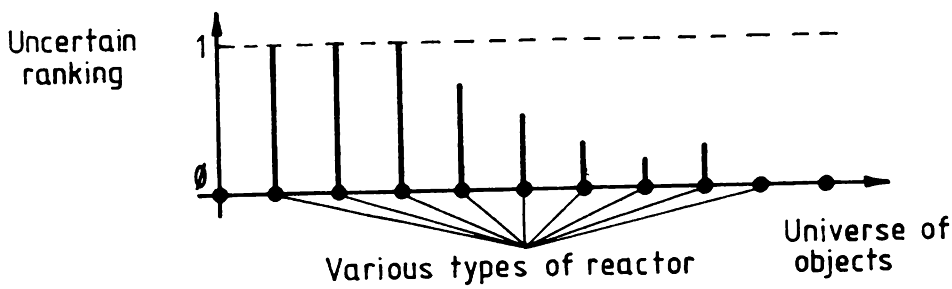

Fig. 3. Ranking of objects by fuzzy membership function

5. FUZZY RULES AND MODELS

In the *fuzzy rules* the human or machine experiences are expressed in the form of fuzzy if - then - else statements. The *fuzzy algorithms and models* are usually built from fuzzy rules. In the traditional fuzzy models the operation of the investigated system is described by *production rules*, without any a priori knowledge about the quantitative relations.

Conventionally, the fuzzy contollers and the fuzzy heuristic algorithms in the process synthesis can also be based on the *fuzzy inference*, represented by a previously defined set of the production rules. In the second generation of fuzzy models the rules are dynamically modified and/or a learning cycle is organized above them. As an example for the learning fuzzy models, a special controlling algorithm is represented in another paper of this volume more detailed.

6. STRUCTURES AND FUZZY STRUCTURES

The engineering systems can often be represented by networks (e.g. technological schemes), nets (e.g. controlling algorithms), or lattices (e.g. possible building elements in solving synthesis problems). In these *structures* both the *relation determining the generating elements* and the *relation defining the possible combinations* may be fuzzy.

In Table 1 the secondary *ranking and compatibility relations* used for the description of the various structures are reviewed. As it can be seen from the Table, in each group four cases are distinguished accordingly to the crisp or fuzzy character of the initial set and the subset relation. The underlined relations have practical significance in chemical engineering.

Table 1.
Survey of secondary relations determining structural models
(fuzzy subsets are marked with the $\sim$ symbol)

Relations	In a single set	Between sets	In power set
Rankings	$\underline{A \subset H \times H}$	$\underline{A \subset H_1 \times H_2 \times \cdots \times H_n}$	$\underline{A \subset P(H)}$
(the subsequent	$A \subset \tilde{H} \times \tilde{H}$	$A \subset \tilde{H}_1 \times \tilde{H}_2 \times \cdots \times \tilde{H}_n$	$A \subset P(\tilde{H})$
elements are	$\underline{\tilde{A} \subset H \times H}$	$\underline{\tilde{A} \subset H_1 \times H_2 \times \cdots \times H_n}$	$\underline{\tilde{A} \subset P(H)}$
ordered)	$\tilde{A} \subset \tilde{H} \times \tilde{H}$	$\tilde{A} \subset \tilde{H}_1 \times \tilde{H}_2 \times \cdots \times \tilde{H}_n$	$\tilde{A} \subset P(\tilde{H})$
Compatibilities	$B \subset H * H$	$\underline{B \subset H_1 * H_2 * \cdots * H_n}$	$\underline{B \subset P(H)}$
(any two elements	$B \subset \tilde{H} * \tilde{H}$	$\underline{B \subset \tilde{H}_1 * \tilde{H}_2 * \cdots * \tilde{H}_n}$	$\underline{B \subset P(\tilde{H})}$
are compatible	$\tilde{B} \subset H * H$	$\underline{\tilde{B} \subset H_1 * H_2 * \cdots * H_n}$	$\underline{\tilde{B} \subset P(H)}$
with each other)	$\tilde{B} \subset \tilde{H} * \tilde{H}$	$\tilde{B} \subset \tilde{H}_1 * \tilde{H}_2 * \cdots * \tilde{H}_n$	$\tilde{B} \subset P(\tilde{H})$

Let us investigate more detailed the stuctures generated by a *subset of a power set*. In chemical engineering this kind of structures is used for the representation of *possible variants* of process units and technological systems. The $R \subset P(\check{R})$ set contains the feasible ensembles of the building elements $\check{R}$, while the variants are in the $\hat{R} \subset R$ subset. The set of relations is supplied by special elements $\emptyset$ and ω, and in the supplemented set two connectives are introduced for the composition and decomposition of the relations, respectively. The $\hat{r} \in \hat{R}$ variants can be valuated by one or more points of view, some of them may be fussy constraint, as it can be seen in Table 2.

Table 2.
Derivation of fussy and valuated structures

STRUCTURES	$\longrightarrow$	FUZZY STRUCTURES
$\langle R, \emptyset, \omega, \cup, \cap \rangle$ $\hat{R} \subset R \subset P(\check{R})$ $E_\alpha(\hat{r}), \tilde{E}_\beta(\hat{r}), \ldots$		$\langle \tilde{R}, \emptyset, \omega, \cup, \cap \rangle$ $\hat{R} \subset \tilde{R} \subset P(\tilde{R})$ $E_\alpha(\tilde{r}), E_\beta(\tilde{r}), \ldots$
$\downarrow$		$\downarrow$
VALUATED STRUCTURES	$\longrightarrow$	VALUATED FUZZY STRUCTURES
$\langle R, \emptyset, \omega, \cup, \cap; f, F, \max, \min \rangle$ $\hat{R} \subset R \subset P(\check{R})$ $E_\alpha(\hat{r}) \equiv f_\alpha(\hat{r}) \equiv f_\alpha(\hat{r})$ $E_\beta(\hat{r}) \equiv f_\beta(\hat{r}) \equiv F_\beta(\hat{r})$ $f(r_i \cap r_j) = \min[f(r_i), f(r_j)]$ $F(r_i \cap r_j) = \max[F(r_i), F(r_j)]$ $f(r_i \cup r_j) = \max[f(r_i), f(r_j)]$ $F(r_i \cup r_j) = \min[F(r_i), F(r_j)]$ $f(\emptyset) = 0 \quad F(\emptyset) = 1$ $f(\omega) = 1 \quad F(\omega) = 0$		$\langle \tilde{R}, \emptyset, \omega, \cup, \cap; f, F, \max, \min \rangle$ $\tilde{R} \subset \tilde{R} \subset P(\tilde{R})$ $E_\alpha(\tilde{r}) \equiv f_\alpha(\tilde{r}) \equiv F_\alpha(\tilde{r})$ $\tilde{E}_\beta(\tilde{r}) \equiv f_\beta(\tilde{r}) \equiv F_\beta(\tilde{r})$.

In the case of the *fuzzy structures* either the generating relations, or the subset relation selecting the appropriate combinations form the power set is fussy.

7. FUZZY VALUATED STRUCTURES

On the contrary, in the *fuzzy valuated structures* only the valuation above the crisp relational algebra is fussy. In detail the $\hat{r} \in \hat{R}$ variants are characterised by a well defined, unambiguous value, while their parts and building elements can be valuated by uncertain intervals between their pessimistic (f) and optimistic (F) values. There are general rules for the calculation of the change in the pessimistic and optimistic values.

The fussy valuation of the crisp structures is used for example in the formalisation of various synthesis problems in chemical engineering. In these applications similarly to the engineer's way of thinking from the applicability of the realized variants the uncertain values associated with their building elements are modified, next in the knowledge of these uncertain values a new variant is proposed, recursively.

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