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Towards an Expert System for Powder Production Processes : (I) the Atomization Process

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ABSTRACT. The practical definition for the expert system, as a system simulating the expert methods and knowledge in dealing with or manipulating special tasks is presented. The application of such a system in powder technology is attempted. The main features of the proposed system design are documented. It constitutes, actually, another part of an effort towards building an expert system for powder technology. It deals with the parameters of each powder production process, such as atomization, in relation to certain required powder's characteristics. It extracts, and finds out the effect of each individual process parameter on the powder characteristics, and models and formulates these relations. The relational model, and the related system software modules are designed. The Structured Query Language (SQL) is used as a standard database management language, to build up the major block programs of the system software modules. The suggested expert system is meant to be flexible, easy to implement, modify and extend. The powder production by the atomization process is given as an example of how one can control the process parameters to get certain specific powder characteristics.

KEYWORDS: Powder technology, manufacturing systems, process selection, expert systems, software design.

1. Introduction

The powder technology field is one of the most suitable fields for expert systems implementation. The area contains a huge amount of variables, information and data, which are mostly empirical. Analytical analysis is rare and extremely difficult to obtain due to the complex nature of this field.

The area of powder production processes is considered to be one of many important parts in the field of powder technology and constitutes a major part of its 'science'. In the literature, vast information is available on the numerous powder production processes [1-4]. However, most of the research activities, in this area, tend to concentrate on the individual process parameters with the main intention of producing successfully a powder for a specific application[5,6]. Consequently, a systematic investigation of the effect of the different process parameters and their inter-relations on the process as a whole and on the final powder characteristics are limited and scattered. Therefore, each company has its own practice in achieving these goals. This is actually an 'art', which depends heavily on the individual experience (i.e. of the technologist) and huge experimental trials.

Furthermore, each production process has its own parameters, and its environmental factors. Not only that, some powder characteristics are interdependent on each other for the same powder type[1-3, 6, 7]. This, therefore, makes the relations among powder characteristics and the production process parameters very complicated and extremely difficult to obtain. Hence, most relational parameters available are empirical. Also, it is clear that this field involves high experience content. Thus, this field is an ideal candidate for expert systems. Also, as stated above, each powder producer or company has its own individual expertise and knowledge. These experiences and knowledge should be documented (i.e. knowledge based) and manipulated, and aided by an expert system, so that, the work can be carried out independent of the expert. Thus, the experts may be utilized for research and development work, rather than supervising and carrying out daily routine activities.

Though the work in this paper is mainly concerned with software design, as will be shown in the next sections, it presents a basic portion of an expert system. In fact, it constitutes the first step in the realization of any system (i.e. the design step). This step, is usually followed by the design implementation step needed towards building the expert system. Usually, this can be carried-out by the software engineer, where he can employ any programming language and any suitable computer system to construct the needed package or utilizing an expert shell.

Thus at this stage, for benefit completion, it is important to give a brief account of the expert system. Basically, an “expert system” is a computer program that represents and reasons with knowledge of some specialist subject with a view to solving problems or giving advice[8]. It consists, mainly, of a knowledge base and the inference engine. Also, it contains in addition a few sub-systems, namely: (i) User interface is the vehicle through which the user views and interacts with the system. (ii) Developer interface is the vehicle through which the knowledge engineer develops the system. (iii) Explanation facility provides explanations on the reasoning of the system. (iv) System interface links the expert system to external programs such as databases, spreadsheets, algorithms, tables, empirical relations, etc., which work in a support role for the system. An expert system may completely fulfill a function that normally requires human expertise, or it may play the role of an assistant to a human decision maker. The term knowledge-based system is sometimes used as synonym for 'expert system' although, strictly speaking the former is more general. However, the process of constructing an expert system is often called knowledge engineering, and is considered to be 'applied artificial intelligence'[9-13]. In recent years, expert systems witnessed intense research activities and are widely applied in many fields and industries[14,15]. Consequently, the work described here falls in this category and presents a contribution in this direction where the application of expert system in powder technology field is attempted.

The work presented in this paper tends to address these issues in relation to the atomization process. It constitutes another part of an effort towards building a complete expert system for powder technology, described by Radwan and Es-Saheb[16]. The first part, proposed by the authors[17], has dealt with the materials selection, and processes selection in general with respect to the powder characteristics. Meanwhile, the work presented here deals with the parameters of the process in relation to certain required powder characteristics. The suggested expert system is meant to be flexible, easy to implement, modify and extend. The main objectives, however, are to extract and find out the effect of each of the production process parameters on the powder characteristics, and to model and formulate these relations. Meanwhile, the secondary objective is to design and formulate the rules, which may be applied to the selected process.

2. System Structure

The production of powder by the atomization process is one of the most versatile and widely used processes[4, 6, 7]. Thus, the production of powder by the atomization process has been chosen in this work as a typical example to illustrate how to relate available process parameters to the powder characteristics and how it is implemented in our suggested expert system. The system assumed that, each powder characteristics-process parameters relation is documented in a table. Thus, each table is believed to be a knowledge base, contains the individual expertise knowledge, or intensive experimental work, which relates each powder characteristics and the proper process parameters.

As reported in the literature[3, 6, 18], the powder characteristics can be classified into primary and secondary powder characteristics. The primary characteristics are mostly process dependent. However, in the atomization process in particular and in the other powder production processes generally, the shape characteristics which is considered as process inherited characteristics, are excluded from the powder characteristics-process parameters relation, as shown in Fig. 1. Meanwhile, the relation between the primary and secondary characteristics is displayed in Fig. 2. Based on this, the relational model following and the software modules for the system are designed. The details of these are presented in the following sections.

Now, since the atomization process is selected to demonstrate the implementation of our suggested 'expert system', it is important to state that, each process of powder production has its own parameters. Thus, the atomization process, particularly, has many parameters related to; (i) The melt, such as the melt temperature, pressure and speed; (ii) The nozzle arrangements and conditions, such as, the nozzle cross-section area, length, friction, number of nozzles and the geometric arrangements; (iii) The jet parameters, such as temperature, pressure and flow. (iv) The cooling media used, such as, water, air, steam, argon, and nitrogen, etc. (v) In addition to several environmental factors. These are displayed in Fig. 1.

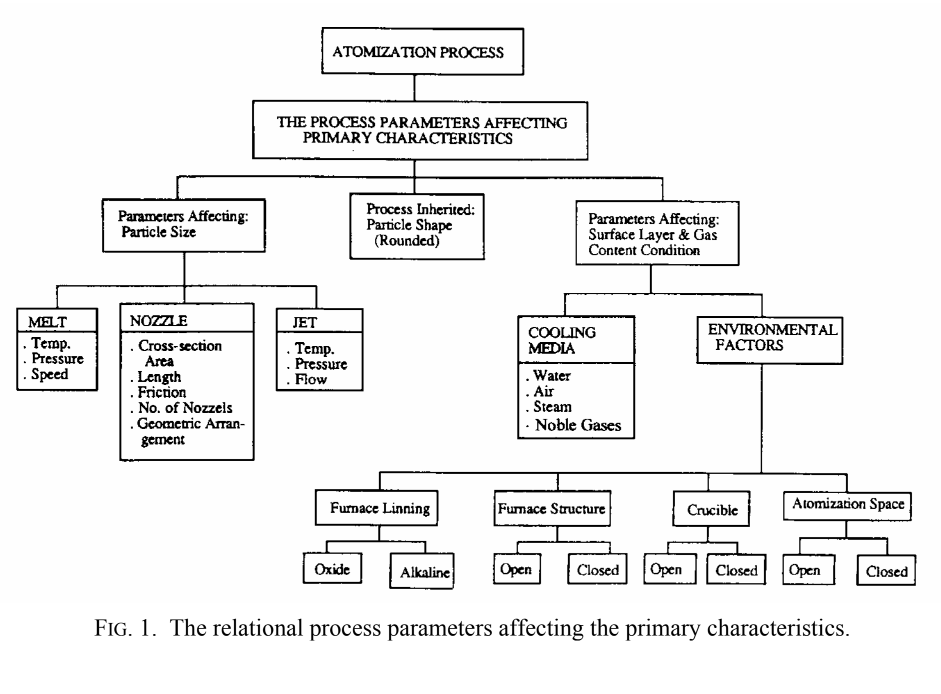

FIG. 1. The relational process parameters affecting the primary characteristics.

However, as stated above there are some inherited process characteristics for each production process, such as the particle shapes in the case of atomization process. This process is known to produce only rounded particle (i.e. drop like) shapes of various sizes. These particle sizes are heavily affected by the melt, nozzle and jet conditions and characteristics. Meanwhile, the other powder characteristics related to the surface particle properties such as the amount of surface oxide, the absorbed gas layer and gas content are affected by these factors as well as the cooling media and some environmental conditions. These parameters can be characterized as high or low. Ranges can be set for high and low values according to experience or experimental work. The proposed system is flexible enough, so that it can accommodate any modification or updating activities.

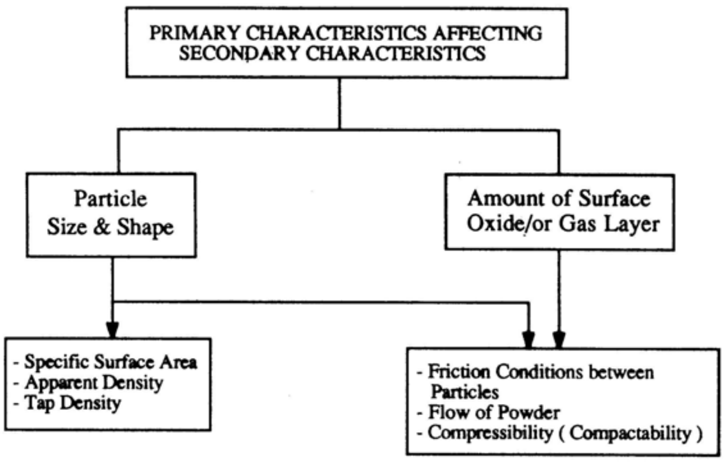

FIG. 2. The relationship between primary and secondary characteristics.

In recent works by Radwan and Es-Saheb[16, 17], they showed how the powder production process can be selected. Now, the next task in the completion of the system would be the selection of the production process parameters which affect the related powder characteristics. Again for the atomization process; The shape is considered to be constant, while the particle size may be controlled by the melt, nozzle and jet parameters. For example, the melt parameters, which contribute to the size variations, and may be considered are: the temperature of the melt, the pressure and the speed (i.e. the flow). Furthermore, for the nozzle we may consider the nozzle's cross-section area, length, friction condition, geometric arrangement and the number of nozzles. Also, for the jet parameters we may consider the jet's temperature, pressure and its flow type. Therefore, these three major parameters; the melt, nozzle and jet may be considered as composite attributes[19] to the size of the particles. Consequently, these may constitute a relation with the following headings:

{PCHAR, MELT, NOZZLE, JET}

where:

PCHAR : powder characteristics
MELT : composite attribute made of these headings;
{MTEMP, MPRES, MSPEED}
MTEMP : melt temperature;
MPRES : melt pressure;
MSPEED: melt speed.

NOZZLE : the composite attribute of the nozzle parameters, which includes the following headings;
{NAREA, NLEN, NFRIC, NNUM, NGEOM}
NAREA : nozzle cross-sectional area;
NLEN : nozzle length;
NFRIC: nozzle friction conditions;
NNUM: number of nozzles;
NGEOM : the geometric arrangement of nozzles.
JET : the jet composite attributes, which in turn has the following headings;
{JTEM, JPRES, JFLOW}
JTEM : jet temperature;
JPRES: jet pressure;
JFLOW : the jet flow condition (laminar, turbulent, mixed, fast, slow, etc.).

This relation which relates the particle size to the melt, nozzle and jet parameters may be called MNJ (Melt-Nozzle-Jet) relation.

As mentioned above, the other powder characteristics involved are the amount of surface oxide, adsorbed gas layer and gas content. These characteristics are mainly affected by the process cooling media and other environmental conditions. The cooling media may be water, air, steam, or any noble gas (e.g. argon, nitrogen, etc.). However, as far as the environmental conditions are concerned, there are several factors contributing in this aspect. For example, the furnace lining and structure, the crucible material and geometry (open/close type), etc., as seen in Fig. 1. Thus, the cooling media, and the environmental factors attributes, which are related to the powder characteristics, (such as the amount of surface oxide, adsorbed gas layer, moisture, and gas content), all may be included in a relation named CMEF (Cooling-Media-Environmental-Factors). This relation will include the following headings:

{PCHAR, CM, EF}
where:
CM : composite attribute for the cooling media parameters, and consists of:
{WATER, AIR, STEAM, ARGON, NITROGEN,...}
EF : composite attribute for the concerned environmental factors, such as:
{OXLIN, ALKLIN, OPENFS, CLOSFS, OPENCR, CLOSCR,...}
where:
OXLIN : acidic furnace lining;
ALKLIN : alkaline furnace lining;
OPENFS : open furnace structure;
CLOSFS : closed furnace structure;
OPENCR : open crucible;
CLOSCR : closed crucible;
…………………………..

The MNJ and CMEF relations can be joined together as a natural join[20] due to the common attribute (i.e. heading) PCHAR. The result, thus, is a relation called MNJCMEF.

As far as the other powder characteristics, such as the specific surface area, apparent density, tap density, friction conditions, and flow, etc., are concerned, it is clear that, all of these properties are mainly related to the fundamental and primary particle size and shape characteristics. In addition, the powder flow and friction conditions are also related to the adsorbed gas layer or/and the amount of surface oxide (i.e. the particle surface conditions). The higher these parameters are, the higher is the friction condition and consequently, the lower is the flow of the powder.

Again, the rules for θ - restriction[20] may be applied to extract the proper parameters, which satisfy certain characteristics required or recommended from the user side. These rules have been handled previously by the authors[17]. Thus, it is known by now that, the "θ" stands for any chosen simple scalar comparison operator (=, ≠, ≥, ≤ etc.). This can be seen if one considers the relation MNJCMEF which displays the merits of this operation. Therefore, to illustrate this for a given particle size, for example, there is only one recommended value, or Null for each attribute presented in the relation such that:

MNJCMEF WHERE PCHAR θ Pchar. 1 AND
PCHAR θ Pchar. 2 AND

PCHAR θ Pchar. n ;

- Null for unrelated parameter.

While, the attributes of MNJ relation have integer values, the attributes of CMEF relation have binary [1/0] or boolean [true/false] values. So that, the final result will be a table or a relation with tuples t, which include certain required characteristics and their related parameters.

3. System Software Modules

It is well known that expert systems are usually built using Rule-based programming languages like Prolog, or LISP. However, our ultimate objective, as stated above, is to achieve such a complete system for powder technology. But, due to the complex nature of this problem, a complete expert system will be very huge, diversified, and difficult to achieve. Thus the strategy adopted, as suggested by the authors in earlier works[16,17], is to divide the system into parts (i.e. sub expert systems), later to be integrated to form a complete expert system. Therefore, in this work a part of this system (i.e. sub system) is presented, which deals with the powder production processes. It concentrates, as a first step, on the software design and the related modules.

Obviously, at this stage of design and for these type of relational systems described above, the Structured Query Language (SQL) is usually used to build up the system's software modules. Particularly, it is known also to be a suitable language for searching databases for retrievable information. It is known that, according to SQL/92[21,22], a relation is represented as a table and each attribute type (i.e. heading) is presented as a domain[23], which contains all the attributes values. Thus, for each attribute a domain is created carrying the name of its attribute. For example, the syntax for creating a domain for the temperature of the melt (MTEMP) attribute is:

```
CREATE DOMAIN MTEMP INTEGER (4);
```

which is a simple integer data type. However, the powder characteristics domain may include letters and numbers, this may be created as:

```
CREATE DOMAIN PCHAR CHAR (10);
```

Also, as mentioned above, the domains of the cooling media and environmental factors are binary or boolean. Therefore, these may be formulated as:

```
CREATE DOMAIN WATER BOOLEAN;
```

The domains of the other attributes can be created using the same SQL syntax. Thus, when all the domains are declared a base table can be created to hold and relate all these domains to a primary domain such as PCHAR domain. Also, there is a base table for each process to relate its parameters to the concerned powder characteristics. Therefore, for example the base table of the atomization process can be created using SQL/92 as:

```
CREATE   TABLE   MNJCMEF   (PCHAR, MELT, NOZZLE, JET,
CM, EF), PRIMARY  KEY  (PCHAR);
```

As noticed earlier the parametric attributes are presented as composite attributes. This is done only for the sake of simplifying the presentation, otherwise it is not accepted by SQL syntax. Hence, the domains which are defined or declared in the previous section would be presented instead. Also, the values of the primary key PCHAR are not null by default. On the other side, null values are accepted by the other domains. Thus, for example; the melt, nozzle and jet attributes may have values null against the other attributes of the powder characteristics such as; the amount of surface oxide, adsorbed gas layer and gas content, and vice versa.

The user interface with the MNJCMEF base table may be thought of as a snapshot table[19, 24] named USINPUT. This includes two domains; the PCHAR domain and a user input domain called INUSER2. The INUSER2 is in fact a binary or a boolean domain, which is filled by the user, for each powder characteristic value. It is assumed that, the PCHAR attributes are displayed on the screen, and the user has to give 1 for a true value, otherwise null. The creation of the snapshot is as follows:

```
CREATE  SNAPSHOT  USINPUT  AS
        (PCHAR, INUSER2),
REFRESH  EVERY  10  MINUTES;
```

When joining together the two tables USINPUT and MNJCMEF, on the condition that the matching is considered under the true values for INUSER2, the result will be by a view table as a window showing the restricted true tuples only, from the MNJCMEF table. Hence, this will high light the related parameters for the required specific powder characteristics.

Finally, as an example for a data manipulation operation, a retrieval operation to extract some parameters to control the atomization process, in order to get certain powder characteristics concerning the particle size, amount of surface oxide, and its gas content, is given. This expressed by SQL, will be as follows:

```
SELECT  MNJCMEF.*
FROM  MNJCMEF
```

WHERE MNJCMEF. PCHAR = ------------ particle size
AND MNJCMEF. PCHAR = ------------ amount of surface oxide
AND MNJCMEF. PCHAR = ------------ gas content;

As mentioned above, the PCHAR domain is the domain within the MNJCMEF relation, which holds the values of the powder characteristics which are affected by the related parameters of the powder production process. Also, the SELECT here will reveal full details of all the parameters which satisfy the required powder characteristics.

As stated above the expert system shells can be used. In fact, these shells are intended to allow non-programmers to take advantage of the efforts of programmers who have solved a problem similar to their own[12]. It is clear that all shells are not suited to all tasks. Unfortunately, it is difficult to be rigorous in one's recommendations concerning what shell should be used for what problem. This is because we do not have very clear ideas concerning how the broad range of expert system tasks should be classified. Though the modern shells are more flexible than earlier shells, the general problem of selecting the appropriate expert system tools is still an important issue and causes some uncertainty. However, Hayes-Roth, et al.[13] proposed some very general issues to consider when selecting an expert system building tool. High level languages give programmers a fast prototyping tool, so that more flexible designs can be explored and evaluated at relatively low cost in terms of time and effort. The user interface will typically not be as 'friendly' as that provided by a shell, but a fluent programmer will nonetheless be able to make rapid progress. Production rule languages, object-oriented programming languages, and procedural deduction systems usually provide the expert system builder with a few more degrees of freedom than a shell with regard to the details of such things as the specification of control and the handling of uncertainty[8].

These issues become essential in constructing the final intended expert system for powder technology. However, for the level of design involved and presented at this stage of the work, the designed system has to be, simple, tested and verified. This, in fact, is conducted by implementing the proposed design utilizing 'Visual-Basic' programming language. This is an important step before going any further in building the final system. Thus, for this purpose, a complete computer program package (using Visual-Basic) is developed, constructed and tested. The preliminary results obtained from this package confirm the success of the software design presented. The discussion of the full results, the system flexibility, capability and extension as well as the description of the program including the flow chart, data-base creation, modifications and some display aspects together with other future features and the general future extensions of the work, such as the inclusion of, empirical formulas, characteristic charts, statistical particle size distribution, other powder production processes, the automation of knowledge acquisition, the possible use of expert shells, etc. will be the subjects of future publications.

4. Conclusion

The practical definition for the expert system, as a system simulating the expert methods and knowledge in dealing with or manipulating special tasks is presented. In this regard, first, the relation between the primary powder characteristics and the powder production process parameters is defined. Thus, the relational model and software modules are designed. The Structured Query Language (SQL/92) is implemented in constructing the system software modules. This language (i.e. SQL) displayed good capability, and flexibility in this type of applications. Therefore, these concepts are realized in the system so that it is possible to find out the powder production process's parameters, which satisfy certain powder characteristics of size, shape, and surface conditions. This suggested system is capable of providing the user with the required parameters in order to control the process and achieve the desired powder characteristics, similar to a human expert. The designed system is successfully tested using a computer package developed in Visual-Basic. The preliminary results obtained, thus far, are very positive and encouraging. However, more work and effort is still needed in order to achieve the final complete expert system for powder technology.

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نحو نظام خبرة لأساليب إنتاج المساحيق : (1) أسلوب التذرير

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المستخاص . تم تقديم التعريف العملي لنظام الخبرة ، كنظام يحاكي طرق الخبرة والمعرفة في التعامل أو تناول المهام الخاصة . وتمت محاولة تطبيق هذا النظام في مجال تقنية المساحيق ، حيث تم توثيق الملامح الرئيسة لتصميم النظام المقترح والذي يمثل في الواقع جزءًا آخر ضمن الجهود الرامية إلى بناء نظام خبرة متكامل لتقنية المساحيق . ويتعامل هذا النظام مع عوامل أسلوب إنتاج كل مسحوق على حدة بهدف الحصول على خصائص للمسحوق بذاتها . وبالتالي فإن النظام يقوم باستخلاص وإيجاد تأثير كل عامل من عوامل الأسلوب بمفرده على خصائص المسحوق ، ومن ثم يقوم بنمذجة وصياغة هذه العلاقات . وقد تم تصميم نموذج العلاقات ووحدات برامج النظام ذات العلاقة . وقد استخدمت لغة "سكويل" كلغة قياسية لإدارة قواعد البيانات ، في بناء قطاعات البرامج الرئيسة في وحدات برامج النظام . وقد روعي أن يكون نظام الخبرة المقترح مرنًا ، وسهل التطبيق ، والتعديل وكذلك يمكن توسعته . ولتوضيح عمل نظام الخبرة المقدم ، فقد استخدم أسلوب إنتاج المساحيق بطريقة التذرير كمثال لبيان كيفية التحكم في عوامل الأسلوب للحصول على مسحوق ذي خصائص معينة بذاتها .