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DETERMINATION OF THE INFLUENCE FACTORS IN DUST EXPLOSION VIA ROUGH SET: AN APPLICATION ON SYSTEM CONTROL

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ABSTRACT

With the growing evolution of the chemicals and materials, the steps of chemical process have become increasingly complicated and sophisticated. There is a concern that treated dust of sugar, when produced on an industrial scale, will result in serious explosion accidents. There include test of explosion sensitivity and data processing by minimum ignition energy tester (MIET) and rough set, respectively. Five important factors of explosion discussed in dust of sugar are particle size, particle composition, temperature, as well as the relative humidity of environment. The orders of significance are particle concentration > temperature > particle size > humidity. The temperature explosive range of powdered sugar is about 19°C, and it will explode when the humidity is between 55% and 75%. When the particles of dust trend to minimum, the more amount of dust is required.

Keywords: Chemical process, explosion accidents, minimum ignition energy tester (MIET), rough set, important factors of explosion.

1. INTRODUCTION

In recent years, dust explosion hazard is always abominable, as well as an urgent problem of solution. On February 07, 2008, there are a series of sugar dust explosion at imperial sugar manufacturing facility in Port Wentworth, Georgia, and USA. (Vorderbrueggen 2001; Chang and Lin 2006). The colored powder disaster happened in new Taipei city resulting in 527 people injured (Liaw 2016). Under certain conditions, sugar can cause a dust explosion hazard. Some internal and intrinsic factor may affect the explosion properties of dust, not determining by a single factors. Therefore, all factors may affect the experiment that should be listed and analyzed the correlation between each other. Hence, we attempted to combine academic research with industrial demand and actively seek process safety and hazards elimination to reach zero disaster and business continuity (Chiu *et al.* 2016; Hajime *et al.* 2016).

The main influence features of dust explosion and features can be summarized as follows (Eckhoff 2003).

1. Chemical properties of the dust: The size of the amount of gas generated from the oxidation reaction, the size of the combustion heat, the heat generation rate and gases, all are relevant to the strength of the explosion.
2. The distribution of the size and degree of dispersion particle: After a period of time being proceeded, the dust in the air will subside naturally. It is generally believed that particle size is between 10 to 200 μm. However, there is large difference of a variety of dust, whereby the same reasons vary depending on explosive dust particle sizes.
3. Flammable gas: In the mixing system, since the initial temperature, the system pressure, the content of the inert medium, floating in space and the wall material and the size of the ignition energy hybrid system all can make explosive limit change.
4. Temperature: Explosion limit data are related to the initial temperature of the mixture. The higher the initial temperature, the more likely the reaction tends to cause diffusion.
5. Concentration of oxygen: The higher the concentration of oxygen, the dust more easy to explode. Therefore, to reduce the concentration of oxygen, then, it can increase the lower limit of dust explosion and prevent the explosion of dust.
6. Pressure: When system pressure increases, the explosion limit range has expanded and upper explosive limit will increase. It is mainly due to the pressure rise, so that molecules move closer distance, increasing the probability of collision to make the combustion reaction easier. The explosion limits expand, especially the upper explosive limit significantly improves. When the pressure decreases, the explosion limits shink. When the pressure falls below a certain value, the upper and lower limits will eventually overlap. At this point, the pressure is called the critical pressure of the mixed system, which is below the critical pressure, and the system will not explode.
7. Ignition strength: The higher intensity of ignition energy, the more wide-spread concentration range of spontaneous combustion is. Especially, the upper explosive limit will be moved toward a higher gas content direction.
8. Humidity: Generally speaking, combustible gas mixture of air and relative humidity have negligible impact on the width of the explosion, However, when it is extremely dry, the corresponding explosive range will be expanded.

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Sugar dust is tested by minimum ignition energy tester (MIEA) and discussed itself required minimum ignition energy system with different practical size and amount, temperature, and humidity, finding the crucial influence factor of dust explosion (Callé *et al*. 2005; Wu and Wu 2008).

In 1982, Professor Z. Pawlak (Pawlak 1982) presented the basic concept of rough set theory, which is based on the difference between upper approximation and lower approximation in the function of classification (Wen and Lee 2012). Meantime, the rough set theory has found plenty of real-life applications, such as in medical data analysis, finance, banking, engineering, voice recognition, image processing, and others (Kuncheva 1992; Maji and Roy 2002). The actual measurement data combined with the rough set theory analyzed the impact of dust explosion influence factors. This paper also analyzed and simulated the relationship of each relevant factor to infer the characteristics and composition of the sample, and predict explosion safety threshold, which can kick off effective early warning systems.

2. EXPERIMENTAL STUDY OF THE DUST EXPLOSION

2.1 Sample

Dust with powdered sugar was used as the object of explosion. Here the powdered sugar (sucrose) was directly obtained from the market. We used screen mesh with four different scale, > 420, 420 ~ 210, 210 ~ 105, and < 105 μm, to classify out samples.

2.2 Research Methods and Framework

The previous studies indicated seven factors influenced dust explosion, based on MIET as used in this article, a total of five quantifiable factors were established. Corresponding analytical mathematical methods can be made, and then the computer toolbox is used to analyze the weighting of each influence factor. The overall framework was shown in Fig. 1.

2.3 Minimum Ignition Energy

The equipment is shown in Figs. 2 and 3 (van den Bulck 2005; Wu and Wu 2008; Cesana and Siwek 2016; Tsai *et al*. 2018). It links existing hardware circuit, and a practical instrument to streamline the way, which is a complete analysis of the nature of the material, requiring minimum ignition energy detection circuit.

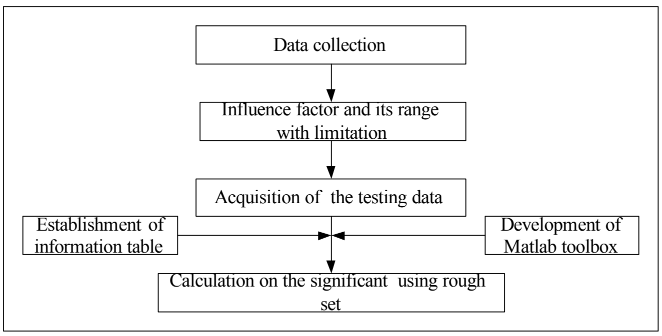

Fig. 1 Whole structure of the research flow chart

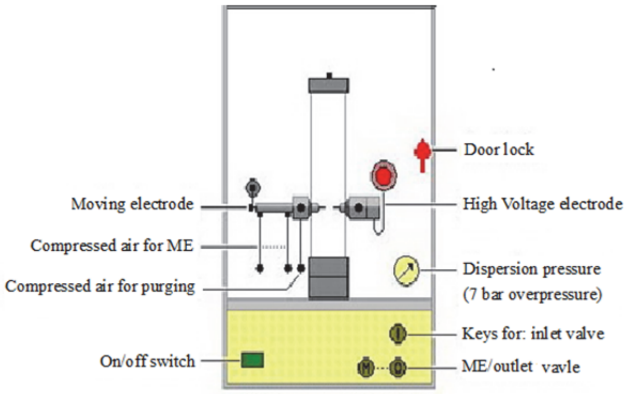

Fig. 2 Front view of MIET

Fig. 3 Outlook of MIET

2.4 Mathematics Model

The analysis steps of rough set are listed below (You and Wen 2013).

1. Information system
   $IS = (U, A)$ is called information system, where $U = \{x_1, x_2, x_3, \ldots, x_n\}$ is the universe finite set of object and, $A = \{a_1, a_2, a_3, \ldots, a_m\}$ is the set of attribute.
2. Information Function
   If there exist a mapping f_a: $U \rightarrow V_a$, then V_a is the set of value of a, called the domain of attribute a.
3. Discrete calculation
   The mathematics model is defined as

$$t = \frac{V_{\text{max.}} - V_{\text{min.}}}{k} \tag{1}$$

   where $V_{\text{max.}}$: Maximum value in the data. $V_{\text{min.}}$: Minimum value in the data.
   According to the results, we can acquire the intervals corresponding to attribute value as follows.

$$\{[d_0, d_1], [d_1, d_2], \ldots, [d_{k-1}, d_k]\} \tag{2}$$

   where: $d_0 = V_{\min}$, $d_k = V_{\max}$, $d_{i-1} < d_i$, $i = 1, 2, 3, \ldots, k$, k is the grade of discrete.
4. Lower approximations and upper approximations
   If $A \subseteq U$, then the lower approximations and the upper approximations are defined as

$$\underline{R}(A)=\{x\in U\,|\,[x]_R\subseteq A\}=\bigcup\{[x]_R\in\frac{U}{R}\,|\,[x]_R\subseteq A\},$$
$$[x]_R=\{y\,|\,xRy\} \quad (3)$$

$$\overline{R}(A)=\{x\in U\,|\,[x]_R\cap A\neq\phi\}$$
$$=\bigcup\{[x]_R\in\frac{U}{R}\,|\,[x]_R\cap A\neq\phi\},[x]_R=\{y\,|\,xRy\} \quad (4)$$

In other words, the lower approximation of a set is the set of all elements that surely belongs to U, whereas the upper approximation of U is the set of all elements that possibly belongs to U

5. Indiscernibility: An indiscernibility relation is defined as for any x_i and x_j, if x_i is identical to x_j, then x_i and x_j have all the same properties
6. Positive, negative and boundary: Based on the mentioned above, the positive, negative, and boundary are defined as

$$pos_R(X)=\underline{R}(X),\ neg_R(X)=U-\overline{R}(X),\ bn_R(A)$$
$$=(A)-\overline{R}(A) \quad (5)$$

7. Dependents: The dependents of attributes is defined as

$$\gamma_c(D)=\frac{|pos_c(D)|}{U} \quad (6)$$

Means, under $a\in C$, the ratio is in the whole set.

8. Significance: Under $S=(U, C\cup D, V, f)$ and $a\in C$, the significant value of attributes is defined as

$$\sigma_{(C,D)}(a)=\frac{\gamma_c(D)-\gamma_{c-\{a\}}(D)}{\gamma_c(D)} \quad (7)$$

3. RESULTS AND DISCUSSION

According to the construction information table, and using the soft-computing method by the rough set, we can analyze the weighting of influence factors to explosion (Wen *et al*. 2010; Tsai *et al*. 2018; Tsai *et al*. 2018; Yang *et al*. 2018).

1. Based on the state of the actual test, since the oxygen concentration is fixed, four factors were selected by using MIET results, as presented in Table 1.
2. According to the definition of rough set, we must first make discrete logarithm value. Since the data in particle size and particle concentration are in discrete state, according to the characteristics of temperature and humidity, this study used a quartered discrete. The discrete values are given in Table 2. In addition, we also analyzed the discrete of influence factors without non-explosion shown in Table 3.

Table 1 Five analysis factors for MIET results

Number of factor	Particle size/μm	Particle composition/mg	Temperature/°C	Relative humidity/%	Experimental energy/mJ	With or without explosion?
01	>420	1,200	20.7	55	300	Yes
02	>420	1,200	20.7	56	100	Yes
03	>420	1,200	18.4	61	30	No
04	>420	900	18.5	66	300	Yes
05	>420	900	19.0	65	100	Yes
06	>420	900	17.3	61	30	No
07	>420	600	19.3	63	300	Yes
08	>420	600	19.4	63	100	Yes
09	>420	600	17.3	61	30	No
10	420 ~ 210	1,200	19.8	73	300	Yes
11	420 ~ 210	1,200	19.6	72	100	Yes
12	420 ~ 210	1,200	20.1	72	30	No
13	420 ~ 210	900	19.6	72	300	Yes
14	420 ~ 210	900	19.9	71	100	No
15	420 ~ 210	900	20.2	71	30	No
16	420 ~ 210	600	19.8	73	300	Yes
17	420 ~ 210	600	19.8	72	100	No
18	420 ~ 210	600	20.1	71	30	No
19	210 ~ 105	1,200	20.9	66	300	Yes
20	210 ~ 105	1,200	20.8	66	100	Yes
21	210 ~ 105	1,200	20.6	67	30	No
22	210 ~ 105	900	20.9	66	300	Yes
23	210 ~ 105	900	20.9	66	100	No
24	210 ~ 105	900	20.9	66	30	No
25	210 ~ 105	600	19.8	69	300	Yes
26	210 ~ 105	600	20.0	70	100	Yes
27	210 ~ 105	600	20.8	69	30	No
28	< 105	1,200	20.8	65	300	Yes
29	< 105	1,200	20.8	66	100	Yes
30	< 105	1,200	20.8	67	30	No
31	< 105	900	20.8	70	300	Yes
32	< 105	900	20.8	70	100	Yes
33	< 105	900	20.7	67	30	No
34	< 105	600	21.3	75	300	Yes
35	< 105	600	21.1	71	100	No
36	< 105	600	20.9	70	30	No

3. Substituting the data in Tables 2 and 3 into rough set equations and verified through toolbox, the significance of influence factors are shown in Fig. 4 and Table 4 (Wen and You 2016). In addition, the significance of influence factors with non-explosion are shown in Fig. 5 and Table 5.

Table 2 Four grades discrete of influence factors

Number of factor	Particle size/	Particle composition	Temperature	Relative humidity	Experimental energy
01	4	3	1	1	3
02	4	3	1	1	2
03	4	3	1	1	1
04	4	2	1	1	3
05	4	2	1	2	2
06	4	2	1	2	1
07	4	1	1	1	3
08	4	1	1	1	2
09	4	1	1	1	1
10	3	3	2	3	3
11	3	3	2	3	2
12	3	3	3	3	1
13	3	2	2	3	3
14	3	2	3	3	2
15	3	2	3	3	1
16	3	1	2	3	3
17	3	1	2	3	2
18	3	1	3	2	1
19	2	3	3	2	3
20	2	3	3	2	2
21	2	3	3	2	1
22	2	2	3	2	3
23	2	2	3	2	2
24	2	2	3	2	1
25	2	1	3	2	3
26	2	1	3	2	2
27	2	1	3	2	1
28	1	3	3	2	3
29	1	3	3	2	2
30	1	3	3	2	1
31	1	2	3	3	3
32	1	2	3	3	2
33	1	2	3	2	1
34	1	1	3	3	3
35	1	1	3	3	2
36	1	1	3	3	1

Table 3 Four grades discrete of influence factors without non-explosion

Number of factor	Particle size	Particle composition	Temperature	Relative humidity	Experimental energy
01	4	3	1	1	2
02	4	3	2	1	1
04	4	2	1	1	2
05	4	2	1	2	1
07	4	1	2	1	2
08	4	1	2	1	1
10	3	3	2	3	2
11	3	3	2	3	1
13	3	2	2	3	2
16	3	1	2	3	2
19	2	3	3	2	2
20	2	3	3	2	1
22	2	2	3	2	2
25	2	1	2	2	2
26	2	1	3	2	1
28	1	3	3	2	2
29	1	3	3	2	1
31	1	2	3	3	2
32	1	2	3	3	1
34	1	1	3	3	2

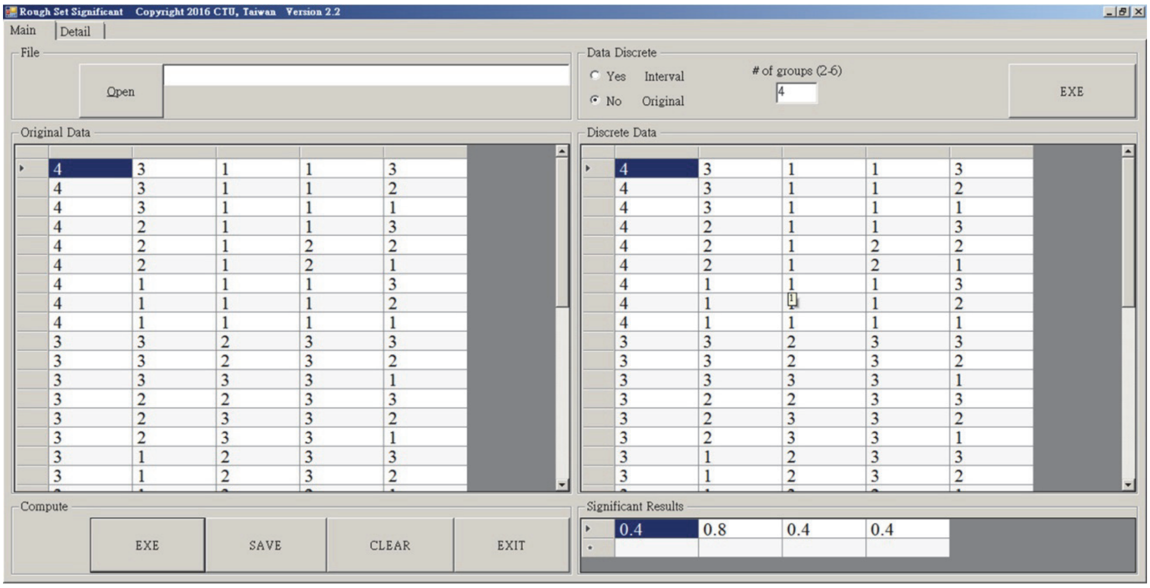

Fig. 4 Verification using toolbox

Table 4 Significance of influence factors fewer than four grades

Factor	Particle size	Particle composition	Temperature	Relative humidity
Weighting of 4 grades	0.4	0.8	0.4	0.4

Table 5 Significance of influence factors under four grades without non-explosion

Number of factor	Particle size	Particle composition	Temperature	Relative humidity
Weighting of 4 grades	0	0.6	0.4	0.2

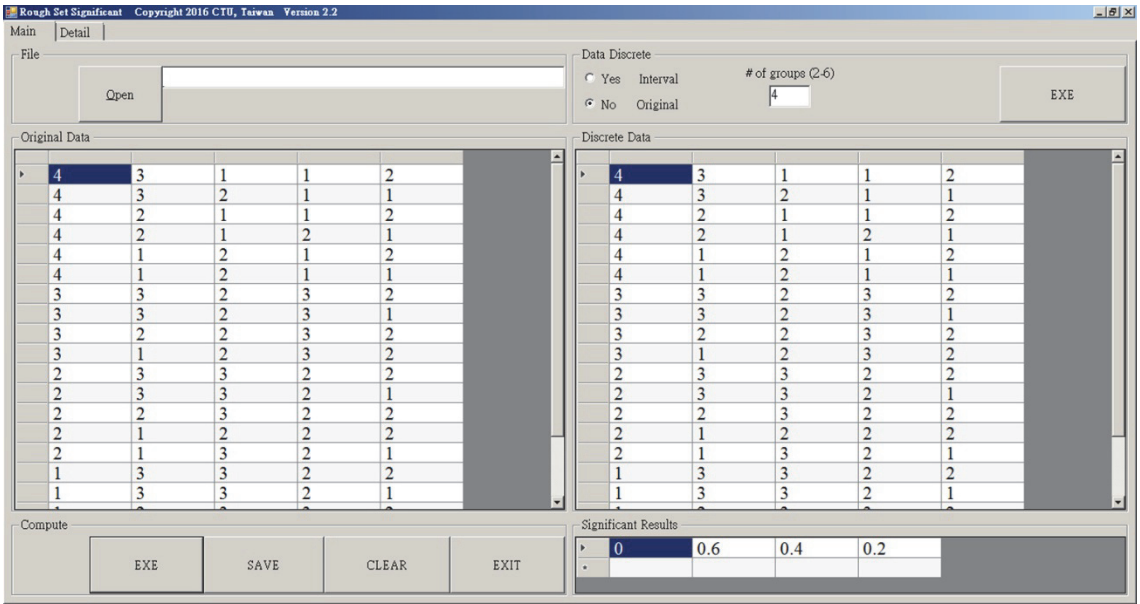

Fig. 5 Verification using toolbox without non-explosion

Through the calculation results from rough set, we can draw conclusions into two parts:

1. No matter what the state is in exploration state or non-explosion state, about the influence factors, the weighting of particle composition was 0.8, and the weighting of particle size, temperature and humidity all reached 0.4, it can receive that the weighting of particle concentration is two times of the other three factors obviously.

2. Under the explosion state, the weighting of particle composition was 0.6, the weighting of temperature was 0.4, the weighting of humidity was 0.2, and particle size seems did not have any influence in exploration.

4. CONCLUSIONS

Since dust explosion cases often occur among life, and powdered sugar is often used in our daily life (i.e., bakery shops and food manufactures), this paper used powdered sugar as tested substances. The minimum ignition energy was imposed high-voltage tester to make the powdered sugar reach explosion energy, and then the impact of environmental factors on powdered sugar can be identified. Through the actual test and the rough set analysis, the order of importance of the influence factors can be listed as follows: Particle concentration > temperature > particle size > humidity, which is in good agreement with actual situation. The temperature explosive range of powdered sugar is about 19 degrees Celsius, and it will explode when the humidity is between 55% and 75%. When particles reach their minimum, if the amount is not enough, it will no long explode. However, the biggest reason influence the state of substances is temperature. This can be learned from Formosa Fun Coast Water Park explosion in new Taipei city, Taiwan, which happened in summer, 2014.

In this article, the subject was only powdered sugar. In the future, it is suggested to extend to other materials, such as corn flour, wheat flour, and cornstarch. Furthermore, the difference of oxygen, such as 21%, 16%, and 12%, can test and analyze the oxygen's impact on explosion. In addition, except using rough set theory, other soft-computing methods can also be used, like the grey system theory and the fuzzy theory, to make cross-comparison. It is believed that more convincing and feasible results can be reached.

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