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# Explosion of rice flour at different concentration and moisture content

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**Abstract.** The dust explosion characteristics of commercial rice flour towards different concentration were analysed. Experiments were performed in 20 L spherical explosion chamber to obtain maximum explosion overpressure ( $P_{max}$ ), rate of pressure rise ( $dP/dT$ ), and minimum explosibility concentration (MEC) of undried and dried commercial rice flour. The dust samples and air mixtures were ignited by two chemical ignitors at ignition time of 100 ms. The Kistler Piezoelectric pressure sensors were used to quantify the propagation of pressure wave during the explosion process. The moisture content of the samples were measured by using proximate analysis. The  $P_{max}$  was obtained at the highest pressure over the range of concentrations.  $P_{max}$  for undried rice flour and dried flour are 10.0 bar and 10.4 bar respectively at 1000 kg/m<sup>3</sup>. Both of the  $P_{max}$  were attained at the highest level of concentration. The highest value of  $dP/dT$  of undried was 70 bar/s at 1000 kg/m<sup>3</sup> but for dried rice flour, the highest value obtained was 63.5 bar/s at 750 kg/m<sup>3</sup>. MEC for both dried and undried was 500 kg/m<sup>3</sup>. This study concluded that as the concentration increases, the severity of dust explosion would also increase and the presence of moisture decrease the severity of the rice flour explosion but not too significant at ignition time of 100 ms.

## 1. Introduction

Dust explosion involving food industries specifically from flour dust has been a threat to humans and property for a long time, mostly takes place in various unit operations. It may lead to a significant problem of injuries, fatalities, destruction of equipment and property loss. Severe dust explosions may not only cause loss of life and properties but may also lead to undesirable environmental emissions [1]. One of the first recorded catastrophic of dust explosion was written by Count Morozzo, that took place in a flour warehouse in Turin, Italy in 1785 [2]. Department of Safety and Health in Malaysia DOSH reported that on 17<sup>th</sup> of March 2008, dust explosion occurred at a tunnel of Malayan Flour Mills factory in Lumut, Perak while carrying out welding works. The explosion from mixed types of flour killed four people and two were in serious injuries.

The explosion behaviour of the dusts generally depends on the physical and chemical characteristics of the dust. It is crucial to know the physical characteristics and dust behaviour as well as dust explosibility data in order to apply an effective protection and safety systems available to prevent and mitigate the dust explosion in industries. Knowing the minimum explosible dust concentration is very important as an explosible dust cloud may be formed during operation or transportation of the dust. The minimum explosible concentration (MEC) or also known as lowest explosible limit is the lowest concentration of dust cloud dispersed in air that can propagate an explosion upon ignition [3, 4]. When the concentration level of dust flammable dust cloud below



minimum explosibility concentration during operational condition or other conditions cannot be avoided, other safety practices must be in place to control the formation of hazardous dust cloud such as safe housekeeping practices and minimize or completely remove the presence of ignition sources [5]. The maximum explosion overpressure,  $P_{\max}$  was obtained from the highest corrected value of explosion overpressure over a wide range of fuel concentration. The rate of the pressure rise ( $dP/dT$ ) was defined from the maximum slope of the tangent through the point of inflexion in the rising portion of the pressure versus time curve [6]. The results of  $dP/dT$  will be significant when multiplied by the cube root of the chamber to obtain deflagration index ( $K_{st}$ ). It is also known as volume-normalized maximum rate of pressure rise [7]. The results of explosion severity may be used to design the basis for explosion protection and mitigation such as explosion relief venting and explosion suppression but it depends entirely on the validity of the cube root law [2, 8]. The experiments were done in a 20 L spherical explosion chamber at ignition time of 100 ms.

This paper is aim to provide fundamental information on explosion severity characteristics and explosibility of undried and dried rice flour. This research focus on the roles of moisture content and the effect of different dust concentration in dust explosion.

## 2. Materials and method

### 2.1. Sample preparation

Samples used in the research was commercial rice flour. Those samples were commercial flour in a packaging used for cooking and baking. As mentioned in the procedure by Cesana and Siwek [6] the dust sample should have a median particle size not exceed  $63 \mu\text{m}$  and should be in a dry state. Particle size distribution, PSD were done in Malvern Mastersizer. After that, the samples would be stored in a glass bottle with tight lid in order to minimize the probability of moisture loss. Upon testing, the dusts would be dried at  $75^\circ\text{C}$  for two hours in an oven at ambient pressure to get rid of the moisture [6]. However, since the research required that the samples were also tested without drying, some of the samples would not undergo the drying process. As mentioned by the procedure by Cesana and Siwek [6], it is allowed for not drying the sample in justified exceptional cases.

### 2.2. Moisture content

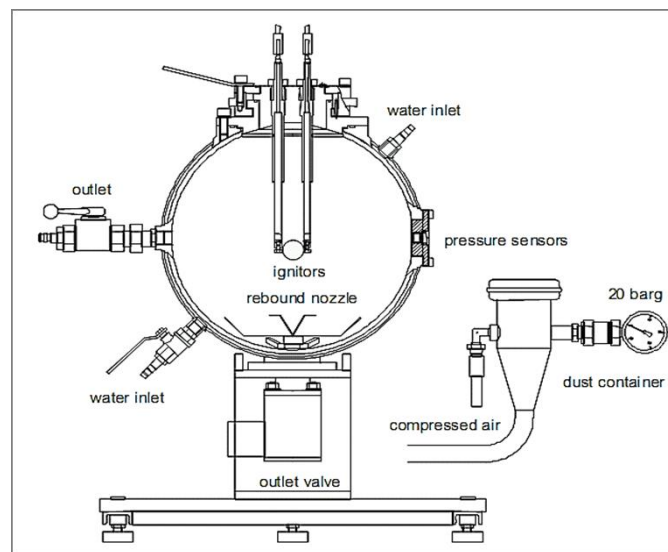
The analysis was carried out according to British Standard 1016 Part 6; Analysis and testing of coal and coke: Proximate analysis of coal [9] for moisture content. To carry out the moisture content test, an empty glass crucible (diameter of 6 cm) was weighted. Then, approximately  $1 \pm 0.1$  g of the sample was added to the crucible. The new weight of the crucible and the sample were recorded. The crucible and the content of samples were placed in an oven for one hour at a temperature of  $105 \pm 5^\circ\text{C}$  as a drying process. The crucible was then cooled in a desiccator and reweighed. The amount of moisture in the sample was then calculated by using Equation (1):

$$\% \text{ of Moisture} = \frac{\text{Mass of water removed (g)}}{\text{Mass of original sample (g)}} \quad (1)$$

### 2.3. Development of Dust Explosion

The explosibility and severity characteristics data reported here were obtained in the 20 L spherical chamber as shown in figure 1. The chamber was made of stainless steel and was rated to resist up to 30 bar (static pressure). The explosion experiments were performed by using two chemical ignitors as the standard ignition source. The ignitors were trimmed by using scissors or pliers to expose the wire before it was connected to the ignition leads. The ignition delay time  $t_v$  was fixed at 100 ms. The pressure inside the spherical chamber was measured by two "Kistler" piezoelectric pressure sensors. The pressure transducers were mounted on the wall of the chamber. In the experiments, dusts were loaded directly to the storage container and would be dispersed with the rebound nozzle connected to

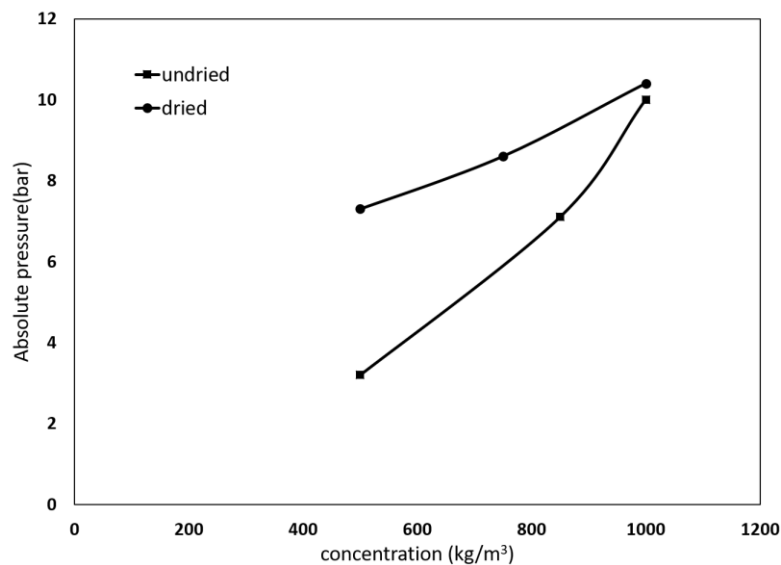
an outlet valve located at the bottom of the chamber by using compressed air pressurized at 20 bar (gauge). A water jacket surrounds the spherical bomb for the control of the internal wall temperature. The dust concentration loading was started at 10 g before gradually increased until constant pressure achieved. The same method was used to determine the MEC by gradually stepping down by step change of 10 g until there was no explosion/flame propagation shown on captured data. The chamber was interfaced with a computer, which controls the dispersion/firing sequence and data collection by using control system named KSEP. As part of the experimental programme, two repeat tests would be performed on each test and these demonstrated good reproducibility, with peak pressures varying by less than  $\pm 5\%$  in magnitude.



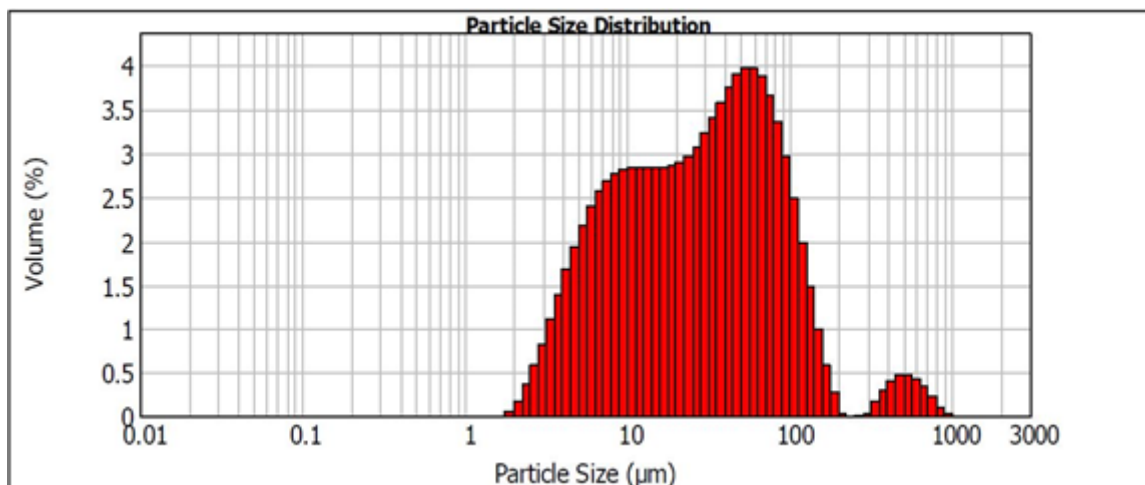
**Figure 1.** Schematic diagram of Siwek 20 L spherical chamber [6].

### 3. Results and discussion

Figure 2 shows the result of absolute pressure at the time of ignition ( $P_m$ ) as a function of dust concentration for undried and dried rice flour at ignition time of 100 ms. The graph shows that absolute pressures of both undried and dried rice flour increase as the concentrations increase with steep rise. The moisture content is 7.79% for undried rice flour and 2.47% for dried rice flour.  $P_{max}$  for both undried rice flour and dried one are almost the same and obtained at the highest level of concentration of  $1000 \text{ kg/m}^3$ .  $P_{max}$  for undried rice flour is 10 bar, a bit lower than  $P_{max}$  of dried rice flour, 10.4 bar. It shows that the severity of the samples, represented by  $P_{max}$  are quite high when the samples were exploded at ignition energy of 100 ms. A study by [10] showed that ignition time played notable role towards the severity of coal dust explosion as their  $P_{max}$  gave the trend of increase at first but then decrease with the increase of ignition delay time. Figure 3 shows the distribution of rice flour particle sizes with median diameter,  $D_{50}$  at  $28.77 \mu\text{m}$ . Pang, Zhao [11] studied the explosion characteristics such as flame propagation behaviour and maximum explosion overpressure of four samples of polyethylene (LDPE) with different sizes in the range of  $<30 \mu\text{m}$  as the finest,  $50 \mu\text{m}$  to  $100 \mu\text{m}$ ,  $75 \mu\text{m}$  to  $200 \mu\text{m}$ , and the range of  $100 \mu\text{m}$  to  $200 \mu\text{m}$  as the coarsest of all. He found that the explosion severity would increase with the decrease of the particle sizes. The rice flour samples in this study were easily exploded in the explosion chamber with quite high values of  $P_{max}$ . MEC for undried and dried rice flour as illustrated in figure 2 are  $500 \text{ kg/m}^3$ . Even though the  $P_{max}$  of both undried and dried rice flour do not have much in difference, the trend of the graph of dried rice flour in figure 2 is steeper than graph of undried rice flour whereby the absolute pressure at concentration of  $500 \text{ kg/m}^3$  for dried and undried rice flour are 7.3 bar and 3.2 bar respectively.

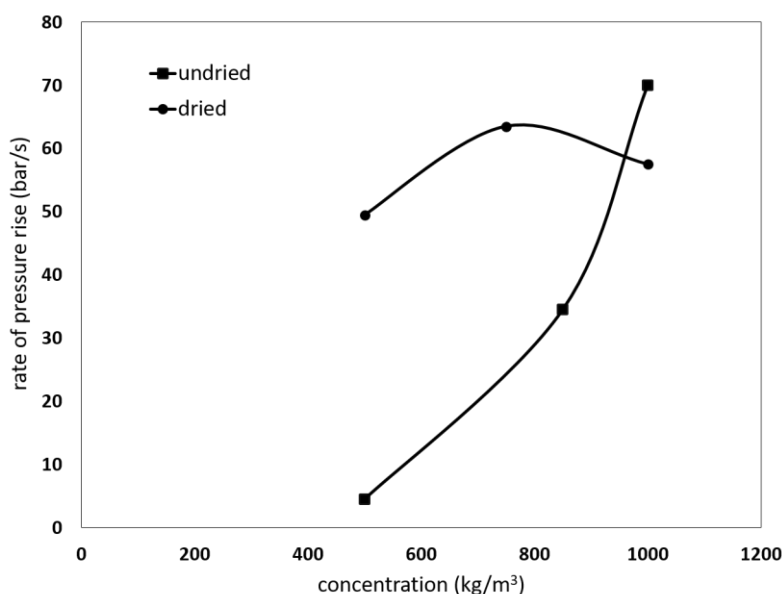


**Figure 2.** Absolute pressure at the time of ignition ( $P_m$ ) as a function of dust concentration.



**Figure 3.** Particle sizes distribution for both undried and dried samples.

Figure 4 depicted that the rate of the pressure rise ( $dP/dT$ ) of the undried rice flour presents a trend of first increase and then decrease with the increase of dust concentration. The rate of pressure rise for dried rice flour increases with the increase of dust concentration until reaching its maximum at  $1000 \text{ kg/m}^3$ . The maximum rate of pressure rise for undried and dried rice flour are  $70 \text{ bar/s}$  and  $63.5 \text{ bar/s}$  respectively. The graph of dried rice flour is much steeper than graph of undried rice flour as shown in the figure 4 even though the maximum  $dP/dT$  of undried rice flour is higher than the maximum  $dP/dT$  of dried rice flour. The value of  $dP/dT$  is very crucial to get the value of dust constant or cube root law,  $K_{st}$ . The value of  $K_{st}$  is one of the parameters to measure the severity and regarded as a fundamental parameter to calculate the vent sizing [12].



**Figure 4.** Rate of pressure rise ( $dP/dT$ ) as a function of dust concentration.

#### 4. Conclusion

The severity of dust explosion for rice flour samples were evaluated from a series of absolute pressures measured in 20 L spherical chamber.  $P_{max}$  for undried rice flour is 10 bar while  $P_{max}$  for dried rice flour is only 0.4 bar higher than the undried rice flour. However, the trend of graph shows that the severity for dried rice flour is much higher than undried rice flour. They both share the same value of MEC at  $500 \text{ kg/m}^3$  which shows that they were easily exploded in the explosion chamber due to small particle size with median diameter,  $D_{50}$  at  $28.77 \mu\text{m}$ . Results of maximum  $dP/dT$  show the opposite with results for  $P_{max}$  which shows that maximum  $dP/dT$  of undried rice flour is higher than dried rice flour at  $70 \text{ bar/s}$  and  $63.5 \text{ bar/s}$  respectively. However, the trend of the whole results of  $dP/dT$  for dried rice flour generally shows that dried rice flour is severe than undried rice flour. This study concluded that, the severity of the samples increases as the concentration increases and the presence of moisture has pronounced influence towards severity as it may decrease the severity of the rice flour.

#### Acknowledgements

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#### References

- [1] Tascón A 2018 *Powder Technol.* **338** 438
- [2] Eckhoff R K 2003 *Dust explosions in the process industries* (Burlington: Gulf Professional Publishing)
- [3] Ebadat V 2010 *J. of Loss Prevention in the Process Ind.* **23**(6) 907
- [4] Going J E, Chatrathi K, Cashdollar K L 2000 *J. Loss Prevention Process Ind.* **13**(3) 209
- [5] Abbasi T, Abbasi S A 2007 *J. Hazardous Materials* **140**(1) 7
- [6] Cesana C, Siwek R 2000 *Operating Instructions 20 L Apparatus* (6th ed) Birsfelden, (Switzerland: Kuhner AG)
- [7] Amyotte P R, Eckhoff R K 2010 *J. Chem. Health Safety* **17**(1) 15
- [8] Reyes O J, Patel S J, Mannan M S 2011 *Ind. & Eng. Chem. Research* **50**(4) 2373
- [9] British Standard I 1999 *BS 1016-104*. (London: British Standards Institution)
- [10] Wang S, Shi Z, Peng X, Zhang Y, Cao W, Chen W, et al. 2019 *Powder Technol.* **342** 509

- [11] Pang L, Zhao Y, Yang K, Zhai H, Lv P, Sun S 2019 *J. Loss Prevention Process Ind.* **58** 42
- [12] Fumagalli A, Derudi M, Rota R, 2016 *J. Loss Prevention Process Ind.* **44** 311