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การประเมินความเสี่ยงฝุ่นระเบิดของแป้งข้าว แป้งข้าวเหนียว และแป้งมันสำปะหลัง ที่ความเข้มข้นที่แตกต่างกัน

DUST EXPLOSION RISK ASSESSMENT OF RICE, GLUTINOUS RICE, AND TAPIOCA STARCHES AT DIFFERENT CONCENTRATION

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บทคัดย่อ

แป้งเป็นส่วนผสมหลักในการทำอาหาร โดยการผสมกับวัตุดิบอื่นๆ การศึกษาด้วยการทดลองครั้งนี้ได้ทำการสังเกตุลักษณะการระเบิดของแป้งข้าวจ้าว แป้งข้าวเหนียว และแป้งมันสำปะหลัง ซึ่งเป็นส่วนผสมหลักในอาหารไทย และอาหารจีน การทดลองทำการจุดระเบิดในเครื่องมือทดลอง 1.2 L Hartmann และสังเกตุด้วยการถ่ายภาพด้วยกล้องความเร็วสูง การศึกษาพบว่าแป้งทำอาหารซึ่งเป็นผลิตผลทางการเกษตรทั้งสามชนิด ระเบิดอย่างรุนแรงที่ความเข้มข้นระหว่าง 747 – 962 g/m^3 เนื่องจากยังไม่มีกฎหมายควบคุมกำกับเพื่อป้องกันการระเบิดของฝุ่นในอุตสาหกรรมการผลิตอาหารในประเทศไทย ดังนั้นจึงมีความจำเป็นอย่างยิ่งในการทำให้อุตสาหกรรมการผลิตอาหารตระหนักถึงอันตรายนี้ และควรโน้มน้าวให้ผู้ที่มีอำนาจออกกฎหมายบังคับให้มีระบบป้องกันการระเบิดของฝุ่นในพื้นที่การผลิตอุตสาหกรรมอาหาร

Abstract

Starch is the primary ingredient for food processing, by blending with other ingredients inside the mixer. This experimental study carried out to observe the explosibility of rice, glutinous rice, and tapioca starches, the common ingredients for Thai and Chinese foods. The series of experiment on set inside 1.2 L Hartmann cylindrical, observed and filmed by high-speed camera. The results of these experiments indicated that these three agricultural-food starches exploded violently at the concentration between 747 – 962 g/m^3. Since there was no regulatory requirement for dust explosion prevention for food processing industry in Thailand, obvious urgent need to inform food-starch processors to aware of potential hazards and convince the authorities to mandate dust explosion prevention system in food-starch processing facilities.

Keyword: Starch / Dust Explosion / Concentration

Introduction

Food-starch processing industry is an important economic sector to Thai economy due to high local consumption of starch-based food and for export, the country earned USD 350 million from rice and glutinous rice starches [1], and USD 3,000 million from tapioca starch annually [2]. Rice, glutinous rice, and tapioca starches are common ingredients, one of the must have, for Thai and Chinese foods and deserts recipes. The appearance of these starches looks very much the same, but they will look different when heated and create a different mount-feel when consumed. These starches are extracted from rice seeds and tapioca roots, then pressed and submerged under water, after a period then the moisten intermediate product is brought to be dried. The final stage of this process is to grind and dry inside the hot wind and cold wind cyclones until it is dry. The dry starch is then filtered through the sifter, for size according to the specification required by the customer, and finally packed in the bags of finished product ready to deliver for food processing. In the food-starch processing facility, starch will be unloaded from the bags into the blending mixer, where these fine dry particles can be exploded when suspended in the air and ignited by flame or spark.

The food-starch explosion incidents reported occasionally in Asia, the major incident happened on 24 Feb 2010 when the corn starch powder exploded at Qinhuangdao Lihou starch factory in Hebei province in China resulted in 21 workers killed and 47 others injured [3][4].

The horrible incident of misuse of starch was reported on 28 Jun 2015, corn starch powder exploded in the concert party at a water park in Taipei, Taiwan. The incident occurred while audience were attending the concert atmosphere, colored corn starch powder was sprayed over the crowd to make the concert's stage effects and turned into a fireball when the thick cloud of starch particulates ignited and then consequently created secondary explosions over thousands of innocent people and resulted in over 500 people injured and 2 victims died from severe burns [5].

Recently, on 24 Feb 2021, it was the potato starch powder explosion in an industrial building in Taus, Singapore where 3 workers killed, and 7 others injured. According to the Ministry of Manpower's Occupational Safety and Health Division, this explosion occurred while starch powder being transferred from packaging bags to blending mixer, particulates cloud formed in the enclosed area ignited and exploded [6].

In Thailand, there were two tapioca starch powder explosion incidents reported. The first occurred on 6 Aug 2011 at Esan starch factory in Nakorn Ratchasima province resulted in 9 workers injured. The second occurred on 29 Aug 2014 at Nong Hai starch factory in Udon Thani province, resulting in 4 workers injured. The reason why very few starch dust explosions had been reported is because of the inadequate incident reporting and investigation system in this country and lack of knowledge and awareness of dust explosion hazard in public [7].

Due to missing regulation and standard for dust explosion prevention in Thailand. Thus, many food-starch processing plants and finished-product handling facilities around the country were not aware of the risk of dust explosion hazards in their own processing facility. Therefore, it is essential to promote dust explosion hazard awareness for the food-starch industry that food-starch particulates can be severely exploded. This study aimed to provide evident-based risk assessment of food-starch dust explosion phenomenon, latent hazard that could turned out to be catastrophic incidents.

Objective

These experiments can be able to show the explosibility characteristics of three types of food-starch ingredients, rice, glutinous rice, and tapioca which are commonly known as normal food ingredients.

Methods

The explosion set inside a 1.2-liter chamber confinement, well-known Hartman's test equipment [8][9]. The dust cloud of rice, glutinous rice, and tapioca powder to be produced by air blast over agglomerates collected inside the chamber as same as the environment of blending mixer.

A piece of filter paper placed on top of the 1.0395×10^{-3} m^3 Hartmann explosion cylinder chamber, to relief the pressure developed in the chamber. The 0.5 bar pressured air hose connected to the chamber, at the basement (ASTM 2001) [10], which will produce air blast over agglomerates to create dust cloud. The high-speed camera, at 1080p resolution at 120 frames per second, is located close to the chamber for recording each experiment as shown in figure 1.

Figure 1: Experimental Equipment Set up.

The spark plugs with minimum ignition energy of 30-80 mJ, sufficiently energetic source to ignite the dust cloud, inserted into the middle of the chamber as shown in Figure 2. The electrical supply to the spark plugs can be generated to maximum energy of 200 mJ by adjusting the delay time of the energized circuit at 0.5 seconds.

Figure 2: 1.2 L Chamber equipped with two spark plugs.

Sample preparation

All samples were dried before testing which moisture content less than 1 – 2% and the experiments conducted at room temperature at 25 ^{0}c. After each experimental test completed, the chamber was cleaned before starting the next experiment.

Results

The explosibility tests of three types of food-starches powder, rice, glutinous rice, and tapioca recorded in Table 1. Four sample categories, 2 grams, 1.75 grams, 1 gram, and 0.75 grams prepared for explosibility test separately or each type of food-starch powder.

Table 1: The explosibility test results of rice, tapioca, and glutinous starches

Experiment	1	2	3
	Rice Starch	Glutinous Rice Starch	Tapioca Starch
1 (2 g)	△	△	△
2 (1.75 g)	✓	✓	✓
3 (1 g)	✓	✓	✓
4 (0.75 g)	✓	✓	✓

Note: ✓ = Explosion, ✗ = Neither explosion nor combustion, △ = Combustion (Ignited)

1 Rice Starch

Figure 3 shows experiment 1 that captures pictures of rice starch powder from started to finish:

1. Experiment (1.1) (weight of 2 g) where the powder ignited (A) and then the flame burns the paper (B) placed on the top of the vessel which can be visually observable by the smoke over the paper as the result of combustion.

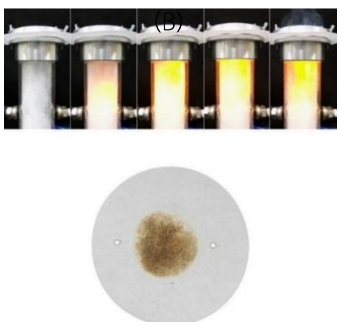
2. Experiment (1.2) (weight of 1.75 g) where the powder ignited (A) and the paper (B) burnt and ruptured as the resulted of the flame which can be seen on top of the paper.

3. Experiment (1.3) (weight of 1.0 g) where the powder ignited and exploded. The paper (B) burnt and ruptured as the result of the combustion; very intense flame can be seen over the paper.

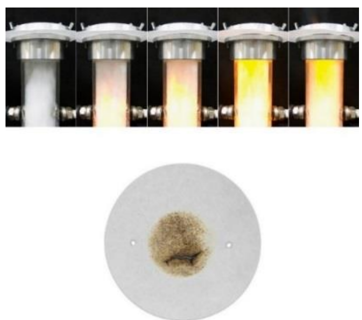
4. Experiment 1.4 (weight of 0.75 g) where rice starch powder ignited and exploded (A) and the paper (B) ruptured as the result of the explosion which flame occurred very rapidly followed by severe explosion as a result.

This evident shown that rice starch powder can be severely exploded at the concentration of 747 g/m^3

1.1 (A)



1.2 (A)



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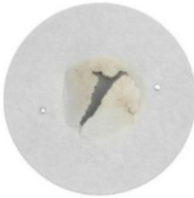
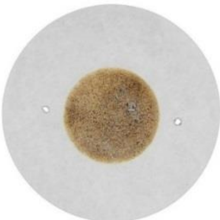


B

Figure 3: Rice Starch Experiment, 1.1 (2.0 g), 1.2 (1 .75 g), 1.3 (1.0 g) and 1.4 (0.75 g).

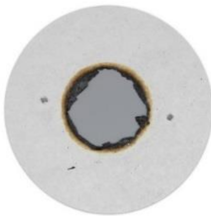
2. Glutinous Rice Starch

2.1 (A)



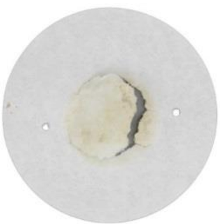
B

2.2 (A)



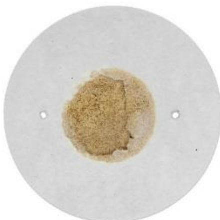
B

2.3 (A)



B

2.4 (A)



B

Figure 4 Glutinous Starch Experiment, 2.1 (2.0 g), 2.2 (1 .75 g), 2.3 (1.0 g) and 2.4 (0.75 g)

Figure 4 shows experiment 1 that captures pictures of glutinous rice starch powder from started to finish:

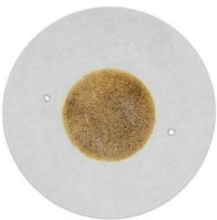
1. Experiment (1.1) (weight of 2 g) where the powder ignited (A) and then the flame burns the paper (B) placed on the top of the vessel which can be visually observable by the smoke over the paper as the result of combustion.
2. Experiment (1.2) (weight of 1.75 g) where the powder ignited (A) and the paper (B) burnt and ruptured as the resulted of very intense flame which can be seen on top of the paper.
3. Experiment (1.3) (weight of 1.0 g) where the powder ignited and exploded. The paper (B) burnt and ruptured as the resulted the combustion and explosion, very intense flame can be seen over the paper. This evident shown that glutinous rice starch powder can be severely exploded at the concentration of 962 g/m^3,
4. Experiment 1.4 (weight of 0.75 g) where glutinous rice starch powder ignited and exploded (A) and the paper (B) ruptured as the resulted of the combustion and explosion which flame occurred very rapidly followed by severe explosion as a result.
   This evident shown that glutinous rice starch powder can be severely exploded at the concentration of 747 g/m^3

3. Tapioca Starch

Figure 5 shows experiment 1 that captures pictures of Tapioca starch powder from started to finish:

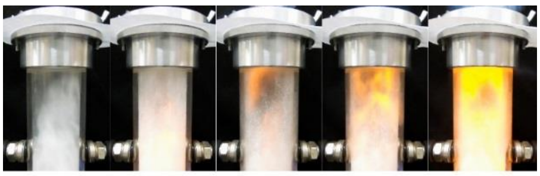
1. Experiment (1.1) (weight of 2 g) where the powder ignited (A) and then the flame burns the paper (B) placed on the top of the vessel which can be visually observable by the smoke over the paper as the result of combustion.
2. Experiment (1.2) (weight of 1.75 g) where the powder ignited (A) and the paper (B) burnt and ruptured as the resulted of very intense flame which can be seen on top of the paper.
3. Experiment (1.3) (weight of 1.0 g) where the powder ignited and exploded. The paper (B) burnt and ruptured as the resulted the combustion and explosion, very intense flame can be seen over the paper. This evident shown that glutinous rice starch powder can be severely exploded at the concentration of 962 g/m^3,
4. Experiment 1.4 (weight of 0.75 g) where glutinous rice starch powder ignited and exploded (A) and the paper (B) ruptured as the resulted of the combustion and explosion which flame occurred very rapidly followed by severe explosion as a result.
   This evident shown that glutinous rice starch powder can be severely exploded at the concentration of 747 g/m^3

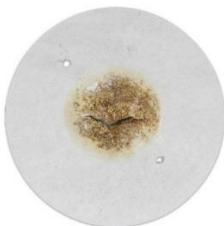
3.1 (A)



B

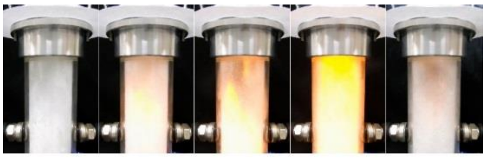
3.2 (B)

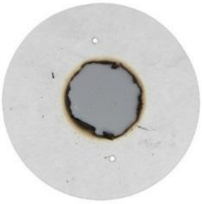




B

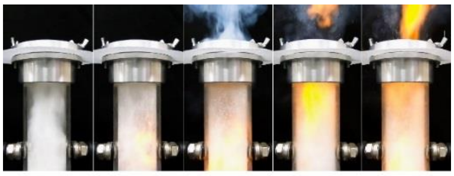
3.3 (A)

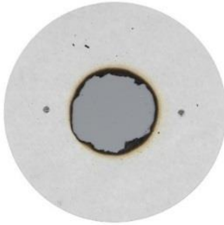




B

3.4 (A)





B

Figure 5: Tapioca Starch Experiment, 2.1 (2.0 g), 2.2 (1 .75 g), 2.3 (1.0 g) and 2.4 (0.75 g).

Discussion

In general, it holds true that higher dust concentrations lead to more violent explosions, aligning with theoretical expectations. Consequently, non-explosive flashovers were occasionally observed even when dust concentrations were elevated. However, if the amount of dust is so small that it does not reach the Minimum Explosible Concentration (MEC), an explosion will not occur, even if there is enough ignition energy. Another critical factor that merits attention is Minimum Ignition Energy (MIE). During this experiment, the available kit was limited to generating a maximum of 200 mJ of energy. This constraint resulted in flashes rather than full-scale explosions as the dust concentration increased.

Notably, while data for the Minimum Explosible Concentration (MEC) is available for rice starch (MEC: 60 g/m³) and tapioca starch (MEC: 125 g/m³) [7], such data is currently unavailable for glutinous rice starch. Nevertheless, our study's findings indicate that glutinous rice starch has the potential for violent explosions, akin to tapioca starch. Therefore, it is imperative to raise awareness about the safety considerations of glutinous rice starch, a staple in many food and dessert recipes, predominantly sourced from northeastern Thailand manufacturers.

The primary objective of this experiment was to assess the risk of explosive dust and advocate for the establishment of a minimum standard to ensure adequate dust explosion protection measures in Thailand. These experiments underscore the significance of handling agricultural-food starch ingredients, particularly in the manufacturing process, transportation, and warehousing, with heightened caution. While no reported incidents of rice starch or glutinous rice starch dust explosions exist, it is essential to recognize that such explosions can potentially occur. Consequently, regulatory requirements should be promulgated to establish a minimum standard to ensure dust explosion protection measures are in place and a precautionary approach, including training and education, must be extended, especially to small starch factories across the country and the general public.

Limitations and Areas for Future Study

The experimental tests have provided valuable insights, but certain limitations should be acknowledged to enhance the depth of understanding.

Limitation 1: Ignition Energy and Test Kit Constraints

The tests were constrained by the limitations of the explosion chamber and energy source. These constraints restricted the ability to generate ignition energy values exceeding 200 mJ and work with powder amounts greater than 1.75 grams. Consequently, non-explosive flashovers were occasionally observed even when dust concentrations were elevated. These limitations stemmed from the capabilities of the test kit (1.2 Hartman), which could not provide the necessary ignition energy for certain conditions.

Limitation 2: Particle Size Measurement

Another limitation pertained to the unavailability of equipment in the laboratory for measuring the size of dust particles. In explosive environments, the size of dust particles plays a crucial role, with smaller particles exhibiting a greater potential for explosion. This limitation leaves uncertainty about whether the observed flashovers were influenced by insufficiently small dust particle sizes.

Areas for future study, to address these limitations and advance the understanding of food-starch explosibility, several areas for future research are suggested:

Advanced Testing Instruments: Future studies should consider employing larger testing instruments, such as 20-L or 1-m^3 chambers, following established ASTM standards [10]. These larger chambers will allow for more extensive investigations into dust explosibility characteristics.

Minimum Ignition Energy (MIE): Conducting experiments to determine Minimum Ignition Energy (MIE) will provide valuable insights into the energy required to ignite food-starch dust clouds. This data will enhance the ability to assess the risk of dust explosions [11].

Maximum Explosion Pressure (P-max): Assessing maximum explosion pressure (P-max) will help understand the potential destructive force generated by these explosions. This knowledge is essential for developing safety measures and preventive strategies [12].

By addressing these limitations and exploring these areas for future study, the aim is to deepen the understanding of the explosibility properties of food-starch ingredients and contribute to improved safety practices in their handling and processing.

Conclusion

All three food-starches, rice, glutinous, and tapioca starches have similar explosibility, which severely explosive at 747 g/m^3 and 962 g/m^3.

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