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NUMERICAL STUDIES ON AN ACCIDENTAL FLASH FIRE AT A WATER FUN PARK BY FLACS SOFTWARE

by

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A severe accidental fire with 'explosion' resulting from spraying colored corn flour powder occurred at a water fun park in Taiwan. The possible fire scenarios were studied in this paper using flame acceleration simulator (FLACS). Environmental conditions including wind action and solid boundary conditions were deduced based on government fire investigation and video records, and were used as the input parameters in simulation. Simulation results indicate that upon ignition of the sprayed powder, the maximum overpressure in the open space was only 0.03 bar gauge, with a dust flash fire generated without having an explosion. These environmental conditions or parameters and the simulation results together would give a fire scene that agrees with the accident observed, indicating that appropriate environmental parameters had been identified. Therefore, CFD simulation with carefully selected parameters can be used to reproduce explosion scenarios and to identify key factors in supporting accident investigations.

Key words: *accident investigation, CFD model, corn flour dust, explosion, environmental conditions*

Introduction

Incidents of combustion and explosion from dust have been reported both locally and overseas. For instance, dust was reported to have accumulated on the floor of a pharmaceutical factory in the USA and then became airborne. Eventually, the dust was ignited and resulted in casualties [1]. Explosion caused by accumulated dust from grinding rubber in a factory in the USA has also been reported [1]. Explosion occurred from ignition of dust of combustible material appearing above the stove in a factory in the USA [2]. In a sugar factory in the USA explosion from overheating of sugar powder by the conveyor belt bearings was reported [3]. Another explosion occurred in China from dust accumulating in a pipe in a food warehouse with nearby sparks from welding spatter [4]. These incidents involving casualties

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reveal that the hazards associated with dusts could be catastrophic. Isolated sparks could lead to serious fires or even explosions.

A flash fire accident involving the ignition of colored corn flour powder spray in a water fun park occurred in Taiwan [5, 6]. There are no specific fire safety requirements imposed by the authorities on such activities in this part of the world. No standard tests are specified for evaluating the fire hazards of using different powders. In dense urban cities such as Taipei and Hong Kong, fire and explosions in residential areas might lead to big disasters. The disastrous explosion of dangerous goods in Tianjin is a good lesson to learn from [7], though that case was an extreme event. The potential fire and explosion hazards of spraying powder in an open space should be carefully studied in order to propose appropriate fire safety management schemes.

Fire investigation was carried out to identify the possible causes of the Taiwan fun park accident to avoid having similar cases. In the past, full-scale experiments were commonly used to reproduce the fire scenarios in investigations. However, large prohibitive resources are required. On the other hand, CFD model can be used to study the possible scenarios of incident and to identify key factors causing the accident. Such an approach was used in investigating the hydro-power plant fire in Taiwan by using fire dynamics simulator (FDS) [8, 9]. A hotel fire scene in Taiwan was also successfully rebuilt [10]. The FDS was also used to investigate an ammonia fire accident by successfully reconstructing the scene [11]. The CFD based simulation was made to investigate the fire scene of an arson fire in Quakers Hill, Sydney [12]. There are many similar works on powder explosion with numerical studies [13-15]. An effective numerical algorithm was developed for a gas-melt two-phase flow and used to simulate a polymer melt filling process [16, 17]. The suggested algorithm can deal with the moving interface and discontinuities of unknowns across the interface. A fractal two-phase fluid model for polymer melt filling process was developed to deal effectively with the unsmooth front interface [18].

For explosion accident, the FLACS was used to investigate the fire [19, 20]. These simulation studies show that when explosion occurred, the results of reduced-scale experiments and those of CFD-FLACS matched fairly well. Consequently, FLACS was also used for studying propane leakage explosion in a garage recently [21].

The FLACS was developed in Norway to model ventilation, leakage and diffusion of gas, explosion of steam and gas, propagation of explosion, jet fire/pool fire and explosion of dust, *etc.* [19]. Key equations on conservation of mass, momentum, transport equations of enthalpy, the mixture fraction and fuel mass fraction, turbulent kinetic energy and its dissipation rate were solved numerically by finite-volume method. Full-scale experiments were conducted to verify and validate the accuracy of the FLACS simulation results [22, 23]. One of the functionalities of FLACS is the simulation of dust explosion [24, 25]. Thus the software is employed for simulation in the present study.

The incident

The incident occurred at a water fun park in Taiwan on 27 June 2015, leading to 15 fatalities and 484 injuries [5, 6]. The major cause of the incident was the continuous spraying of colored powder made from corn flour and food pigments during the party. Dust explosion occurred and then fire spread rapidly and led to the disaster. The investigation results reveal that the illumination lamp at the scene induced a high temperature and the corn flour in air was ignited. The flame then propagated towards the people near the swimming pool. The staff at the stage attempted to suppress the fire by spraying CO_2 from a fire extinguisher. As a result, the colored flour powder nearby was struck into the air. Furthermore, the corn flour deposited on the floor was also raised into the air when people started to evacuate. All these resulted in a higher concentration of powder, which was then ignited to give a faster fire spread rate. In addition, the ground and the swimming pool floor had a difference in level of 2 m, causing difficulties in evacuation. As a result, there were serious casualties in this incident.

After the water fun park incident, a series of investigations were conducted by different government departments. Investigation of the incident included all details, such as fuel and ignition sources. However, their focus was on responsibility clarification, not much on the scientific fire investigation. Thus, investigations were only carried out on the ignition source and not the entire incident.

Knowledge of the explosion hazards of combustible powder in that incident is limited. Corn flour powder is flammable with a minimum auto-ignition temperature of 420 °C as reported [5]. The hazard level of flammability of dust can be determined by the explosion index, K_{st}. For corn flour powder having an average particle size of 16 μm, K_{st} is 158 bar m/s [26]. Explosion of dust can only occur when fuel and oxidant is mixed in appropriate proportions together with sufficiently large ignition energy [26].

After investigating the background information of the incident site, it appeared that only combustion, but not explosion of dust, had occurred. Therefore, relevant information collected was taken as input parameters in FLACS to perform simulations of a possible dust fire with explosion in the water fun park. The target is to reproduce the scene of the incident with data matching the fire investigations. This would provide a scientific basis to justify the estimated data for supporting the investigation results and to identify the key causes.

Computational methods

In the present study the explosion incident was simulated using FLACS. In FLACS, in order to simplify computation, the combustion process was solved by only using a one-step reaction. This can be expressed by the continuity equation, momentum equation, energy equation, turbulence kinetic energy equation, turbulence kinetic energy dissipation rate equation, fuel composition equation, and mixture composition equation in FLACS [27].

In FLACS, turbulence is modeled using a RANS approach. In this approach fluid velocity components and scalar quantities such as pressure, temperature and so on are separated into mean and fluctuating components. The mean values are obtained by solving the transport equations while the fluctuating components are obtained by using a model based on the standard k-ε model [25].

The k-ε model is used to model turbulence in explosion whereas the beta model is used to model the change of combustion reaction rate, which can be confirmed for the simulation explosion process effectively. Note that the algebraic sub-grid scales-variational multiscale finite element method [16, 17] was used to solve the polymer melt filling process, the first time ever performed for the two-phase flow of polymer melt filling process.

Discrete equations are derived from the control volume integral method. Staggered grid technique is used, central difference scheme is used for the diffusion term, and mixed difference scheme is used for the convection term, local linearization method is used for the source term. The SIMPLE pressure correction algorithm is applied and extended to the additional source term of the compression work for the enthalpy equation of compressible flow. Furthermore, the special flame acceleration solver is used to solve the explosion shock wave, which can account for the interaction and influence of the flame with the gas pipeline, fire extinguisher boxes, distribution box, *etc.*, and can compute the gas explosion shock wave directly [28].

The software has three parts. The first part is the computer aided scenario design, a preprocessor, utilizing the input data to define the explosion model for computing simulation. This part contains the computational grid, porosities, geometry model, and scenarios. The second part is called the FLACS simulator, the core solver of the software. It can solve the Navier-Stokes equations and add variety of model modifications. The third part is the FLOWVIS version. It is a postprocessor, used to present the numeral computing results visually. The compressible conservation equations of mass, momentum, turbulence kinetic energy are solved by finite volume method on a 3-D Cartesian grid in FLACS.

The fire investigation reported that the cause of the incident was due to spraying of the corn flour dust towards the hot illumination lamp. This immediately led to ignition of the corn flour with flame propagating towards the audiences at the front of the stage. According to the descriptions from the investigation authority, a wind speed of 2 m/s might be blowing along southwest towards the site on the day of incident. This part should be further investigated.

The simulation domain

This study used the dust explosion module in FLACS v10.4r2 to simulate the fire of dust in the water fun park.

The simulation domain was set at 160 m (length) by 80 m (width) by 20 m (height). A uniform grid size of 1 m was used [27, 29]. Related objects, such as the swimming pool, the stage, scaffolding and the nearby trees, *etc.* in the environment were all included in the simulation domain. A total of 512 people were evenly distributed on a floor area of 128 m^2 located at the front of the stage to simulate the actual situation during the incident. A photograph of the water fun park and the schematic diagram for FLACS simulations are shown in fig. 1(a) and 1(b), respectively.

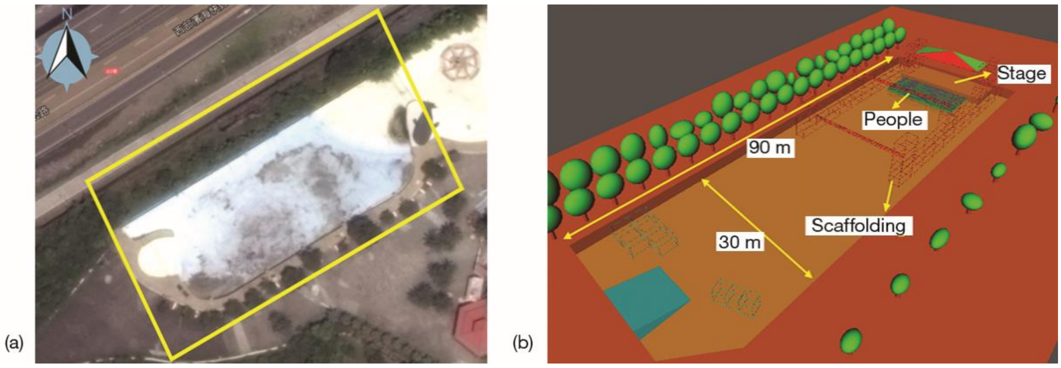
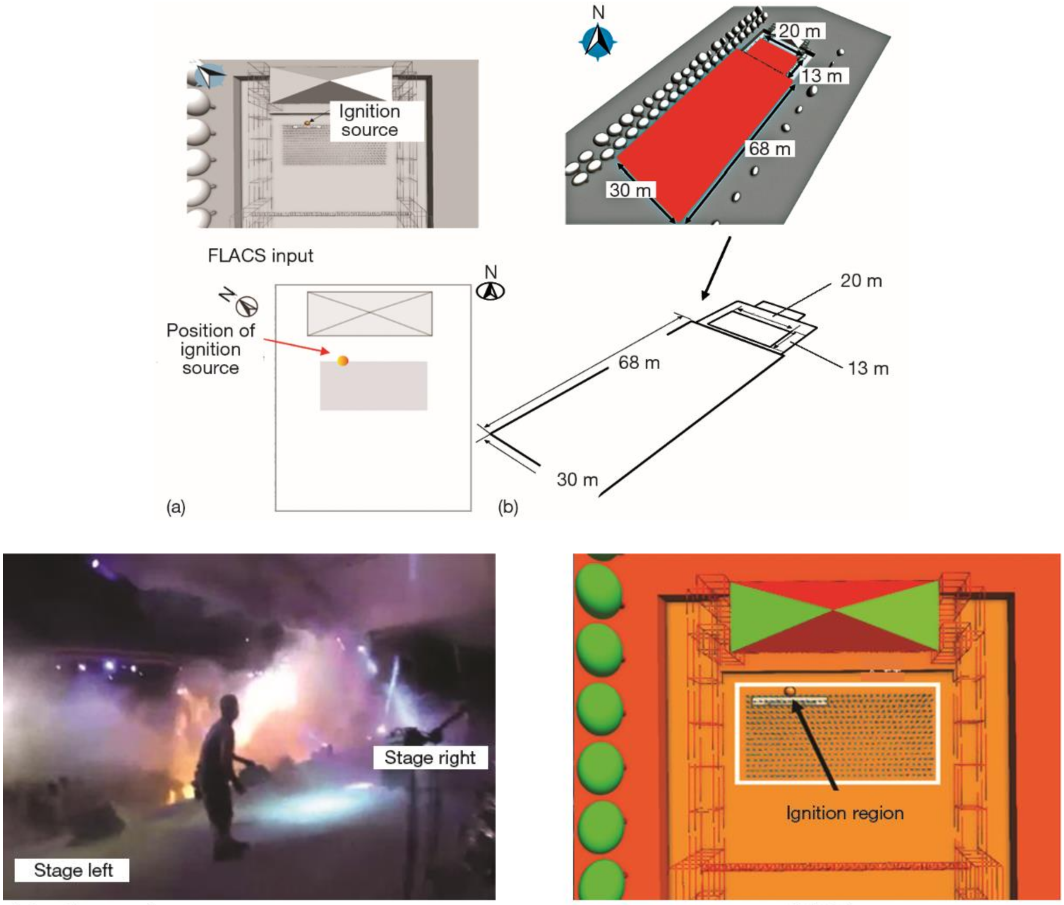


Figure 1. The water fun park; (a) photograph of accident and (b) model for FLACS simulation

The ignition source was located at the front right side of the stage as shown in fig. 2(a).

For simulation using FLACS in this study, the corn flour dust covered the region near the swimming pool at the front of the stage as shown in fig. 2(b). The height of the corn flour dust was 4 m. As reported in fire investigations, corn powder was sprayed to the stage lamp. As in fig. 2(c), corn powder was ignited by the hot lamp. In this paper, an ignition source of 10 J was put in the front of the stage as in fig. 2(c).



(c) Photograph (https://www.youtube.com/watch?v=1tq2RbigQzY) FLACS input

Figure 2. Schematic diagram; (a) position of ignition source, (b) region with corn flour dust, and (c) ignition

This is because steel cylinder was put on both sides of the stages so the sprayed powder can be distributed to the whole space as in fig. 3. Two powder clouds were as in fig. 3(c). Fire investigation report pointed out that flame did not spread to left front side of the stage. To simulate the scenario matching with the report, corn powder cloud was sprayed to 50% of total floor area, and front right of stage as in fig. 3(c) for better matching with the fire investigation report. Color powder concentration was referred to 125 μm corn powder tested by GexCon AS as in fig. 2(c). At powder density 500 g/m^3 (laminar burning velocity 0.155 m/s; Fraction burnt: 0.451) [30] as in fig. 3(d), burning speed is the maximum. Therefore, density of color powder is taken as 500 g/m^3.

At the fun park explosion and fire site, 499 people were injured by heat; 41 persons with burning area over 80%; 240 persons from 40% to 80% in this study, stage front 16 m × 8 m had 512 people (4 persons/m^2 occupancy load) [31].

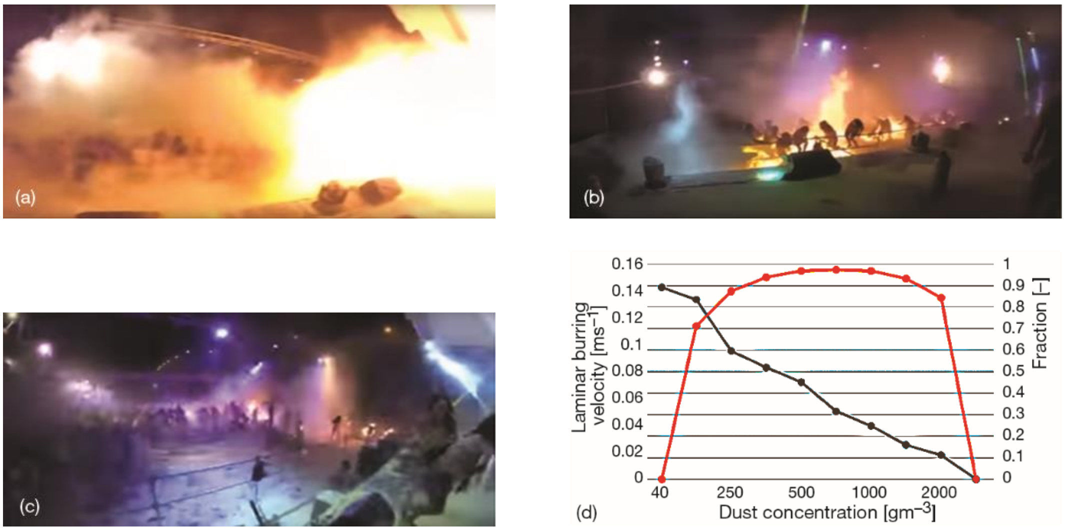


Figure 3. The incident; (a) corn flour dust was ignited in front of the stage (https://www.youtube.com/watch?v=1tq2RbigQzY), (b) flame in front of the stage (https://www.youtube.com/watch?v=1tq2RbigQzY), (c) flame spread from the stage (https://www.youtube.com/watch?v=1tq2RbigQzY), and (d) corn powder concentration distribution (DESC 1.0, file modified 26.01.2008 by T.S., GexCon AS [30])

Simulation scenarios

Three scenarios under the same ambient temperature of 31 °C and wind speed 2 m/s but with other conditions different were allowed to report at the present moment:

- Scenario 1: No people and southwest wind, being the suspected scenario in the fire investigations.
- Scenario 2: No people and northeast wind resulting from turbulence effects due to ambient conditions.
- Scenario 3: With 512 people and northeast wind.

The *Wind* boundary condition was set up at the boundaries with wind. Euler condition was used at the other boundaries. Properties for corn flour powder for the dust/fuel parameters of FLACS are shown in tab. 1.

Table 1. Corn flour powder parameters

Parameter	Numerical values
Particle density	1180 kg/m^3
Particle diameter	15 μm
Enthalpy of formation	-4.85×10^6 J/kg
Specific heat capacity	4.0×10^2 J/kgK
Dust concentration	500 g/m^3
Fuel mass fraction	0.294

Results

Scenario 1

Scenario 1 was conducted according to the information proposed, but without concrete evidence, by the investigation authority. The wind speed was 2 m/s blowing along southwest of the swimming pool towards the stage. The results of simulation show that under this condition, wind would drive a large amount of corn flour dust towards the stage and induce fire, fig. 4. The simulation results are different from the actual direction of fire spread recorded in the water fun park incident [6], fig. 3. Such results are unlikely to cause serious injuries to the audience at the front of the stage. As the simulated results for the flame propagation are different from those observed during the incident, two more scenarios were simulated and analyzed.

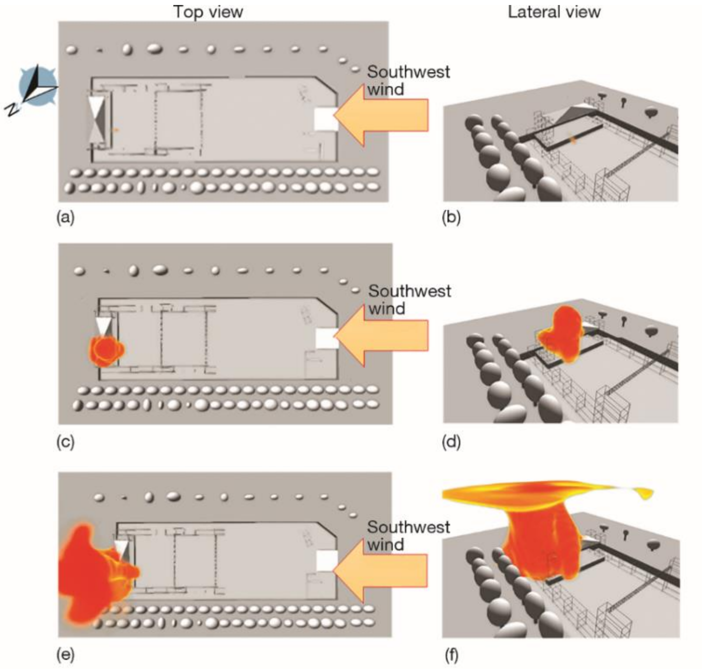


Figure 4. Fire propagation for Scenario 1; (a) 1 second after igniting dust, (b) 1 second after igniting dust, (c) flame 3 second after igniting dust, (d) flame 3 second after igniting dust, (e) flame 10 second after igniting dust, and (f) flame 10 second after igniting dust

Scenario 2

For Scenario 2, wind blew from the northeast caused by turbulence effects in adjacent buildings. The wind direction was opposite to that in Scenario 1. Simulation results shown in fig. 5 indicated that when the corn flour dust was ignited, flame appeared only near the front of the stage. From the air-flow field at the position of 80 m in fig. 6, return air (shown by the brown arrow in the figure) appeared at the front of the stage since wind from the northeast entered the stage. Continuous supply of dust to the ignition point due to this return air stream sustained burning only near to the front of the stage. Combustion could not propagate towards the swimming pool. Again, the simulation results of Scenario 2 did not match with the observed incident.

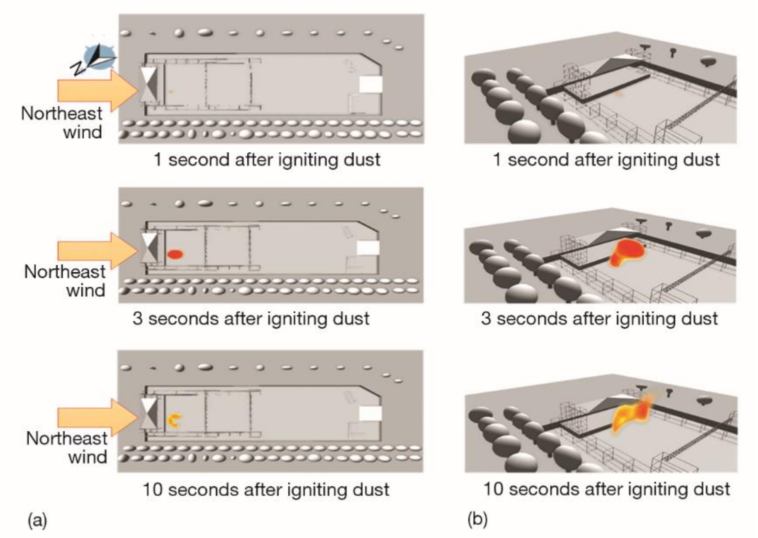


Figure 5. Fire propagation for Scenario 2; (a) top view and (b) lateral view

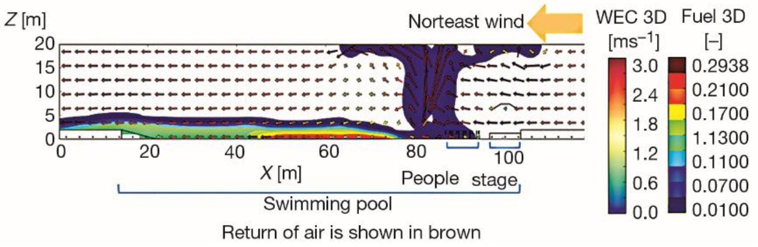


Figure 6. Distribution of flour dust (fuel) and air-flow after ignition of dust; return of air is shown in brown (*for color image see journal web site*)

Scenario 3

Both Scenarios 1 and 2 without people did not give simulation results matching with the observation. In the actual incident, fire occurred on the left side of the swimming pool as the hot lamp ignited the corn flour dust. The flame propagated towards the direction of the swimming pool. People on the right of the stage were not affected. Therefore, people were included in the simulation in Scenario 3 with wind speed and direction being the same as in Scenario 2.

The simulation results are shown in fig. 7. It is observed that when the wind was blowing towards the swimming pool, flame would propagate towards the swimming pool. In Scenarios 1 and 2, people were not included in the simulation. In such scenarios, the corn flour powder would fall onto the floor rather than on the people. As proposed by Eckhoff [32], a dust explosion pentagon on dust, oxygen, ignition source, confinement, and the mixing state of reactant can be used to describe explosion. Thus the presence of people would provide a means for forming a dispersed distribution rather than a layer on the floor. This would provide appropriate dispersion to satisfy the explosion pentagon criteria. The simulation results of Scenario 3 matched well with the observed incident. Consequently, this study indicates that wind was blowing towards the swimming pool from the northeast when the incident occurred, and the presence of people is also a key factor for the fast spreading of fire.

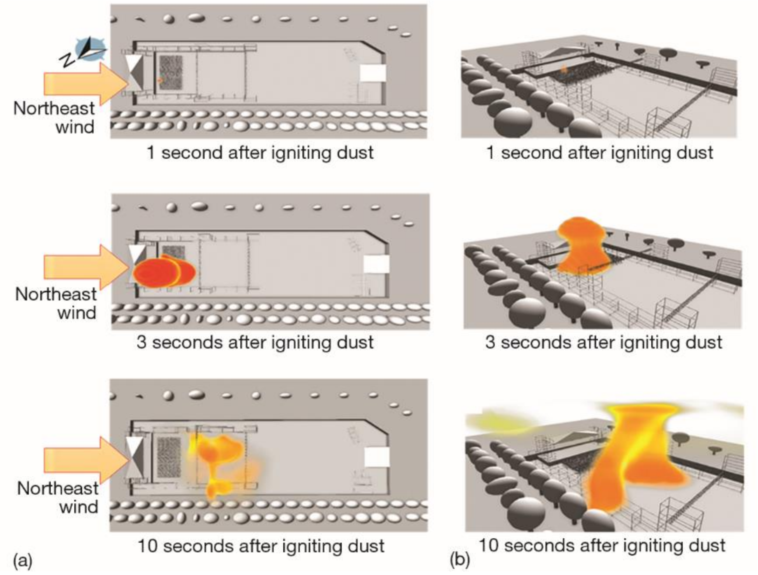


Figure 7. Fire propagation for Scenario 3; (a) top view and (b) lateral view

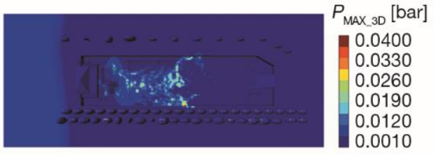


Figure 8. Distribution of value of peak gauge pressure in Scenario 3 (*for color image see journal web site*)

The distribution of maximum gauge pressure (overpressure) at each position for Scenario 3 is shown in fig. 8. The maximum gauge pressure was only about 0.03 bar in the region of simulation of the incident after the corn flour dust was ignited. Such a low gauge pressure could only lead to tumbling of people but not hurt them [33]. In fact, all the injuries in the water fun park incident were burns instead of injuries from explosion. Hence, this incident only involved minor explosion.

Discussion

Flash fire and explosions associated with natural products such as flour, grain, wood, feedstuff, starch, cork, sugar malt and bark are well-known [34]. Colored powders and liquid dyes are made of natural herbs and flowers [35, 36]. More detailed chemical compositions in the colored powders and liquid dyes available in the market can be searched from the relevant websites [37]. Lead oxide for black, copper sulphate for green, chromium iodide for purple, aluminium bromide for sliver, mercury sulphite for red and Prussian blue for blue are listed [37, 38]. Some chemicals found in some of these products can be toxic [35, 36, 39, 40]. Both natural and artificial products such as cornstarch from flowers and herbs consisting of hydrocarbon chains are combustible.

There is no detailed information available about the colored powder commonly used in spraying activities, suspected to be food grade cornstarch [37-42]. The organizer of the event in the water fun park in Taipei claimed that the powder complied with the requirements of the U.S Food and Drug Administration after the incident [43].

Flammable powder is no longer allowed to be used in many places after the disaster in the water fun park above, but the testing standard is not clear. Organizers of colored powder spraying events have changed to the use of liquid dyes which are non-flammable [43, 44]. Such liquid dyes are tested by igniting dye poured on a flat surface with a lighter [45].

Some planned events involving colored powder spraying have been cancelled or postponed since it is difficult to get approval from local authorities [46]. However, there is still no control on the use of colored powder. The potential hazard [47-49] of these powder spraying activities should be properly addressed.

Conclusions

The software FLACS was applied to simulate flame spread in a water fun park incident in Taiwan 2015 in this paper. Simulations were performed using different wind directions including that provided by the investigation authority. Based on the results of simulation, the following concluding remarks can be made.

- The simulation results on Scenarios 1 and 2 with wind blowing from southwest and northeast cannot reproduce the water fun park incident without including people on the site.
- For wind blowing from northeast together with the inclusion of people in the simulation, the results match well with the actual scenario of fire of corn dust in the water fun park incident.
- Despite the incident being described as explosion of dust in the media, the results of simulation indicate that the maximum gauge pressure was only 0.03 bar upon ignition of corn flour powder. Consequently, the incident should be classified as an incident in which explosion only played a minor role, with fatalities and injuries mainly resulting from rapid flame spread, not due to overpressure.

The present study shows that in addition to a strong enough heat source at some location and the spraying of a large amount of corn flour powder, the conditions of wind direction and speed, together with the presence of objects for forming a dispersed powder distribution, like people in the present study, are also decisive in powder explosion or rapid flame spreading.

The present study demonstrates that CFD based model can be applied in fire investigations with appropriate input parameters. For example, correct estimated wind speed and direction together with proper boundary conditions based on the presence of people and trees would give correct information of the complete process of the incident. Only a few full-scale burning tests are then required to fully support the conclusions of fire investigations, if instructed by the court to do so.

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References

[1] ***, U.S. Chemical Safety and Hazard Investigation Board, Investigation Report-Dust Explosion (report no. 2003-07-I-NC), Washington: The Institute, 2004

[2] ***, U.S. Chemical Safety and Hazard Investigation Board, Investigation Report–Combustible Dust fire and -explosion (report no. 2003-09-I-KY), Washington: The Institute, 2005
[3] ***, U.S. Chemical Safety and Hazard Investigation Board, Investigation Report-Sugar Dust Explosion and Fire (report no. 2008-05-I-GA), Washington: The Institute, 2009
[4] ***, www.safehoo.com, Analysis of Four Powder Explosion Incidents – In Chinese, 2009 http://www.safehoo.com/Case/Case/Blow/200907/27068.shtml
[5] Hsieh, M. H., *et al.*, Protecting Safety During Dust Fires and Dust Explosions – The Example of the Formosa Fun Coast Water Park Accident, *The Journal of Nursing*, *63* (2016), 1, pp. 5-11
[6] ***, YouTube, Powder Explosion on Stage, 2015. https://www.youtube.com/watch?v=1tq2RbigQzY
[7] ***, *The Standard*, Is this an Atomic Bomb? Top News, p. 6, August 14, 2015
[8] Chi, J. H., *et al.*, Using Fire Dynamics Simulator (FDS) to Reconstruct a Hydroelectric Power Plant Fire Accident, *Journal of Forensic Sciences*, *56* (2011) 6, pp. 1639-1644
[9] ***, National Institute of Standards and Technology, Fire Dynamics Simulator, 2017, https://pages.nist.gov/fds-smv
[10] Chi, J. H., Reconstruction of an Inn Fire Scene Using the Fire Dynamics Simulator (FDS) Program, *Journal of Forensic Sciences*, *58* (2013), 1, pp. 227-234
[11] Ho, S. P., *et al.*, FDS Model Simulates and Reconstructs the Ammonia Fire Accident Scene., *Proceedings,* 11th Asia-Oceania Symposium on Fire Science and Technology, 2018, Taipei, Taiwan, 2018
[12] Yuen, A. C. Y., *et al.*, Fire Scene Investigation of an Arson Fire Incident Using Computational Fluid Dynamics Based Fire Simulation, *Building Simulation 7* (2014), Oct., pp. 477-487
[13] Ban, T., *et al.*, Principal Component Analysis of the Effect of Coal Quality Indexes on the Maximum Explosion Pressure of Coal Dust, *Thermal Science*, *25* (2021), 3B, pp. 2183-2189
[14] Jia, Z. W., *et al.*, Propagation Law of Flame in a Pipeline Produced in Gas Explosion Numerical Analysis and Experimental Verification, *Thermal Science*, *25* (2021), 3B, pp. 2199-2204
[15] Ban, T., *et al.*, Effect of Ignition Energy on Coal Dust Explosion, *Thermal S*cience, *24* (2020), 4, pp. 2621-2628
[16] Li, X. J., *et al.*, Effects of a Cavity's Fractal Boundary on the Free Front Interface of the Polymer Filling Stage, *Fractals, 29* (2021), 7, 2150225-784
[17] Li, X. J., *et al.*, Variational Multi-Scale Finite Element Method for the Two-Phase Flow of Polymer Melt Filling Process, *Int. J. Numerical Methods for Heat & Fluid Flow*, *30* (2019), 3, pp. 1407-1426
[18] Li, X. J., *et al.*, A Fractal Two-Phase Flow Model for the Fiber Motion in a Polymer Filling Process, *Fractals*, *28* (2020), 5, 2050093
[19] ***, GexCon AS, *FLACS User's Manual* v10.4. Norway, 2015
[20] Wingerden, K. V., *Investigations of the Buncefield Accident,* Fontenay-aux-Roses, France, 2009
[21] Ng, Y. W., *et al.*, Numerical Simulations on Explosion of Leaked Liquefied Petroleum Gas in a Garage, *Building Simulation*, *10* (2017), 5, pp. 755-768
[22] Skjold, T., Flame Propagation in Dust Clouds: Challenges for Model Validation, *Proceedings,* 8th International Symposium on Hazards, Prevention and Mitigation of Industrial Explosions (ISHPMIE), Yokohama, Japan, 2010
[23] Castellanos, D., *et al.*, Validation of the DESC code in simulating the effect of vent ducts in dust explosions, *Industrial & Engineering Chemistry Research 52* (2013), 17, pp. 6057-6067
[24] Eckhoff, R. K., Dust Explosion Prevention and Mitigation, Status and Developments in Basic Knowledge and in Practical Application, *International Journal of Chemical Engineering, 2009* (2009), ID 569825
[25] Launder, B. E., Spalding, D. B., The Numerical Computation of Turbulent Flows*, Computer Methods in Applied Mechanics and Engineering, 3* (1974) 2, pp. 269-289
[26] Eckhoff, R. K., *Dust Explosion in the Process Industries*, 2nd ed., Elsavier, Amsterdam, The Netherlands, 1997
[27] Vyazmina, E., Jallais S., Validation and Recommendations for FLACS CFD and Engineering Approaches to Model Hydrogen Vented Explosions: Effects of Concentration, Obstruction Vent Area and Ignition Position, *International Journal of Hydrogen Energy*, *41* (2016), 33, pp. 15101-15109
[28] Li, Z., *et al.*, Numerical Analysis of the Characteristics of Gas Explosion Process in Natural Gas Compartment of Utility Tunnel Using FLACS, *Sustainability, 12* (2020) 1, pp. 153-166
[29] Gant, S., Hoyes, J., *Review of FLACS Version 9.0: Dispersion Modelling Capabilities,* Health and Safety Laboratory, Bukton, UK, 2010
[30] ***, DESC 1.0, file modified 26.01.2008 by T.S., GexCon AS

[31] ***, National Health Insurance Administration, Medical Care Situation on Anniversary of the Powder Explosion Incident. Ministry of Health and Welfare, 13 June 2016. https://www.mohw.gov.tw/cp-2628-19100-1.html
[32] Eckhoff, R. K., Current Status and Expected Future Trends in Dust Explosion Research, *Journal of Loss Prevention in the Process Industries*, *18* (2005) 4, pp. 225-237
[33] Zalosh, R. G., *Industrial Fire Protection Engineering,* Willy, New York, USA, 2003
[34] Bartknecht, W., *Dust Explosions – Course, Prevention, Protection,* Chapter 2 – Historical Review, Springer, Verlag, Berlin, Germany, pp. 2-23, 1989
[35] ***, Radha Kishan Color World, http://www.holicolor.co.in
[36] ***, Kwality Colors, http://www.holicolor.in
[37] Navdanya, A. G., *Biodiversity for Natural Colors*, 2001. http://navdanya.org/attachments/Biodiversity_and_Seed_Sovereignty5.pdf
[38] ***, w4to40: Kids Portal for Parents, What are natural colors of Holi?, 2015, http://www.4to40.com/kids-questions-answers/social-science-questions-answers/what-are-natural-colors-of-holi
[39] ***, Gulal Powder, http://gulalpowder.com
[40] ***, Essentials for Education, Holi Powder, 2017, https://www.essentialsforeducation.co.uk/product/holi-powder-event-throwing-powder.php
[41] ***, The Color Run, http://thecolorrun.com
[42] ***, Festival Powder, http://festivalpowder.com/color-run-powder
[43] ***, *Sing Tao Daily*, Hongkongers Injured in Taipei Fireball - In Chinese, June 29, 2015
[44] ***, *The Standard*, Powder Inferno Casualties Top 500, June 29, 2015
[45] ***, *The Standard*, Concern Rises Over AsiaWorld Events, June 29, 2015
[46] ***, *The Standard*, Off-color: Events Pulled After Taiwan Tragedy, July 8, 2015
[47] Novozhilov, V., Application of Heat-Balance Integral Method to Conjugate Thermal Explosion, *Thermal Science*, *13* (2009), 2, pp. 73-80
[48] Wu, L. Y., He, J. H., Explosion-Proof Textile with Hierarchical Steiner Tree Structure, *Thermal Science*, *16* (2012), 2, pp. 343-344
[49] Wang, L. L., *et al.*, Numerical Investigation of Gas Dispersion Effect on Laser Detection of Natural Gas Pipeline Leak, *Thermal Science*, *22* (2018), Suppl. 2, pp. S607-S615

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