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Original article

Hazardous atmosphere in the underground pits of rice mills in Thailand

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Background: Asphyxiation is the most dangerous hazard in confined spaces. In Thailand, several large rice mills have underground pits in order to transport moist paddy to baking machines. Prolonged unbaked paddy piles can produce several gases that can displace oxygen inside the pits.

Objective: This study describes concentrations of hazardous gases and oxygen content inside the underground pits of rice mills in Thailand.

Methods: At six randomly selected large rice mills in this study, fresh paddy piles were divided into four groups, based on moisture content (<14%, 15-20%, 21-30%, and >30% wet basis (w.b.)). Gas measurement was conducted with direct reading instruments including infrared spectrophotometer (Miran 1BX for CO_2, N_2O) and toxic gas detector (QRAE plus for CO, NO_2, % O_2 and flammable gas) at three different depth levels (top, middle, bottom) inside the pits.

Results: The concentrations of CO_2, CO, N_2O, NO_2, and % O_2 were in the ranges of 1.7-5438 ppm, 0-61 ppm, 0-4.9 ppm, 0-0.8 ppm, and 19.9-21.6%, respectively whereas concentrations of flammable gas (% lower explosive limit; [%LEL]) were not detected. The highest concentrations of gases were at the middle depth pit level, inside the paddy piles with the highest moisture contents (>30% w.b.). The detected concentrations of gases were higher than limit values based on time-weighted average but below limits immediately dangerous to life.

Conclusion: Although oxygen-deficient atmosphere was not detected under the working conditions of the survey. The findings demonstrated that concentrations of hazardous gases were dependent on both storage time and the moisture content of paddy piles. Measures should be developed to ensure that entry into these pits strictly complies with safety laws.

Keywords: Confined space, hazardous atmosphere, hazardous gases, paddy, rice mill

Deaths occurring in confined spaces have been reviewed and reported at various sites in many countries [1]. In Thailand, occupational fatality reports required by law are incomplete [2]. During the last 20 years, between one to three cases per year of confined space fatalities have occurred in biomass pits, livestock manure storage pits, sewers and sewage pits, wells, grain silos, underground water sources and pumping stations, shipyard operations, and other sites [3]. In October 2004, a mass casualty incident occurred when seven workers died in an underground pit of a large rice mill in Khon Kaen Province, Northeast Thailand [4]. The report indicated that this incident took place in a pit where wet paddy pile was stored before being transferred to the drying process and asphyxiation was the cause of the deaths [4]. The epidemiology of confined spaces related to fatalities was reviewed.

Thailand is the world's largest rice exporter [5]. According to the Thai Department of Industry, 2006, there are approximately 40,000 rice mills in Thailand [6]. Rice mills are classified into three groups as large, medium, and small, based on their processing capacity [7]. In Thailand, the majority of rice mills is small and serves local customers. There are 483 large rice mills with a production capacity of more than 100 tons per day, which are rapidly replacing the smaller-sized mills

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with products for both local consumption and export. They are characterized as a modernized industry with high technology and mostly located in SuphanBuri, Phichit, and Nakhon Sawan [6].

Because there are no proper storage facilities at the rice fields, and financial reasons that force the farmers to sell their crop as quickly as possible, freshly harvested paddy is generally rapidly transported from the fields to local rice mills [8]. Moisture content and the temperature of paddy, freshly harvested from different areas, may differ considerably. The moisture content of harvested paddy generally ranges from 20% to 25% wet basis (w.b.), and may be as high as 22% to 30% w.b. [8-10]. Drying is needed in order to reduce seed respiration and avoid any damage induced by heat generated by this process [8]. The moisture content of paddy at about 13 to 14% w.b. is considered adequate for storage and milling [8, 10]. The basic goal of industrial rice milling is to transform unhulled paddy rice into hulled and polished white rice [11]. Several large rice mills have a bucket elevator, partially installed underground to transport wet paddy to the baking machine. The paddy delivered to the mill-feed area by truck is dumped at the in-take area or ground level pit, and usually left for a few hours. After that, it is directly transferred through a valve to an underground pit before being drawn by transfer chute to the drying machine in order to reduce its moisture content to 13 to 14% w.b. **(Figure 1).** If the amount of deposited paddy exceeds the loading capacity rate to translocate paddy to the baking machine, the wet paddy may be allowed to stand for one to three days near the in-take area.

Toxic gases are known to be one type of hazard arising in confined spaces. In grain silos, the most hazardous gas produced from fermentation is reported to be nitric oxide. When combined with oxygen, it produces nitrogen dioxide (NO_2) which is commonly referred to as “silo gas” [12]. Carbon monoxide (CO) may be produced from chemical reactions during the composting process or biodegradation of organic materials by microorganisms [13, 14]. Similarly, methane (CH_4) is also produced by anaerobic processes in an organic substrate [15, 16]. A case report published by the Fatality Assessment and Control Evaluation (FACE) Program of the US National Institute for Occupational Safety and Health (NIOSH) indicated that carbon dioxide (CO_2) is always produced during ensilage [17]. Asphyxiation will occur once the oxygen content of the air inside a confined space becomes too low to support life.

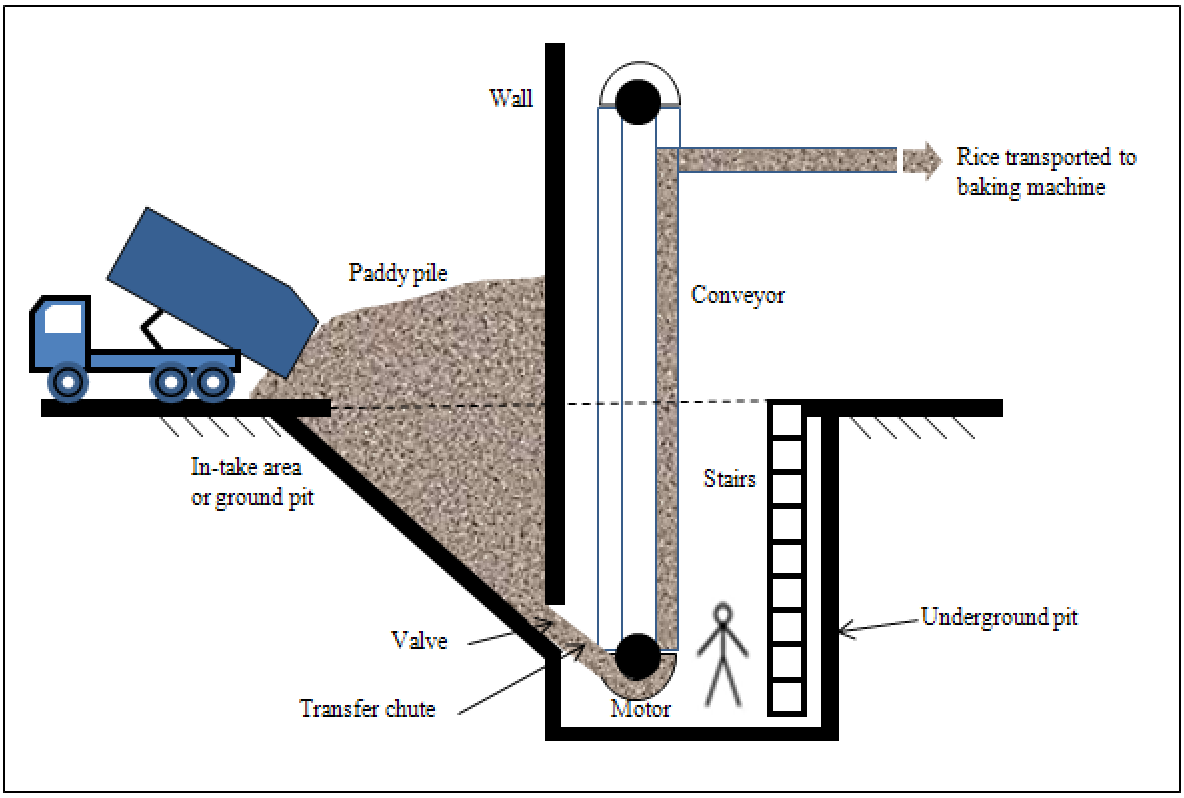

Figure 1. Side view of paddy loading area and underground pit in a rice mill

In Thailand, confined space incidents have occurred at various workplaces. They are rare, but severity can be extreme as a large number of fatalities may occur in a very short period. This suggested that there are conditions where the cause of death is from either oxygen depletion or gas asphyxiation. Therefore, the aim of this study is to determine levels of oxygen-deficient atmosphere and concentrations of hazardous gases in the underground pits of rice mills. The results can be used for safety guidelines at rice mill workplaces in Thailand to prevent asphyxiation associated with grain fermentation at storage sites.

Materials and methods

Study site

A descriptive, cross-sectional study was conducted at six large rice mills in Central, North, and Northeast Thailand. The criteria used to select each rice mill included its production capacity (>100 tons per day) as well as the availability of baking machines, mill-feed areas or ground pits to reduce the moisture content, and underground pits of 3 to 3.5 meters deep. **Figure 2** depicts the layout of the ground pit, paddy pile, and underground pit, which are normally available at large rice mills.

Data collection

Gas measurement was conducted between August 2007 and April 2008 in order to cover the period when paddy had been dispatched from the farms to the study sites. Measurement was performed over three different periods, each of which corresponded to Thailand's three seasons, rainy season (June until September), cold season (October until January of the following year), and hot season (February until May).

When a truck arrived at the rice mill, a sample of paddy was taken to measure moisture content. Then the rice mill process started, depending on the moisture content of the paddy. Generally, the moisture content of wet paddy at the mill could be classified into four groups;<14% w.b., 15 to 20% w.b., 21 to 30% w.b., and >30% w.b. The range of values at each level at some rice mills was less than 10% w.b. It is not easy to identify the real moisture content and the amount of paddy as well as the duration taken before the paddy was sent to baking process.

Each group of paddy was unloaded into the ground pit or receiving area to reduce its moisture content via drying. Gas measurement was conducted during this drying process. Although the drying process usually continues 24 hours a day, gas measurement was conducted only at intervals of 8 hours throughout each day. Consequently, these measurements cannot necessarily represent the conditions throughout the whole day. However, we assumed that the number of measuring times would be sufficient to serve as a guide to conditions in all underground pits of rice mill factories.

This study involved measurements of gas concentrations of each underground pit into which paddy was piled. The concentrations of CO_2 and N_2O were measured with a portable infrared spectrophotometer instrument (Foxboro, Model MIRAN 1BX) while the concentrations of CO, NO_2, flammable gases (% LEL), and O_2 were measured with a multi-gas detector (RAE, Model QRAE plus).

The protocol described by the Occupational Safety and Health Administration (OSHA) 1910.146 [18] for atmospheric testing in a confined space was applied in these measurements. In brief, a gas sample had to be taken from each of three levels (i.e., the

Figure 2. Working areas showing the confined spaces within a large rice mill

top, the middle, and the bottom) of the underground pits using a direct gas detector. The gas samples from the top level were taken at ground level (the top of the pit), whilst the samples at the middle and the bottom levels were taken at 1.5 to 1.75 m and 3 to 3.5 m below the ground level, respectively.

Ambient air samples were collected at approximately 1.5 m above the pit, which was near the workers' breathing zone. The quality assurance protocols included daily zero fresh air calibration of the equipment prior to sampling/testing. This procedure was carried out by exposing the inlet to 'clean' air in order to determine the zero point of the sensor. The measuring instrument was set to give the results at the minimum response time so that the concentration of gases could be read immediately. The definitions of a hazardous atmosphere was based on the oxygen content in the air, the flammability characteristics of the gas, and the concentrations of toxic substances as per the NIOSH publication [19].

Results

During the gas measurement period, air temperature and relative humidity (% RH) ranged from 22.1to 36.5ºC and 40.7 to 82.0%, respectively. Concentrations of CO_2, CO, N_2O, NO_2, flammable gas, and O_2 in the pits at three different depth levels are shown in **Table 1**.

Table 1. Range and median (Interquartile range) for concentrations of hazardous gases and percentage of O_2 in the underground pits of the rice mills at different depth levels

Concentrations of gases at different depth levels	Levels of paddy moisture content			
	<14% w.b. (n=120)	**15-20% w.b. (n=294)**	**21-30% w.b. (n=222)**	**> 30% w.b. (n=63)**
CO_2 (ppm)				
Top	1.7-46	5.2-3149	12-4023	65-5140
Middle	5.4-54	6.4-860	1.9-3978	141-5438
Bottom	12-117	4.2-574	10-3465	138-4980
Median (IQR)	**26 (28.2)**	**68.5 (142.5)**	**416.5 (907.3)**	**3987 (943.5)**
CO (ppm)				
Top	0-3	0-3	0-14	0-61
Middle	0-3	0-3	0-11	0-51
Bottom	0-3	0-3	0-13	0-48
Median (IQR)	**0 (0)**	**0 (0)**	**1 (1)**	**12 (26.5)**
N_2O(ppm)				
Top	0-0.2	0-1.2	0.1-3.9	0.2-4.9
Middle	0-0.3	0-0.9	0-3.5	0.4-4.6
Bottom	0.1-0.4	0-1	0-3.3	0.3-3.7
Median (IQR)	**0.1 (0.1)**	**0.2 (0.2)**	**0.45 (0.5)**	**1 (1.4)**
NO_2 (ppm)				
Top	0-0.3	0-0.5	0-0.8	0-0.2
Middle	0-0.3	0-0.5	0-0.6	0.1-0.6
Bottom	0-0.3	0-0.5	0-0.6	0-0.4
Median (IQR)	**0.1 (0.1)**	**0.1 (0.1)**	**0.1 (0.1)**	**0.1 (0.1)**
O_2(%)				
Top	20.9-21.2	20.9-21.6	20.2-21.3	19.9-20.6
Middle	20.9-21.4	20.5-21.4	20.2-20.9	20.1-20.6
Bottom	20.9-21.4	20.3-21.3	20.2-20.9	19.9-20.6
Median (IQR)	**20.9 (0)**	**20.9 (0)**	**20.9 (0.1)**	**20.4 (0.5)**
Combustible gases(% LEL)	**0**	**0**	**0**	**0**

CO_2 concentration increased as the level of moisture content increased. The measurement results showed that the concentration of CO_2 was in the range of 1.7 to 117 ppm with a median of 26 ppm for the <14% w.b. group; 4.2 to 3149 ppm with a median of 68.5 ppm for the 15 to 20% w.b. group; 1.9 to 4023 ppm with a median of 416.5 ppm for the 21 to 30% w.b. group; and 65-5438 ppm with a median of 3987 ppm in the >30% w.b. group. The highest concentration was 5438 ppm in the >30% w.b. group whereas the lowest concentration was 1.7 ppm in the <14% w.b. group. In this survey, there was considerable heterogeneity in gas concentrations at different pits levels and with respect to three levels of the pits where the gas samples were taken **(Table 1).** For all samples, the CO_2 concentration found at the middle level in the >30% w.b. group was higher than the value of the threshold limit value - time weight average (TLV-TWA) standard (5,000 ppm) [20], but it was below the value classified as hazardous atmospheric condition by the threshold limit value - immediately dangerous to life or health (TLV-IDLH) standard [20].

CO concentrations were in the range of 0 to 61 ppm and these concentrations increased as moisture content increased: 0 to 3 ppm with a median of 0 ppm in the <14% w.b. group; 0 to 3 ppm with a median of 0 ppm in the 15 to 20% w.b. group; 0 to 14 ppm with a median of 1 ppm in the 21 to 30% w.b. group; and 0 to 61 ppm with a median of 12 ppm in the >30% w.b. group. The highest concentration was 61 ppm in the > 30% w.b. group while the lowest was 0 ppm, which occurred in all groups. For all readings, the concentration of CO was below the TLV-IDLH standard [20] and very low concentrations were found in three of the four groups (i.e., <14% w.b., 15 to 20% w.b., and 21 to 30% w.b.) at all pit levels. In the >30% w.b. group, CO levels were higher than in all other groups and the highest concentrations were found to be at the top level, that is at the ground level or the top of the pit. The CO concentrations at this level of moisture content can increase up to over 25 ppm TLV-TWA standard [20]. Though such an increment is not necessarily dangerous nor immediately life threatening, it could be potentially hazardous in a confined workspace.

The concentration of nitrous oxide (N_2O) ranged from 0 to 0.4 ppm with a median of 0.1 ppm in the <14% w.b. group; from 0 to 1.2 ppm with a median of 0.2 ppm in the 15 to 20% w.b. group; from 0 to 3.9 ppm with a median of 0.45 ppm in the 21 to 30% w.b. group, and from 0.2 to 4.9 ppm with a median of 1 ppm in the >30% w.b. group. The highest concentration was 4.9 ppm in the >30% w.b. group while the lowest concentration was 0 ppm in all groups, except 0.2 ppm in the >30% w.b. group. The highest N_2O concentration in each sample group was found at the top levels. Not all measured values of N_2O concentrations exceeded the TLV standard values [20].

The NO_2 concentration was 0 to 0.3 ppm with a median of 0.1 ppm in the <14% w.b. group; 0 to 0.5 ppm with a median of 0.1 ppm in the 15 to 20% w.b. group; 0 to 0.8 ppm with a median of 0.1 ppm in the 21 to 30% w.b. group; and, 0 to 0.6 ppm with a median of 0.1 ppm in the >30% w.b. group. Additionally, the highest NO_2 concentration was 0.8 ppm in the 21 to 30% w.b. group whilst the lowest level in all sample groups was 0 ppm but all measured values were acceptable according to the TLV standard [20]. Combustible gases (% LEL) were not detected in any samples of all paddy groups at all levels of the pits.

The O_2 concentration in the underground pit once the paddy had been piled (divided into four groups by its moisture content: <14% w.b., 1 to 20% w.b., 21 to 30% w.b., and >30% w.b.) ranged from 19.9 to 21.6%. The O_2 concentration range was 20.9 to 21.4% (median 20.9 %) in the <14% w.b. group; 20.3 to 21.6% (median 20.9%) in the 15 to 20% w.b. group; 20.2 to 21.3% with a median of 20.9% in the 21 to 30% w.b. group; and 19.9 to 20.6% (median 20.4%) in the >30% w.b. group. The highest O_2 concentration was 21.6% in the 15 to 20% w.b. group and the lowest was 19.9 % in the >30% w.b. group. Based on regulatory standards, the minimum permissible oxygen level was <19.5% [18].Thus, all pit areas met the standards. The minimum O_2 concentration in the >30% w.b. group was 19.9% compared with the OSHA permit-required confined spaces regulation limit of 19.5% [18].

Discussion

This study employed direct reading instruments that allowed us to quickly identify high-risk areas in confined spaces or potentially hazardous areas before entering them. Based on our observations, it is reasonable to assume that direct reading instruments are suitable for measuring environmental conditions in underground pits of rice mills. Sample collection may be conducted when the rice was piled at the ground pit.

The highest CO_2 concentrations were found at >30% w.b. (high moisture group), probably because aerobic respiratory activities normally take place under at higher moisture contents [21]. Moreover, this higher level was also found at the top and the middle levels of the pits, probably because it is heavier than air and can displace oxygen gas. However, CO_2 concentrations were still lower than the hazardous level defined in the TLV-IDLH standard [20]. These values are inconsistent with several studies in which higher levels of CO_2 had been found in forage tower silos [22, 23] and its concentration started increasing within five minutes after ventilation had been stopped [22]. In these reports, CO_2 concentration always exceeded the safety standard. The lower levels in these studies may have resulted because the conveyor and bucket elevators were operated while the measurements were taken in our study. In a study by the NIOSH FACE Program [17], CO_2concentrations decreased from 2% to <1% within 3 minutes once the ventilation started.

The results of our site survey indicated that CO was found in the pits, similar to a study conducted by Hellebrand [24], in which grass was composted for a few days. Moisture content may play an important role in determining CO concentrations. It is unlikely that CO in our study was actually present in the quantity indicated in the silo study by Groves and Ellwood [22] but the CO concentrations in the highest moisture sample group were higher than other sample groups in all of the study sites. Furthermore, the highest CO level was found at the ground level or the top of the pit, possibly due to the lower molecular weight of CO, compared to those of other gases. CO concentrations were found to be higher than the TLV-TWA, but did not exceed the TLV-IDLH. Some degree of ventilation induced by the running bucket conveyor could be the cause of this.

The presence of silo gas comprising mainly NO_2, within silos, has been well documented. It was reported that NO_2 levels exceeded the threshold limit value – short term exposure limit (TLV-STEL) standard in hay and grain storage silos [25] and were produced during the early stage of silage-making before the accumulation of this gas occurred on top of the silage [22]. Similarly, Kedan [25] reported that NO_2 levels exceeded the TLV-STEL in hay and grain storage silos after six days. Moreover, silo gas formation started immediately after the forage had been stored inside a silo and reached its peak within 2 to 3 weeks after storing [22]. These previous results are at variance with our study in which lower concentrations of both NO_2 and N_2O in all sample groups were found. It may be possible that the few hours during which harvested paddy was piled prior to baking process, were not long enough for the formation of both gases. In addition, the measurements were taken while the machine was operating and this allowed some ventilation that decreased NO_2 concentration to less than the TLV-STEL standard within 16 minutes after ventilation in the silo had begun [23].

Flammable or combustible gases were measured as % LEL. In the current study, none was detectable at any levels of the pit area. The same measurement in the silos examined in the NIOSH FACE Program gave similar results. Thus, a study of flammability of silo gases is unlikely to be of particular interest [23].

O_2concentrations in the pit were lowest when moisture was highest, perhaps because O_2 itself was consumed in the production of CO_2, CO, N_2O, and NO_2 when paddy with a moisture content over 30% w.b. was piled at ground level. O_2 concentrations measured were 19.9-20.6%, especially at the middle and bottom levels of the pit. However, we found O_2 values were close to normal (i.e. 20.9% = normal) for the samples with lower moisture content. By contrast, O_2 concentrations were lower in all areas of the headspaces of silos [23, 25]. Although wet paddy was piled at the ground level, much higher than the underground base, gas that is heavier than air such as NO_2 emitted from the piled paddy could flow downward to the underground pit and displace O_2 inside the paddy pile.

Hypothesized reasons for low or decreased O_2 concentrations in the pit were: 1) Hazardous gases formed inside the piled paddy could flow downward, under gravity, and displace the O_2 inside the pit, 2) The lack of ventilation fans in the pit and, 3) The conical shape of the mill feed into the pit.

O_2 concentrations close to normal may be the consequence of operating the conveyor that induced forced ventilation. A similar situation was also reported in the silo where O_2 concentrations were restored to the ambient levels within 8 to 20 minutes [23]. While such values measured from the pits at all study sites met the safety standards, the minimum O_2 concentration of 19.9% (the minimum permissible oxygen level) was found at the bottom level of the pit where the paddy with highest moisture was piled.

Consequently, this may cause a potentially hazardous situation for workers in this type of confined space.

Conclusion

The concentrations of most gases presented in this report were below those of TLV-IDLH standards but the findings indicate their potential to create a hazardous work environment. In addition, their highest concentrations and the lowest oxygen levels were measured from the paddy with the highest moisture content (>30% w.b.). The middle level of pits was where the highest concentrations of most gases were found.

Where we found there was no hazardous atmosphere in the confined spaces studied, according to current occupational exposure levels, it is evident that an oxygen-deficient atmosphere could develop and present an important hazard in underground pits where paddy is piled at the ground pit in order to reduce its moisture content. The data show that the higher and the longer the wet paddy is piled, greater quantities of hazardous gases could be formed and replace O_2 inside the pit. Our findings indicated that hazardous gases produced from fermentation inside wet paddy pile could track through the underground pit once wet paddy was dumped from a truck into an empty ground pit. Therefore, the risks are likely to be greatest for those working in the innermost areas of the pit.

Therefore, in order to prevent hazardous conditions and protect workers in mill pits, we recommend that rice mills should provide appropriate procedures to decrease moisture content of fresh paddy. Rice mills management must raise the awareness of workers about the potential dangers of confined spaces. An emergency rescue service should be available during the entire entry procedure to ensure prompt entrant rescue. Finally, properly trained workers able to perform their duties during rescues and use any equipment should be available.

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