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Bowtie Method: Study of Occupational Health and Safety Risks in Cement Production Process

Metode Bowtie: Studi Risiko Keselamatan dan Kesehatan Kerja pada Proses Produksi Semen

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ABSTRACT

The kiln area is an area that has a very complex hazard potential in the cement production process. This study aimed to assess the risks of occupational safety and health during the production process in the kiln area of PT. X uses the bowtie method. This study used a qualitative descriptive design. The informants used were three managers of the clinker production department, one safety manager, and one field operator. Research data were collected through interviews and observations. The data were analyzed qualitatively using the bowtie method. The study results stated that hot dust could be dangerous if it comes out of the system caused by positive pressure, such as the Induced Draft Fan (IDF) turning off, causing losses such as burns to workers. Heat can be dangerous if it experiences a significant increase due to excess fuel, causing losses, such as health-related illnesses. Preventive controls were carried out such as routine inspections. Mitigation controls were carried out such as light signals. Escalation factors can thwart hot dust and heat control, such as the deformation of raw meals. Escalation factor control, such as the implementation of work instructions. PT. X has carried out control in the kiln area, but additional controls are needed.

ABSTRAK

Area kiln merupakan area yang memiliki potensi bahaya yang sangat kompleks dalam proses produksi semen. Penelitian ini bertujuan untuk mengkaji risiko keselamatan dan kesehatan kerja selama proses produksi di area kiln PT. X menggunakan metode bowtie. Penelitian ini menggunakan desain deskriptif kualitatif. Informan yang digunakan adalah tiga orang manajer departemen produksi klinker, satu orang manajer keselamatan, dan satu orang operator lapangan. Data penelitian dikumpulkan melalui wawancara dan observasi. Data dianalisis secara kualitatif menggunakan metode bowtie. Hasil penelitian menyatakan bahwa debu panas dapat membahayakan jika keluar dari sistem yang disebabkan oleh tekanan positif, seperti Induced Draft Fan (IDF) mati, sehingga menyebabkan kerugian seperti luka bakar pada pekerja. Panas dapat membahayakan jika mengalami peningkatan signifikan karena kelebihan bahan bakar sehingga menyebabkan kerugian, seperti health related illness. Pengendalian preventif yang dilakukan seperti inspeksi rutin. Pengendalian mitigasi yang dilakukan seperti sinyal lampu. Faktor eskalasi dapat menggagalkan pengendalian dari debu panas dan kontrol panas, seperti deformasi raw meal. Pengendalian faktor eskalasi, seperti penerapan instruksi kerja. PT. X telah melakukan pengendalian di area kiln, tetapi perlu adanya penambahan pengendalian.

INTRODUCTION

Improving infrastructure in developing the economy and basic services is one of the agendas of the *Rencana Pembangunan Jangka Menengah Daerah (RPJPN)* 2005-2024. Infrastructure improvements are carried out on dams, irrigation, toll roads, new roads, bridges, flyovers or underpasses, drinking water channels, sanitation and slings, slum cultivation, and housing. The increasing in infrastructure is directly proportional to the increasing demand for cement used as a basic building material, so cement factories must ensure that the production process remains normal to meet demand.[1]

One aspect that can ensure the production process can run optimally is to ensure the safety and health of workers. Occupational safety and health are very important to be applied in the production process so that workers can avoid the risk of accident and occupational disease so that the production process continues and workplace productivity can be achieved optimally.[2]

Cement plant, where the production process happens, has a variety of potential hazards that can affect Workers' Healthy and Safety as well as the surrounding environment.[3] Potential hazards and risks that can arise from these hazards in the form of dust which can cause respiratory disorders, noise which, can cause hearing loss, toxic gases (CO, CO_2, NO_X, SO_2), electrical hazard, kiln thermal load hazard, fire, and work accidents due to material handling.[3–5]

Several studies have shown the statistics of accidents in the cement industry, including research by Sah, et al in cement industries of Nepal showed that in 2017 until 2018 where 305 accidents consists of 291 minor accidents and 14 major accidents.[6] The research of Fresenbet, et al conducted at two cement factories in West Shoa Zonal Capital Ambo, Ethiopia on October 15-December 15, 2020 showed that there were 48.9% of workers who reported experiencing workplace injuries during the last 12 months.[7]

Workers in cement factory are at risk of being exposed to occupational hazards that cause workplace injuries, death, and health problems such as allergies, damage to workers' hearing, and respiratory problems.[8] The cement production process is divided into two stages, namely 1) the crushing, mixing and roasting of raw materials (silica, calcium carbonate, oxides of alumina and iron), 2) milling of clinker. Cement production goes through a series of processes such as crushing, raw material handling, grinding clinker, blending, packing and shipping of the final product of cement clinker. During all these processes, health and safety hazards are unavoidable for workers.[8]

The kiln area, one of the areas where clinker is produced, has the most potential hazards. Potential hazards in the form of dust, toxic gases, high heat radiation, noise, heavy workload, and additional materials.[5,8] To minimize losses such as accidents, health problems, environmental damage and other material losses, due to existing hazards, risk analysis is needed. One method that can be used to assess or analyze occupational safety and health risks in the cement industry is the bowtie method.

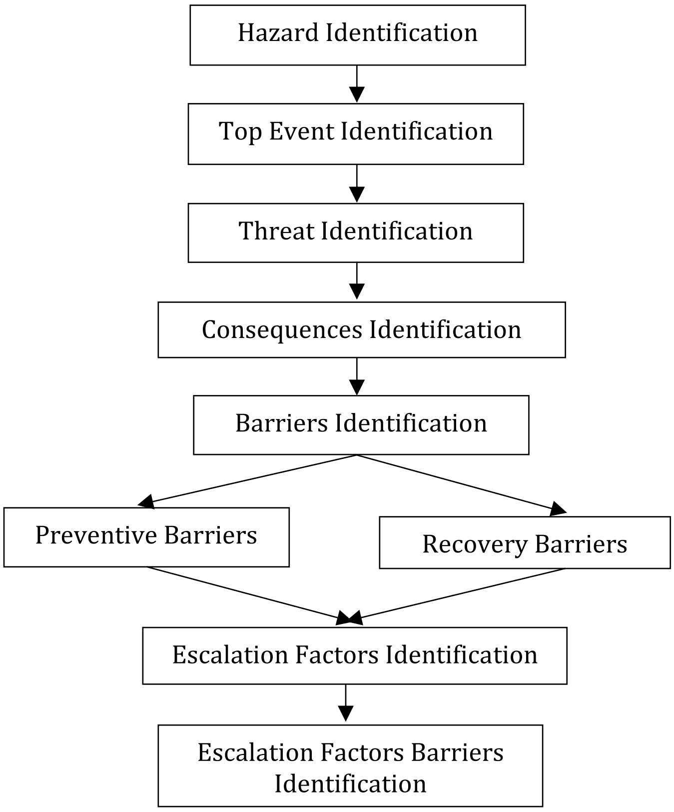
Bowtie method is a method used to analyze and describe risk paths from causes to impacts with simple diagrams.[9] This method is also recommended by ISO 31000 because it can be used to determine the cause and effect of hazard so that control can be carried out against the hazard.[10] In Ardi's research (2020), this method is used as a risk analysis based on causality so that the results of significant risk and high risk are obtained for workers.[11]

The analysis of bowtie method starts from the top event, which is an event that releases danger. Then the causes and consequences of the incident will be determined so that control measures (barriers) can be found to reduce the likelihood of the incident and the severity of the consequences of incident. Therefore, the purpose of this study is to analyze any possible risks of work accidents that can occur, identify the source of causes, impacts, and controls on the risk of work accidents at PT. X.

MATERIAL AND METHOD

The design used in this study is descriptive with qualitative design. This research was conducted on kiln areas in one of the biggest cement industries in Indonesia. The informants in this study consisted of three managers of the clinker production department, one safety manager, and one field operator, who were selected based on purposive sampling. Data collection was collected by interviews, observations, and document review. Processed data is displayed into bowtie diagrams and narratives.

Analysis of occupational safety and health risks in the kiln area using the bowtie method. The bowtie method is a qualitative analysis to show causal relationships in high-risk scenarios. Risk analysis begins with the determination of high risk in the kiln area through hazard identification data that has been made by the company and then consults it to informants. Afterward, the identification of a top event which is the first state when the hazard is not controlled, identification of the threat (potential cause) and its impact to determine the losses of the top event, and identification of preventive control and control barriers so as not to cause or aggravate the impact. Next, identification of escalation factors (circumstances that can reduce the effectiveness of preventive controls and barriers) and identification of barriers to escalation factors to prevent escalation factors from occurring. The research flow using the bowtie approach is shown in the figure below (Figure 1).



Source: Secondary Data, 2015[12]

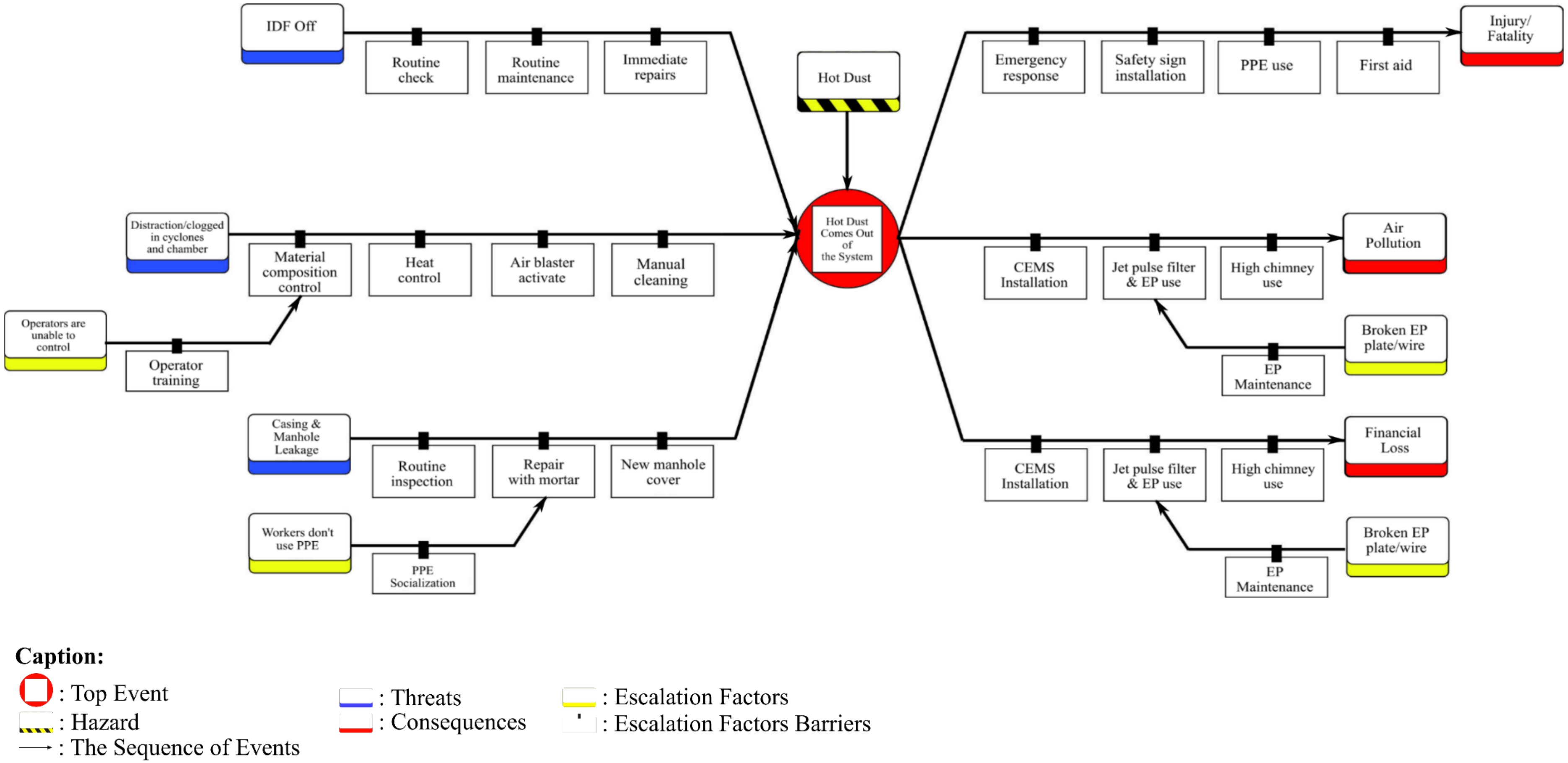
Figure 1. Risk Analysis with the Bowtie Method

RESULTS

Identification of potential hazards is conducted at each stage of the production process in the kiln area by taking into account activities, materials, or situations that may cause harm or disease due to work. The hazard analyzed in this study is that hazard with a high level of risk as part of normal production process in the kiln area. Based on the results of hazard identification that refers to the data of Hazard Identification, Risk Assessment, and Risk Control (HIRARC), direct observation, and interviews with informants, it is found that potential hazards that have a high level of risk in the kiln area of PT. X ishot dust and a hot working climate. Then, the analysis was carried outby using the Bowtie method, see Figures 2 and 3.

Hot dust which gets out of the system is a hazard with a top event. IDF failure, blockage in the cyclone and camber area, and explosion due to incomplete combustion are three threats that can cause dust to be discharged from the system. A few steps may be done to prevent hot dust from escaping the system when the IDF fails, including routine checks, routine maintenance, and immediate repairs. Many measures can be taken to prevent hot dust from escaping the system when a dead-end arises in the cyclone and chamber area, including material composition control, hot control, air blaster active, and manual cleaning.

Material composition control can fail if the operator is unable to control it. However, this can be avoided by operator training. When casing and manhole leaks occur, a few steps may be done to prevent hot dust from entering the system, including routine inspections, mortar repairs, and the installation of new manhole covers. When workers do not utilize PPE, mortar repairs can fail, but this can be avoided by socializing PPE. When heated dust escapes the system, it can cause injury/fatality, air pollution, and financial loss, among other things. Before inflicting injury/fatality, various safeguards can be done before inflicting injury/fatality, including emergency response, safety sign installation, PPE use, and first aid. Before producing air pollution and financial losses, numerous safeguards can be taken before producing air pollution and financial losses, including the installation of CEMS, the use of jet pulse filters and ESP, and the use of high chimneys. Jet pulse filters and ESP can fail due to a broken ESP plate / wire, although ESP maintenance can prevent this (Figure 2).



Source: Primary Data, 2020

Figure 2. Bowtie Diagram of Hot Dust

Heat is a hazard that has a high probability of occurrence, especially increased heat. Excess fuel and less material are two risks that might cause heat to rise. When there is a surplus of fuel, a Pfister can be used to reduce the heat before it becomes unbearable. Bearing failure can cause Pfister to fail, however this can be avoided with proper maintenance training. When the material is insufficient, some steps can be taken to prevent the heat from rising, such as regulating the material. Material control can fail if operators are unable to control it, although this can be avoided with proper operator training. Three things can happen when the increased heat such as tool malfunction, heat-related illness, and clinker production disruption. Numerous safeguards can be performed before causing a tool malfunction, including fuel descent and inching kiln. Control with fuel descent can fail to owe to bearing failure, however maintenance training can help prevent this. Several precautions can be taken before causing heat-related illness, including working on the job instruction, PPE use, and first aid. Before disrupting clinker production, numerous safeguards can be taken, including fuel descent, air blaster activation, and hand cleaning. Control with fuel descent can fail to owe to bearing failure, however maintenance training can help prevent this (Figure 3).

Hot dust is one of the cement forming materials that can be dangerous if it goes outside the system. Hot dust can get outside the system in case of a control failure from the operator which causes the pressure to become unstable and stretched between the constituent components of the system, making a pathway for hot dust to come out of the system. Meanwhile, a hot working climate occurs because the temperature at work increases due to the uncontrollable release of hot dust. In addition, heat can also increase as a result of the excessive burning of coal. Based on the research results, it is determined that the top event of hot dust is its release from the system and the top event of the hot working climate due to the increasing of uncontrollable heat temperature.

Sudden positive pressure is a potential cause (threat) of the hot dust release from the system. Positive pressure occurs because the Induced Drive Fan (IDF) is turned off so there is no airspeed to maintain pressure. In addition, disturbances or dead ends in cyclones chambers and explosions from incomplete combustion can also result in positive pressure. This is determined based on the results of interviews that have been conducted. Meanwhile, the potential causes of increased heat are excess fuel and oxygen and less material.

"Hot dust is caused by positive pressure, sohot dust can come out of the system. This positive pressure can occur because the fan is off so there is no airspeed to maintain the pressure. Disruption in the cyclone can also cause the same positive pressure if there is an explosion due to imperfect combustion. So, from the CO that reacts, hot dust can come out of the leaking casings." (MAF)

Hot dust and hot working climates can have effects on workers. Hot dust can cause losses in injuries, burns and even death. In addition, air pollution and financial losses can also occur. Meanwhile, heat that continues to increase during the production process can affect the tool, heat related illness, and Clinker production disruption. Based on work accident data of PT. X, it isfound that there are field workers exposed to hot dust when making up the closing of check hole where there was a sudden positive pressure. In addition, from the observations it is determined that the heat in the kiln area can reach three meters from the tool assess that workers can experience heat related illness complaints due to heat exposure.

Controlling the hot dust and hot working climate is needed to protect the workers. To avoid the releasing heat dust from the system, it needs routine checks and maintenance on the IDF and immediate repairs to control the IDF to keep it rotating. In addition, to keep the cyclone or chamber area from experiencing interference, material and heat control carried out. When a cyclone or chamber is disrupted, to prevent hot dust from escaping the system, the activation of the air blaster is carried out. If there is a dead-end in the chamber due to dust building up, manual handling will be done to break down the impasse. Observations and document review show that air blasters have been installed at some of kiln area points and maintenance is carried out periodically. In addition, the use of lights, installation of hazard signs, the manufacture of work permits, and the use of personal protective equipment are also carried out to minimize workers exposed to hot dust. Meanwhile, heat is controlled so it does not cause harm by controlling excess fuel and oxygen.

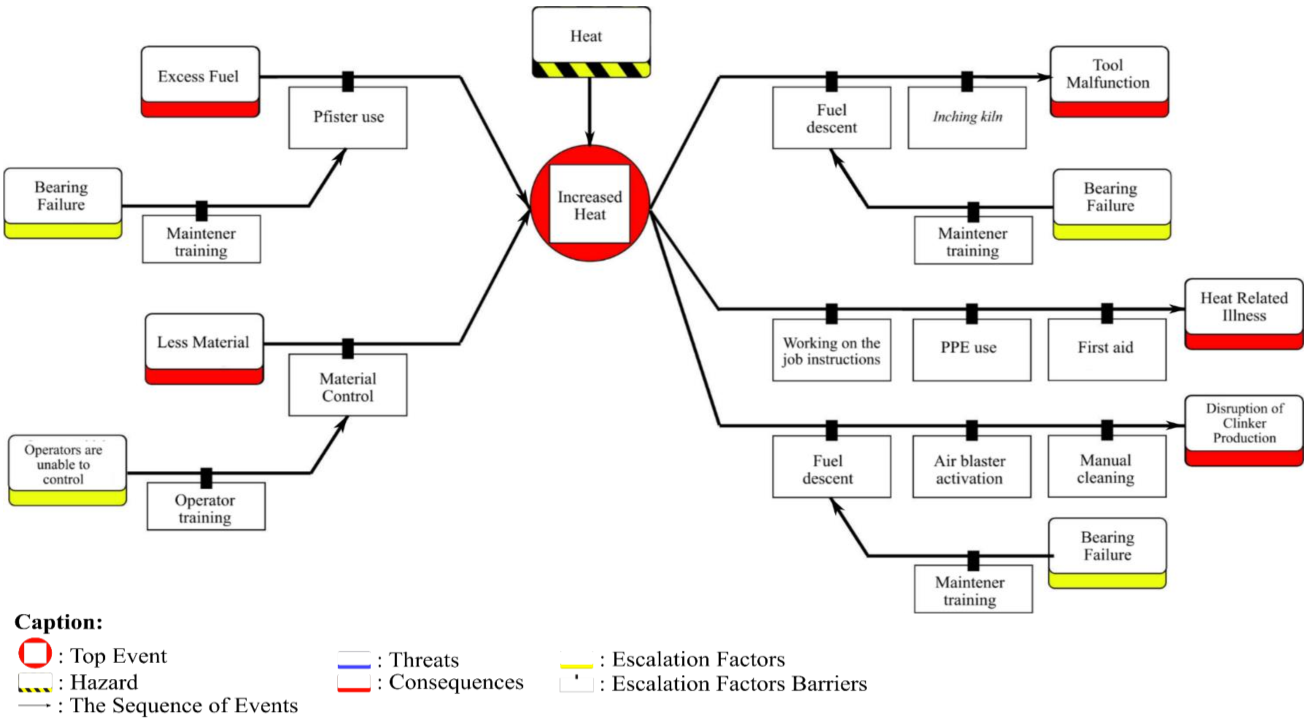
"We control the material composition and combustion heat, and for heat, dust does not come out continuously we activate the air blaster so that air fired into the dead end can also be cornered manually." (IS)

From the results of the study, it is determined that preventive control is carried out to prevent the release of hot dust by preventing incomplete combustion. Therefore, the preventive control is the installation of a gas analyzer to monitor oxygen so that it can be immediately handled if there is an excess, Pfister feeder to regulate fuel, and weigher control by the Central Control Room (CCR) to regulate or control the material.

The results also showed that control barriers were carried out so that hot dust does not cause burns to workers. These are in the form of work permit manufacturing, installation of safety signs, and inspection of K3 object equipment. To reduce the serious impact of burns, workers are required to use PPE and perform first aid. In addition, prevention is also carried out in the form of good housekeeping, safety patrol, and safety education through safety meetings, safety talks, and safety induction. Barrier controlto overcome air pollution due to dust and financial losses is the use of Continuous Emissions Monitoring System (CEMS), increased dedusting system utilization, such as double jet pulse filters and optimization of inspection and maintenance on Electrostatic Precipitator (ESP) components and baghouses.

Meanwhile, barrier control is carried out so that heat does not damage work equipment, namely fuel reduction and inching kiln. To prevent workers from experiencing a heat related illness, working based on the instructions and use of PPE. To overcome the disruption of clinker production, namely the decreasing of fuel and activation with air blaster.

Controls carried out on hot dust, and hot working climates can fail. The results showed that some controls may fail, such as workers' non-compliance with PPE use due to forgotten or uncomfortable workers, poor material and fuel, slabs or broken ESP wires, and use of Pfister feeder due to damage to seals or bearings. Failure of control can be overcomed by controlling the cause of failure. The results showed that the control was carried out by PT. X, in order to determine the cause of failure is working based on work instructions, socialization of the use of PPE, routine maintenance of ESP and the use of bypass pipes.



Source: Primary Data, 2020

Figure 3. Bowtie Diagram of Heat

DISCUSSION

Hot dust and hot working climates are at high risk during the production process in the kiln area. This classification is in accordance with several studies which state that the high potential hazards that exist in the kiln area are dust, hot gases, toxic gases, high heat radiation, noise, and high workloads.[5,8] Hot dust in the clinker production process consists of dust mixed with hot gases, while the hot working climate is the temperature that increases due to combustion reaches 1800°C in the burning zone.[13] Based on HIRARC (Hazard Identification, Risk Assessment, and Risk Control) assessment by PT. X, workers have a degree of likelihood (likelihood of exposure) to hot dust and hot working climate in the moderate category, while the severity assessment is assessed to cause disability and even death, very serious impacts on the environment, and losses of up to 100 million.

Hot dust has a high risk if it is outside the system. This can occur because the pressure inside the system is unstable or experiencing the sudden positive pressure that is affected by the operator's ability to control pressure. In addition, heat has a high risk and becomes dangerous when the combustion temperature increases significantly. According to the standard, the heat in the burning zone should be no more than 1800 °C. Based on Brinell's hardness to temperature linkage diagram, the strength of steel can be reduced when the temperature is more than 300°C.[14] During the production process, steel which is the constituent component of the kiln shell has a temperature range between 200°C to 250°C.[14] Therefore, heat can become dangerous when the temperature increases from 100°C to1800°C in the burning zone without control.

Sudden positive pressure that can make hot dust out of the system is three potential causes: an inactive Induced Draft Fan (IDF), a dead-end in the chamber or cyclone area, and an explosion from imperfect combustion. The IDF serves to dissipate hot gas by dumping combustion residual gas into free air, so when the IDF is off, the fan rotation speed will slow down and make the pressure in the system become high in accordance with Bernoulli's law, pressure is inversely proportional to fastness.

Similar to the IDF, the impasse in the chamber or cyclone area causes the absence of the material flow that enters the system until the pressure in the system becomes high. In addition, explosions can occur when imperfect repairs of excess fuel form carbon monoxide. This process is in accordance with Hasnah et al. research, namely imperfect combustion in coal can cause explosions.[15,16] Increased heat also has three potential causes: excess fuel and oxygen, as well as less material feed. This cause is in line with the research of Rohmawati and Dzulkifih, namely oxygen in large quantities will produce high heat.[17]

Hot dust which comes out of the system can cause losses in the form of burns, air pollution and financial losses. Burns suffered by workers can cause injury and even death during complications. This loss is in accordance with research conducted by Karahan and Akosman, namely the risk of serious injury, death, and respiratory problems has the potential to guide kiln area workers.[8] In addition, hot dust can also cause air pollution and financial losses.

A significant increase in heat can cause losses in the form of tool damage, heat-related Illness, and clinker production disorders. The damage to the tool is affected by coating durability and the effectiveness of fireproof brick which is the heat retainer of kiln system, so that when the heat retainer melts then the kiln shell becomes incandescent. This damage is in accordance with research Ammarullah et al. in 2018, namely fireproof stone as kiln insulation can be damaged due to thermal load thus reducing the life of rotary kiln.[18] Heat related illness is experienced by workers who do not pay attention to work instructions when working in areas with a radius very close to the heat source and for a long time in line with Arianto and Prasetyowati in 2019, there is a link between the hot work environment and heat related illness complaints.[19]

Because of the large loss of hot dust comes out of the system and the heat that increases, control is carried out on the potential. Controlling to keep the IDF rotating, namely, routine inspection, routine maintenance, and immediate repairs. Control of the chamber or cyclone area deadlocked to control the pattern of operation, activate the air blaster, and corner the dead-end. The activation of air blaster aims to destroy clogging material, so that positive pressure only lasts a short time, according to Putra et al. research in

2018, namely air blaster serves as a tool that can release clumps (coating) material.[20] Blast control from combustion is not perfect, namely the installation of a gas analyzer and the use of a pfister feeder. The assumption of coal and excess oxygen, as well as less material bait, namely the use of pfister feeders and weighers in accordance with Rohmawati and Dzulkiflih research in 2017, namely the optimization of the combustion process in kilns is influenced by the control of exhaust gases O_2, CO, and NOx.[17]

Pfister feeder (fine coal feeder) is a coal feeder equipped with a heavy flow measuring device. Coal feeder is controlled by a controlling system based on PLC (Programmable Loci Control) and DCS (Distributed Control System). Where the desired setpoint flow rate entered in the dine coal feeder controlling module through the operator work station to get optimal combustion results.[21]

Hot dust that has came out of the system and heat that has increased can be directly controlled so that losses do not occur or do not get worse. Control in hot dust so that there is no burn, namely the use of light signals, installation of hazard signs, and work permits, while to minimize the severity is to use PPE. A momentary outage is a signal which indicates that workers should not be around the kiln area. Work permits are used on jobs related to flames as well as heights, such as patching activities.

The use of Personal Protective Equipment (PPE) can fail when workers do not use it appropriately and completely. This failure can be controlled by giving workers understanding towards the importance of personal protective equipment with socialization in accordance with zahara et al. research in 2017, namely compliance with the use of personal protective equipment has a close relationship with knowledge and behavior.[22]

Controlling on hot dust not to cause environmental pollution and financial losses, namely the use of CEMS, ESP, jet pulse filters, and high chimneys. CEMS is a sensor that continuously monitors air quality emission, while ESP and jet pulse filters are served to reduce the severity of dust coming out of the system.[23] In addition, bag filters can reduce dust emissions, and more effective in removing dust than Electrostatic Precipitator (ESP).[24]

Heat control is used to keep the tool away from the damage, namely lowering the amount of fuel and inching kiln. Decreased amount of fuel through the Pfister feeder includes immediate control, medium inching kiln includes controls performed when the heat is over controlled. Heat control so as not to cause heat related illness, namely the use of refractory bricks and steel coatings, work according to instructions, and the use of personal protective equipment. Refractory bricks and steel coatings act as insulation to reduce heat that creeps into the environment. The refractory bricks used in the kiln area has a high resistance toward temperature.[25,26] Heat control so it is not causing disruption of clinker production, namely a decrease in the amount of fuel and activation of air blaster. Decreased amount of fuel including immediate control as heat increases. A late drop in fuel can lead to the formation of a large snowman. If a snowman has been formed then the control that can be done, namely the activation of the air blaster.

Controls are carried out to prevent hot dust from escaping the system or heat increases and controls that are undertaken to reduce the severity or prevent losses which can fail or become ineffective. Control of operating patterns can fail when raw meals or coal fed into the system undergoes deformation. This failure can be controlled by the work instructions to control the operating parameters. In addition, the use of Electrostatic Precipitator (ESP) and baghouse filters can prevent any particulate matter escaping the process.[27,28]

ESP usage can fail when there is a broken building wire that causes electrode and anode to dust to decrease. This failure can be controlled through regular ESP maintenance in accordance with Doddamani's research, namely component repair and replacement and routine maintenance as well as checking can improve ESP efficiency.[29] Juarsyah et. al also mentioned by analyzing the Pfister feeder (fine coal feeder) control system in the combustion process against the level of CO gas produced and optimizing the PLC Fine Coal Feeder program to reduce fuel flow automatically before the CO gas level exceeds the protection limit on the ESP, it is expected to minimize interference with the ESP, equipment damage, environmental impact and operational losses.[21]

CONCLUSION AND RECOMMENDATION

Hot dust comes out of the system and a significant increase in heat are potential hazards with a high risk in the kiln area. Potential causes of such potential hazard become hazardous, namely the inactive IDF, dead-ends in the chamber or cyclone area, and explosions from imperfect combustion, excess fuel and oxygen, and less material feed. The impact of the potential hazard is in the form of burns, air pollution, financial losses of heat-related illness, damage to tools, and disruption of clinker production. Preventive control that can be done are routine inspection and maintenance, immediate repair, control of operating patterns, activation of air blaster, matching, installation of the gas analyzer, the use of Pfister feeder, and weigher, while mitigation control is carried out, namely the use of light signals, installation of safety signs, work permits, use of PPE, CEMS, ESP, jet pulse filter, and high chimney, fuel drop, inching kiln, the use of fire bricks and steel coatings, work according to instructions and activation of air blaster.

The escalation factors are the deformation of a raw meal or coal controlled by the application of work permit, damage to seals or rotary feeder bearings controlled by the installation of bypass pipes, do not use controlling PPE socialization, and damage to ESP components controlled through routine maintenance. Advice is given in the form of risk assessment at each stage of the production process in the kiln area, provision of electrolyte fluid during direct monitoring inching kiln, installation of heat signs, and dissemination of PPE use.

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