Research paper

Coal transfer facility fire at Taichung power plant-A case study

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Abstract

The Taichung thermal power plant, which is equipped with ten coal-fired steam generation units with total capacity of 5,500 MW in Taiwan, accounts for 20 % of the total power supply around the island with 23 million population; it is also the second largest coal-fired power station in the world. Coal is the main fuel used in the thermal power plant; during operation, it is transported on enclosed belts throughout the plant. However, spontaneous ignition of coal stockpiles increases the fire hazard for an entire power plant. Conveyor belts are widely used for coal transportation. However, there is a continuous fire risk in these facilities, and the occurrence of such an incident, in fact, is just a matter of time. Conveyor belts contain large amounts of polymeric materials; several factors can cause a fire, including frictional heat of the belt, malfunction of bearings of rollers, and coal which falls over a belt that must be properly governed to minimize the fire risk. Coal transferring facilities typically are exposed to fire risks because of two sources of ignition that need to be seriously considered. The first is the coal spontaneous ignition; the second is the conveyor belt used for coal transportation (hot burning coal, damaged bearings over-heating, roller, belt slip, and so on). This study focused on a conveyor belt fire in the Taichung thermal power plant on May 28, 2014. Based on the case analysis, the requirements and other mitigating factors affecting conveyor belt entry fires are thoroughly discussed, including fire detection systems, fire suppression devices, and cleanup of combustibles.

Keywords: coal-fired steam generation units, fire hazard, coal transferring facilities, mitigating factors

1. Introduction

Since 1945 in Taiwan, the Taiwan Power Company (Taipower) has shouldered the responsibility of power supply, whose business scope includes generation, transmission, distribution, and sales. Practically speaking, thermal power generation is a low-cost baseload power source and also the major source of electricity in Taiwan. In 2013, thermal power accounted for more than 76.3 % of Taipower's generated energy, 1.5 % of hydroelectric power, nuclear power accounted for 18.8 %, and renewable energy accounts for 3.4 %[1].

There are three major coal-fired power plants operating in Taiwan, including Taipower's Linkou, Taichung, and Hsinta power plants. The Taichung power plant consists of ten coal-fired generation units with capacity of 550 MW each, accounting for 20 % of the power supply in Taiwan that is currently the world's second largest coal-fired power plant.

This case study focused on the fire investigation and related fire operation techniques involved in this incident. It then analyzed coal-fired conveyor potential risks, and protection measures from international regulations, including fire detection, sprinkler system, and system maintenance to discuss the current status of coal-fired conveyor management in Taiwan.

2. Coal thermal power plant operation

A typical thermal power plant which converts thermal energy to mechanical energy can be divided into Rankine cycle, combined cycle, gas turbine, and diesel generator.

Figure 1 Layout of conveyor systems.

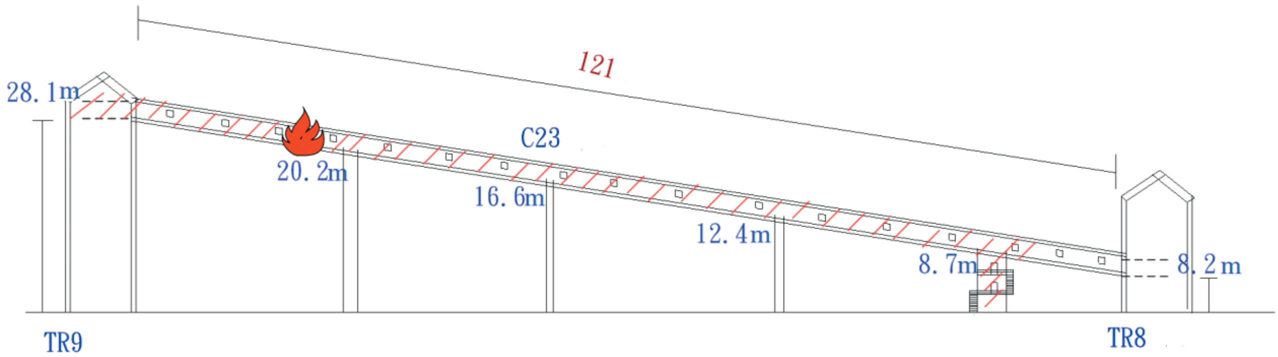

Figure 2 Layout of the conveyor system involved in the fire.

The Taichung power plant system was established to meet the long-term national economic development needs and energy diversification policy, as well as growth industry and commerce in the central region of Taiwan in the 1980s. The main operating module is the Rankine cycle, which uses coal as fuel. Its principle is the use of steam cycle, turning the chemical energy of fossil fuels to generate heat by combustion reaction, so that water is heated, and the steam from the water in the boiler is pumped into the turbine which drives an electrical generator. When the steam passes through the turbine, it is condensed in a condenser and recycled to where it was heated; this is the Rankine cycle. Finally, the electrical generator converts mechanical energy into electrical energy and delivers the latter to the country.

Coal is an essential element in the history of the industrial revolution. The physical and chemical properties of coal play a vital role in the spontaneous combustion involving large amount of coal. The standard of coal gross calorific value (GVC) for Taipower is between 5,000–6,400 kcal kg^{-1}. The samples were prepared according ISO standard methods (ISO 1988), and analyzed according to the following standard methods. The following is the composite result of analysis given in Table 2.

Taipower procures ca. 27 million tons of coal each year. It could lead rapidly to a major accident and damage because of spontaneous combustion both in indoor coal bunkers and outdoor coal stockpiles. A local fire (even a smoldering fire) caused by coal handling facilities failures might be a catastrophic event, affecting the electricity supply, not to mention the social outcry that may ensue. Coal from an unloading wharf before entering the boiler house must go through a complex and dense transport network in Taichung power plant (coal yard area of 68.0 hectares) which is transported on a conveyor length of 48.0 km. It is a major threat to an area of 277.5 hectares surrounding the power plant.

3. Experimental

3.1 Brief description of the fire

At 16:21 on May 28, 2014, information from Taichung Harbor Fire Brigade reached the Taichung power plant control center duty officer that the coal conveyor belt was on fire. The layout of the conveyor systems is shown in Figure 1. When the rescue vehicles arrived at the scene, TR9 transfer tower smoked overhead. C23 conveyor was connected to TR9 and TR8 transfer towers, and almost the entire coal conveyor-belt systems were in full blaze; especially, conveyor belt breakage fell above the weighbridge, with the fire burning fiercely focused on the bottom. After the fire was controlled, a 100 m conveyor belt was damaged along with a burning area of about 400 m^2. Apart from the conveying equipment burning, the fire did not spread elsewhere, and no casualties were reported. The layout of the conveyor system fire is schematized in Figure 2.

3.2 Areas covered by fire

When first responders arrived, tower TR9 burst out with a large amount of smoke overhead, as shown in Figure 3. The fire impact area from TR9 to the

Figure 3 Tower TR9 smoke overhead while the fire service was on scene.

Figure 5 Tower TR9 showing discoloration.

Figure 4 Weighbridge in full blaze.

Figure 6 Weighbridge bending from the heat.

weighbridge structure is shown in Figure 4. The conveyor ramp from north to south has an average height of approximately 20 m; in addition, there was considerable smoke and flame, with falling fly ash with smell of burning coal and rubber. Both sides of the enclosed conveyor and TR9 tower windows showed opened.

At initial stages of the fire, the plant staff attempted to use fire hydrants for the first response. The fire service used aerial ladder top-down water jet to attack the flames and cracked the windows around for ventilation. Connected to the transfer towers TR9 and TR8, conveyor C23, almost the entire coal conveyor-belt systems were in full blaze, especially conveyor belt breakage fell above the weighbridge. The fiercely burning fire was focused at the bottom. At 17:22 on May 28th, the fire was reported to be under control; at 19:13, the fire had been extinguished and continued to cool, and overhaul was carried out.

4. Results

4.1 Fire investigation

Fire investigation on transfer tower TR9, with metal heat discoloration growing close to TR8 (Figure 5), indicated that the C23 conveyor tunnel sheet metal was discolored and bent from the heat (Figure 6). Above the weighbridge was the serious part of the fire destruction. The weighbridge close to TR8 side was slightly heated by radiation[2].

Two power switch boxes showed slight surface discoloration in TR9; during the incident, the switches were in the "OFF" position. From examining the electrical wiring, there was no short circuit. According to the plant staff, no welding job was in progress.

Between the fourth and fifth windows on C23 conveyor tunnel, sheet metal fell off discolored and bent due to the heat. The bottom of the conveyor showed yellow-white discoloration after being heated, as shown in Figure 7. To clean up the conveyor tunnel on TR9 side at about 20 m, a through cut of the lower belt wire was made to remove the accumulation of coal and wash the floor process. It unveiled 1.0 m long, 0.3 m wide of heat discoloration traces as shown in Figure 8. By observing the position of the conveyor tunnel floor heat discoloration, it can be confirmed that it was the only spot where sheet metal fell off.

Figure 9 shows that there was no trace of heat on the tower TR8 surface. Therefore, the second floor of tower TR8 was where the broken conveyor belt slipped beneath the pulley, and a large amount of coal accumulation was found around the transit facility, upper layer, and conveyor support frame, as demonstrated in Figure 10.

Figure 7 On tower TR9 side at the range of 19.0–20.0 m (outside).

Figure 8 On tower TR9 side at the range of 19.0–20.0 m (inside).

Figure 9 Tower TR8 no heat trace on north side.

From the TR8 transfer tower towards tower TR9 was about 15.0 m, presenting a demarcation point in the conveyor tunnel system. Conveyor belt toward tower TR9 side remained as wire as the fire broke down (Figures 11 and 12); toward the tower TR8 side was only slightly heated. The linear head sensor and sprinkler head both functioned while the fire occurred, but were not effective

Figure 10 Coal accumulation around transport facilities.

Figure 11 Broken conveyor belt slipped.

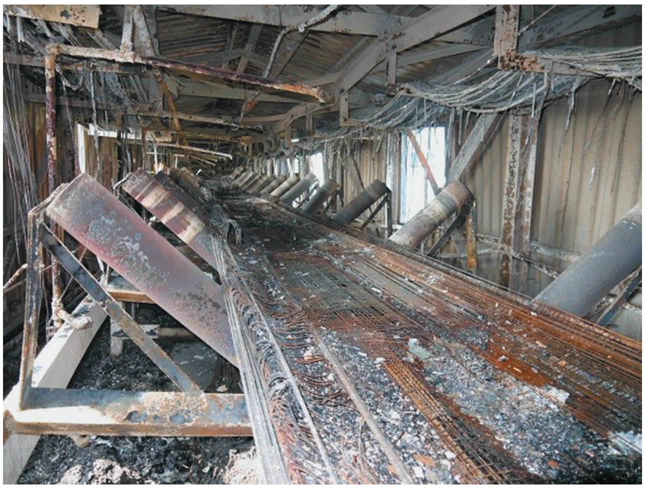

Figure 12 Conveyor belt remains.

due to the leaking and low pressure.

TR9 transfer tower showed heat discoloration, which was closer to the conveyor tunnel and there turned to be more serious. It shows the burnout on tower TR9 and C23 due to the fire flow from the conveyor tunnel. On the bottom of the conveyor tunnel, only the fourth and fifth windows toward tower TR8 appeared discolored as yellow-white after heating, which may be due to the longer burning period. Therefore, the tower TR9 transfer tower's fourth and fifth windows toward tower TR8 was the spot of initial burning with credible possibility.

4.2 Root cause of fire

According to the situation after the burning site, TR9 tower's two power switches were in the off position during the incident. Investigating the wire on both sides of conveyor tunnel revealed that traces of short circuit were missing, so a fire cause may exclude electrical equipment factors.

Another witness narrated that there was no explosion and no welding job in progress. After the scene was examined, no welding trace was found. Therefore, the fire cause may exclude welding factors and even arson.

The conveyor tunnel on TR9 side was at about 20 m, the auxiliary conveyor belt rollers leaned north; the top roller bearings were heated and bent more than others. The conveyor system found coal accumulation around the floor and upper roller bearings. According to the staff statements, the conveyor system had been shut down at 23:00. The malfunction of bearings of rollers supporting the belt might have run hot, with coal accumulation of contact with the surrounding parts which might have produced easy heat accumulation.

In summary, the scene confirms fire burning conditions; the root cause of fire due to coal's spontaneous combustion and equipment was heated up locally, initiating a local fire which promptly spread along the conveyor belt surfaces.

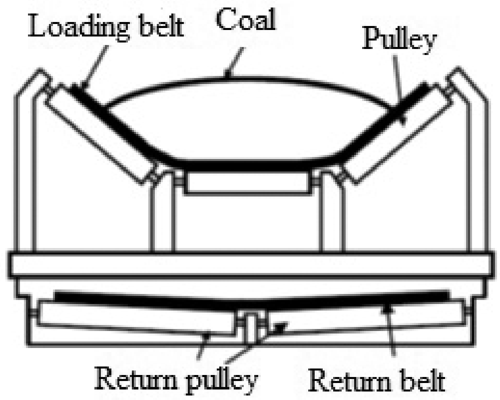

Figure13 Typical conveyor system.

Figure14 Conveyor belt in action.

5. Discussion

5.1 Design of conveyor system

Most conveyor belts are made of a synthetic resin or rubber (Figures 13 and 14), such as polyvinyl chloride (PVC), acetal compound ($R_2C(OR')_2$), polyethylene, and nylon. Although a conveyor belt has flame retardant properties, once a fire breaks out, the conveyor belt itself may contribute to the fire spread and even become a part of propagating of the flame along the belt surfaces.

In general, a typical conveyor belt fire grows in three stages:

- Smoldering stages of coal heating, due to overheated equipment or operating friction, to the point of flaming.
- Flaming stages of a small coal fire, which ignites a conveyor belt nearby.
- Fire combining coal and conveyor belt, which increases in intensity to the point of sustained flame spread[3].

Because the coal conveyor system is normally used only on special occasions, there are no fire safety design specifications and regulations for coal conveyor systems in Taiwan. The only interpretation is that continuous operation of the conveyor belt makes it easy to generate high temperature, so an automatic sprinkler system or outdoor fire hydrant should be properly established as well as timely activated.

According to Taiwan fire safety regulation "Standard for Installation of Fire Safety Equipment Based on Use and Occupancy," Article 40 states: Outdoor fire hydrant diameter should measure at least 63.0 mm and location of it should be within a 40.0 m radius of the outer walls of the building ground floor. Nozzle discharge pressure should be at least 2.5 kgf cm^{-2} or 0.25 MPa, and discharge flow rate should be at least 350.0 L min^{-1}. A fire hose warehouse should be located within a 5.0 m radius of the hydrant. The fire hose warehouse should contain at least two fire hoses having a length of at least 20.0 m and a diameter of 63.0 mm, one dual-purpose beeline spray nozzle with a diameter of at least 19.0 mm, and a valve-type hydrant switch[4]. The reaction force for outdoor fire hydrant (F) can be expressed as Equation (1):

$$F = 1.5\, d^2 P: \tag{1}$$

F: Reaction force (kgf)
d: Nozzle diameter (cm)
P: Nozzle pressure (kgf cm^{-2})

$$F = 1.5 \times 1.9^2 \times 7 = 37.9 \text{ (kgf)}^{5)} \tag{2}$$

The reaction force for an adult to operate fire nozzles is no more than 18.0 kgf. Although the outdoor fire hydrant pressure is 7.0 kgf cm^{-2}, the lift might be able to reach the height of the protection object, which will result in barriers to holding the fire nozzle because of the reaction force. While the nozzle discharge pressure was at 7.0 kgf cm^{-2} with a diameter of 19.0 mm, the reaction force reached 37.9 kgf. Therefore, there should be at least two operators to govern the nozzles. Rescue efficiency and personnel safety is a critical issue. Furthermore, the coal conveyor system in the Taichung power plant is an enclosed conveyor tunnel, which will be even using an outdoor fire hydrant. It will result in the implementation of the external cooling which is unable to attack the fire.

Coal conveyors are mostly used in the mining industry in the USA. The fire data for underground coal mines show that fires in belt entries account for 15 %–20 % of the incidents. New regulations have been enforced that any unplanned fire not extinguished within 10.0 minutes needs to be reported to the Mine Safety and Health Administration (MSHA)[6]. A fire that is not extinguished in the early stage may require hours or even days to be extinguished.

The following best practices that have been developed by MSHA will reduce the risk of conveyor fires.

- Conduct thorough safety examinations on conveyor belts.
- Remove all combustible accumulations along the conveyor belt.
- Take out potential sources of fire, such as hot rollers or belt misalignment.

Because Taichung power plant is located in a coastal region with strong winds, the plant uses an enclosed conveyor belt to avoid coal dust from escaping during transport. The related specifications NFPA and FM Global standards are listed in the following sections.

5.2 Requirements from NFPA

The fire riser, fire sensor, and sprinkler layout are shown in Figure 15; the conveyor system should have an appropriate interlocking system installed between the detection system and the conveyor units to shut down operation. Once a fire is detected, it will immediately interrupt the conveyor belt system to avoid or alleviate the spread of fire. The water spray application rates should apply to most ordinary combustible solids or liquids from 6.1 to 20.4 L m^{-2} min^{-1} of protected surfaces. The water supply should be capable of supplying both the design flow rate and 946.0 L min^{-1} for hose streams for a minimum duration of 1.0 hr. Open nozzles should be installed to supply direct water on the surface to extinguish fire in hydraulic oil, the bell, and the driver units[7].

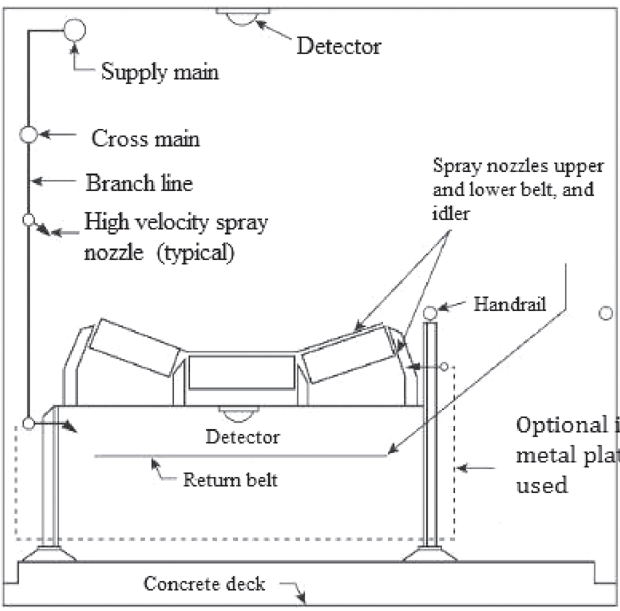

Figure15 Fire equipment for conveyor system.

5.2.1 Driving unit

A water spray system should be equipped to provide adequate protection over the power units, the driver rolls, the take-up rolls, and the hydraulic-oil units. The net rate of water application for the driver unit should be not less than 10.2 L m^{-2} min^{-1}.

5.2.2 Conveyor belt

A water spray system should be installed to automatically moisturize the conveyor system. Water discharge patterns should envelop at a net rate of no less than 10.2 L m^{-2} min^{-1}. Water spray system protection for belt conveyors should accomplish either of the following:

- Extend onto transfer belts, transfer units, and transfer buildings.
- Interlock in such a manner that the water spray system protecting the feeding belt will automatically activate the water spray system to protect the fire segment of the downstream units.

5.3 Requirements from Factory Mutual Insurance Company (FM Global)

FM Global recommends regular inspections of conveyor galleries to ensure there is no buildup of debris beside or under the conveyor. Prudent and superior housekeeping will help reduce the possibility of ignition due to friction from a buildup of debris underneath or beside the conveyor belt. Interlock indoor conveyors are recommended that will shut down automatically on sprinkler water flow or fire detection if continuing operation could spread fire to other areas. Fire spreading to other areas will overtax the sprinkler system. If they meet the following conditions, the system may dispense with sprinkler equipment[8]:

- Conveyor belt width is less than 1.2 m.
- The conveyor belt is at least 70 % open, or the conveyor is a roller type that is at least 50 % open.
- No accumulation of combustible material below the conveyor.

Those who do not meet the above criteria should install a sprinkler system; the layout information of the sprinkler configuration is given in Table 1. Ensuring that the maximum sprinkler coverage does not exceed 9.0 m^2, FM Global quick response sprinklers are installed with a K factor of 8.0 and a temperature rating of 74.0 °C. The water supply should be designed for a duration of 1.0 hr and include 950.0 L min^{-1} hose stream. Provide (in easily accessible locations) either of the following statements on manual protection options for indoor conveyors, as illustrated.

- Small water hose stations with combination nozzles (solid stream and spray) for mop-up operations after a fire. This is the preferred option for manual protection.

Table 1 Layout of the sprinkler configuration.

Belt width [m]	Style of sprinkler	Sprinkler spacing [m]	Sprinkler location
0.6–1.8	Pendant	3.7 m	Along the center line of the belt
	Sidewall	3.7 m	Along one side of the belt
>1.8	Pendant	3.7 m	Along the center line of the belt
	Sidewall	3.7 m	Staggered along both sides of the belt (i.e., sprinkler heads on one side were spaced 7.4 m apart)

Table 2 Certificate of sampling and analysis.

Parameter	Sample	Certified value	Test standard
Gross calorific value	As received basis	6,392 kcal kg^{-1}	ISO 1928
Ash content	Air dried basis	15.3 PCT	ISO 1171
Sulfur content	Air dried basis	0.42 PCT	ISO 19579
Volatile matter	Air dried basis	25.5 PCT	ISO 562
Fixed carbon	Air dried basis	56.7 PCT	By difference
Moisture in analysis sample	Air dried basis	2.5 PCT	ISO 11722
Total moisture	As received basis	9.0 PCT	ISO 589
Grindability (HGI)	Index points	54 PCT	ISO 5074
Size	Above 50 mm	2.0 PCT	ISO 1953
	Under 2 mm	17.3 PCT	ISO 1953

- Portable fire extinguishers located within 15.2 m of the conveyor. For conveyors on mezzanines, provide extinguishers at readily accessible locations on the mezzanine level. In addition to this fixed fire safety equipment, FM Global has also made the following recommendations for the control of fire sources.
- Provide interlocks to shut down the feed system where heated materials are discharged onto belts if the material exceeds a safe temperature or if the belt or cooling system is being shut down.
- Render motion-sensing switches or other devices to detect a slipping or jammed conveyor. Interlock the motion sensors to shut off drive power when the belt stops or slows down more than 20 % of normal speed. Interlock contributing conveyors should be installed so no operating conveyor can discharge material to a terminated downstream conveyor.
- Prohibit smoking around all combustible conveyor belts or conveyor belts that transport combustible materials.

Since the conveyor length is from tens to hundreds of meters, installation of smoke detectors might generate false alarms because of contamination from transport content and airflow in the conveyor tunnel. Heat or temperature sensor cables are an optimal choice, as they are robust and resistant to harsh surroundings and have proven to be sensitive to abnormally increase temperature and thereby to detect a fire at an early stage.

The causes of conveyor belt fire include frictional heat of the belt, malfunction of bearings of rollers, coal which falls over a belt, and so on. Once the equipment is heating up abnormally, a local fire could be initiated which spreads promptly along the beltline. In some cases, it may even ignite and incur an explosion of ash. To enable highest sensitivity, the sensor cable should be mounted near the conveyor belt (1.0 to 1.5 m).

5.4 Fire measurements in Taichung power plant

The standard of coal gross calorific value (GVC) for Taipower is between 5000–6400 kcal kg^{-1}. The samples were prepared according ISO standard methods (ISO 1988), and analyzed according to the following standard methods. The following is the composite result of the analysis given in Table 2.

Spontaneous ignition is the common cause of coal fires. The coal's temperature begins to climb above ambient, along with the oxidation and chemical reaction which produce CO, CO_2, and H_2O molecules at ca. 70–85 °C. The rise of the temperature produces more stable coal-oxygen complexes due to the loss of moisture. The ignition temperature of bituminous coal is approximately 160–170 °C and of anthracite coal, nearly 185 °C[9].

Taichung power plant implemented a traditional coal conveyor belt system from the coal unloading dock to the stockpile or bunker. The fire regulations in Taiwan do not have specific laws for coal conveyor belts. However, with the plant conveyor belt, the lengths are up to 48.0 km. The Taichung power plant follows the NFPA fire safety standards in designing a coal conveyor belt system for safety reasons, as shown in Figure 16.

According to computational fluid dynamics (CFD) simulation results, Yuan and Smith[9] showed that the sprinkler location is the key point for the fire suppression. At sprinkler locations of 0.6 and 2.1 m, the fire was extinguished before it developed, and the sprinkler activation times were shorter. The sprinkler system within the conveyor tunnels uses two sets of system protection. A large open-flow sprinkler, i.e., deluge valve system, with the net rate of water application no less than

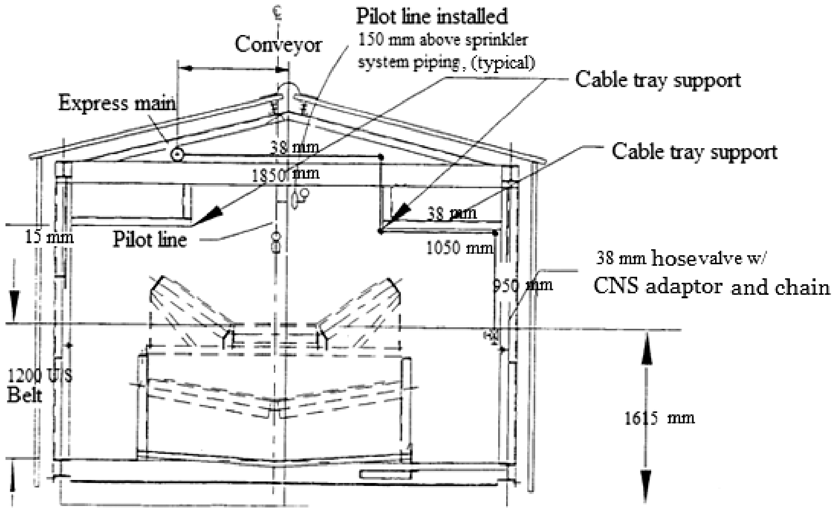

Figure16 Fire prevention system design chart.

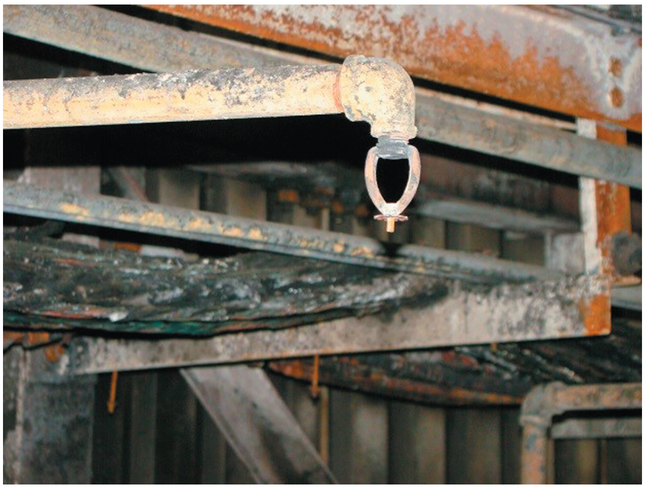

Figure17 Damaged sprinkler after fire.

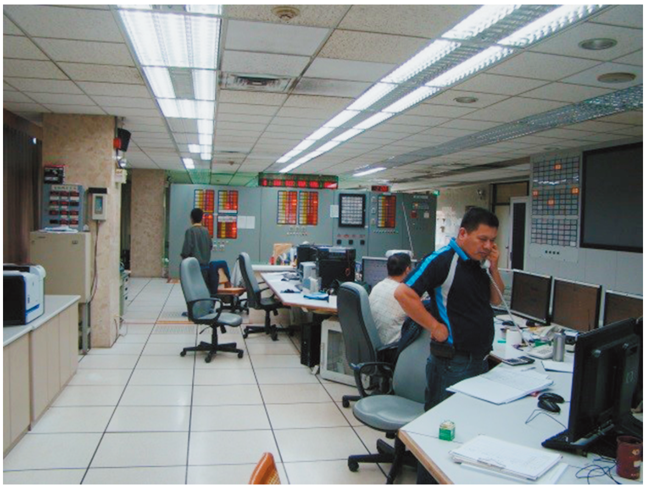

Figure19 Control center in Taichung power plant.

Figure18 Layout of the sprinkler in Taichung power plant.

Figure20 Fire alarm control panel located in the control center.

10.2 L m^{-2} min^{-1}, the fire pump water flow is 1566.3 LPM. Automatic sprinkler protection is provided overhead along the center line of the belt with sprinkler spacing of 2.14 m.

Another system is the enclosed moisture type sprinkler system, sidewall sprinkler with sprinkler spacing of 2.14 m, temperature rating of 79.0 °C; two sprinklers are designed with a pitch of 45° to protect the bottom of the conveyor belt from fire, as shown in Figures 17 and 18.

The enclosed conveyor tunnel had temperature sensor cables and sprinkler sensors. Meanwhile, when the fire occurred, temperature sensor cables and sprinkler sensors were active but not useful, due to maintenance on the fiber -reinforced plastic pipeline line. The deluge water spray system was shut down temporarily. Although the deluge water spray system was opened immediately, due to leaking pipes and lack of water pressure, it still could not suppress the fire.

Taichung power plant set up a coal storage control building to monitor the coal-related facilities operation (Figure 19). The seventh floor control center was staffed by two supervisors and two duty officers with three shifts. Furthermore, electrical equipment inspectors and mechanical equipment inspectors were responsible for the machinery and equipment around the plant. When the fire occurred, the fire alarm and fire extinguishing equipment, including both signals, were confirmed to be in action, as shown in Figure 20. After duty officers were informed of the fire, and confirmation was made through windows of TR9 transport tower smoke overhead, the fire department was quickly and timely notified.

6. Conclusions

Fire investigation found that the scene was not under construction or maintenance on the day fire occurred, while the conveyor had been shut down at 11:00 on May 28, 2014. According to the standard operating procedure for the coal conveyor system, the coal was to be emptied before the system was stopped. Based on previous experience, there had been some cases of long-term coal accumulation, because coal spontaneous combustion or transfer facilities with heat accumulation triggered the local fire. After a comprehensive fire scene investigation, fire service dispatch records and observer reports with witness statement, the possible fire cause was identified as coal's thermal accumulation triggering spontaneous combustion.

Acknowledgments

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