Smoke Evacuation in Industrial Buildings

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Abstract

Smoke occurs as a result of solid and liquid particles carried in the air from the burning of materials created from the combustion of gases. A dark colored smoke screen is formed. It may be toxic and explosive which make evacuation and responding to the fire more difficult. All these problems can be overcome with an appropriate smoke evacuation system. Smoke evacuation systems can be divided into two categories as natural and mechanical systems. However, they can vary according to needs, the people intensity; materials found in the structure and area, architectural features and design standards. The modelling based on the scenario planned for the most appropriate smoke evacuation system was carried out in compliance with international standards and local regulations. In this study, a vehicle part warehouse belonging to the Oyak Renault automobile factory was established inexactly the same way as the original. Using the CDF based PHONEICS system it was designed that a fire broke out in the warehouse and in the design, parking lot fire data were taken into consideration as given in British Standard (BS) standards 'Components for smoke and heat control systems' section 7. Vehicle parts found in the warehouse were in parallel with vehicles which had installation completed in the parking lot without a sprinkler. The smoke emerging as a result of the fire, which had an area of 5×5 m^2 and 8MW magnitude and broke out in the warehouse (without sprinkler) whose area and volume were 4680m2 and 37206m3 respectively, was tested with 6 smoke evacuation fans activated at the beginning of the fire. The Total Fan capacity was designed as 10 volume/hour and 15 volume/hour, evaluated according to the maximum CO amount, vision and temperature by simulation for both situations. As a result of the tests performed, ideal visibility distance for evacuation and intervention was ensured with smoke fans at a capacity of 15 volume/hour.

Keywords: Smoke evacuation, CFD, Smoke evacuation, Fire safety in industrial buildings

1. Introduction

Ignition source, fuel and oxygen combine resulting in combustion. Chemical changes are observed on the structures of objects after they reach ignition temperature. Solid-liquid particles of burning materials and gases form smoke. The majority of deaths in building fires are caused by poisoning from emitted gases rather than structural collapses or burning (19).

The toxic and asphyxiation properties of smoke are the main cause of deaths. Smoke mass expanding gradually during combustion causes the increase of environmental temperature and the spread of the fire. Gases emitted with the fire obstruct evacuation by creating a smoke cloud that limits visibility distance. This situation increases the risk of death by extending the time during which people are exposed to toxic and asphyxiating gases (13). In addition, the smoke cloud caused by the fire prevents the fire department from reaching the scene and responding to the fire. The same situation also prevents the medical department from helping people who are exposed to poisonous smoke. Time losses affect the health of people who are at the scene of the fire and trying to find exits for evacuation. This danger is more dominant in multi-storied buildings. Smoke reaches upper floors by spreading through areas such as stairs and elevator shafts, giving more damage to the people on upper floors when they are trying to leave the building by the stairs.

2. Smoke Control in Industrial Buildings

Smoke caused by a fire breaking out in industrial buildings affects the health of the operators working in the area. In addition, chemicals are exposed to heat and explosions may occur (1). These can only be prevented by taking smoke under control with some precautions. It is important to prevent the spread of smoke through safe environments and create safe environment conditions at the scene of the fire by evacuating the necessary areas (13). Smoke control can be ensured by carrying out the following;

- Division with smoke curtains
- Evacuating smoke mechanically or naturally,
- Compression,
- Providing a clean air supply.

In designing smoke evacuation systems the followings are taken into consideration;

- The structure of the building,
- Physical features,
- Intended use,
- Fire load.

The design aim of smoke evacuation systems changes according to the intended use of the building. In buildings such as shopping centers, cinemas and schools, creating safe escape routes is the most important criterion. Therefore, it is aimed to create a smokeless area necessary for evacuation by holding smoke 2-3 m above the floor (10). In these kinds of buildings a compression system is set up in stairwells where smoke can spread by moving through other floors. The aim of compression is to ensure that environment pressure is higher than the pressure value of the fire location by providing a clear air supply to the environment. In this situation, smoke can spread through the environment when doors are opened for evacuation in case of fire and this should be prevented by taking the precautions mentioned above.

As warehouses, manufacturing workshops and industrial facilities have high ceilings and non-segmented areas, compression systems are not sufficient. Therefore, different solutions should be offered in order to control smoke. In these structures, smoke can be removed to the external environment through evacuation dampers opened in the ceiling of the structure. Smoke evacuation dampers found on the ceiling of the structure can be opened by connecting to the central automation system. In addition, the system can be opened as a result of melting the wires which keep the dampers closed. The working principles of a designed smoke control system can be created depending on the scenarios covering automatic detection and extinguishing systems. However, smoke screens can lose their effect depending on ceiling height. In such a situation, the building is divided into zones and smoke can be controlled with evacuation dampers and clean air fans for every zone.

A second method in smoke evacuation in multi-storied buildings is the implementation of mechanical smoke evacuation systems. In buildings with sprinklers, smoke evacuation zones are placed in parallel with sprinkler zones and fire is extinguished at the point it begins. Smoke is evacuated from this area before spreading.

In an industrial building, the biggest factor with an impact on the amount of smoke is the fire load. Fires are divided into three categories of small, medium and great by taking fire load into consideration. Fire load is obtained by multiplying lower calorific vales and weights of materials and then dividing the result by the area in which they are found.

Fan capacities in mechanical evacuation systems can be identified according to the smoke flow rate calculated accordingly (3). If natural clearance is used, smoke amount is also taken into consideration in the calculation of optimum clearance.

3. Material and Method

In this study, an evaluation was made of the environment conditions caused by a fire breaking out in a vehicle parts warehouse of an automobile factory and the suction power of the most appropriate system necessary for the evacuation of smoke. The modelled warehouse was a large area and of 7.5 m in height. In the structure, there was no sprinkler or smoke evacuation system. There was a fire risk because of the flammable properties of the vehicle parts stored in the warehouse. There were no permanent employees working in the area. Periodically, four people at most comprising logistics operators and specialists undertake duties for stock control, loading and unloading. The existing emergency doors are open and their positions meet the requirements of fire regulations. Therefore, it is thought that there will not be a problem in terms of evacuating smoke.

In the modelling, the aim was to create a clean sub-region for evacuating smoke quickly, making the intervention of the fire department easier and to be able to save parts with the least damage. In order for the fire department to respond to the fire effectively, the field of vision should be open. In warehouse fires, saving the stored raw materials or products as well as employees working in the warehouse or environment is of vital importance. Furthermore, workplace management should act within the scope of the projected budget in order to maintain its existence. Therefore, choosing the most ideal, appropriate and economic smoke evacuation system is very important in the modelling.

The program we chose for the study that we carried out was the **CDF based PHONEICS** program (12). This program is used to perform simulations for evaluating the tests that are necessary for the appropriate smoke evacuation system. With this program, smoke movement, temperature and visibility distance can be tracked through three dimensional images. CDF (Computational Fluid Dynamics) (1) is a programming system that analyses the movement of fluids. With classical fluid dynamics, simple flat sheet solutions can be easily performed but for complicated geometries and variable viscosities CDF analyses are more reliable and appropriate. CDF gives the opportunity for analysis of many different parameters and does not cause deterioration of the fluid property.

In the program, the t2 fire model included in NFPA 92 was used. In this modelling, the square of fire growing duration increases in direct proportion to calorific power. The point at which the fire reaches fixed calorific power is its largest point. Calorific load does not increase from this point and continues to be fixed. In evaluating scenarios, the duration taken for the fire to reach its highest calorific power is considered to be the fire duration and smoke control system modelling for the evacuation of smoke is studied.

In the program, the required data regarding the designed warehouse (control volume) was obtained at different moments and heights thanks to the detector (propre) placed in the area where the fire might have broken out. Due to this data, the correct fan was selected.

As the warehouse is an area where only vehicle parts are stored, the fire load of our control volume was accepted as 8MW which is the parking lot (without sprinkler) fire load given in the BS standards. The fire generating area was accepted as 5x5m2 which is again given in the same standards and in compliance with the layout of control volume (4).

The sprinkler system is a factor which considerably affects fire load. If there is a sprinkler, the fire load in the control volume decreases to 4MW.

To respond to a fire in the warehouse the most important matters are temperature and field of vision. In this environment, there are no permanent employees and the area is large. Therefore, the density of toxic gases will be low. Temperature and field of vision should be analyzed and evaluated for the fire department to respond to the fire more easily and for employees to be evacuated quickly. The most appropriate evaluation height was determined as 2m by considering the average human height. This value is a little higher than the average human height (2). For safety purposes, PPM values at 2m height and different heights were also checked.

General Data of the Vehicle Parts Warehouse of the Automobile Factory:

The dimensions of the warehouse in question are 130x36x7.95 meters. It is rectangular shaped and has a total area of 4680m^2. The walls are made of 10 cm thick rock wool filled between metal sheets, and 2-hour fire-resistant metal sandwich panels. The roof coating is a single layer metal sheet. There are two 3.5x4 m guillotine doors on the northern side of the building, another 3.5x4 m guillotine door on the southern side of the building towards the middle of that side and another 3.5x4 m guillotine door on the east corner of the northern wall of the building. In total 4 guillotine doors with a total area of 14m2 are kept open for materials supply. Two of the operator entry doors with a width of 90 cm and height of 220 cm, are located on the northeast and southwest corners towards the opposite directions while the other two are located on the northern wall 30 meters apart. The doors are barred and open outwards. They are kept closed while not in use.

15m2 guillotine doors are used to provide fresh air on 3 fronts of the building, providing 60m2 ventilation areas in total. Boundary conditions are considered as fresh air entrance from the doors. The smoke coming out of the guillotine doors during the fire was not taken into account assuming that it must be within the minimum range.

2 scenarios were assayed for the logistics warehouse in this study. The duration of the fire was determined as 600 seconds for both scenarios. A setting was prepared where the vehicle parts were burning slowly because of an electrical installation breakdown and the fire reached its highest fire load value at the end of 600 seconds (Table 3.1).

Table 3.1 Development of Fire Duration Values According to Fire the Type of Combustible (NFPA 92)

Burnig rate according to fire the type of combustible	Development of fire duration value
Slow	600
Medium	300
Fast	150
Ultra-fast	75

4. Evaluation

Scenario 1:

A 10 volume/hour air exchange was divided among 6 fans and each fan made smoke evacuation 62010m^3 per hour. The 600 seconds were evaluated taking into account that the fire reached its peak in 600 seconds. At the end of this period PPM value was 1321 and the temperature was approximately 21,20^{0}C, posing no risk. Nevertheless, the visibility distance was insufficient for the firefighters arriving 10 minutes after the fire broke out (Figures 3.1-3.2-3.3). Consequently, a second scenario was tried.

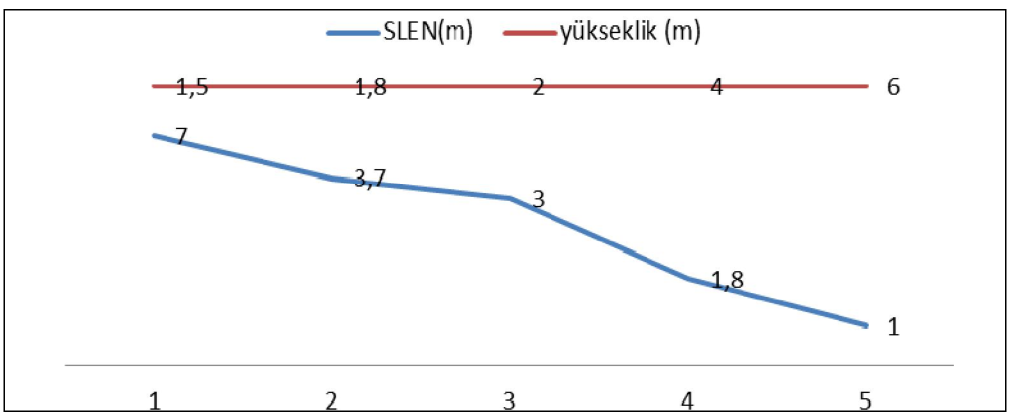

Diagram 4.1: (Volume/Time)Slen Distance Depends on the Height of the Smoke Discharge Capacity at 600 S. (Scenario 1)

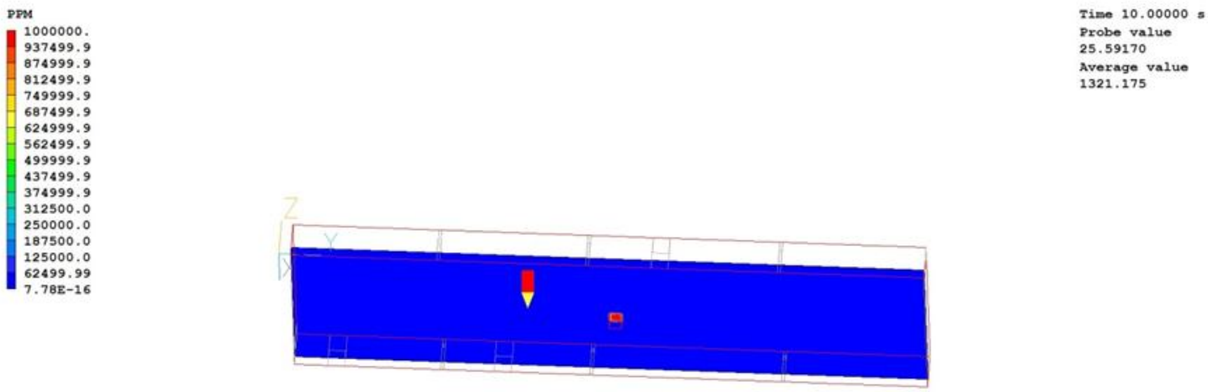

Diagram 4.2: PPM Status at 2m.height from Basement at the End of 600 Seconds

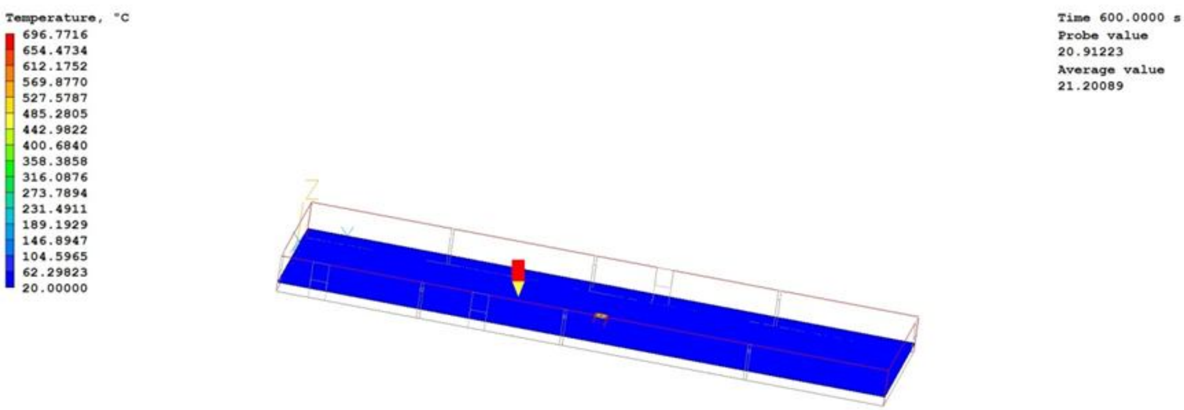

Diagram 4.3: Temperature Values 2m height from Basement at the End of 600 Seconds

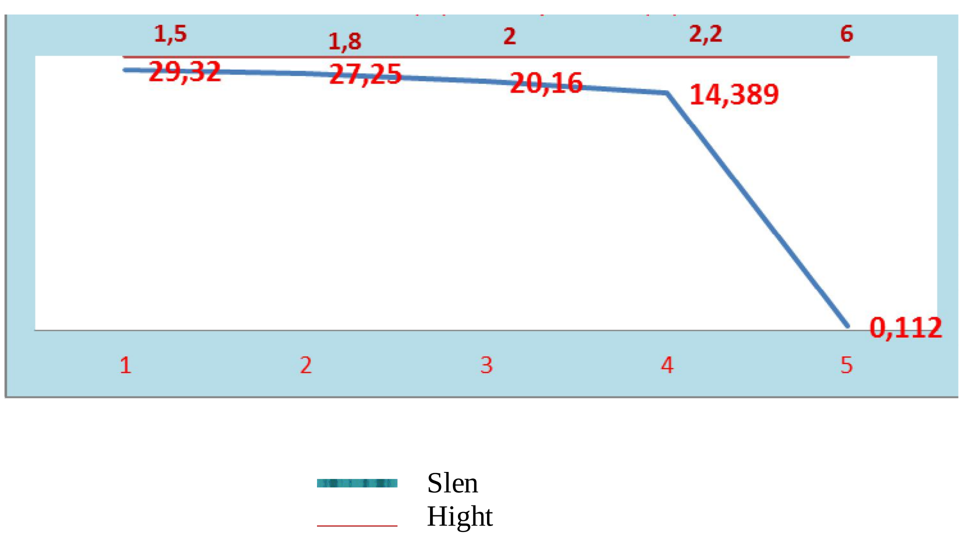

Diagram 4.4.Slen Distance Depends On the Height of the Smoke Discharge Capacity at 600s (Scenario2)

Scenario 2:

The smoke evacuation fan capacity which was set as 10 volume/hour and understood to be insufficient was increased to 15 volume/hour. The capacity of each fan was readjusted as 25,8372 m3/seconds. They were activated as soon as the fire broke out just as in scenario 1. 300 iterations were estimated in the program for the 600 seconds long fire. The condition of the fire was checked every two seconds.

Visibility at 2 meters of height increased from 3,7 m to 20,16 m in the second trial (Figure 4.4). This is an appropriate visibility distance both for evacuation and intervention. 10 minutes is a very long duration for evacuation in a building in which there is a maximum of 4 people. Thus the evacuation would be completed before the fire reaches its peak unless there is an exceptional situation such as an accident. The temperature was 21.20^{0}C and the PPM value was 3081 at 2 meters above the floor at the end of 600 seconds (Figures 4.5-4.6). The temperature and PPM values do not pose any risk for the firefighter teams.

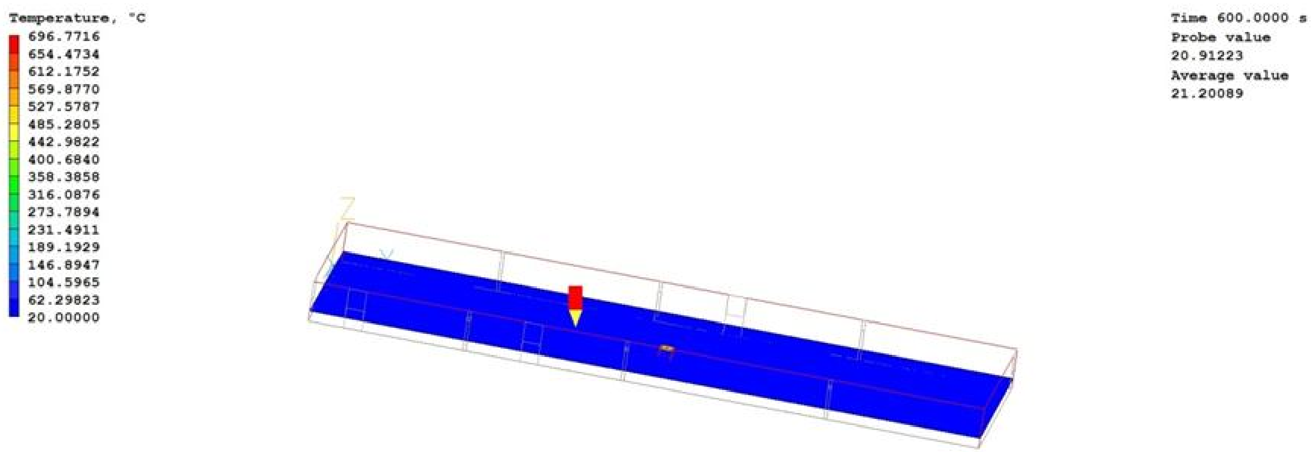

Diagram 4.5: Temperature Values at 2m height from Basement at the End of 600 Seconds

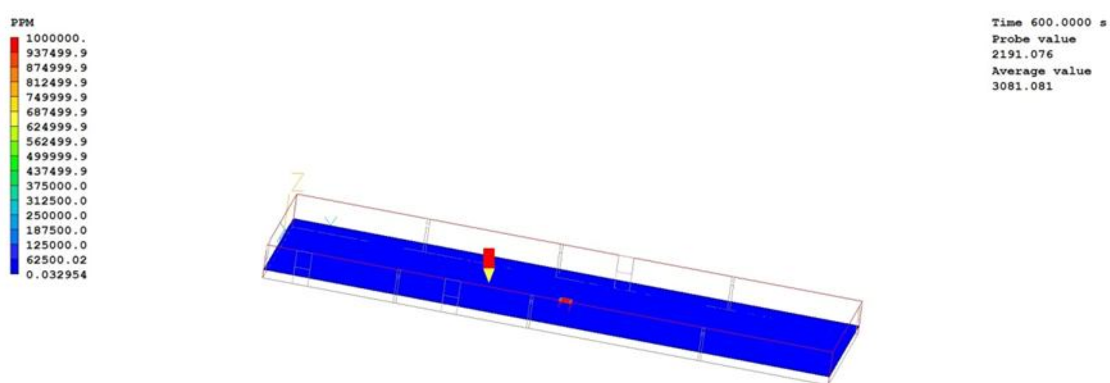

Diagram 4.6.PPM status about 2 meters height from basement at the end of 600 seconds

5. Conclusion

The study covers a vehicle fire reaching up to 8MV thermal power which started in an area of 5×5 m^2 in the 7.95 m high warehouse without a sprinkler with a floor area of 4608 m^2. The CFD based flair programme was used for the fire. 6 fans making 10 volume/hour air exchanges in total were active during 600 seconds, which resulted in 3m visibility distance at 2 meters above the floor, which is known as the highest level of clearance below the smoke.

The possibility of people still being evacuated in the building in the 10^{th} minute of the fire was very low considering the number of people in the building. However, for whatever reason, the fire department arrived on the scene after 10 minutes and 3m of visibility distance was not sufficient for intervention. Finding the center of the fire, then bringing the equipment to the center is very dangerous and difficult in smoke density with only 3m of visibility distance. Temperature and PPM did not pose any danger (14).

A trial-and-error method was implemented to find the most appropriate smoke evacuation fan flow rate. The capacity of the fans was increased up to 50 % considering the smoke density produced by the vehicle parts. In total 15 volume/hour air exchange smoke evacuation continued for 600 minutes during the last trial. The lowest visibility distance at 2 meters of height detected during and at the end of these 600 minutes was 20.16 meters. This visibility clearance is suitable for both evacuation and intervention according to NFPA 92. The smoke density increased rapidly starting at 2.2 meters and the visibility decreased to less than 1 meter parallel to the height.

It is understood from this study that a smoke evacuation system with industrial fans at 15 volume/hour air exchange provides an appropriate clear bottom height in the warehouse of an automobile factory.

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