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Effects of different fuel on development of fire inside the compartment

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The present experimental work performed using three different fuels to measure the effect of fuels on fires development inside the compartment. The size of fire test facility is 4 m×4 m×4 m and vent is provided at door 2 m height and 1 m width. The fuels selected on different nature are – diesel, methanol, and isopropanol. The fuel source is created at centre of compartment of size 0.4 m. The different sensors: thermocouples, heat flux meters are used to investigate the thermal environment. It is observed that growth of fire inside the enclosure is mostly affected by types of fire/fuel sources. The yield of smoke and product gases is found higher in diesel fuel.

Keywords: Heat release rate, diesel, methanol, isopropanol, temperature.

Introduction

With the increasing populations and globalization, the demand for buildings for housing and commercial purpose is increasing. Risk of building and life simultaneously is increasing. Delichatsios *et al.*[1] predicted the equation for measurement of enclosure gas temperature using McCaffrey, Quintiere, Harkleroad (MQH) equation in an under ventilated enclosure using Industrial Methylated Spirit (IMS) having 91% ethanol. Tofilo *et al.*[2] performed experimental studies under different fuel conditions to estimate the heat fluxes towards the compartment boundary.

The different fuel fire experiments were conducted by Jain *et al.*[3,4], Nyati *et al.*[5] using the cooking oil such as groundnut, sunflower, mustard and soybean. They concluded that rate of formation of CO was a crucial parameter to design the fire safety system. The critical value of the rate of formation of CO was found to be 10 ppm/s, thereafter, there exists possibility to catch fire.

Ditch *et al.*[6] performed pool fire experiments, burning rate was determined in case of different fuel and fire sizes. Based on the experimental data obtained, correlation was developed for calculating the burning rate. They found that the burning rate depends on the rate of gasification, pool diameter and smoke height.

Kim *et al.*[7] studied the flame region of methanol fire. Oscillation region was developed near to both stable and unstable regions. Oscillation period was highest in the case of the unstable region compared to stable region. Chow and Chan[8] conducted experiments using different fuels under natural, forced, no ventilation conditions and various gas extraction rates. Flame height was found constant for methanol and poly methyl methacrylate (PMMA) fuel, but in case of wood it decreased with increasing gas extraction rate. Concentration of carbon monoxide was constant at large extraction rate and temperature inside the compartment decreased with increase in gas extraction rate. Beyler[9] studied the CO, CO_2 and total hydrocarbon in different fire conditions. They observed that concentration of these species was function of global equivalence ratio. Li *et al.*[10] developed a model to estimate flashover conditions under different fuel sources.

There have been a number of fires, both historical and more recent, which have raised concern regarding fire safety in such buildings. These codes and standards are required to be upgraded regularly. Therefore, there will always be a need for continuous improvements in methodology of fire safety engineering which can be achieved through better measurements, large-scale fire experiments and verified methods of prediction.

Materials and methods:

A full scale fire test facility has been designed to perform the large-scale compartment experiments. The fire test enclosure is size of 4 m×4 m×4 m, with vent of size 2 m height and 1 m width. A fire source is created at centre of enclosure of size 0.4 m diameter and 12 cm height. The fire enclosure is shown in Fig. 1. Experiments are performed on different fuels: Diesel (Exp. 1), methanol (Exp. 2) and isopropanol (Exp. 3) and total duration of experiment is 1500 s in each experiment to investigate the burning properties. Load cell method is used here to measure the burning rate.

The oxygen depletion calorimeter used to measure the heat release rate. The oxygen depletion factor is determined from eq. (1).

$$\phi(t)=\frac{X_{O_2}^{A^0}\left(1-X_{CO_2}^{A}\right)-X_{O_2}^{A}\left(1-X_{CO_2}^{A^0}\right)}{X_{O_2}^{A^0}\left(1-X_{O_2}^{A}-X_{CO_2}^{A}\right)} \qquad (1)$$

and eq. (2) is used for calculating the heat release rate.

$$\dot{Q}=E\dot{V}_{298}(t)\,X_{O_2}^{A^0}\left[\frac{\phi(t)}{\left(1+0.105\,\phi(t)\right)}\right] \qquad (2)$$

where E is heat release per unit volume, V_{298} flow rate of exhaust system at 298 K and X_{O_2}ambient mole fraction of the oxygen.

Thermocouple trees as shown in Fig. 1 is installed above the centre of liquid pool, corner of compartment and door to measure temperatures. The flame temperature at different distance above fuel surface, ceiling temperature at different locations 1.0 m below the ceiling surface and door tempera-

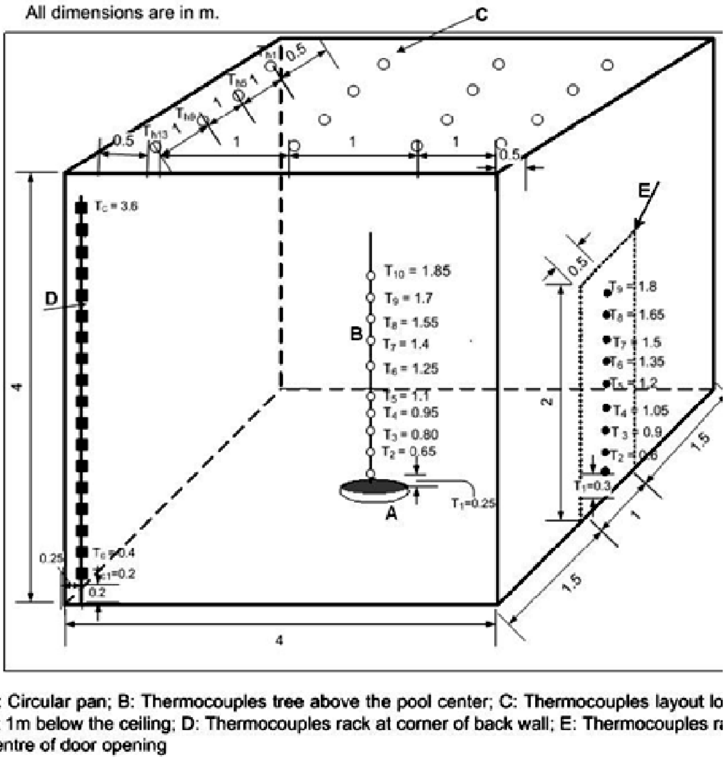

Fig. 1. Fire test compartment.

tures at different locations are measured. Incident heat fluxes at ceiling are measured through heat flux sensors.

The fuel level is maintained at a height of 12 cm during experiment, layout of fuel supplying system was described in Sahu *et al.*[11]. Oxygen gas analyzer: Servomex 4100 is used for monitoring the quality of industrial gas product. Carbon monoxide and carbon dioxide analyzer: Analysis of the oxides of carbon is achieved by IR spectrometer.

A light obscuration is used to measure the extinction coefficient, it is determined from eq. (3).

Extinction coefficient:

$$k = \frac{1}{L}\ln\left(\frac{I_0}{I}\right) \qquad (3)$$

Results and discussion

Fig. 2 represent the heat release rate (HRR) of different fuels with time. The steady heat release rate is found at 800 seconds in Exp. 1, and 300 seconds in case of Exp. 2 and Exp. 3. In a period of steady state, the value is 90, 34 and 81 kW in Exp. 1, Exp. 2 and Exp. 3 respectively. The burning properties of fuel is affected by fuels. The properties of fuel used are given in Table 1.

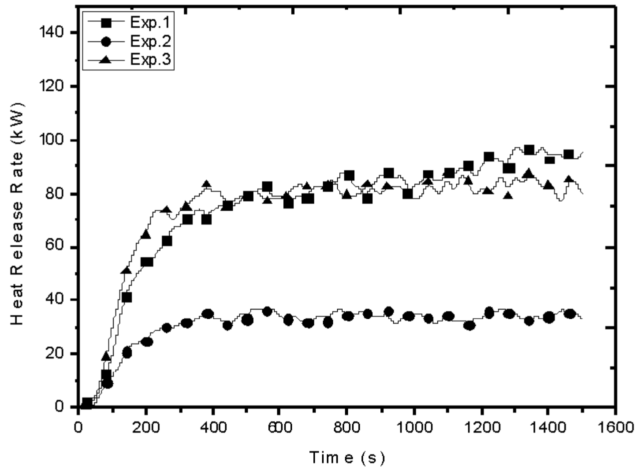

Fig. 2. Variation of heat release rate with time under different fuel fire conditions.

Fig. 3 shows mass loss rate (MLR) with time in different experiment condition. The mass loss rate is 2.225 g/s, 1.79 g/s and 2.87 g/s resulted in diesel, methanol and isopropanol fires respectively.

Table 1. Details of fuel properties

Fuel	Heat of combustion (MJ/kg)	Latent heat of vaporization (kJ/kg)
Diesel	43.5	228
Isopropanol	30.45	663
Methanol	19.94	1101

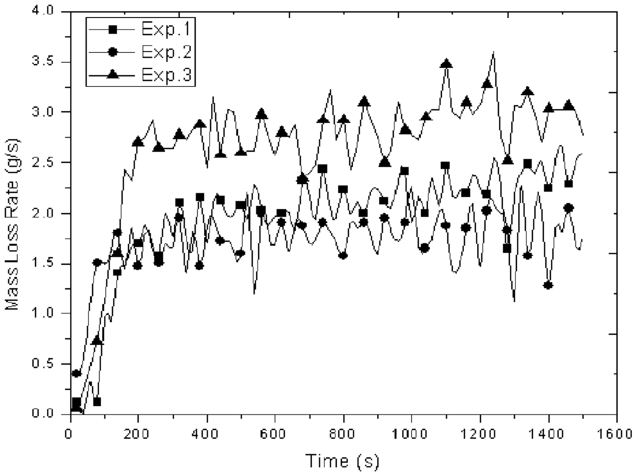

Fig. 3. Variation of mass loss rate with time under different fuel fire conditions.

Extinction coefficient and smoke generation is shown in Fig. 4. The light obscuration system is used for measurement of extinction coefficient and the smoke production rate to determine the properties of burning fuel in terms of smoky or non smoky fuel. The average values of extinction coefficient are 0.78, 0.010 and 0.058 m^{-1} in Exp. 1, Exp. 2 and Exp. 3 respectively. The smoke production rate are found 1.45, 0.019 and 0.11 m^2/s in Exp. 1, Exp. 2 and Exp. 3 respectively. The yield of CO and CO_2 is shown in Fig. 5. The formation of toxic gases highly dependence on air entrainment and formation of thermal environment in the compartment. In addition, enclosure size and ventilation also influences the formation of toxic gases. The avg. CO yield observed 0.0289, 0.0045 and 0.0046 (kg/kg), similarly the avg. values of CO_2 yield observed 3.18, 2.16 and 2.403 (kg/kg) in case of diesel, methanol and isopropanol fuel respectively.

Fig. 6 shows the flame temperatures. The flame temperature profile is similar in Exp. 1 and Exp. 3 , which is in propor-

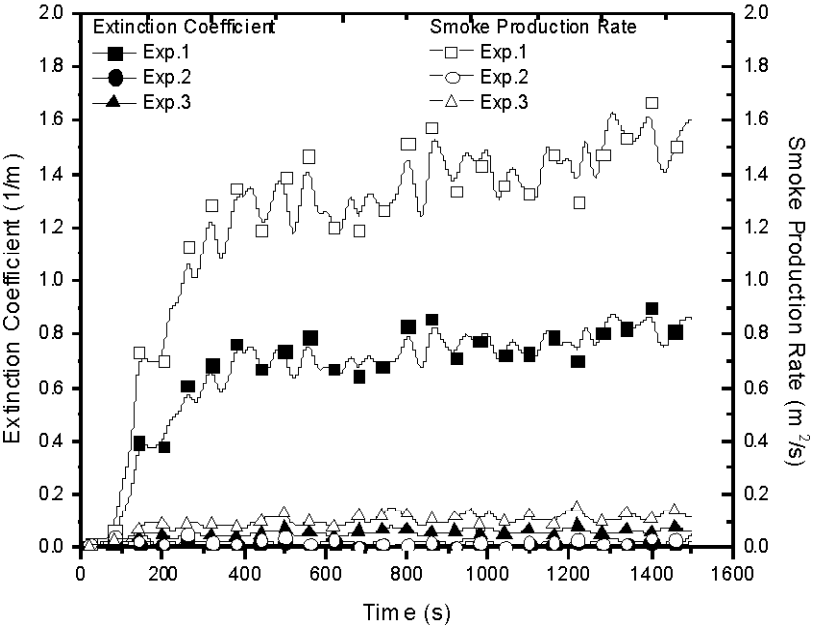

Fig. 4. Variation of extinction coefficient and smoke production rate with time.

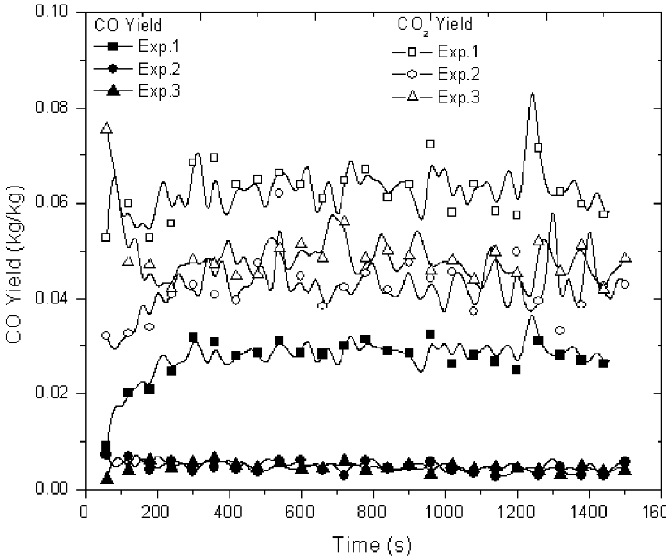

Fig. 5. Variation of the yield of CO and CO_2 in exhaust gases with time.

tion with the heat release rate profile. In case of methanol fire (Exp. 2), temperatures above pool are found to be lower than the diesel (Exp. 1) and isopropanol (Exp. 3) fire. McCaffrey[12] characterized flame into three regions based on the value of $Z/\dot{Q}^{2/5}$ where Z is the height from the pool surface and $\dot{Q}$ is the heat release rate. The flame is categorized into different regions as mentioned in Table 2, using the correlation McCaffrey[12]. In case of diesel and isopropanol fire, intermediate flame zone appears at a height of 0.65 m while in methanol fuel fire it appears at a height 0.35

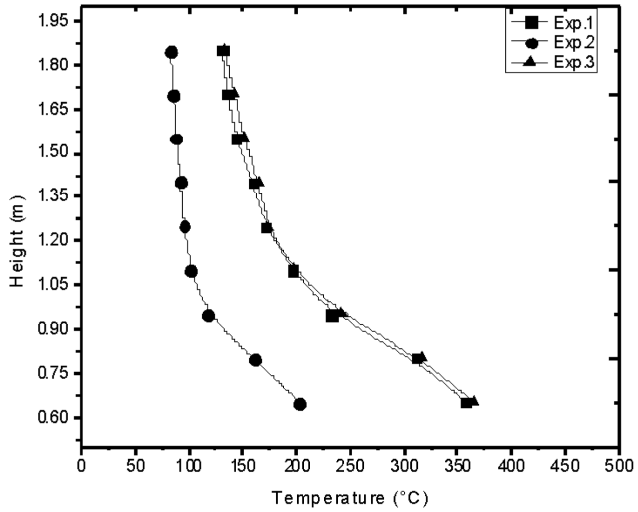

Fig. 6. Variation of temperature with height above the pool surface at time 25 min under different fuels conditions.

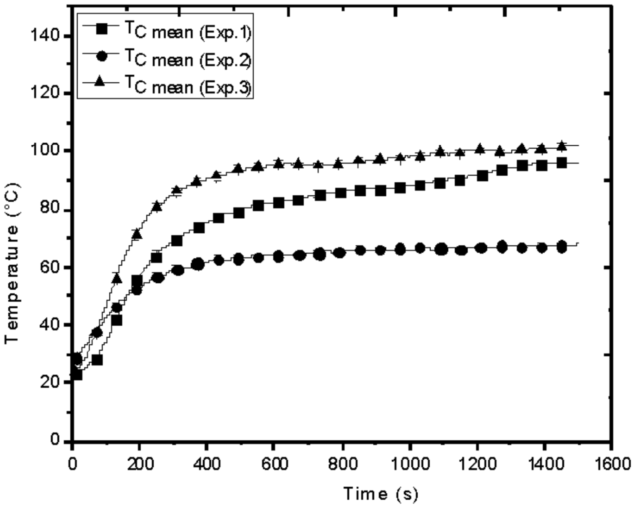

Fig. 7. Variation of mean ceiling temperature with time under different fuels conditions.

Table 2. Summary of flame regions in pan size of 40 cm diameter

Regions	Exp. 1	Exp. 2	Exp. 3
Continuous	Below 0.65	Below 0.35	Below 0.65
Intermittent	0.65–1.25	0.35–0.8	0.65–1.25
Plume	above 1.25	above 0.8	above 1.25

*All dimensions in m.

m above the pool pan surface. The flame height is resulting lower in methanol fire compare to diesel and isopropanol fire due to sufficient availability of air near to flame base to complete the combustion. The higher air entrainment from vent resulting in tilting of flame and also, cooling effect on temperature development inside the enclosure.

The ceiling temperature with time is shown in Fig. 7. The maximum temperature is estimated 96, 68 and 101°C in diesel, methanol and isopropanol fuel fires respectively. The temperature profiles are found to be similar in Exp. 1 and Exp. 3, with a maximum difference of 5°C. The ceiling temperature is vary with longitudinal direction. The standard error of mean is found to be 2°C, 1°C and 2°C in case of Exp. 1, Exp. 2 and Exp. 3 respectively

Fig. 8 shows the corner temperature with height. The distribution of thermal environment with height of compartment is observed about 1.0 m above the floor in all the three. The product gases are move upward due to buoyancy effect, accumulated at ceiling of compartment, after that its descent, and make a layer of hot zone. The lower zone is cold zone where temperature is approximately at ambient temperature.

The knowledge of development of temperature along the height of compartment is useful to understand the zone inside the compartment.

The temperature at doorway centerline is shown in Fig. 9. The thermal discontinuity occurs at approximately height of 1.0 m above the floor in all fuels conditions. The doorway profile is useful for predicting the hazardous condition at the vent location and helps in mitigation of fires.

The heat that is released during burning of fuel radiated at different boundary of compartment. The variation of ceiling heat flux with time under different fuel fire is shown in Fig. 10. The profile of ceiling heat flux is found to be similar in Exp. 1 and Exp. 3, due to development of temperature and heat release rate is almost similar in both experimental conditions. The maximum ceiling heat flux is found to be 2 kW/m^2 in isopropanol fire.

Fig. 11 (a-c) shows the flame image at different time interval. Image of flame of diesel fire appearing as sooty and turbulent as compare to isopropanol and methanol fuel fire.

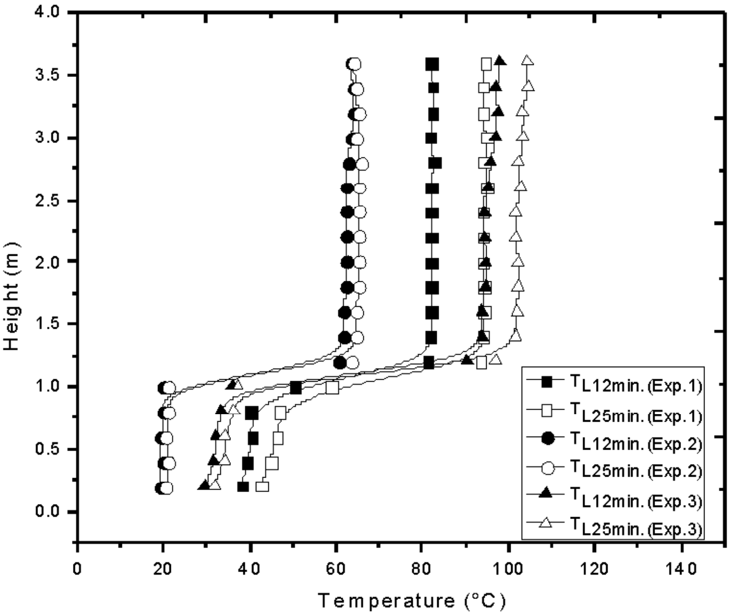

Fig. 8. Comparison of corner rack temperature with time at different height of compartment.

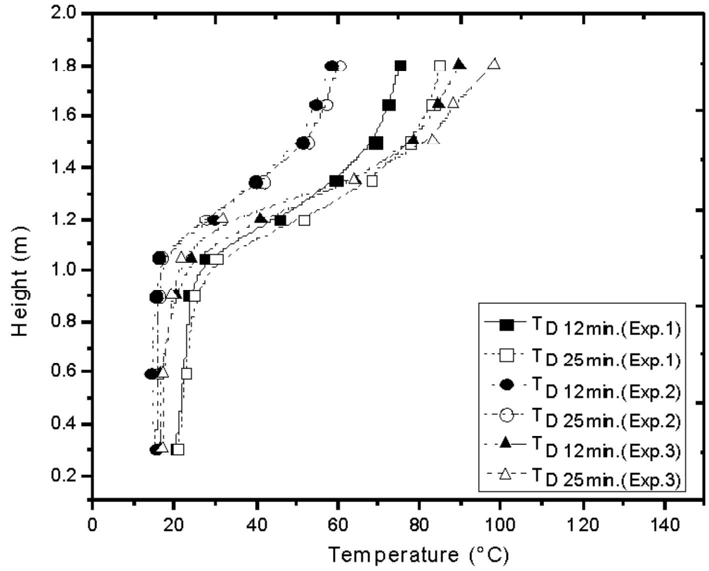

Fig. 9. Variation of doorway temperature with door height at different time interval.

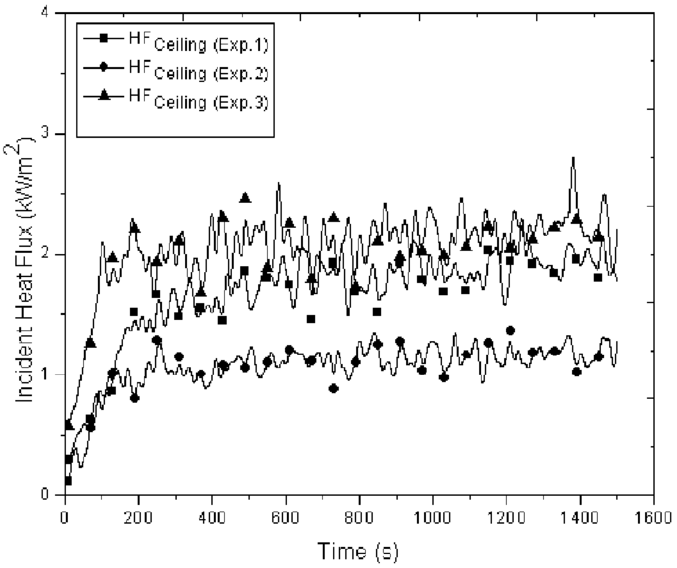

Fig. 10. Incident heat flux variation with time at ceiling surfaces under different fuel conditions.

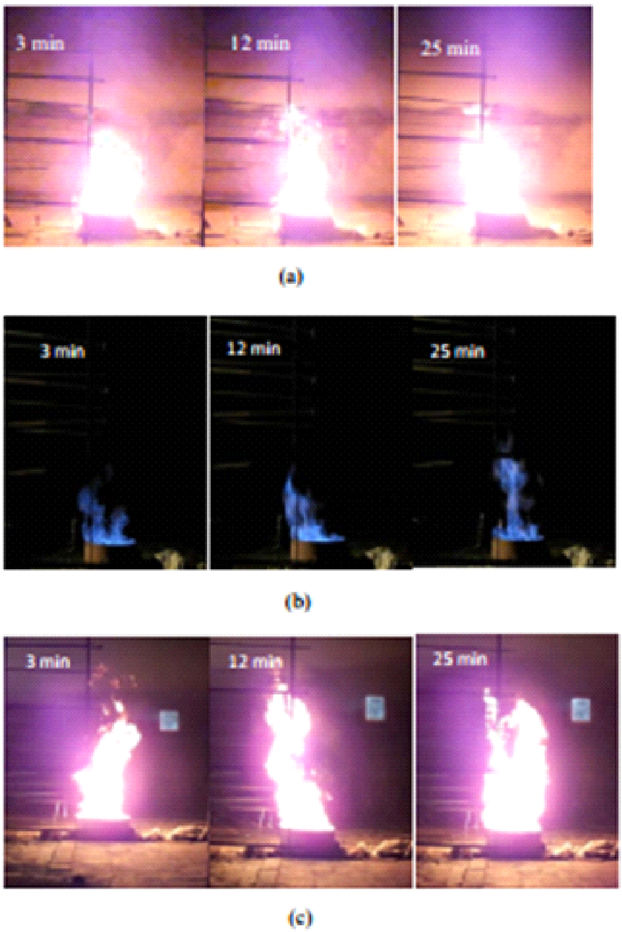

Fig. 11. Images of flame in (a) diesel, (b) methanol and (c) isopropanol fuel at time t = 3 min, 12 min and 25 min.

Conclusion

The present work is useful to understanding the burning properties and thermal environment of different fuels. In present study, fire condition is over ventilated in all experiments. It is observed that the growth of fire inside the compartment mostly affected by presence of fuel types/fire sources. The yield of smoke and toxic gases is resulted higher in aromatic fuel. The fire hazard in a building is caused by rapid rise of temperatures, presence of high concentrations of toxic gases like CO and smoke. The smoke can significantly reduce the visibility thus reducing the possibility for the people to reach escape routes. These experimental results would be useful for the design of fire detection and fire protection systems. These studies will be helpful to upgrade the fire safety system in atrium conditions where fire at low load.

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