SIMULATION OF POOL FIRE FOLLOWING THE LEAKAGE OF A DIATHERMIC OIL USED IN THE PACKAGING INDUSTRY

Almerinda Di Benedetto[a], Valeria Di Sarli[b], Francesco Berardini[c], Mario Mensitieri[c]

[a]Università degli Studi di Napoli Federico II, Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale, Napoli, Italy
almerinda.dibenedetto@unina.it
[b]Consiglio Nazionale delle Ricerche (CNR), Istituto di Ricerche sulla Combustione, Napoli, Italy
valeria.disarli@irc.cnr.it
[c]Icimendue srl, Marcianise, Italy
francesco.berardini@mensitieri.com, mario.mensitieri@mensitieri.com

INTRODUCTION

In many packaging industries, heat transfer is performed by using a diathermic oil that is heated in furnaces and then circulated by pumps within a closed circuit. The working temperature (250°C) is generally higher than the flash point (200°C), with consequent increased risk of fire.
If an accidental loss of containment of flammable liquid generating a pool onto the ground (or water) occurs, it can be ignited, thus creating a pool fire. A buoyancy-driven turbulent non-premixed flame is formed above the pool. The supply of sufficient oxidants for combustion by the air entraining into the flame allows the sustainment of the pool fire. Large toroidal vortex structures, which re-circulate at the vicinity of the flame, are generated and significantly affect the fire evolution.
Pool fires represent a serious hazard for industrial applications. They are the cause of the majority of accidents occurring in chemical process industries [1-4]. Furthermore, pool fires may trigger explosions, thus causing huge loss of life and property.
Risk assessment in industrial applications requires the availability of reliable methodologies and tools to predict fire properties (flame height, fire duration, radiant heat, etc.). To date, the evaluation of the severity of exposure to pool fires mainly relies on empirical or semi-empirical models [5,6]. However, such models do not take into account the role of turbulence, which is a key parameter in affecting the interaction among the spatio-temporal evolution of the fire, the flow velocity and the entrainment of the ambient air.
In order to fully simulate the unsteady interaction among combustion reaction and distribution of temperature, velocity and turbulence, the most reliable approach is based on the solution of the Navier-Stokes equations coupled with the energy and species conservation equations (CFD models for reactive systems).
In this work, we aimed at estimating the consequences of a pool fire of a diathermic oil used in the packaging industry. To this end, a Large Eddy Simulation (LES) based CFD model was developed with the aid of the Fire Dynamics Simulator (FDS) code (http://firemodels.github.io/fds-smv/). The LES approach grasps the inherently time-dependent nature of turbulent flows and, therefore, is particularly fit for simulating transient combustion phenomena such as flame propagation during the course of fires and explosions [7-10]. From LES results, flame height and shape, and temperature, velocity and smoke concentration profiles were obtained.

1 MODEL

1.1 Turbulence

The Large Eddy Simulation (LES) approach was adopted. Therefore, simulations resolved the time-dependent behavior of large scale turbulent motions, such as the characteristic puffing instabilities in buoyant plumes. The effects of small scale (unresolved) turbulence was modelled by using the Smagorinsky model [11].

1.2 Combustion and radiation

Combustion was modelled using the step mixture fraction based model. This is a conserved scalar quantity that represents the mass fraction of one or more components of the gas at a given point in the flow field. By default, the mass fractions of unburned fuel and burned fuel are explicitly computed. The major reactants and products of combustion (fuel, O_2, CO_2, H_2O, N_2, CO and soot) are all pre-tabulated functions of the mixture fraction [12].

Thermal radiation was included in the model via the solution of the radiation transport equation for a gray gas. The equation was solved using a technique similar to a finite volume method (FVM) for convective transport [12]. The thermal radiation from the flame was a function of both flame temperature and chemical composition.

1.3 Computational domain and grid

Figure 1 shows the frontal view (left) and the top view (right) of the computational domain (12 m x 15 m x 5.5 m - length x width x height) representing a boiler room. The pool was rectangular in shape (1 m x 1 m). It was positioned at the center of the chamber floor.

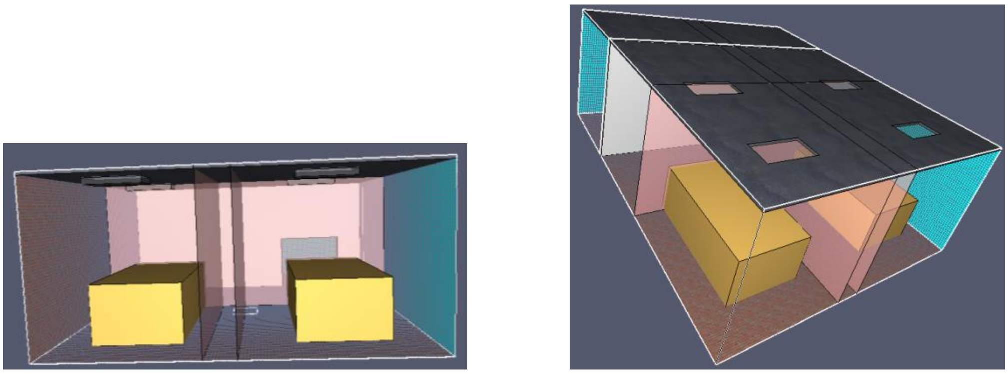

Fig. 1. Computational domain: Frontal view (left); Top view (right).

The computational grid was Cartesian and cubic cells were used. The total number of grid cells was 990000.

2 RESULTS AND DISCUSSION

In Figure 2, the temperature maps are shown as computed across a plane perpendicular to the pool at different time instances.

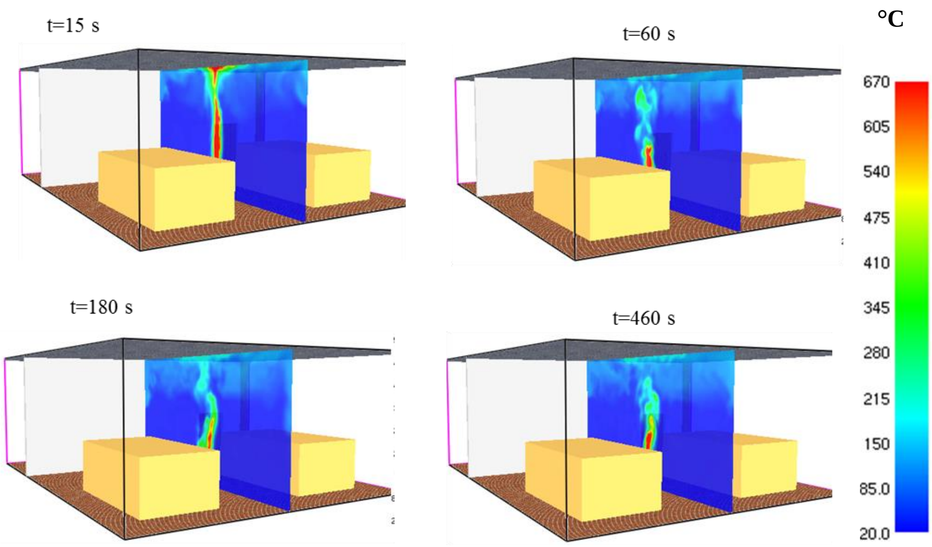

Fig. 2. Temperature maps computed across a plane perpendicular to the pool at different time instances.

Even the roof sees temperatures as high as 670°C. This suggests that the pool fire can thermally stress the chamber.
The time sequence of velocity vector maps of Figure 3 shows that high velocities are reached (up to 7 m/s).

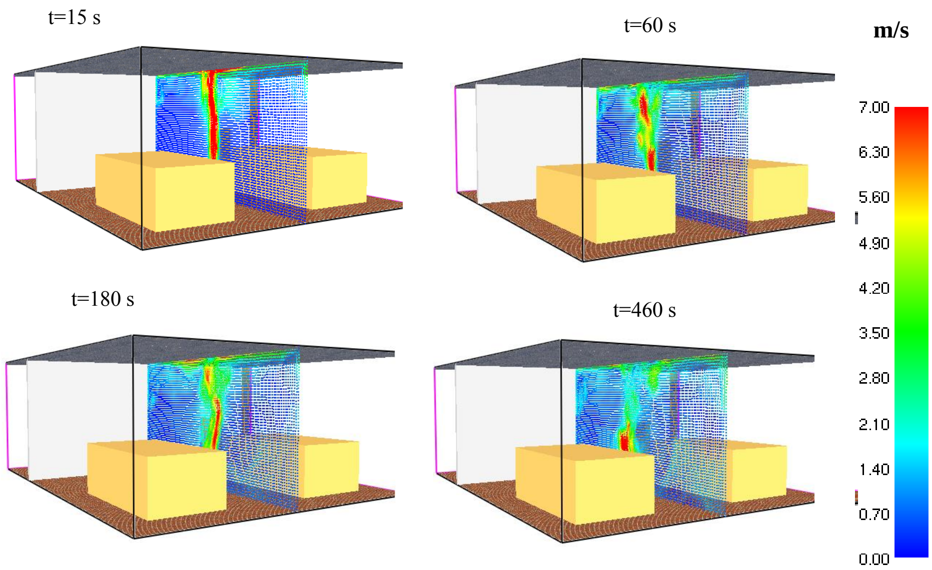

Fig. 3. Velocity vector maps computed across a plane perpendicular to the pool at different time instances.

Figure 4 shows the time sequence of smoke concentration maps.

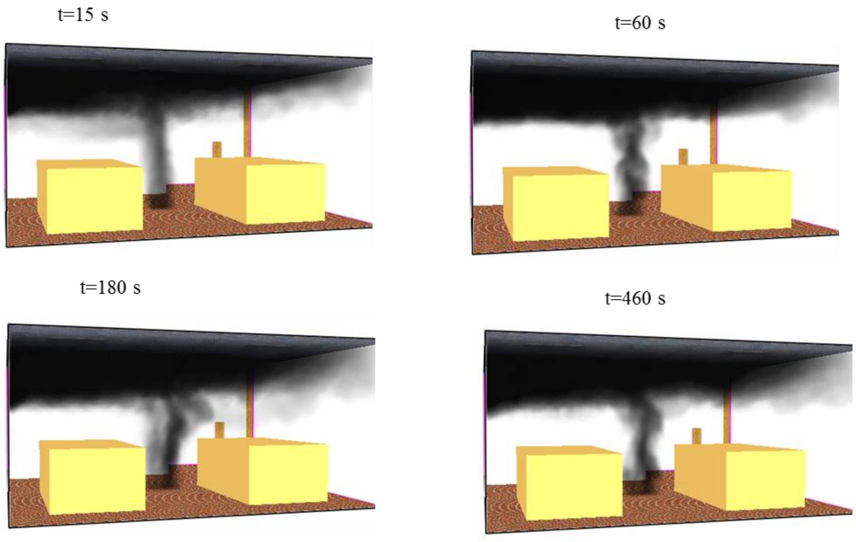

Fig. 4. Smoke concentration maps computed at different time instances.

Thanks to the presence of exit sections placed on the roof, the smoke concentration is not very high in the low part of the chamber. Smoke mainly concentrates close to the roof due to the upwind velocity of the combustion products.
Figure 5 shows the iso-temperature (T = 500°C) surfaces as computed at different time instances.

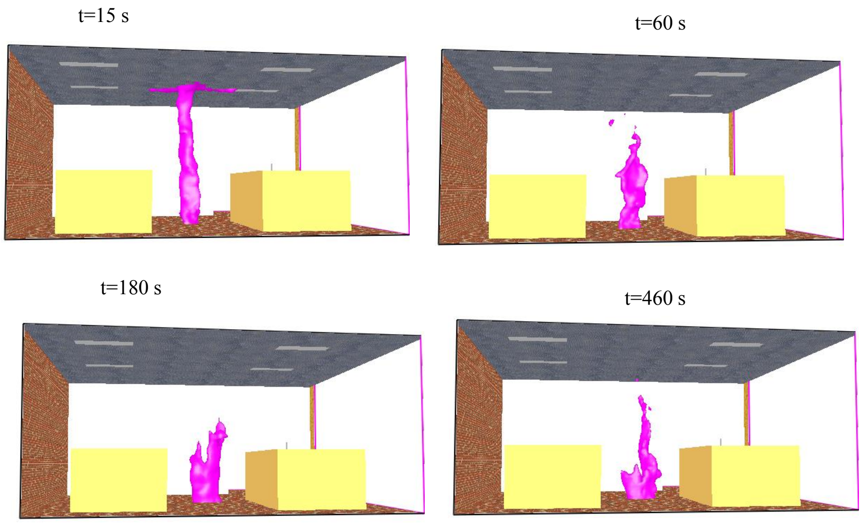

Fig. 5. Iso-temperature (T = 500°C) surfaces as computed at different time instances.

From those iso-surfaces, the flame height can be derived. Over the time, the flame reaches the roof. This result suggests that the height of the roof is not sufficient for preserving the room from pool fire damages.

3 CONCLUSIONS

In this work, a LES-based CFD model was developed to estimate the consequences of a pool fire of a diathermic oil used in the packaging industry. Numerical results have shown that, under the simulated conditions, the flame height is such that the fire can reached the roof, potentially causing severe damages. Indeed, even the roof can see temperatures as high as 670°C. Thanks to the presence of exit sections placed on the roof, the smoke concentration is not very high in the low part of the chamber. Smoke mainly concentrates close to the roof due to the upwind velocity of the combustion products.

REFERENCES

[1] Planas-Cuchi E., Montiel H., Casal J., 1997. "A survey of the origin, type and consequences of fire accidents in process plants and in the transportation of hazardous materials". *Process Safety and Environmental Protection*, ISSN 0957-5820, Elsevier Limited, Vol. 75, pp. 3-8.

[2] Khan F.I., Abbasi S.A., 1999. "Major accidents in process industries and an analysis of causes and consequences". *Journal of Loss Prevention in the Process Industries*, ISSN 0950-4230, Elsevier Limited, Vol. 12, pp. 361-378.

[3] Tauseef S.M., Abbasi T., Abbasi S.A., 2010. "Risks of fire and explosion associated with the increasing use of liquefied petroleum gas". *Journal of Failure Analysis and Prevention*, ISSN 1547-7029, Springer, Vol. 10, pp. 322-333.

[4] Persson H., Lönnermark A., 2004. "Tank Fires - Review of fire incidents 1951-2003". SP Fire Technology, SP Report 14, ISBN 91-7848-987-3, ISSN 0284-517.

[5] Babrauskas V., 1983. "Estimating large pool fire burning rates". *Fire Technology*, ISSN 0015-2684, Springer, Vol. 19, pp. 251-261.

[6] Mudan K.S., 1984. "Thermal radiation hazards from hydrocarbon pool fires". *Progress in Energy and Combustion Science*, ISSN 0360-1285, Elsevier Limited, Vol. 10, pp. 59-80.

[7] Di Sarli V., Di Benedetto A., Russo G., Jarvis S., Long E.J., Hargrave G.K., 2009. "Large eddy simulation and PIV measurements of unsteady premixed flames accelerated by obstacles". *Flow, Turbulence and Combustion*, ISSN 1386-6184, Springer, Vol. 83, pp. 227-250.

[8] Di Sarli V., Di Benedetto A., Russo G., 2009. "Using large eddy simulation for understanding vented gas explosions in the presence of obstacles". *Journal of Hazardous Materials*, ISSN 0304-3894, Elsevier Limited, Vol. 169, pp. 435-442.

[9] Di Sarli V., Di Benedetto A., Russo G., 2010. "Sub-grid scale combustion models for large eddy simulation of unsteady premixed flame propagation around obstacles". *Journal of Hazardous Materials*, ISSN 0304-3894, Elsevier Limited, Vol. 180, pp. 71-78.

[10] Di Sarli V., Di Benedetto A., Russo G., 2012. "Large eddy simulation of transient premixed flame-vortex interactions in gas explosions". *Chemical Engineering Science*, ISSN 0009-2509, Elsevier Limited, Vol. 71, pp. 539-551.

[11] Smagorinsky J., 1963. "General circulation experiments with the primitive equations. 1. The basic experiment." *Monthly Weather Review*, ISSN 0027-0644, American Meteorological Society, Vol. 91, pp. 99-164.

[12] McGrattan K.B., Hostikka S., Floyd J.E., 2010. "Fire Dynamics Simulator (Version 5) - User's Guide". NIST Special Publication, Vol. 1019, pp. 1-186.