Comparison of simplified and advanced simulation of a fire in a factory of XPS panels

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Subject: Investigating possible deviations between advanced (performance-based or 'realistic') and simplified calculations of initiation and spread of a fire in buildings. The comparison is done on a case of a fire in a factory for production of insulation panels made of extruded polystyrene (XPS).

The study

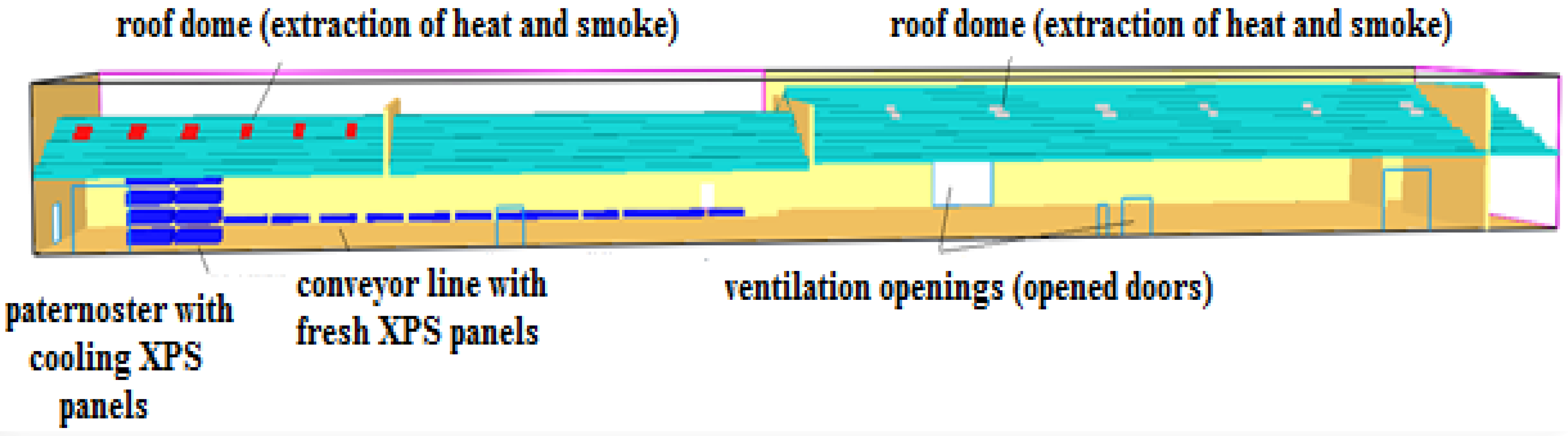
Fires in production-storage facilities are one of the most common industry accidents. In some of these facilities, ignitions of produced or stored products and goods are even a regular part of the everyday production process. In factories for production of extruded polystyrene (XPS) beads, for example, ten such incidents per year are to be expected as reported in [1]. This is so, because production of XPS involves flammable gases, usually pentane, which is given off all the time, i.e. in the highest amounts for a short while after manufacture but in non-negligible amounts also afterwards during storage and transport.

Let us consider an example of a typical hall for production of panels of XPS as shown in Figure on the right. Suddenly one of the panels on the production line ignites and is after that transferred along the line (conveyor) to the place for cooling (local storage of the produced plates or so called 'paternoster'). Here the flame from the burning plate transfers to the other 143 panels also cooling down in the paternoster. The roof surfaces are non-flammable and have embedded evenly distributed smoke and heat extraction domes which open together with the activation of the fire alarm (immediately after ignition of the first panel). For purposes of post-fire repair of the damaged roof beams above the paternoster (steel truss beams), the question arises regarding what temperatures have these beams been actually exposed to during fire and for how long. We will seek the answer using a computerized fire simulation.

Computer simulation of the fire

Computer simulation of a fire means: (i) simulation of the progressive ignition of combustible objects located within the fire compartment and the release of heat and gaseous products during their combustion (**pyrolysis and combustion models**); and (ii) simulation of the transport of released heat and smoke across the compartment and the rest of the building (**radiation and CFD models**).

What follows will be dedicated to presentation of pyrolysis and combustion models for a case of commercially-used XPS, which were developed by the author for purposes of later computer simulation of the discussed XPS fire. For purposes of the development, one of the major manufacturers of XPS was asked for assistance who kindly provided more samples of fresh XPS panels and sent them for analysis to laboratories of Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia (ZAG). In order to keep the samples as fresh as possible during the transportation, the plates were surface-smoothed immediately after production and tightly wrapped in an impermeable foil. After the development of the pyrolysis and combustion models, these models were embedded into a model of the discussed fire of the XPS production hall. The latter was prepared in FDS [2] which was further used for fire-related CFD and radiation analyses.



Combustion model: Chemical reaction in the gaseous phase (stoichiometric equations) was defined as follows:

$CxHyOzNv + n_{O2}\,O2 \rightarrow n_{CO2}\,CO_2 + n_{H2O}\,H_2O + n_{CO}\,CO + n_{SOOT}\,soot + n_{N2}\,N_2.$

Here the fuel was defined by the molecular formula (H5C6-CH = CH2)n. The coefficients n_{CO2}, n_{H2O}, n_{CO}, n_{SOOT}, n_{N2} were determined by testing the collected XPS samples in a cone calorimeter with FTIR (Fired Transform Infrared Spectroscopy) analyzers.

Simplified pyrolysis model: According to reports of eyewitnesses of a fire in an XPS production hall that had similar basic characteristics as the fire analysed in this paper (the reports were collected from private archives of Fire laboratory and fire engineering of ZAG), the flame captured the entire paternoster in approximately 5 minutes. The flame had a maximum intensity during the next 5 minutes and was after that gradually decaying for another 20 minutes until it went out completely. If we lean on these data and the data on the mass of XPS that burns in the fire and its effective heat of combustion, then the fire discussed in this paper can be modelled as a simple surface burner of a predefined HRR.

Advanced pyrolysis model: The fundamental endeavour in the development of the advanced model of the selected XPS was a correct definition of the set of the so called material kinetic and thermal coefficients (i.e. basic coefficients of exact equations of material thermal degradation). This required numerical fitting (e.g. by using numerical tools such as genetic algorithms as proposed in [3]) of the set of the model's equations to results of high-temperature material experiments, i.e. TGA (thermogravimetric analysis), DSC (differential scanning calorimetry) and cone calorimetry. In order that with only one model different possible situations could be described to which a material can be exposed during a fire, these experiments were carried out at different heating rates and different concentrations of oxygen.

Results and discussion: The results of the advanced model are shown in figure below. From the figure (see especially the calculated HRR) it is evident that in the simulation the flame reached its highest intensity until the end of the 3rd minute, started slowly decreasing after the elapsed 7th minute, and then faded away almost completely after 25 minutes leaving some of the mass of XPS unconsumed. Between the 3rd and the 7th minute the maximal gas temperature around the steel roof beams above the burning paternoster reached up to above 1300°C, however, these temperatures were decreased significantly (to an average temperature of <600°C) between the 7th and the 25th minute.

The results of the simplified model led toward somewhat different conclusions which could be, nevertheless, still considered as good enough for a rough first estimation of the expected fire. They suggested that the maximal gas temperature evolved around the steel roof beams above the burning paternoster was roughly 1100°C. In the decaying fire phase the temperature was decreasing linearly until the cool down in the 30th minute (the average gas temperature of this phase was around 600°C). While some results were obviously overrated and were therefore 'on the safe side' the others were, however, under-predicted. Thus, whenever a higher reliability of results is required, the use of an advanced method is recommended.

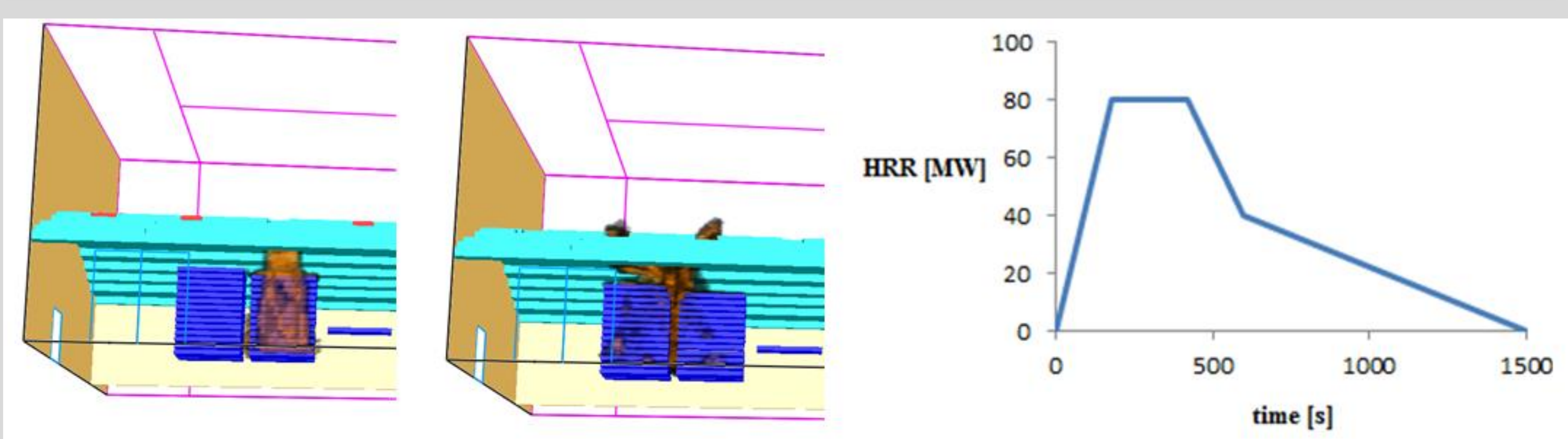


Figure: Results of the advanced model: gradual transfer of flames from the first burning panel across all panels in the paternoster (left), graph (smoothed) of the calculated HRR (right).

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