Field Model Simulations on Air Movement of the Room-Corner Fire Test

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ABSTRACT

The air flow and temperature distribution induced by a fire in the ISO Room-Corner fire test was studied by field modelling technique. Two fire field models, UNSAFE-N and the one developed by Chow were applied. The experiment on melamine faced particle board carried out by SP was taken as the example to compare with, but not validate the predicted results. Combustion processes were not simulated and so the fire was taken as a heat source with varying heat release rate and burning area fitted from experimental data. It is found that both models can give good prediction on the indoor air flow and temperature induced by the fire.

KEY WORDS: Fire simulations, computational fluid dynamics, room-corner fire tests, aerodynamics.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>a, b, c</td>
<td>coefficient of the linear equations</td>
</tr>
<tr>
<td>Ei</td>
<td>mass source errors</td>
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<tr>
<td>( \rho )</td>
<td>air density</td>
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<tr>
<td>k</td>
<td>turbulent kinetic energy</td>
</tr>
<tr>
<td>( R_s )</td>
<td>residual source term</td>
</tr>
<tr>
<td>( R_{\text{rel}} )</td>
<td>absolute residual error</td>
</tr>
<tr>
<td>( R_{\text{ref}} )</td>
<td>reference value of ( R_s )</td>
</tr>
<tr>
<td>( T )</td>
<td>absolute temperature</td>
</tr>
<tr>
<td>t</td>
<td>time</td>
</tr>
<tr>
<td>u, v, w</td>
<td>velocity components in directions x, y and z respectively</td>
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<tr>
<td>( \Gamma_i )</td>
<td>effective exchange coefficient of the property ( \phi )</td>
</tr>
<tr>
<td>( \varepsilon )</td>
<td>dissipation rate of turbulent kinetic energy</td>
</tr>
<tr>
<td>( \phi )</td>
<td>flow variables of air</td>
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</table>
The following are the key points in the field model by Chow [8]:

Key notes for UNSAFE-N [3,7] are:
- The geometrical configuration of the chamber in the SP experiment was of length 3.6 m, width 2.4 m and height 2.4 m as shown in Fig. 1a. Temperatures were measured in 12 points in locations as shown in Fig. 1 as well. Thermocouples P1 to P6 were used to measure the temperature distributions at the ceiling. The vertical temperature profile inside the room was measured by thermocouples P6 to P12 as shown in Fig. 1b. Those key positions were marked while working out the computing domains. The room was divided into 41605 parts with 45, 33 and 33 parts along the x-, y- and z-directions.

The coefficients $a_i$, $a_j$, and $b_i$ are described elsewhere.

Key notes for UNSAFE-N [3,7] are:
- Algebraic model for describing turbulence;
- Upwind differencing scheme in discretizing the conservation equations;
- SIMPLE algorithm for solving the pressure-velocity linked equations.

The following are the key points in the field model by Chow [8]:
- $k$-$\varepsilon$ model;
- Power law difference scheme;
- SIMPLER algorithm.

### NUMERICAL EXPERIMENTS

For the ISO 9705 [4], a test room is constructed of non-combustible materials with length 3.6 m ± 0.05 m; width 2.4 m ± 0.05 m; and height 2.4 m ± 0.05 m. A doorway is constructed at the centre of the shorter wall of width 0.8 m ± 0.01 m; and height 2.0 m ± 0.01 m. Apart from that, no other openings are allowed. A 0.17 m square propane gas burner is taken as the ignition source. It is placed on the floor at a corner opposite to the wall with the doorway. Uniform gas flow is achieved over the entire opening area of the burner by passing propane gas through porous and inert materials such as sand. The burner is in contact with the specimen of the surface materials to be tested.

The geometrical configuration of the chamber in the SP experiment [6] was of length 3.6 m, width 2.4 m and height 2.4 m as shown in Fig. 1a. Temperatures were measured in 12 points in locations as shown in Fig. 1 as well. Thermocouples P1 to P6 were used to measure the temperature distributions at the ceiling. The vertical temperature profile inside the room was measured by thermocouples P6 to P12 as shown in Fig. 1b. Those key positions were marked while working out the computing domains. The room was divided into 49005 parts with 45, 33 and 33 parts along the x-, y- and z-directions.
The fire was coupled with a burner of size 0.17 m by 0.17 m, height 1.0 m located at the corner of the chamber, and the burning area increased as in Fig. 2. The heat release rate of the burner increased linearly from 0 to 100 kW in the first ten minutes.

The set of test results [6] on melamine faced particle board was selected to assess the two field models. There, melamine faced particle boards were placed in the ceiling and the other three walls except the one with the door. The lining product was ignited by the propane gas burner. It was observed from the recorded video taken during the tests that fire spread along the walls and ceiling. The estimated transient burning area and the rate of heat release including the thermal power due to the burner are shown in Figs. 2a and 2b respectively.

Simulations were performed with UNSAFE-N [3,7] and the self-developed CFD code by Chow [8] in an Intel-Pentium 133. The time step was 0.005 s for UNSAFE-N model, and the total CPU time was about 144 hours. The time step was 0.25 s for the model by Chow [8], and the total CPU time was about 384 hours. Two types of boundary conditions: solid wall boundary and free boundary, were used in the numerical experiments with a summary reported earlier.

CONVERGENCE CRITERIA

The following convergence criteria similar to those for the Gauss-Seidel iteration method are used in solving the set of equations given by (2):

\[ \sum \left| \frac{n_{i,ab}}{n_{i,p}} \right| \leq 1 \text{ for all equations} \]  \hspace{1cm} (3a)

\[ \sum \left| \frac{n_{i,ab}}{n_{i,p}} \right| < 1 \text{ for at least one equation} \]  \hspace{1cm} (3b)

A residual source term \( R_p \) at the point \( p \) is defined as:
The transient temperature predicted at thermocouples P1 to P12 are shown in Figs. 4 and 5. On the ceiling positions P1 to P6, results predicted at P1 and P3 by UNSAFE-N agreed well with the experiment, however, the agreement was not so good for Chow's model. At P2, results predicted by UNSAFE were also better than Chow's model, though both sets of predicted curves deviated away from the experimental curve. The deviations were quite large at P4 and P5. There were large deviations on the predicted curves by the two models from the experimental results at P6.

For the vertical distributions near the doorway, results predicted by both models were similar from P7 to P10, but deviated quite far away from the experiments. There are bigger deviations for results predicted by Chow's model from experiment than those by UNSAFE-N.

FIGURE 3. Predicted flow field at a vertical plane across the fire

The transient temperature predicted at thermocouples P1 to P12 are shown in Figs. 4 and 5. On the ceiling positions P1 to P6, results predicted at P1 and P3 by UNSAFE-N agreed well with the experiment, however, the agreement was not so good for Chow's model. At P2, results predicted by UNSAFE were also better than Chow's model, though both sets of predicted curves deviated away from the experimental curve. The two models deviated quite far away from the experiments at P4 and P5. There were large deviations on the predicted curves by the two models from the experimental results at P6.

For the vertical distributions near the doorway, results predicted by both models were similar from P7 to P10, but deviated quite far away from the experiments. There are bigger deviations for results predicted by Chow's model from experiment than those by UNSAFE-N.
Contours for the turbulent viscosity \( \mu_t \), expressed in terms of a multiple of the laminar viscosity \( \mu_l \), across that vertical fire plane are presented in Fig. 6. Both models indicated that the turbulent viscosity was at most 100 \( \mu_l \), at the positions above the gas burner.

The contours for turbulent kinetic energy \( k \) and dissipation rate of turbulent energy \( \varepsilon \) across the vertical fire plane predicted by Chow's model are shown in Fig. 7. The value of \( k \) was up to 0.2 \( \text{Jkg} \) and value of \( \varepsilon \) up to 0.3 \( \text{Jkg}^{-1}\text{s}^{-1} \).

FIGURE 4. Comparison of temperatures: P1 to P6

FIGURE 5. Comparison of temperatures: P7 to P12

FIGURE 6. Predicted turbulent to laminar viscosity ratios at a vertical plane across the fire
Comparison of the mass source errors for the two models is shown in Fig. 8. Note that the value of $m_a$ was up to 16 kgs$^{-1}$. This means that the average value of $E$, at each cell was very small, i.e. $3 \times 10^{-4}$ kgs$^{-1}$.

Lastly, the mass flow rates of air drawn in and out through the door for the two models are shown in Fig. 9.
CONCLUSION

Two fire field models, UNSAFE-N [3,7] and the one by Chow [8], were applied to simulate the air flow pattern and temperature distribution induced by a fire while carrying out the ISO room-corner fire test [4]. Experiments on the melamine faced particle board carried out by SP [6] was taken as the example for comparison.

- It is found that both fire field models are able to simulate the air flow and temperature distribution. However, the UNSAFE-N gave a better prediction on comparing with the experiment. A possible explanation is that adopting the algebraic turbulence model might give better prediction.

- The transient heat release rate and burning area curves fitted from experiments were taken as the input heat source. Such an approach is practical when combustion process is not simulated. But it is difficult to develop a fire field model with combustion process as the phenomena on turbulence, combustion and thermal radiation have to be included [1,2].

- For the turbulent viscosity $\mu_t$, both models illustrated that the values of $\mu_t$ would be about 100 $\mu$, in most parts of the room. This point has to be considered carefully in understanding the turbulent air flow.

- The convergence criteria in solving the equations are reviewed. Typical results presented in Figs. 8 and 9 should be noted carefully in using the field models.

ACKNOWLEDGEMENT

The authors wish to thank Professor K.T. Yang for allowing the use of UNSAFE-N and his advices on this subject area. The project is funded by PolyU under research account G-V470.

REFERENCES


