Chapter 4
Validation of the CFD Technique

4.1 Introduction

This chapter presents a validation study to determine the accuracy of the simulation results and also to gain acceptance of the CFD method by comparing the results between the experiment and simulation. First of all, the experimental works are described. Then, the simulation results are presented. Finally, the results of temperature distribution, velocity at the inlet and the outlet of the room are compared to determine the accuracy of the CFD method. The condition of a model of a present rubber smoking room is then adjusted.

4.2 Experimental Works

The experiments were conducted with an empty smoking room at Ban Tai - Prik Tok Rubber cooperatives, Sadao district in Songkhla province. Temperature distribution in the rubber smoking room was measured for a long period of time. A portion of the results when the temperature was nearly constant was selected for the steady-state case representation. Furthermore, the velocity results at the burner inlet and the ventilating lid outlets were used for comparing with simulation results in which the boundary conditions and heat source at the nearly steady-state of experiment were approximately the same.

4.2.1 Equipment

Type-K thermocouples were used for temperature measurements. Data logger (DataTaker, DT 500) was used to record the temperatures at 2-minute interval to ensure continuous reading.

Hot-wire type anemometer (Airflow, TA400T) was used for the velocity measurement. Air velocity at burner inlet and the velocity of exhaust gas at the ventilating lids were measured for comparison purpose.

Firewood (rubber wood, Hevea brasiliensis) of known mass was fed to the burner. Sampling of firewood was used to determine the moisture content on dry basis by drying it in a laboratory oven at 105°C until totally dried.

4.2.2 Methodology of Experiment

Experimental procedure is shown in a diagram in Fig. 4.1.

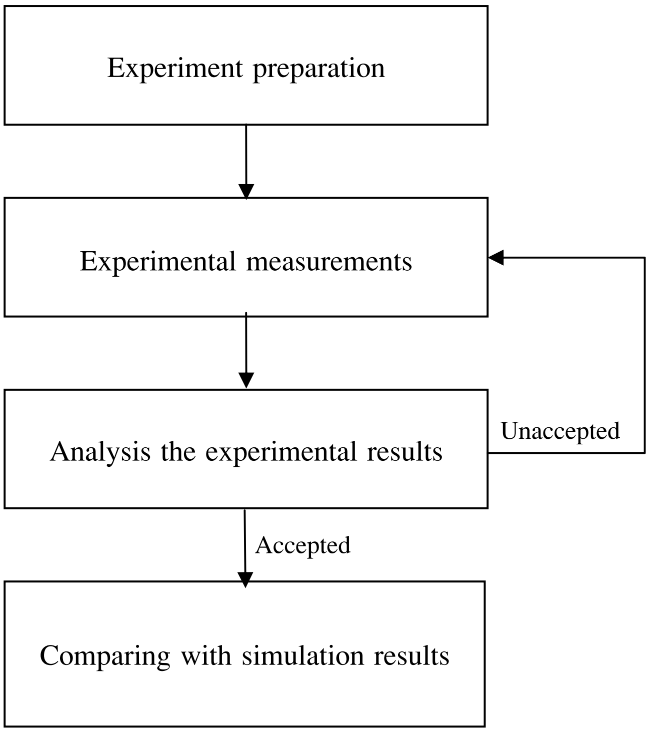

Figure 4.1 Diagram for experimental methodology.

For experiment preparation, accuracy of temperature measurement device was checked. Then temperature measurement probes were installed, and points of velocity measurement were marked. A constant-temperature water bath was used for the calibration of thermocouples. Thermocouples were connected to the data logger and a standard thermometer was directly dipped in the bath as shown in Fig. 4.2. Temperatures of water in a bath were controlled at 30, 40, 50, 60, 70, 80 and 90°C. To obtain a homogenous temperature of water in the bath, mixing was needed. Measurements were repeated 5 times. Temperatures were compared every minute. The temperatures at steady state of both measurements were plotted in a calibration graph as shown in Appendix A.

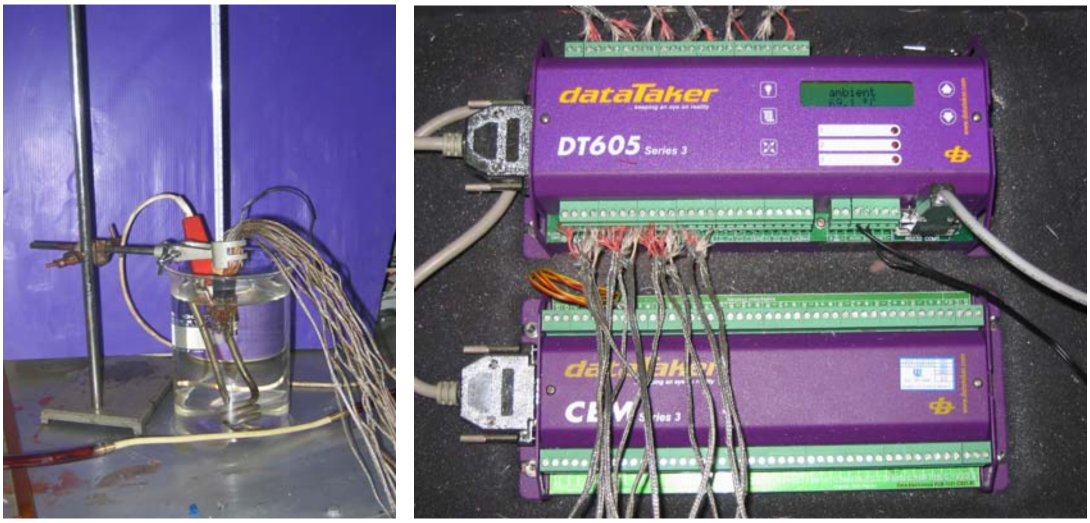

Figure 4.2 Calibration of thermocouple probes with a standard thermometer.

After calibration, all temperature measurement probes were installed at 15 positions covered every part of the smoking room as shown in Fig. 4.3, and 2 positions for ambient temperature and temperature of gas outlet in a chimney (not shown).

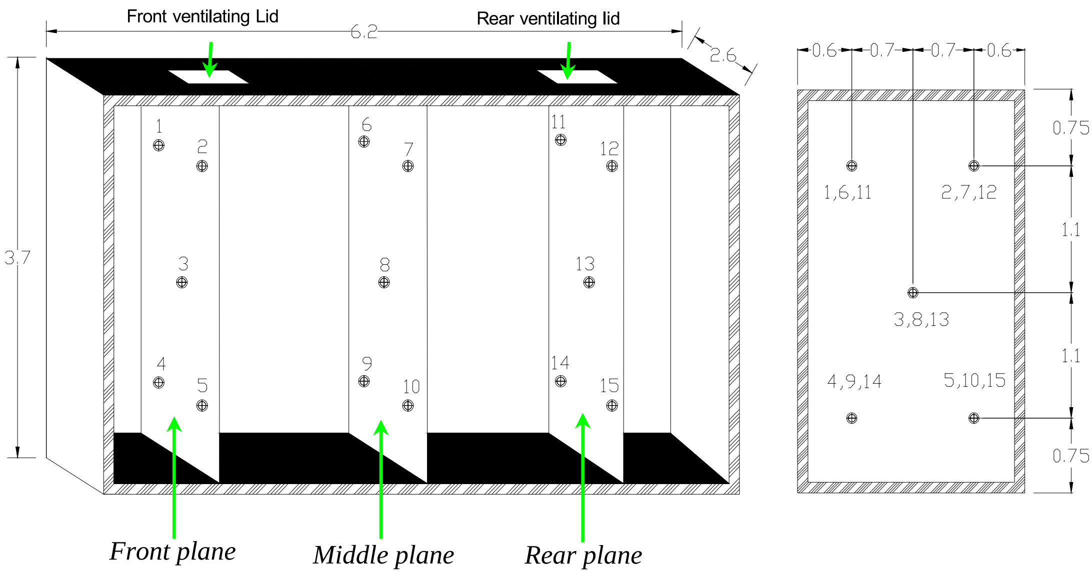

Figure 4.3 Positions of temperature probes on each plane shown from the side view of the rubber smoking room.

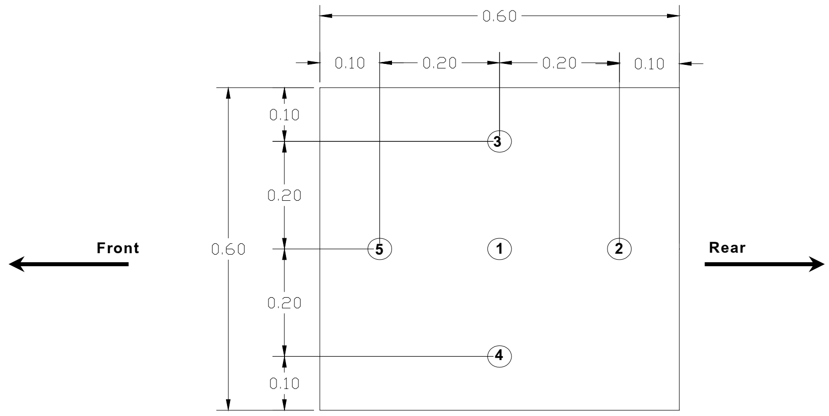

Figure 4.4 The positions of velocity measurement at both ventilating lids shown from the top view.

In addition, velocity measurement was made at 3 positions at the burner inlet (not shown) to calculate average inlet velocity, and 5 positions at each ventilating lid of the smoking room for gas outlet. The positions of velocity measurement at the ventilating lids are shown in Fig. 4.4. There are two identical ventilating lids of the model rubber smoking room as shown in Fig. 4.3.

In the measurement, the temperature was recorded every 2 minutes throughout the experiment using the data logger. Experimental procedure is explained in the following steps:

Step 1: Known weight of firewood was fed in a burner.

Step 2: Temperatures in the smoking room (15 positions) were recorded.

Step 3: Velocity at 3 positions of the burner inlet and 10 positions at both ventilating lids were recorded.

An important process of the experiment is the variation of supply rate of firewood. At the beginning, quantity of firewood was varied to obtain a temperature-fuel consumption relationship. A suitable rate of firewood supply which gives nearly steady-state temperature in the smoking room was determined. This rate was then used throughout the experiment.

In the result analysis, two parameters will be used as representatives in the simulation. First, temperature result of the period which has a minimum standard deviation is used. An average temperature of this period will be presented to compare with simulation results at steady state. Moreover, average ambient temperature at the same period will be used as boundary condition for the simulation.

Second, the moisture content of wood sampling of the experiment will be determined. Heat supply from firewood can be determined from the heating value which is dependent on the moisture content. Heat supply from the firewood will be used to be heat source input supply for the simulation.

Validation of the results will be presented in the section 4.4.

4.2.3 Experimental results

Results of the temperature measurement at 15 positions in the smoking room are shown in Fig. 4.5. Total time for this experiment was 64 hours. The near steady-state results that are used for benchmarking are temperatures during the hours of 50-56. The rate of wood supply in this period was 10 kg/hr (20 kg of wood was added every 2 hours). The temperature used for benchmarking is the average value at every 2 minutes at all positions during this period.

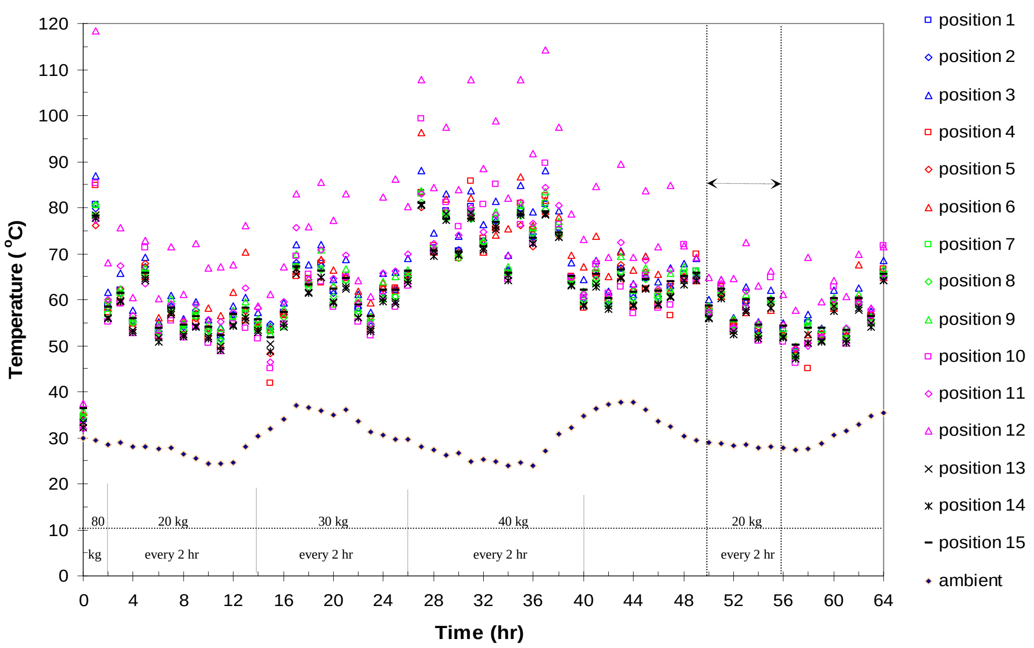

Figure 4.5 Temperature histories at 15 positions in the room and ambient.

Results of velocity measurement on the front and rear ventilating lids of this experiment are shown in Fig. 4.6 and Fig. 4.7, respectively. Average values of velocity at every 2 hours during the hours of 50-56 at all positions will be used in benchmarking results.

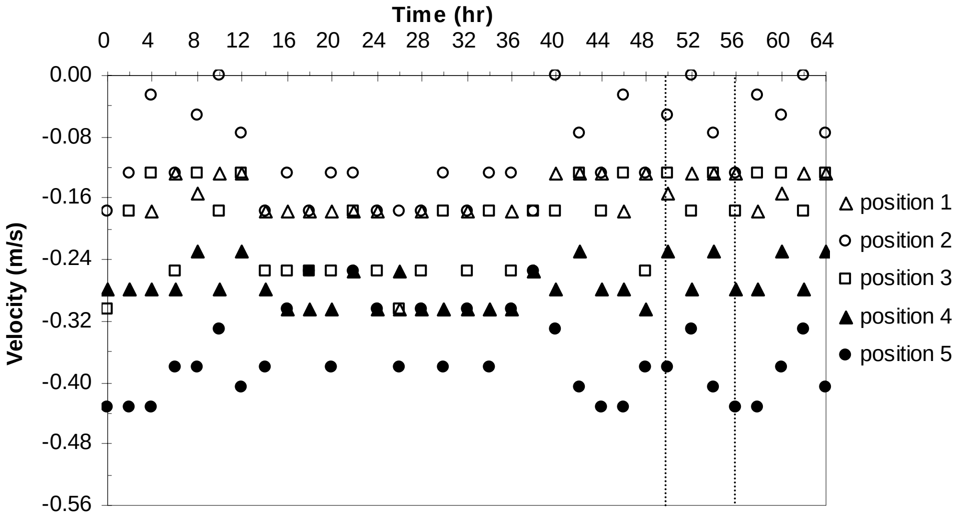

Figure 4.6 Velocity histories at 5 positions on the front ventilating lid.

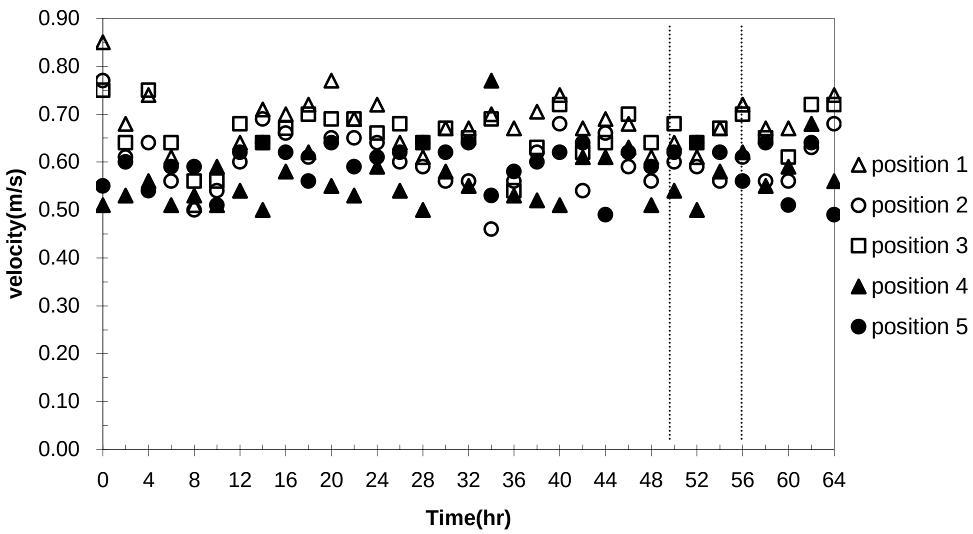

Figure 4.7 Velocity histories at 5 positions on the rear ventilating lid.

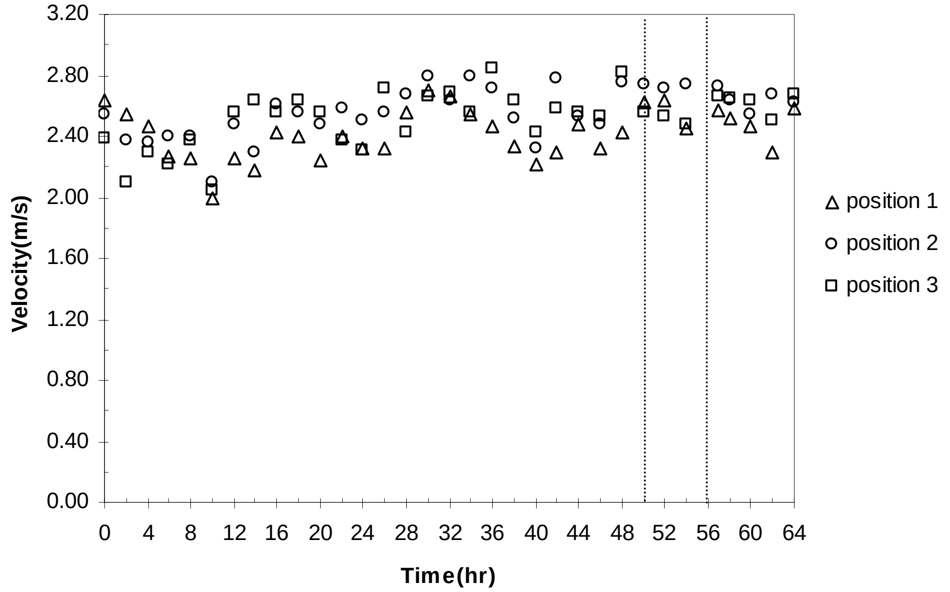

Figure 4.8 Velocity histories at 3 positions on the burner inlet.

Results of velocity histories at the burner inlet are shown Fig. 4.8. Average values of velocity during the hours of 50-56 of this experiment for all positions are also used in comparison with the simulation results as will be shown later in Table. 4.2. Total heat supply rate of this experiment was about 28.78 kW as shown in Appendix A.

4.3 Simulation of an Empty Rubber Smoking Room

Computational Fluid Dynamics technique should be used to study the temperature and velocity distributions in the rubber smoking room because it is quick, inexpensive and effective. In this work, FloVent V5.2 is a CFD software that employs a finite volume method. It was used for the flow and temperature simulation in an empty smoking room. A desktop computer, (Intel Pentium 4, CPU 2.8 GHz and 1 GB of RAM) was used for calculation. Results from CFD simulation will be compared against the experiment results in section 4.2.

Some previous investigations [35] showed that the transition of flow from laminar to turbulence of flow in a room occurs at Re ~ 5000, and it is definitely turbulent at Re = 10^4. In this study, average velocity in the smoking room is about 2.7 m/s. This is corresponded to the Re of $11x10^4$. Therefore, for the prediction of this study, the flow of hot gas in the smoking room was assumed to be turbulent. In fact, the air flow at region near the floor is affected by viscosity at the wall surface. However, the simulation program would solve the problem by using damping, so called "wall-function".

4.3.1 Boundary conditions, materials, and grid setting

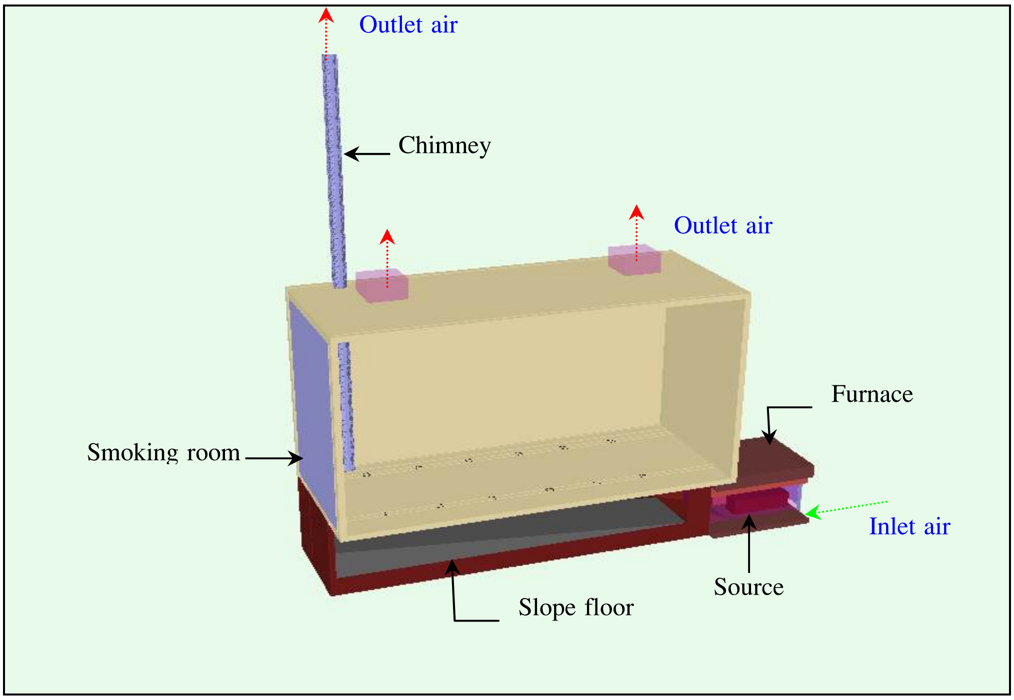

Figure 4.9 The rubber smoking room model.

The model of the rubber smoking room is shown in Fig. 4.9. Static pressure boundary condition which is used to represent the system surroundings was set constant at zero gauge pressure. Outside temperature was set constant at 26.7°C. This value is an average ambient temperature from the experiment during the hours of 50-56. At the beginning, ambient air velocity was set zero in every directions. Details of geometry and material properties of the smoking room are shown in Table 4.1.

Localized grid scheme was used for setting fine grids where high accuracy was needed and coarse grids (maximum distance is 35 cm) were used elsewhere. Local grid of the smoking room has the maximum size of 10 centimeters. Locations of fine grids which include air inlet, heat source, and gas supply ducts and air outlets have the maximum size of 2.5 centimeters. The total number of grids of the current model is 559,569.

The LVEL K-epsilon ($k-\varepsilon$) model which "wall functions" used to bridge the viscosity affected region between the wall and the fully turbulent region was employed to calculate the additional parameters for solving the problem of turbulence flow.

Table 4.1 Details of components, materials, sizes and material properties of the rubber smoking room.

Component	Material	Size	Material property		
			Thermal conductivity (W/mK)	Density (kg/m^3)	Specific heat (J/kgK)
Furnace door	Iron	0.6 x 0.8 m, thickness 5 mm	80.2	7,870	447
Furnace wall	Brick & cement	1.0 x 1.9 x 1.3 m, thickness 0.25 m	1.0/0.72	2,645/ 1,860	960/780
Wall of supply gas room	Brick & cement	2.0 x 6.2x 1.1 m, thickness 0.25 m	1.0/0.72	2,645/ 1,860	960/780
Sloped floor	Concrete (stone mix)	1.1 x 6.0 x 0.5 m	1.4	2,300	880
Smoking room floor	Cement	2.4 x 6.0 m, thickness 0.1 m	0.72	1,860	780
Supply ducts	Iron	Diameter 4 inch, thickness 2 mm.	80.2	7,870	447
Enclosure of the smoking room	Brick	2.6 x 3.7 x 6.2 m, thickness 0.1 m	1.0	2,645	960
Door of the smoking room	Iron	2.4 x 3.3 m, thickness 3 mm	80.2	7,870	447
Chimney	Iron	Diameter 8 inch, long 8 m, thickness 3 mm	80.2	7,870	447
Ceiling	Ceiling tiles	2.4 x 6.0 m, thickness 5 mm	0.056	380	1,000
Ventilating lid	Ceiling tiles	0.6 x 0.6 m, thickness 5 mm	0.056	380	1,000

4.3.2 Simulation results

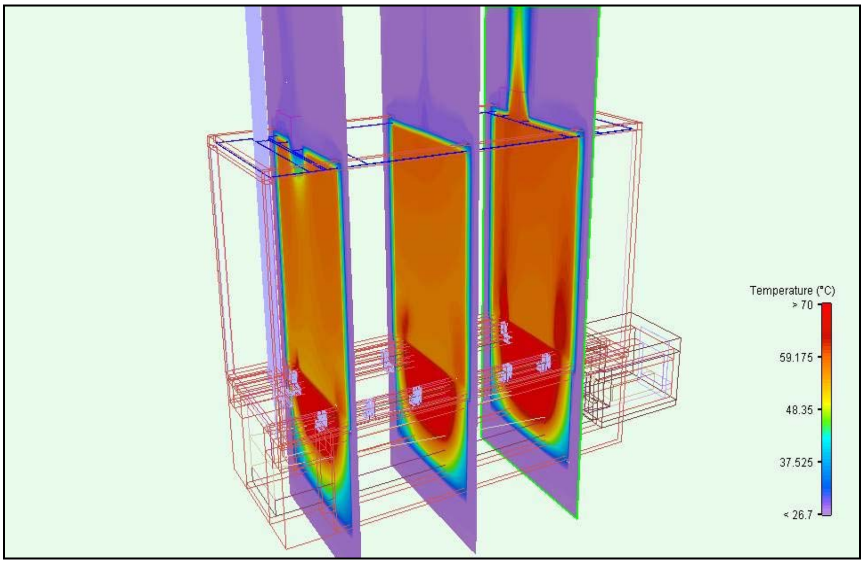

Figure 4.10 The temperature contours on the front, middle and rear planes of the model room.

The temperature contours of the front, middle, and rear planes of the model room are shown in Fig. 4.10. The figure shows that the highest temperature takes place at the bottom edge of each plane, since this area is near the heat source. The temperatures at the rear plane are highest where the front plane temperatures are lowest. Comparison of temperatures from experiment and simulation will be shown later in Figs. 4.11- 4.13 for each individual plane. In these figures, temperatures are plotted against the positions on each plane as indicated in Fig. 4.3.

4.4 Validation of results and discussion

4.4.1 Heat Source

In the experiment, moisture content of the firewood was about 60.5% dry basis. Average heat supply rate of wood in 6 hours was 28.78 kW. However, some heat loss in the room through leakage at the front door and ceiling caused the lower actual heat supply to the rubber sheets. From simulation, it was found that a heat source of 16.0 kW was appropriate. This corresponds to 56% of the heat supply rate from actual case, and results in minimal error between experimental and simulation values.

4.4.2 Temperature

Temperature difference between the experimental and simulation results is 0.12-2.43°C on the front plane (Fig. 4.11), 0.20-1.54°C on the middle plane (Fig. 4.12), and 0.23-4.46°C on the rear plane (Fig. 4.13). Highest deviation is about 4.0%. Agreement between the experimental and simulation results is quite good considering that the flow is natural and uncontrollable. Summary of the temperatures at all positions is given in Fig. 4.14. Deviations at positions 4, 5 and 15 are larger than at others positions because these positions are close to the hot gas inlet, which results in high temperature gradients. Using finer grids near these locations would enhance the accuracy of the simulation. Part of the deviation may result from the unsteady behavior of the experiment.

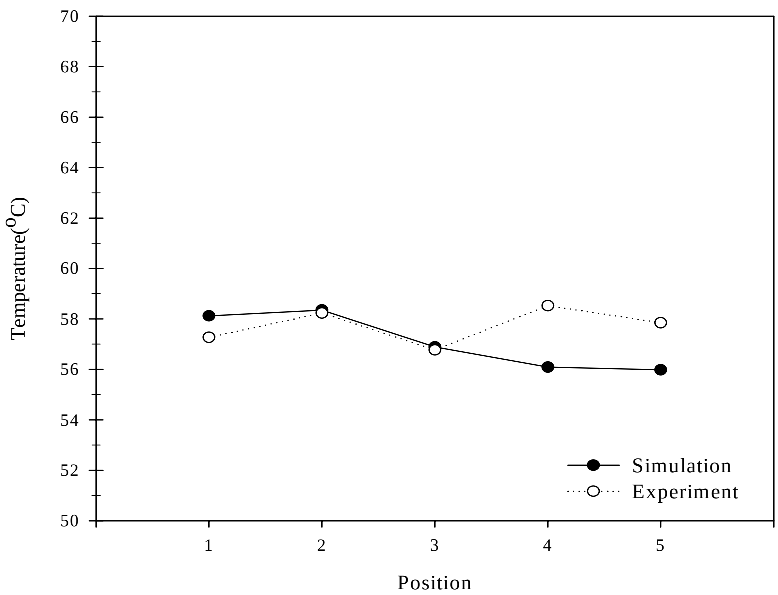

Figure 4.11 Comparison of temperature between the experiment and simulation at the front plane.

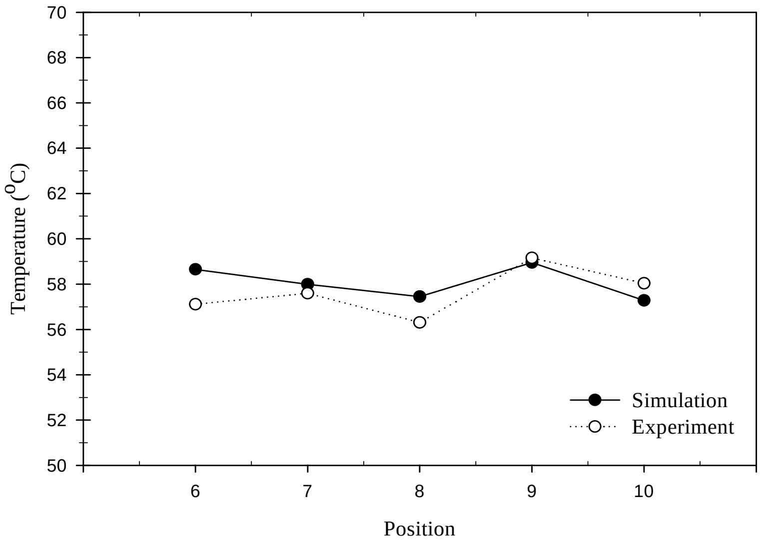

Figure 4.12 Comparison of temperature between the experiment and simulation at the middle plane.

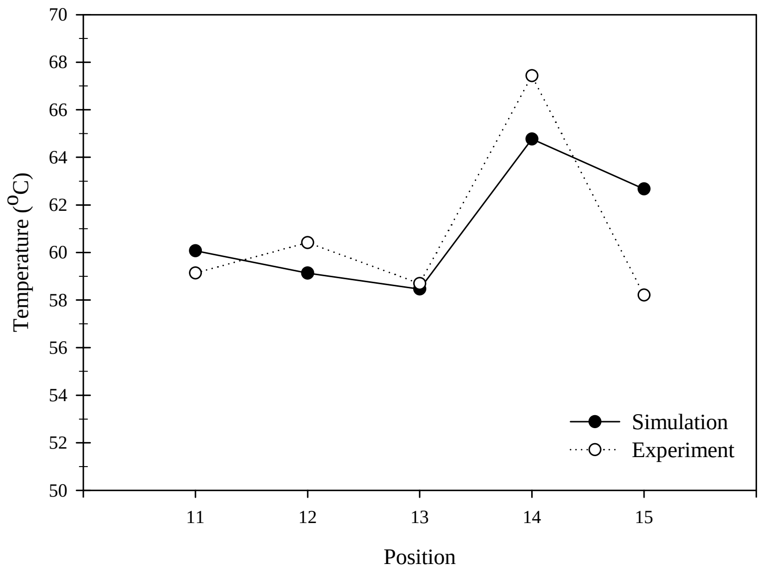

Figure 4.13 Comparison of temperature between the experiment and simulation at the rear plane.

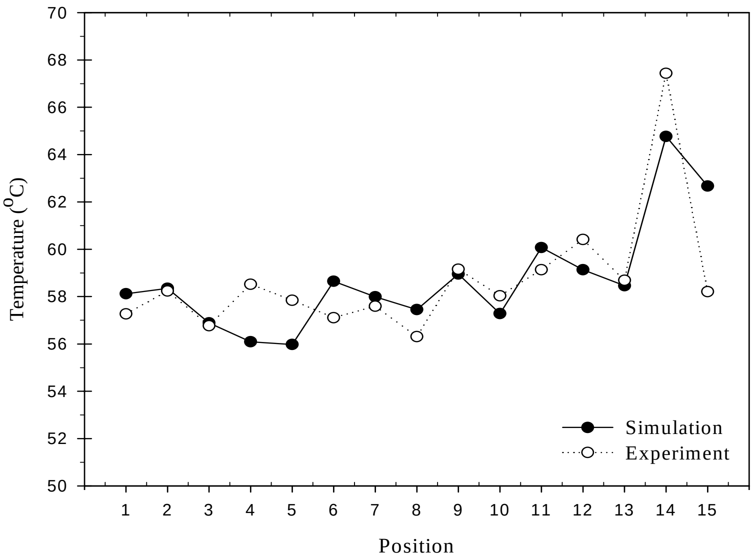

Figure 4.14 Comparison of temperature between the experiment and simulation at all positions.

4.4.3 Velocity

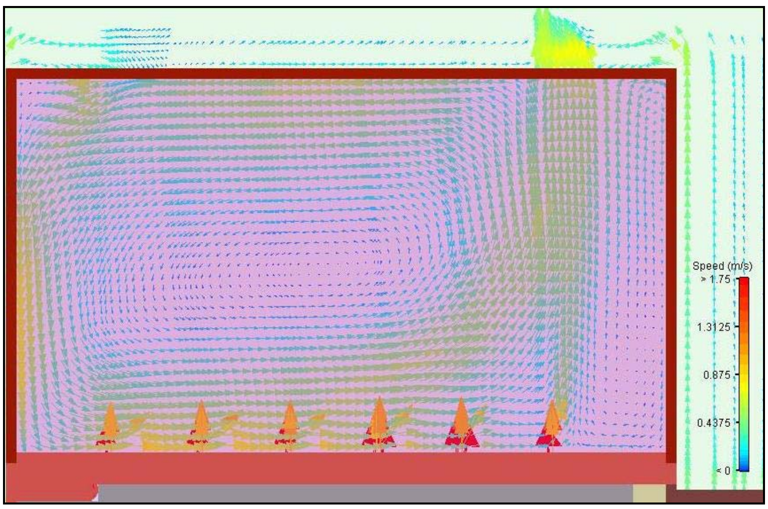

Figure 4.15 The velocity vector plane on the supply duct line in the model room

The velocity vectors of the flow in the model room are shown in Fig. 4.15. A back-flow into the room through the ventilating lid takes place at the front lid. This may result from spatial variation of velocity at hot air supply ducts. Velocity at the supply ducts near the front end is lower than that near the rear end. The circulation of air in the room causes the pressure under the front lid slightly lower than the atmospheric pressure which induces flow of air from outside.

Comparison of velocities is shown in Table 4.2 for all positions. Agreement at all positions is quite good. The largest variation is about 7.7 %. The back-flow at the front ventilating lid is confirmed by the experimental result.

Table 4.2 Comparison of velocities

Position	**Experiment** (m/s)	**Simulation** (m/s)
Burner inlet	2.62	2.84
Front ventilating lid (#1)		
Position 1	-0.14	-0.20
Position 2	-0.06	-0.08
Position 3	-0.15	-0.14
Position 4	-0.26	-0.25
Position 5	-0.40	-0.44
Average	-0.20	-0.22
Rear ventilating lid (#2)		
Position 1	0.66	0.68
Position 2	0.59	0.58
Position 3	0.67	0.70
Position 4	0.56	0.52
Position 5	0.61	0.69
Average	0.62	0.63

4.5 Conclusions

Results from the comparison of the velocity and temperature in the rubber smoking room indicate that the agreement between the experiment and simulation are quite good. Heat supply rate in the simulation for this case is about 56% of total heat supply of wood in the experiment. Therefore, it is possible to use the CFD technique for simulation of the flow in the present rubber smoking room. Simulation of the smoking room that contains rubber sheets and improvement of the room will be considered in the subsequent chapters using the same method.