Experimental Study on Gasoline Pool Fire Using A Full Scale Service Station Model and 1/15 Reduced Scale Model

by

Osami SUGAWA, Kunio KAWAGOE, Yasushi Oka
and Tomoyuki Mizuno*

Center for Fire Science and Technology
Science University of Tokyo
2641 Yamasaki, Noda-shi, Chiba 278 Japan

ABSTRACT
Fire tests were carried out using a full scale model of a semi-enclosed gasoline service station and a 1/15 reduced scale model. Two sizes of fire pool, 10 m^2 with 600 liters and 15 m^2 with 900 liters of gasoline, were used for the full scale tests and a gas diffusion burner was used for the reduced scale model. Fire source located at the end corner or at the opening. Thermal re-radiation contributed the burning rate enhancement of about 24% compared to free burning one, and both convection and wind effect gave about 78% enhanced burning rate at the maximum. Reduced scale model experiments were carried out to compare the flame lengthen from the opening. Good agreement was obtained between full scale and reduced model with regard to the similarity in the correlation on flame length versus dimension-less heat release rate (Q*).

key words : full scale model, reduced scale model, gasoline pool fire, fire whirl, flame length, Karman-vortex

1. INTRODUCTION

Japanese Fire Code for a design of gasoline station building was changed partly in March, 1989. Before the change of the code, a series of full scale fire test had been carried out [1] in order to assess the fire safety of a gasoline station building with one side opeing. Because, if a fire occurred in a service area in such designed station, extended flame may produce a serious fire damage to the upper stories.

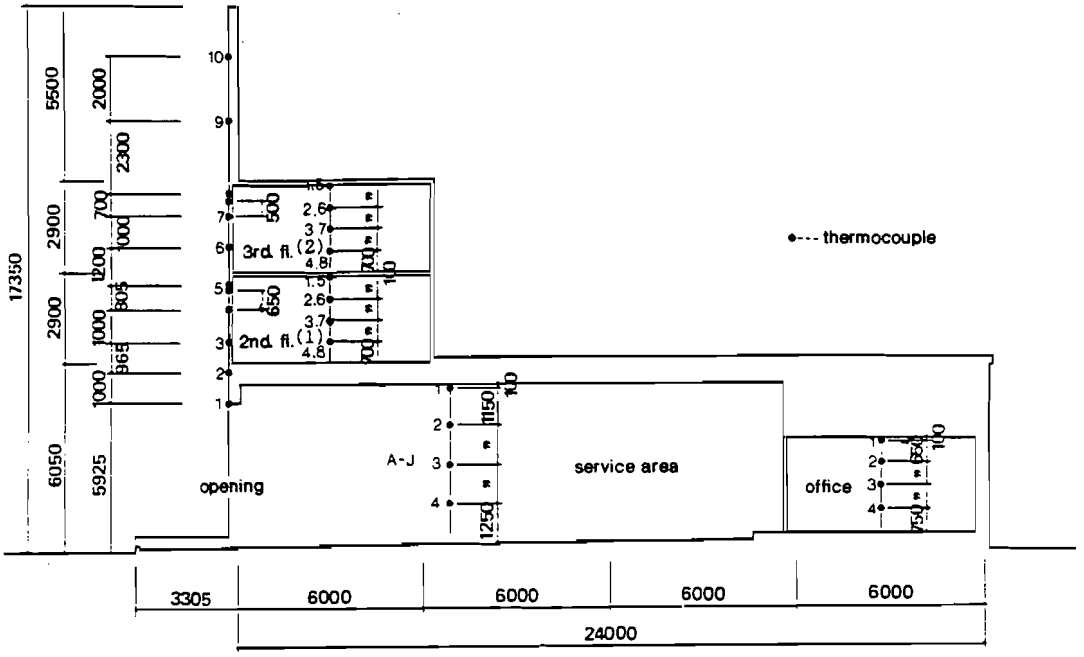
The one of the objectives of the experiments is to obtain the flame behavior extended from an opening of a one-side-opening gasoline service station with multi-story. In this paper, we will present extended flame length behavior with regard to the dimension less heat release rate Q*. Similarity on the flame length as a function of Q* between the full scale and reduced model was considered, but the other similarity were not dealt. Some experimental results are also presented which dealt with a test with a water drencher and tests with a pent roof of 1.0 m and 1.5 m [1].

2. EXPERIMENTAL PROCEDURE

To obtain the basic fire behavior which may occur in a semi-enclosed space for a gasoline service station, a full scale model was built in an open field of which opening faced to almost north. A 1/15 reduced scale model was also composed with a wind generator.

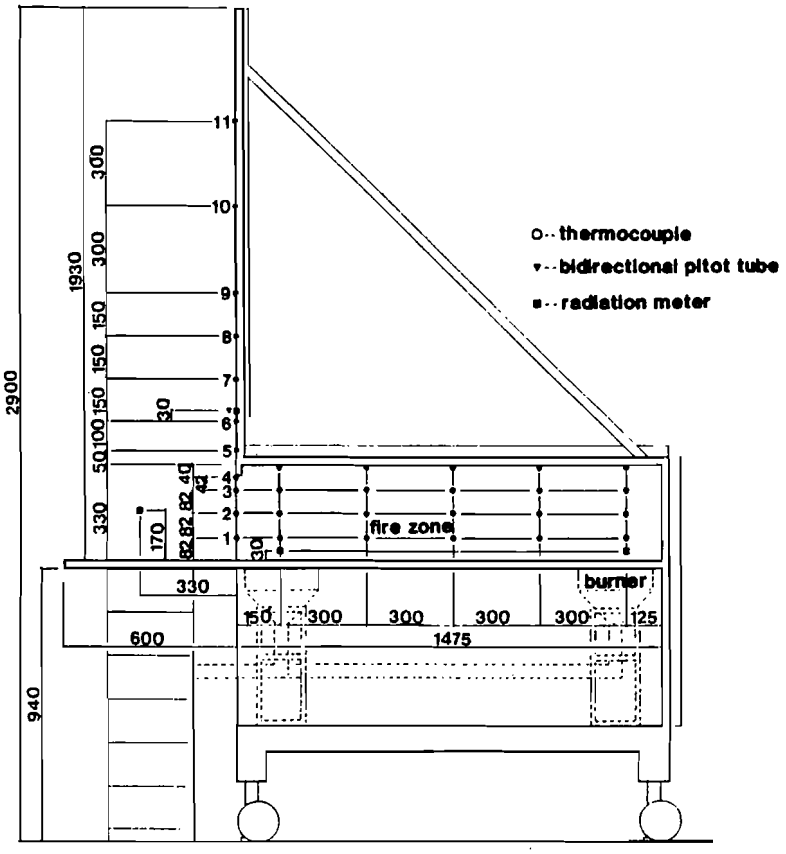
2-1. Full Scale Model

Figure 1 shows the plan and front elevation with the locations



Elevation (Cross Section) of Full Scale model

Figure 1 Full scale model of a gasoline station, side elevation.



1/15 Reduced Scale Model

Cross Section

Figure 2 1/15 reduced scale model of the side elevation, with measuring postions.

of instrumentation attached. The model had partly three story and extended wall which corresponds to another two higher story. Ceiling and wall in a service area were covered with ALC (Autoclaved Lightweight Concrete) panels of 50mm and 100 mm thickness panels. Window sashes of the second and third story were aluminum frame with plastic seal, and wired grass of 6.8mm thickness were set.

The temperatures were measured at 100 points by means of 0.3 mmø K-type thermocouples. Radiative heat fluxes were also measured at 7 points. Hot air velocities were measured at the wall of second floor and at the ceiling of the opening, respectively. The natural wind direction and velocity were measured at the top of the full scale model. Outputs from these sensors were recorded every 10 seconds. The locations of the measuring points are illustrated in Figure 1. Gasoline fuel was ignited electrically and ignition time was adopted as the start time.

For full scale experiments, three pool locations were selected; at the end corner, middle position and at the foot of opening. A pool area was reduced from 15 m^2 to 10 m^2 in the first three experiments. The pool depth was about 30 cm, and of which 23 - 24 cm depth was filled with fresh water prior to each experiment. The fuel depth was about 50 - 58 mm.

2-2. Reduced Scale Model

Figure 2 shows the 1/15 reduced model. The structure of the reduced scale had an iron frame and was covered with ceramic panels of 25mm thickness. A gas (propane) diffusion burner of 27cm x 27cm square was used. Almost the same measurement method employed as in the the full scale model was also employed, and the measuring positionsare also shown in Figure 2.

3. RESULTS AND DISCUSSION

3-1. Burning Behavior

It was obviously expected that enhanced burning rate (burning rate was defined as the decreasing rate of the fuel depth) of gasoline fuel must be given by re-radiation from the hot ceiling and walls. Radiative heat flux at the foot of the flame (at the pool periphery) was also measured. Table 1 shows fire locations, burning rates, and natural wind condition. Observation showed the flame behavior was different depending on the natural wind direction. As the opening faced to downwind of natural wind, a pair of Karman-vortex appeared at the both sides of the opening and which was clearly visualized by dense smoke and as a fire whirl. In this case, hot smoky layer in the service space was well disturbed and thus unclear boundary between hot layer and lower air layer was obtained. As the pool located at the foot of opening and almost south wind was given, turbulent flame plume appeared for first 30 sec and changed to fire whirl within 1 min after the ignition. Fire whirl extended as high as about 18 - 20m with roaring. The diameter of the fire whirl was as almost same size as the pool. The intensive circular wind generated by Karman-vortex sucked out the flame from the original pool surface, so that the flame slid out toward the downstream direction forming an apparent burning area on the floor. The fire whirl disappeared several times corresponding to the breath of natural wind.

In experiments #4, the natural wind was mild as 1 - 2 m/sec with direction of almost north. Two zones of smoke and lower air layer were clearly observed. Flame extended along the ceiling and facade as long as about 30 m from the pool, and extended flame

reached frequently to the wired window glasses of the second floor. The glasses were heated by radiation of about 9 W/cm^2 instantaneously from a fire whirl, and some cracks were observed but they were neither broken down nor fallen down. These glasses performed resistance against the fire propagation into the room with and without the pent roof or water drencher system.

Table 1 Burning Rate and Wind Condition

Exp.	Location of Pool	Burning rate(mm/min)	Natural Wind Condition direction	vel.(m/sec)
1	E	5.27 (0- 9'29")	SSW	2.4
2	M	5.74 (0- 9'35")	NNW	2.5
3	F	7.05 (0- 7'58")	SSW	1.7
4	E	4.93 (0-11'34")	NNE - NE	1.8
5	M	5.18 (0-10'37")	SSE	4.3
6	F	6.5 (0- 8'55")	SSW	1.5
7	F	5.32 (0-10'20")	SE - SSE	2.9
8	F	6.35 (0- 8'40")	SSW	5.8
9	F	6.28 (0- 8'46")	SSW	6.3
10	F	5.24 (0-10'41")	ENE - NNE	4.1

E:end corner, M:middle location, F:foot of the opening

Table 2 Radiative Heat Flux at the foot of Flame

Exp. No.	ave.	max. (W/cm^2)	min.	period (min:sec)
1	5.5	11.79	2.38	0:20 - 6:10
2	11.10	16.26	4.79	0:20 - 9:40
3	7.27	15.06	1.64	0:20 - 8:00
4	11.26	16.79	3.32	0:30 - 12:00
5	9.09	16.53	3.51	0:40 - 10:00
6	8.98	14.78	2.33	0:20 - 8:10
7	10.70	16.80	1.98	0:30 - 10:30
8	5.45	12.21	1.93	0:20 - 8:40
9	3.51	12.32	1.43	0:20 - 8:50
10	9.97	13.17	5.39	0:20 - 3:00

3-2. Burning Rate Enhancement by Radiation and Flow

It have been expected that the heated walls and ceiling produce burning rate enhancement. However, observation indicated that another factor of wind (or convection flow) also gave burning rate enhancement. The highest average radiative heat flux was obtained in test #4, as shown in Table 2. Remembering the average wind velocity and direction as shown in Table 1, we can assume that radiation was the main effect in test #4 which accelerated the burning rate of the fuel. Burning rate of gasoline pool fire in an open field is about 4.0 mm/min [2] - 4.3 mm/min [3] for the turbulent flame. Therefore, it was estimated roughly that the radiation effect gave about 1.14 - 1.24 times greater burning rate in test #4. The outward hot air mass flux of about 52.6 kg/sec was estimated depending on temperature, velocity, and depth under the ceiling at the opening in the test #4. Inflow velocity of about 1

m/sec was estimated assuming the same amount of the inflow mass flux was given into the space. About 1 m/sec wind may give 4% burning rate enhancement according to the equation (1) which Blinov and Khudiakov had proposed [2,4]. Therefore, we could estimate that the re-radiation effect gave 10 - 20 % burning rate enhancement than the the burning rate in open field.

$$m_{wind} / m_{still} = 1 + 0.15\ (u/D) \qquad (1)$$

where, u is wind velocity (m/sec), D is pool diameter (m), and m is burning rate of the fuel.

The wind effect due to convective flow and/or Karman-vortex on a pool fire is quite complex and alternative. The flame temperature is raised due to improved mixing and combustion [2] and resulted in radiant heat fluxes enhancement and this gives greater burning rate. And at the same time, flame thickness above the original pool is reduced due to suction and/or sliding out induced by the vortex flow. This phenomena gave burning rate reduced. Lois and Swithenbank [5], and Yumoto [6] observed a doubling of the burning rate of a hexane pool in a 4 m/sec wind and no further increase for greater velocities. In the experiments of #3, #6, #8, and #9 [1], we observed a fire whirl. And about 20 m/sec circulating velocity was estimated roughly from the picture analysis. Applying the equation (1) with the circulating velocity of about 20m/sec, we can estimate 6.7 - 7.1 mm/min burning rate. The measured average burning rates in these experiments were 6.3 mm/min - 7 mm/min as shown in Table 1. It is not clear of the effects and mechanism of wind on the burning rate enhancement but the equation (1) appears to be well fitted to the results.

3-3. Water Drencher system

In test #9, the water drencher system was set at the soffit of the opening. The system has 6 heads at 2.5 m spacing and 792 l/min of water was sprinkled at the pressure of 3kgf/cm^2. The water pump was initiated 3 min after the ignition and, at 3min 30 sec water sprinkling was started. Figure 3 shows the wall temperatures before and after the water sprinkling. It is clearly observed that the temperatures on the facade dropped 400 - 450 to 70 - 100°C within a few minutes, and the average radiative heat flux on the wall at the second floor level changed drastically 1.8 W/cm^2 to 0.42 W/cm^2. Radiative heat flux to the external point, 5m from the opening and 3m from the ground, showed 1.16 W/cm^2 before the sprinkling and 0.13 W/cm^2 after it.

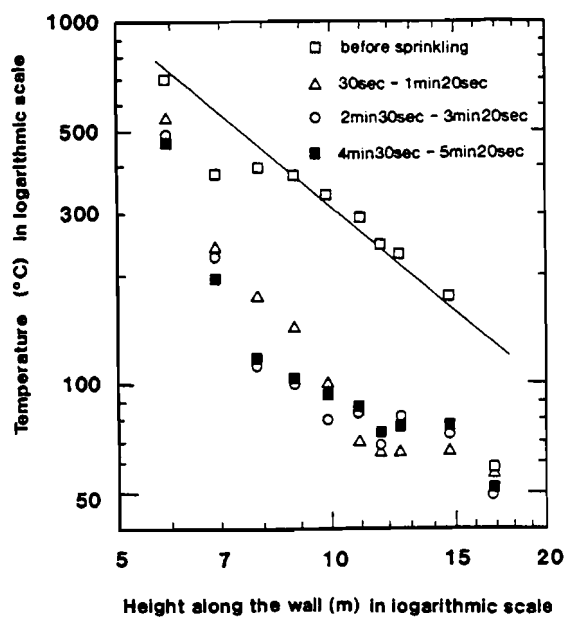


Figure 3 Temperatures along the front wall of the full scale model before and after the drenching.

4. Similarity of Flame Length with Heat Flux

Extened flame length which came out from the opening is an important factor for assessments on fire spread to the upstair. In order to evaluate the extened flame length with changing the heat

flux rate, and with and without wind against the opening, we carried out the supplementary experiment using a 1/15 scale model.

4-1. Estimation of Heat Flux given to the Reduced Scale Model

Dimensional analysis on the relation between flame height and $Q/D^{5/2}$ [7], and its significance is represented often by non-dimensional heat release rate Q^* [8,9,10,11,12]. Where Q^* is defined as $Q^* = Q/ \ Cp \ T \ D^{5/2} \ g^{1/2}$, and Q is heat release rate given by stoichiometric combustion, is hot air density, Cp is specific heat, T is temperature, and g is acceleration constant. These correlations were established for an open fire, however, which implies that burning rate enhancement gives higher flame geometry (in our case longer flame). Dimensionless flame geometry L_f/D depends on the Q^* [12] as in the form of equation (2).

$$L_f = A \ (Q^*)^n/D \qquad (2)$$

where L_f is flame height (length), A is coefficient, D is representative pool length. For convenient sake, we adopt the enhanced burning rate of 5 mm/min as the temporary standard value for the gasoline pool fire. The pool area in the full scale model was 15 m^2 and assuming 100% combustion efficiency, the heat flux is expected about 41 MW. Burning rate increased due to both re-radiation enhancement and wind effects in the full scale tests, and the value of Q^* were estimated between 1 and 2. For these range of Q^*, n = 2/5 is given in equation (3). Employing "k" as a reduced factor of 1/15,

$$k = L_{model}/L_{full} = (Q^*_{model}/Q^*_{full})^{2/5}. \qquad (3)$$

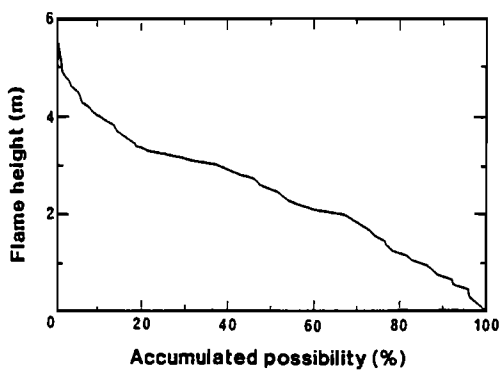
Therefore, the heat release rate have to be given to the reduced model is estimated as

$$Q_{model} = k^{5/2} \ Q_{full}. \qquad (5)$$

We used a diffusion gas burner with propane as a fuel for a reduced model. For about 40 MW gasoline fire in the full scale, about 35 l/min of propane gas fuel must be charged. In order to cover the wide range of the burning rate enhancement, the gas supply rate to the reduced model was chosen from 30 - 50 l/min.

4-2. Comparison of Flame Geometry between Full and Reduced model

Estimation of the flame tip location was carried out on successive 300 frames from the video recordings. The flame tip location was adopted as the highest visible location in each frame. Figure 4 shows the accumulated percentage probability of the flame height measured in test #6. The same process was employed to the reduced scale tests.



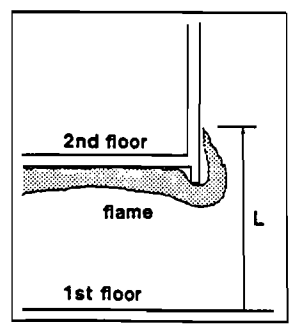


Figure 4 (a) Accumulated possibility of the flame height based on the flame tip location, and (b)flame height definition.

Average flame height was adopted at the 50 % possibility of existence of the flame tip. Flame geometry L/D was estimated depending on the average flame height (L) and characteristic pool/burner length (D), and are plotted as a function of non-dimensional heat release rate Q* as shown in Figure 5. The data of Q* in these figures have influence of 80 - 100 % combustion efficiency. These figures indicate close agreement on the correlation of flame geometry (L/D) and Q* between reduced model and full scale tests.

4-3. Estimation of the Effects of Downstand

When we adopt the similarity on flame length and Q* between full scale and reduced scale models based on the results described in Figure 5, we can discuss on effective length of a downstand which could interrupt of the flame lengthen. Two kinds of the fire source location, at the end corner and at the opening, were employed in a 1/15 reduced model. The flame length which spread out under the downstand was estimated from the successive video recorded frames as the same method as described in the previous section. Figure 6 shows the variation of the external flame length with length of the downstand. The external flame length was evaluated from the level of ceiling height and which was employed as standard height. As the fire source located in the end corner, the external flame length decreased with the increase of downstand length as shown in Figure 6-(a) and (b) with and without the external wind. It is very clear that the 10 mm downstand gave about 10 mm external flame length so that almost no interruption on the lengthen of the external flame was applied by the set of downstand. However, as shown in Figure 6-(c), when the fire source located at the foot of the opening without external wind, 10 mm downstand gave the external flame lengthen more than downstand length. In this case, the existence of downstand provided higher potential of the fire propagation to upstair than without downstand. The downstand interrupt the entrainment of fresh air into the flame zone so that the hot combustible gas spread out under the downstand and then mix and reacts with air (oxygen) outside of the opening. Then the lengthen of the external flame was formed along the wall by the secondary combustion which took place outside of the semi-enclosure.

5. CONCLUSION

It was estimated that re-radiation gave about 20 - 24% burning rate enhancement in a full scale semi-enclosed compartment of which ceiling and walls were covered with ALC panels. Wind/vortex effect gave burning rate enhancement of about 50 - 75 % and is much greater than re-radiation effect in our full scale tests.

When an opening faced to downwind, the flame was sucked out by Karman vortex and made a fire whirl of 18 - 20m high at the front of the opening. Fire whirl may have a propagation potential to upstair and to combustible advertising panels attached to the external wall. To reduce the possibility of fire propagation potential to upstair, the pool which is prepared for collection of leaked gasoline may be located at the end corner.

Reduced scale model provides a powerful tool for the estimation of the extened flame length which took place outside of the opening when a building has a downstand or a pentroof.

6. ACKNOWLEDGMENT

The authors wish to thank to the Petroleum Energy Center (PEC)

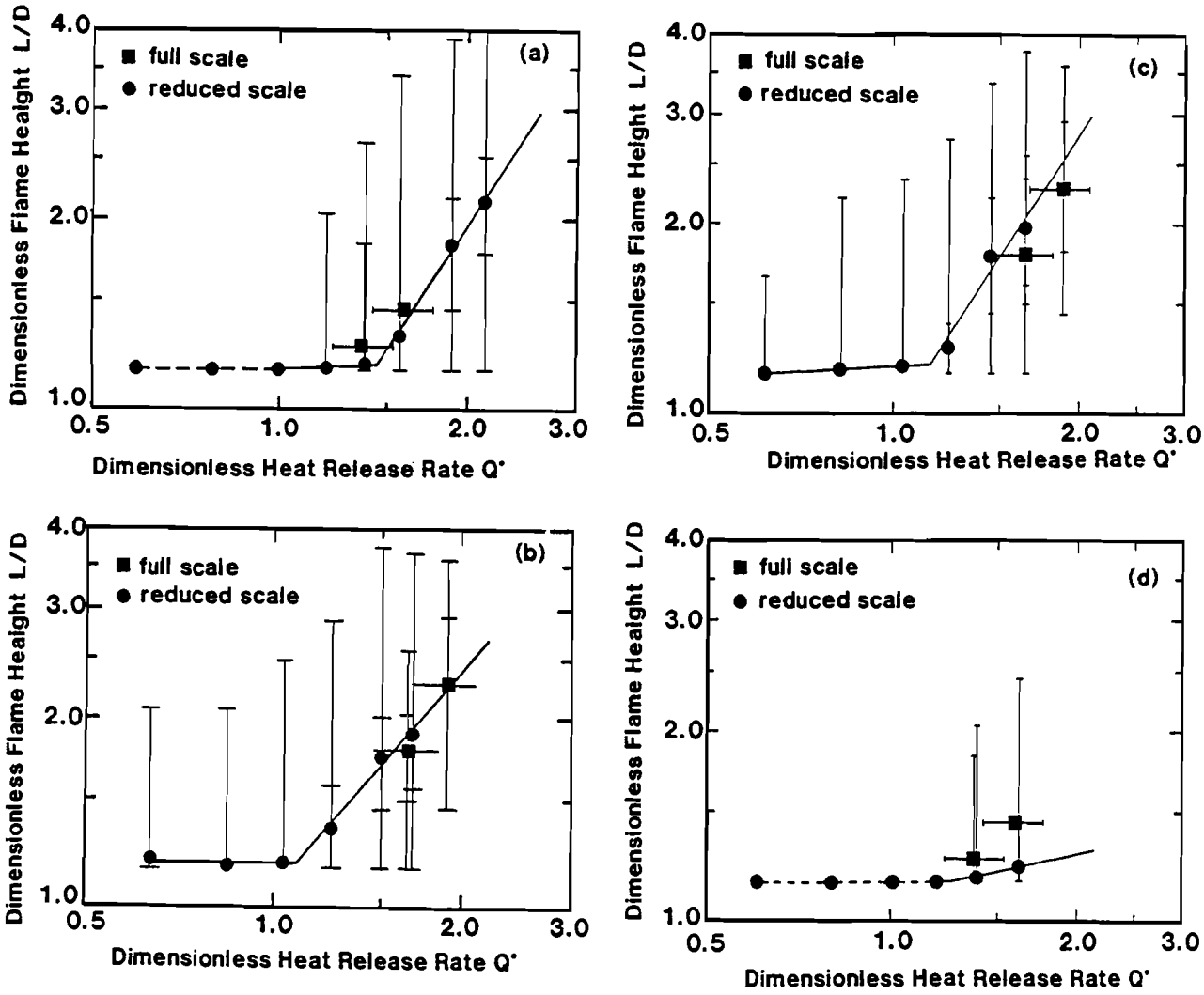


Figure 5 Correlation of the flame geometry (L/D) versus Q*, (a) no wind was given to the reduced model and fire source located at the end corner, (b) no wind was given to the reduced model and fire source located at the front of the opening, (c) wind was given and fire source located at the end corner, and (d) wind was given to the reduced model and fire source set at the front of the opening.

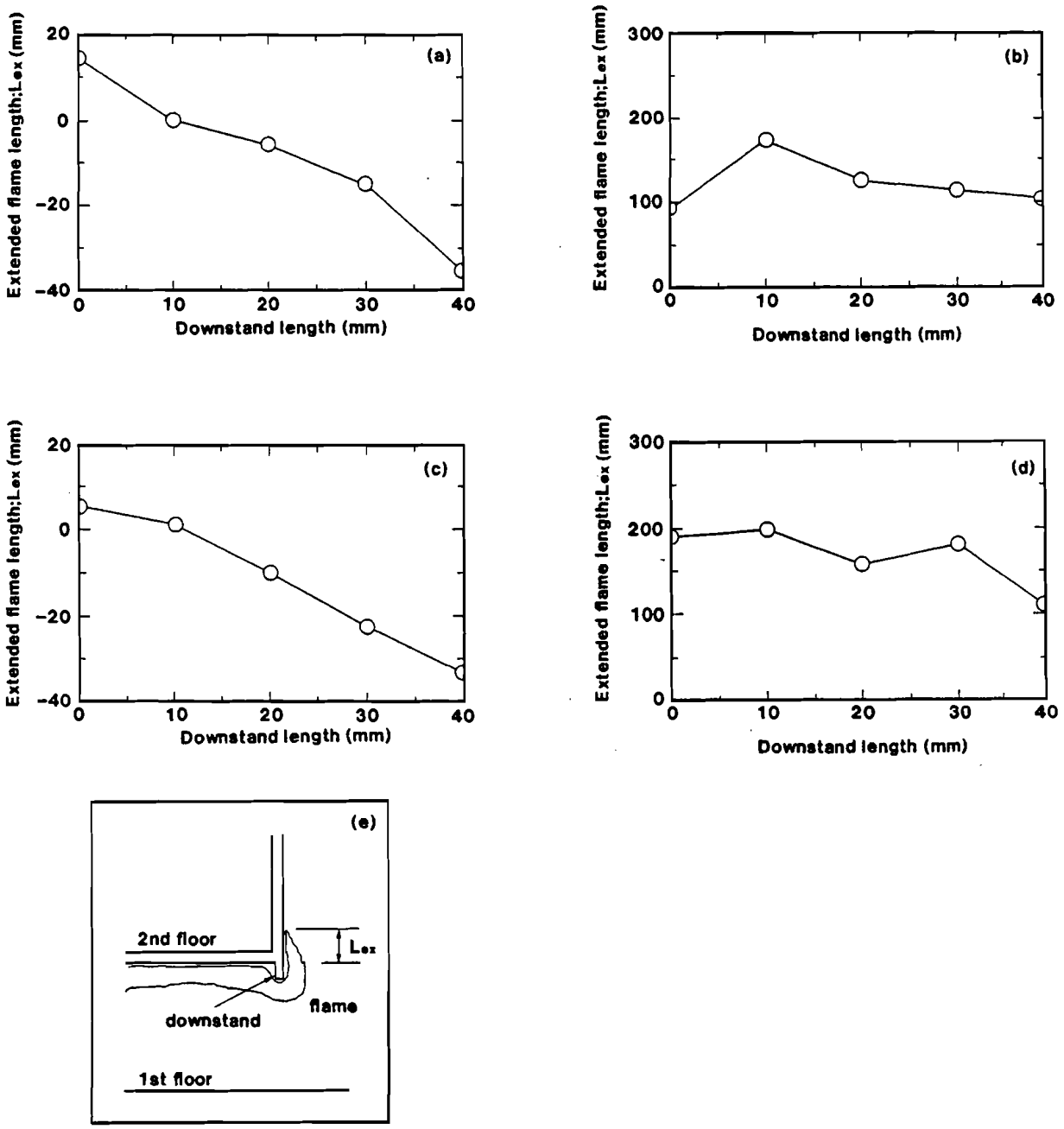


Figure 6 Correlation of the extended flame length from the ceiling versus length of the downstand. (a) no wind was given to the reduced model and fire source located at the end corner, (b) no wind was given to the reduced model and fire source located at the front of the opening, (c) wind was given and fire source located at the end corner, and (d) wind was given to the reduced model and fire source set at the front of the opening, and (e) extended flame length definition.

and Ministry of International Trade and Industry of Japan (MITI) for their financial support. This series of experiments were carried out as a part of PEC-86P06 Project of the PEC. The authors are grateful to Mr. Kazuo Takahashi, who made basic design of the full scale model.

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