# TEST OF TOTAL HEAT FLUX FROM WOOD CRIB FIRE IN AND OUTSIDE COMPARTMENT

by

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*Woo d crib fires were studied by using of ISO 9705 Room. These free burning tests with different heat release rate were conducted inside room and outside room (under the hood). Thermal condition around crib fire was measured by using of thermocouples, total heat flux gauge, gas concentration analyzer, and standard instrumentations for heat release rate measurement in ISO 9705 Room. This paper focuses on the total heat flux to the surrounding area from wood crib fire. The correlation between heat release rate and total heat flux is presented. Wall and space effect is also analyzed.*

Key words: *wood crib, total heat flux, ISO 9705 Room*

## Introduction

Heat flux is the rate of heat flow per unit area. The heat transfer from fires to adjacent surfaces is an important consideration in many fire analyses [1]. Some example applications that may require knowledge of the heat transfer from a flame include heating and failure of structural beam, heat transfer through walls and ceilings, and the ignition and flame spread along combustible surfaces. Flames transfer heat to adjacent surfaces primarily through convection and radiation. Experimental data and empirical correlations have been generated to predict flame heat transfer for a number of common geometries [1]. As it was mentioned the empirical correlations for predicting heat transfer from flames are typically simple to use; however, their use is usually limited to particular type of fire or the geometry of the surface being heated. Many fire tests adopted gas burners [2, 3], such as propane burner, or pool fire [4] as fire sources. Both gas and pool fires are easy to control and duplicate themselves well. The parameters of flame structure, such as average flame length or flame tip length, could be calculated by empirical equations. But the wood crib fire has been considered as a better fire source to simulate fire development inside room. Croce *et al*. [5] used wood cribs as the fuel to investigate the scale modeling hypothesis for quasi-steady enclosure fires. The test presented in this paper also used wood crib fire to study fire development inside room. The room structure was an ISO style test room (in CSIRO, Commonwealth Science and Industrial Organization, Australia). The result can be used to predict thermal condition development in enclosure fires. Different characteristics of wood crib fire can also be seen from the tests.

## Experimental details

Parts of these tests were conducted inside ISO 9705 Room [6]. The other tests were conducted outside ISO 9705 Room under the exhaust hood. The hood covers 3000 mm by 3000 mm area outside the room, as shown in fig. 1. Dimensions of the room are 3600 mm long, 2400 mm wide, and with a height of 2400 mm. There is a single doorway opening to out side centered on the south wall, as shown in fig. 1, with a width of 800 mm and height 2000 mm. The doorway was opened during all inside room tests, but closed during under hood tests.

Exhausted gas is collected by the hood outside the doorway. The data collected in exhaust duct enabled the heat release from the burning inside room to be determined by means of oxygen consumption calorimetric. The instrumentation in the duct met the specifications in ISO 9705. The sampling rate of ISO 9705 is 1 sample/2.5 seconds. Other temperature, heat flux, and oxygen sampling measurements inside and outside the room were conducted by other set of instrumentation system.

For the under hood tests, five Schmidt-Boelter heat flux gauges (from Medtherm Corporation), which were labeled as S1 to S5, were used. These had a range of 0-100 kW/m$^2$, with an 180° view angle. Locations of the test points are depicted in fig. 1. They were all 1200 mm above the floor and facing fire source.

Ten Schmidt-Boelter heat flux gauges, which were labeled as R1 to R10, were used in the inside room tests. R1 to R5 were placed on the wall. R1 was on west wall, R2 was on north wall and R3 to R5 were on east wall. All these five gauges were placed directly through the plywood and gypsum panel comprising the wall and were 1200 mm above the floor. The surface of each gauge was flush with the wall. R6 was placed in the ceiling down to the south-east corner facing vertically downwards. Its surface was flush with ceiling. The distances from R6 center to east wall and north wall were all 200 mm. R7 to R9 were placed on the floor facing vertically upwards. The surface of these gauges was 50 mm above the floor. The position of R7 center was 500 mm to west wall and 500 mm to south wall. The po-

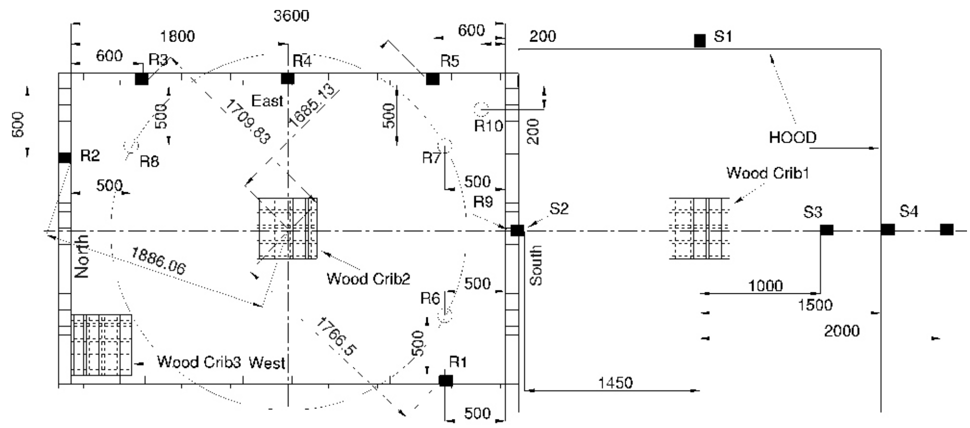


**Figure 1. Location of wood cribs and heat flux gauges**

sition of R8 center was 500 mm to east wall and 500 mm to south wall. The position of R9 center was 500 mm to east wall and 500 mm to north wall. All these gauges were water-cooled with a tube-pump system. R10 was placed in the doorway 1200 mm above the floor pointed to the fire source (wood cribs). All heat flux gauges were connected to a data logger with sampling rate 1 sample/2.5 seconds.

Total eleven tests were conducted, three of them were under the hood and the others were inside the room. The tests under the hood were labeled as Test1, Test2, and Test3, with nominal peak heat release rate 0.5, 1.0, and 1.5 MW, respectively. The cribs were set in the center of the room in four inside room tests which were labeled as Test4, Test5, Test6, and Test7, with nominal peak heat release rate 0.15, 0.25, 0.5, and 1.0 MW, respectively. The cribs were located at the corner of the room in the other inside room tests, which were labeled as Test8, Test9, Test10, and Test11, with nominal peak heat release rate 0.15, 0.25, 0.5, and 1.0 MW, respectively. The positions of these cribs are also shown in fig. 1. The crib consists of different layers and size radiate pine sticks. Under the crib aluminum foil trays filled with 0.5 liter methylated spirits each to ignite the crib fire. The tray size is 290 90 50 millimeter (length width depth). Two trays were used for 0.15, 0.25, and 0.5 cribs, and four for 1.0, and 1.5 MW cribs. The fuel inside trays was ignited by torch.

## Results and discussion

### *Tests under the hood*

Results of three crib tests under the hood are illustrated from fig. 2 to fig. 7. Figure 2 is a double y axis figure of Test1, one axis for heat release rate and the other for total heat flux. Heat release rate (HRR) reached 484 kW in the test. The crib fire was extinguished by fire hose at the end of test. The crib collapsed at nearly 950 seconds causing a shape increase in total heat flux at position S3, which was the closest position to crib fire. The total heat flux at position S3 was more than that at other positions. The total heat flux

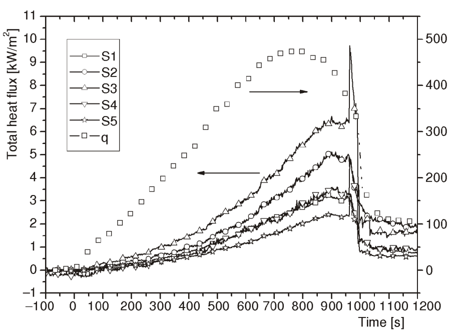


**Figure 2. Time history of HRR and total heat flux in Test1**

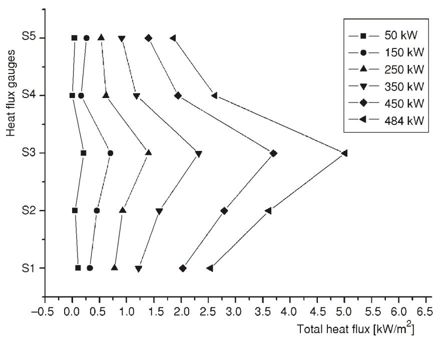


**Figure 3. Total heat flux changes with HRR in Test1**

at position S2, which was in the doorway backed by closed door, had the second high level during the test. The total heat flux at S1 and S4 had almost the same value. S5 had the lowest level of total heat flux as it was the farthest from the crib fire. Figure 3 illustrates the total heat flux corresponding to different levels of heat release rate. Total heat flux increased faster during HRR increased from 350 to 450 kW.

In Test2, S2 value surpassed that of other positions, followed by S3. S1 was lower than S4, and S5 still had the lowest value, as shown in fig. 4. Total heat flux increased faster during HRR increased from 800 to 900 kW, as shown in fig. 5.

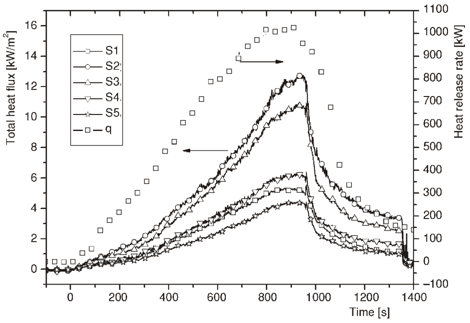


**Figure 4. Time history of HRR and total heat flux in Test2**

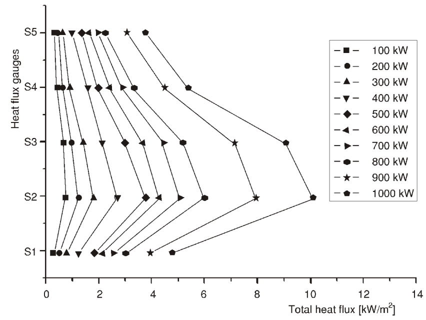


**Figure 5. Total heat flux changes with HRR in Test2**

In Test3, S2 value also surpassed that of other positions, followed by S3. S1 was lower than S4, and S5 still had the lowest value, as shown in fig. 6. Total heat flux increased faster during HRR increased from 1200 to 1400 kW, as shown in fig. 5. But the increase of total heat flux during HRR increased from 800 to 1000 kW was more than that during 1000 to 1200 kW.

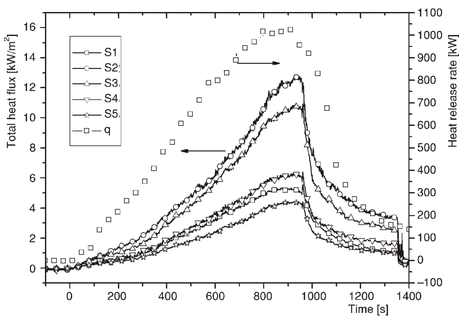


**Figure 6. Time history of HRR and total heat flux in Test3**

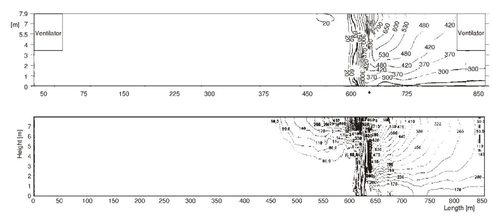

**Figure 7. Total heat flux changes with HRR in Test 3**

*Tests inside room with crib at center*

Figures 8 to 11 illustrates the total heat flux changing with HRR in Test4 to Test7. The crib fire was in the center of the room for these tests.

Figure 8 shows the results from Test4. Heat flux gauge R4 faced fire source directly and was with the shortest distance to the fire source, so it had the largest value in these five wall gauges. R3 and R5 were with the same distance to the fire source. The value of R3 was lower than that of R5 at the beginning of the burning, but it surpassed that of R5 as the HRR increased. The position of R5 was near the doorway and the hot gas passed through it to the hood outside. Less hot gas accumulated around R5 than that at the north east corner. Thus, higher temperature was built up around R3 than R5 with the increasing of HRR. The same situation happened to R1 and R5. R1 was closer to corner than R5, and a bit farther to the fire source than R5. At the beginning of burning, radiation contributed to the total heat flux to the wall more than convection did, and at this time R1 was lower than R5. As more hot gas built up at the corner, convection effect was more than radiation, and this resulted in R1 higher than R5. R6 to R8 were on the floor and their value almost the same at the beginning. As the fire developed, R6 and R7 were more than R8. Gas temperature at floor level was still low during the test. As they were on the floor, the radiation contributed to the heat flux more than convection did. The crib fire was not axially symmetric because the flame declined towards to the doorway. Thus, the radiation from flame to the south part of the floor was more than that to north part. R9 was in the doorway, and it measured the heat flux from radiation of flame and convection of hot gas flowing away from the room through doorway. R9 was higher than those on the floor, but lower than those values when HRR reached to 150 kW. R10 was on the ceiling at the south east corner of the room and it measured the heat flux from the radiation of flame and heat transfer from ceiling jet. R10 had the highest value in these ten gauges due to direct contact with ceiling jet.

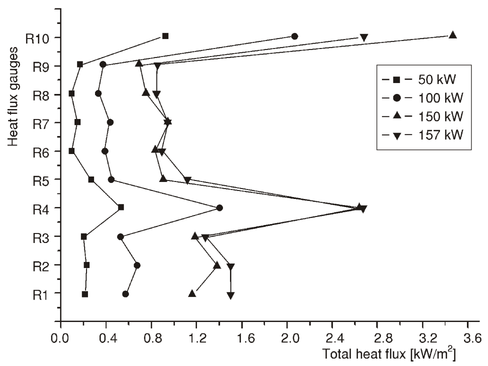


**Figure 8. Total heat flux changes with HRR in Test4**

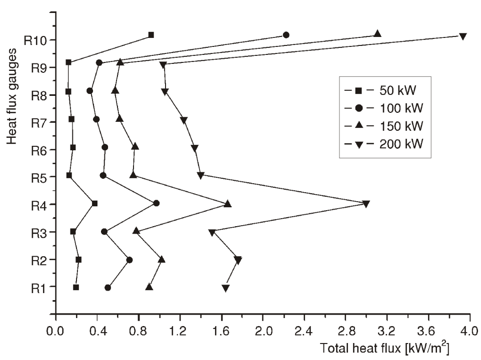


**Figure 9. Total heat flux changes with HRR in Test 5**

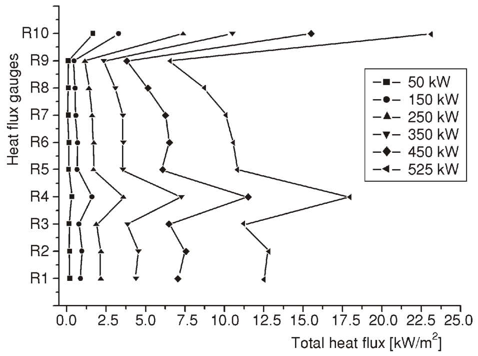


**Figure 10. Total heat flux changes with HRR in Test 6**

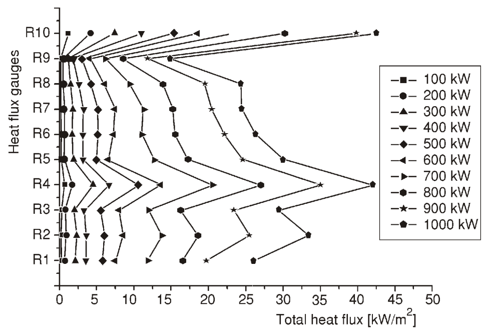


**Figure 11. Total heat flux changes with HRR in Test 7**

Figure 9 shows the results from Test5. These results had the same situation as those from Test4. Wall effect contributed more to the value of R1 and R5 than in Test4, thus R1 was close to R5 despite of the different distance to south wall. Figure 10 illustrates the results from Test6 and the results had almost the same situation as those from Test5. But in Test7, as shown in fig. 11, R5 was quite higher than R1 in the later part of the test. The effect of wall was less than the direct radiation from the fire and heat transfer of direct convection from crib fire. The heat flux to R4 was close to R10 at the end of this test.

*Test 3 inside room with crib at corner*

Figures 12 to 15 illustrates the total heat flux changing with HRR in Test8 to Test11. The crib fire was at the northwest corner of the room for these tests.

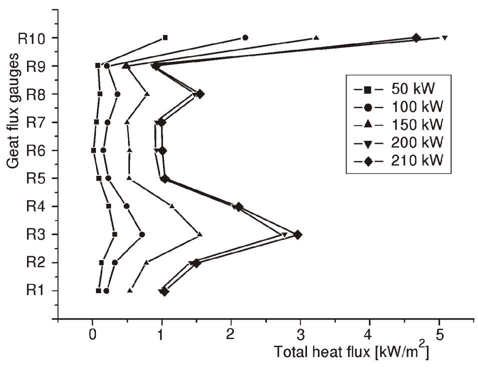


**Figure 12. Total heat flux changes with HRR in Test8**

Figure 12 shows the results from Test8. Out of the five gauges on the wall, R3 faced fire directly and had the highest value. R1 and R5 had almost the same value. R2 was lower than R4, but higher than R5. R8 was closer than other two gauges on the floor, thus had higher value than R6 and R7. The ceiling gauge R10 also had the highest value of these ten gauges.

Figure 13 shows the results from Test9. The situation in this test was quite same as that in Test8. But R2 was lower than both R4 and R5. Figure 14 shows the results from Test10. The tendency kept the

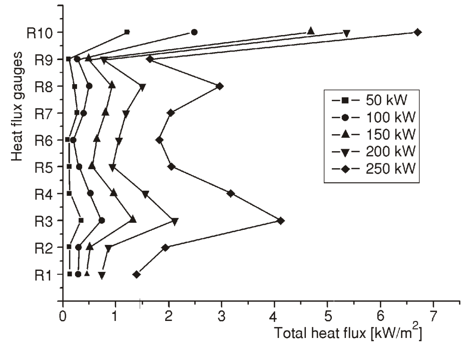


**Figure 13. Total heat flux changes with HRR in Test9**

same shape for almost all gauges in this test as in Test9. But R2 changed back to Test8 which was lower than both R4 but higher than R5. R10 was lower than R3 at the end of test. Figure 15 shows the results from Test11. The most outstanding characteristics of Test11 is the total heat flux to the floor reached to a very high level and were close to heat flux to the wall. The peak heat flux of R3 was not as high as R3 in Test10 even the HRR reached 900 kW in Test11.

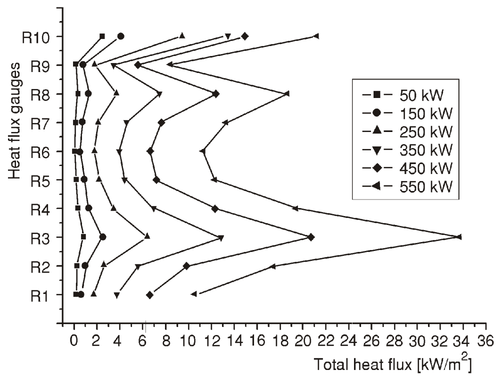


**Figure 14. Total heat flux changes with HRR in Test10**

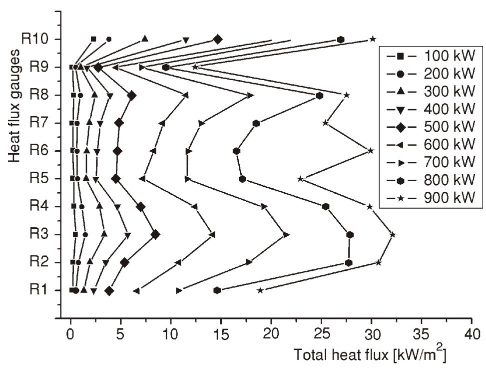


**Figure 15. Total heat flux changes with HRR in Test11**

## Conclusions

In first part of the tests, the more powerful of crib fire, the more wall effect on total heat flux. This tendency could be seen from the value shift of S3 and S2 in Test1 and Test2. In Test1, the value of S3 is more than that of S2 during the test, while in Test2 S2 surpassed S3, so as those in Test3, because of more powerful of crib fire. The wall effect on the heat accumulation from hot gas gathering was enhanced obviously in more powerful crib fires. Figure 16 illustrates the ratio of S2 to S3 in these three tests. The value of S2/S3 larger than 1 implies S2 is more than S3. The increase of total heat flux was not evenly with the increase of HRR. This might be caused by the radiation performance

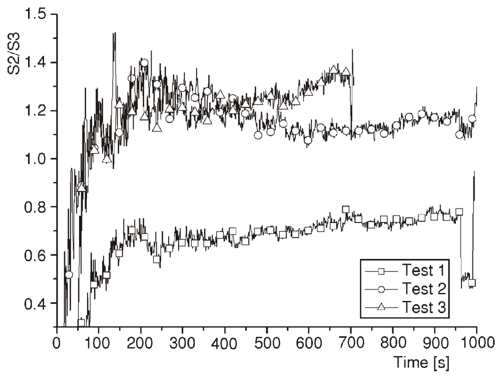


**Figure 16. S2/S3 for the tests under hood**

changing with the structure of crib fire. This is different from that of inside room tests. The increase of total heat flux in almost all positions on the wall changed evenly with the increase of HRR. This difference might be caused by the difference of burning environment around the crib fire. The crib fire which is in relatively larger space, such as in big the shed, the fire could be considered as burns in open space. The radiation contributes mainly to the total heat flux to surrounding area. While inside ISO room, both radiation and hot gas convection contributes to the total heat flux to the wall, floor and ceiling. Hot gas convection changes with HRR smoothly. The joint effect of radiation and convection influences total heat flux. Thus, this resulted in more evenly increase of total heat flux inside room.

Although the under hood tests of were conducted inside a shed, the crib fires had more air supply and more heat dissipation space than those fires which were conducted inside ISO room. Thus, the total heat flux to the surrounding area was quite lower in under hood tests. Figures 17 and 18 illustrates the total heat flux of S2, S4, R3, and R4 at HRR equals to 200 and 500 kW. These gauges were at almost the same distance to the center of fire source. S2 was in front of the wall under hood, as shown in fig. 1. S4 was in open space. R3 and R4 were on the wall facing fire source inside room. Wall and space effect on the total heat flux could be seen clearly in these two figures.

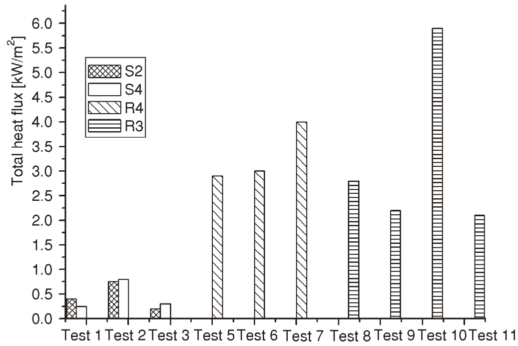


**Figure 17. S2, S4, R3, and R4 value at HRR = 200 kW**

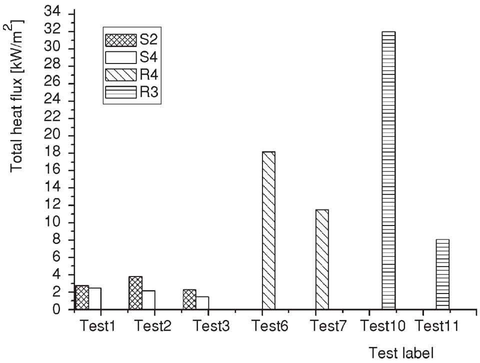


**Figure 18. S2, S4, R3, and R4 value at HRR = 500 kW**

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