Handled by, department
HaukurIngason
+46 105 165197

Fire Test with a front wheel loader

(1 appendices)

The report describe a fire test with a front wheel loader rubber tire under a large laboratory calorimeter. The test was carried out at the Fire Laboratory of SP Technical Research Institute of Sweden 4th of June 2008. The test was financed by Swedish Nuclear Fuel and Waste Management (SKB), Knowledge Foundation (KKS), Luossavaara-Kiirunavaara AB (LKAB) and Swedish Rescue Services Agency (SRV).

Background

The knowledge about heat release rates from rubber tires is limited. This information is very important when one need to estimate the heat release rate from a heavy construction vehicles such as drilling machines, front wheel loader (Figure 1), dumpers etc. The tires constitute a large portion of the burning material in such vehicles. A knowledge about the fire behaviour of large rubber tires is of importance when designing the fire safety in underground constructions, especially in the mineral mining sector and during the construction phase of tunnels or other underground systems. Numerous large heavy construction vehicles can be at place at the same time which increase the risk that one of these vehicles start to burn. A literature survey show that very few fire research works have been carried out worldwide on rubber tires and heat release rates.

Figure 1 A front wheel loader with similar type of rubber tires as used in the test.

In 1993, the Building Research Establishment (BRE) in UK [1] carried out large scale tests under a large calorimeter at the Fire Research Station's Cardington Laboratory. The calorimeter was able to measure up to around 3 Megawatts. Two tests were carried out. In the first test the tires were stacked horizontally and in the second, vertically. In each test a stack of eight tires (total 16) was burned and numerous measurements were made, among them heat release rate. The tires used were ordinary passenger car tires without a steel rim. The exact dimensions are not known. The vertical stacking (eight tire high) produced a far more severe fire than the horizontally stacked tires. The peak heat release rate was measured to be 1300 kW compared to 500 kW for the horizontally stacked one. The reason is the faster fire spread and better flow of air to the centre of the tires.

The Fire Laboratory of SINTEF in Norway presented in 1995 heat release data from two tests (A and B) with rubber tires used for Heavy Goods Vehicles [2]. A pair of dual load-bearing wheels was tested under a laboratory calorimeter. The ignition was simulated by heating up the wheel rims. An insulated pipe was welded to the wheel rims and heated up by a gas fire passing through the pipe. Through conduction the metal wheel rim was heated up to a temperature that ignited the rubber tires. This procedure was done for about 30 minutes prior to ignition. The size of the tires varied, but in test A it was 285/80 R22.5 and in Test B it was 315/80 R22.5. This means that in test A the tire was 285 mm wide with 228 mm (0,8 x 285) high vertical surface and the rim diameter was 22,5 inches (575 mm). The exposed rubber area is estimated to be 4,2 m^2 for test A and 4.8 for test B (dual tires). The measured maximum heat release rate for test A was 878 kW and for test B 964 kW. The time it took to obtain maximum heat release rate was 29 minutes and 27 minutes, respectively, from the ignition. The fire duration was about 60 minutes in both cases.

In 2005, Lönnermark and Blomqvist [3] carried out tests where the maximum heat release rate tests was registered using ordinary passenger car rubber tires. The aim of the tests was to assess the emissions to air and water from a fire in tires. Each test involved 32 passenger car tires without a wheel rim. Two different storage setups were used: heap and pile. Both set-ups represent common ways to store used tires. The heap storage was more spread out. It had a base of 3 x 3 tires with the tires stacked in a certain pattern above. The pile configuration consisted of a base with 2 x 2 tires stacked on each other in a straight vertical pile. This means that there were 8 tires in each stack, total of 32 tires. In both set-ups the tires were placed on a steel pan, 2 m × 2 m, under a large calorimeter. The tires varied somewhat in size, but tires that were as similar as possible were used. The maximum heat release rates from the tests were as follows; heap storage: 3.7 MW, 3.6 MW and 3.7 MW, respectively. For the pile storage the maximum heat release rate was 3.6 MW. The maximum heat release rate in this test occurred after 19 minutes from ignition. Dr Anders Lönnermark at SP Fire Technology reported via personal communication that the heat of combustion from the tests given in [3] was 27 MJ/kg.

It is clear from the studies mentioned here that it is difficult to make a direct comparison between these tests. But if one compare the results based on maximum heat release rate of exterior exposed rubber tire surface area and assume that this external surface area is totally engulfed in flames, the results become more comparable. If we assume a standard passenger car tire to be 195/60 R15 for the BRE and SP tests, the exposed external surface area is estimated to be about 0.75 m^2. This means that the heat release rate per exposed surface area will be 0.11 MW/m^2 for the BRE piled tests (1.3 MW/16/0.74 m^2), 0.21 MW/m^2 and 0.20 MW/m^2, respectively, for the SINTEF tests (0.878 MW and 0.964 MW divided by 4.2 m^2 and 4.8 m^2, respectively) and 0.15 MW/m^2 (3.6 MW/32/0.75 m^2) for the SP piled tests. This rough estimation indicates that the maximum heat release rate for rubber tires per exposed external area is in the range of 0.11 – 0.21 MW/m^2. This information can be used when one would try to estimate the highest heat release rate for a certain size of a rubber tire. One should also have in mind, that there is an important difference between the SINTEF test and the other tests namely the presence of the rim in the SINTEF tests and the way the passenger car tires are piled up, which may influence the estimation of the exposed fuel surface area. The test results presented here will be compared to these earlier studies.

The test set-up

Diesel test

The main objective of the test was to measure the heat release rate from a rubber tire of a front wheel loader. In order to ignite the tire, a relatively large ignition source is required. Therefore, it was decided to use a diesel pool with a steel pan diameter of 1.25 m. The size of that pool was felt reasonable in comparison to the width of the tire (0.67 m). During construction of tunnels the road surfaces are usually made of gravel road (unpaved road surfaced with gravel) and therefore if there will be a leakage of any kind, the liquid will pour into the gravel. This may influence the size of the pool fire. In the literature, the heat release rate measured is usually based on pool fire tests with freely exposed liquid fuel (without a presence of other solid materials such as gravel). Therefore, prior to the main test with the front wheel loader tire, two tests were carried out in order to see the influence of a gravel on the heat release rate. The first test was done under the calorimeter with 25 litre of diesel in the fuel pan and no gravel. The second test was done by putting a 50 mm thick gravel bed with stones sized between 0 and 18 millimeter into the pan and pour it with 25 litre of diesel oil, see Figure 2. The gravel was saturated by diesel, as can be seen in Figure 2, but it was not compacted with any type of vibrating baseplate prior to the tests.

Figure 2 A photo of the diesel pan with loosely compacted gravel with stones sized from 0 – 18 mm. A total of 25 litre of diesel were poured into the 1.25 m diameter pan.

In order to start the test it was ignited by pouring small amount of heptane into the pan (1/2 litre). This made it possible for the diesel to ignite more easily. In Figure 3 the measured heat release rate from both tests are shown. The difference is large and is mainly due to the heat feedback from the flames towards the fuel surface of the diesel and the amount of freely exposed diesel fuel. In the beginning of the test, the diesel which is freely exposed above the gravel surface will burn up easily. After some time the heat release rated peaked and then started to reduce in size as transported diesel fuel vapour further under the gravel surface reduced. As can be seen in Figure 3 both the growth rate and the maximum heat release rate is considerably lower than in the test with freely exposed diesel fuel. This test show that the road surface, especially if it is made of gravel, can influence the size of the initial fire considerably. This must be considered when trying to estimate the fire size and fire growth for vehicles of this type. Photos from the tests are given in Appendix 1.

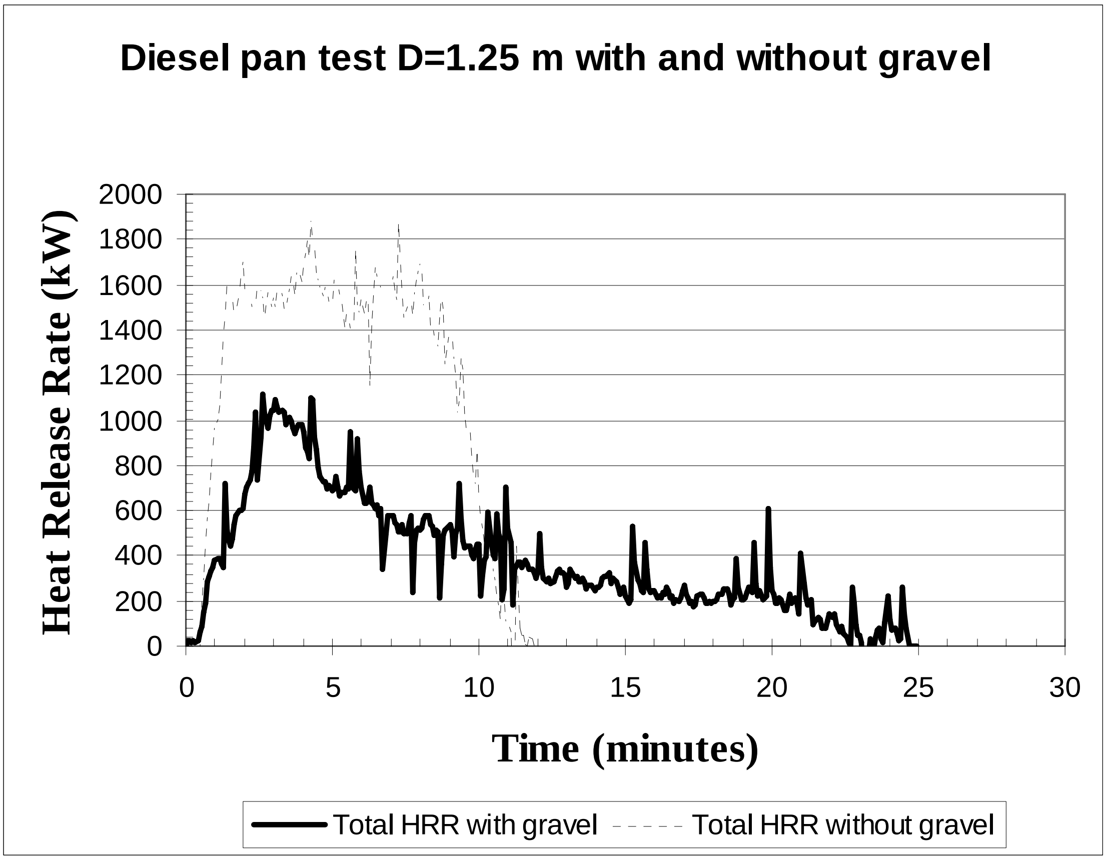

Figure 3 Measured heat release from a diesel pool fire with and without a gravel bed.

The rubber tire

The principal construction of the wheel is as follows. It consists of an air pressurized rubber tire attached to a wheel rim. The wheel rim is the outer circular design of the metal on which the inside edge of the tire is mounted. The bead of the tire is that part of the tire which contacts the rim on the wheel. The bead is reinforced with steel wire, and compounded from high strength, low flexibility rubber. The sidewall is that part of the tire that bridges between the tread and bead. The sidewall is reinforced with rubber and fabric plies that provide for strength and flexibility.

The rubber tire tested was of type Good Year with the identification 26.5R25 Tubeless. It also have the identification GP-4B AT, Unisteel, 193 B Type 65, Radial Construction, Made in Luxemburg, 0301 NJ 0520. The total diameter of the tire was 1.75 m and the total width (tread) was 0.67 m. The tread is the part of the tire which comes in contact with the road surface. The total external and exposed surface area of the rubber tire is estimated to be about 8 m^2. The total weight, inclusive the wheel rim, was 723 kg. After the test, the wheel rim, steel wires in the tire and some left over of rubber were measured. The total weight of steel products was 310 kg and of the rubber 35 kg. This, which means that the rubber in the tire weighted 413 kg in total. Prior to the test, the pressure was released in order to avoid any type of explosion of the tire. The wheel rim was welded to a steel stand in order to stabilize the position of the tire during the entire test. This means that the tire can not collapse to the ground in case of sudden air release or opening up of the tire as may occur in a real fire situation.

A wheel housing was constructed around the rubber tire, see Figure 4. It was constructed to simulate a wheel housing of a real front loader. The width of the wheel housing, which was made of 2 mm thick steel, was 0.3 m. Other measures are given in Figure 4. A photo of the set-up is given in Figure 5. The steel beam that was welded to the rim (Figure 5 and Figure 6) in order to stabilize the tire during the test, was insulated with thermal insulation.

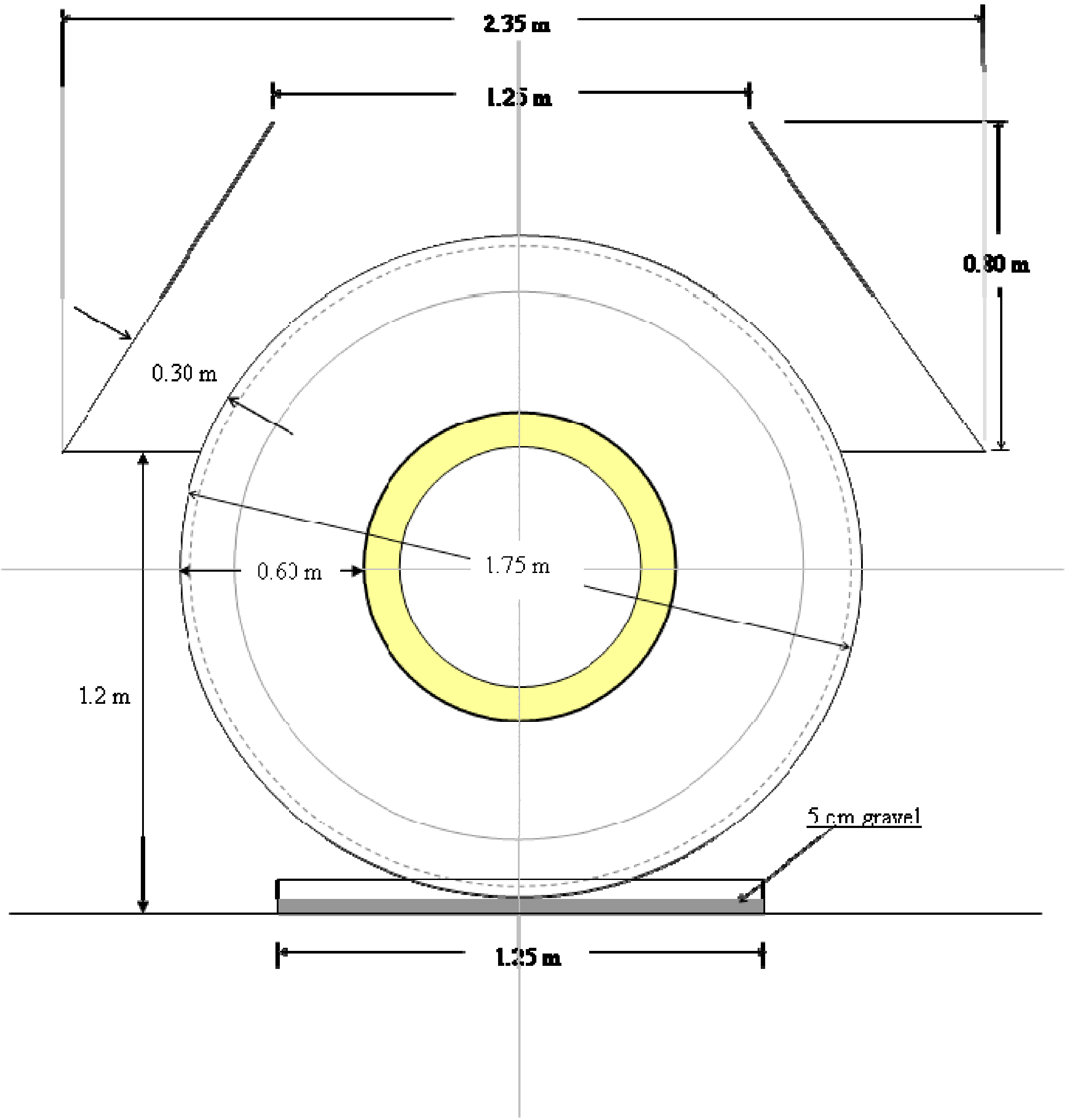

Figure 4 Measures of the test setup of the tire, the steel wheel housing and the pool fire with gravel underneath the tire.

Figure 5 A photo of the test setup of the rubber tire prior to the test. The fire calorimeter is above the rubber tire and a Schmidt-Boelter heat flux meter is 1.5 m beside the tire.

Test results and observations

Fire development

The fire was ignited by pouring 1/2 litre of heptane into the pan mixed with gravel and diesel oil. The rubber tire was mounted directly on the gravel, and thereby blocked a certain portion of the pan fuel surface. The radiation heat flux from the tire and the heat release rate were measured during the test. An attempt to measure the smoke generation was made but due to technical problems these results were not useful at all and therefore not presented here.

In Figure 7, the heat release rate is presented. After ignition the diesel fuel started to burn and flames very soon reached up to the top of the wheel house. After 2:56 minutes a first peak heat release rate of 2.3 MW was measured. The first heat release rate peak can only be explained as a combination of a burning rubber tire (surface layer) and burning diesel. At this time mainly the sidewall (the side seeing the heat flux meter) and the lower parts of the tread were burning. Slightly later, or after 4:16 minutes also the top of the tread was burning, see Figure 9. According to the free burn diesel/gravel pan test without the rubber tire, the peak heat release rate was about 1.1 MW after 2:36 minutes from ignition. This would mean that about 1.2 MW is a contribution from burning rubber.

In Figure 8 a comparison of the initial heat release rate (the first 25 minutes) from the rubber tire test and the test with the diesel pan filled with 50 mm gravel is shown. It confirms that the rubber tire burn more intensively in the beginning of the test. When the first layer has burned off the fire intensity of the tire reduces considerably at the same time as the contribution from the diesel in the pan reduces. After about 23 minutes it is only the contribution from the rubber tire that maintain the fire and the total heat release rate is about 0.4 MW. From now on the fire starts to slowly grow again and increases linearly in size up to about 1 MW after 64 minutes from ignition.

Figure 6 A photo taken just after ignition of the test.

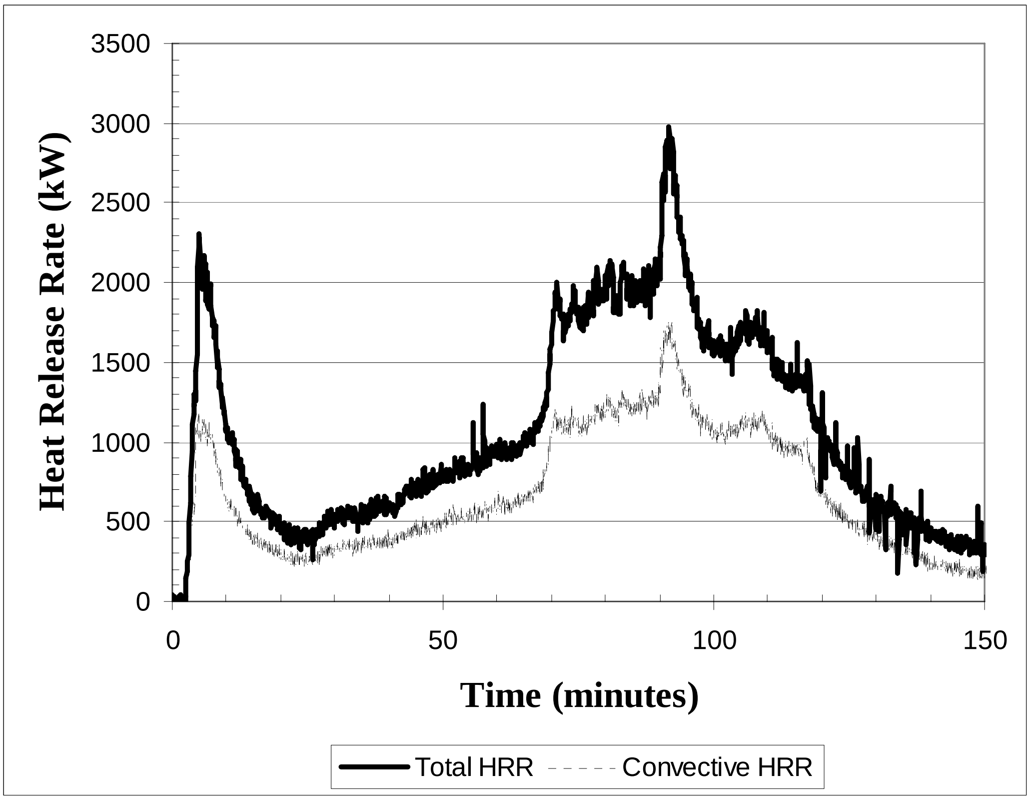

Figure 7 The measured heat release rate during the test with a front loader rubber tire as a function of the time from ignition.

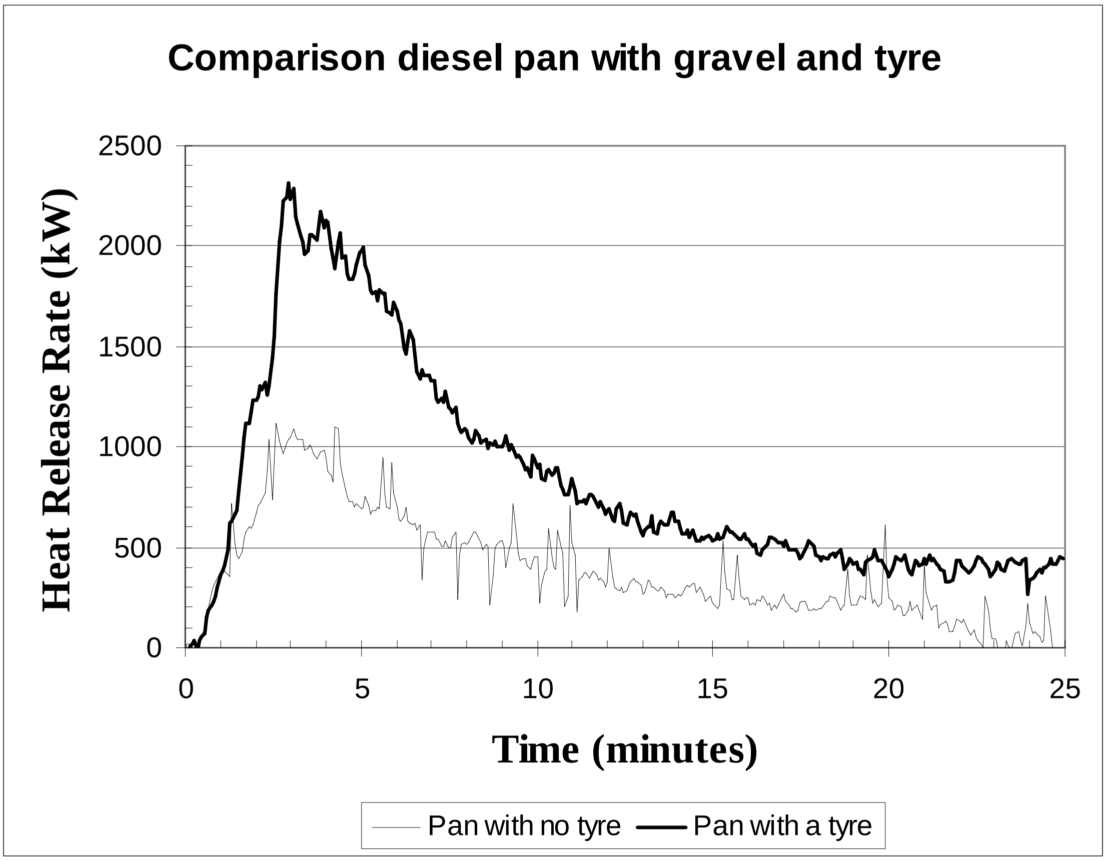

Figure 8 Comparison of the initial heat release rate of the rubber tire test and the test with a diesel pan with gravel.

Figure 9 A photo taken after 4:16 minutes from ignition. The heat release rate is about 2 MWs. The peak heat release rate was 2.3 MW, and occurred after about 3 minutes from ignition.

Figure 10 A photo taken when the first peak has reduced to only 0.4 MW after 20 minutes from ignition.

During this period mostly the tread and the sidewall faced towards the heat flux meter is burning. After 64 minutes the heat release rate starts to increase rapidly and a new peak of 2 MW is obtained after 69 minutes. The reason for this rapid increase is related to the fact that the opposed tire wall became fully involved in the fire. Also in the area between the tire and the wheel rim, one can observe an increase in the size of the flames. This indicates that during this period some increase in pyrolysis gases from the inside part of the tire begin to pour out and burn. From about 70 minutes from ignition and the next 20 minutes, the increase in heat release rate is only moderate. The status of the burning intensity during this period is well represented by Figure 8. The heat release rate is about 2 MW and after about 90 minutes from ignition a sudden increase up to 3 MW is noticed. This state is well represented by Figure 9. This increase is probably related to sudden change in exposed fuel area and access of air to the combustion zone. The fire spread to the inner section of the tier results in higher total heat release rate. After this period the fire starts to decade and after 150 minutes from ignition, the measurements were shut off. The heat release rate was only 0.3 MW at this time. An ember of glowing rubber and some minor flickering flames were observed at this time.

Smoke observations

As no successful smoke measurements were carried out, the smoke production can only be described subjectively. During the first 10 minutes there were some black smoke observed above the tire. This smoke is a combination of the diesel fuel and the rubber. During the period of 10 minutes to 60 minutes, less smoke was produced, see Figure 10. After about 70 minutes from ignition the smoke density evidently increased (see Figure 12) and during the period of 70 to 120 minutes the smoke was relatively thick.

Figure 11 A photo taken after 60 minutes from ignition. The heat release rate is about 1 MW.

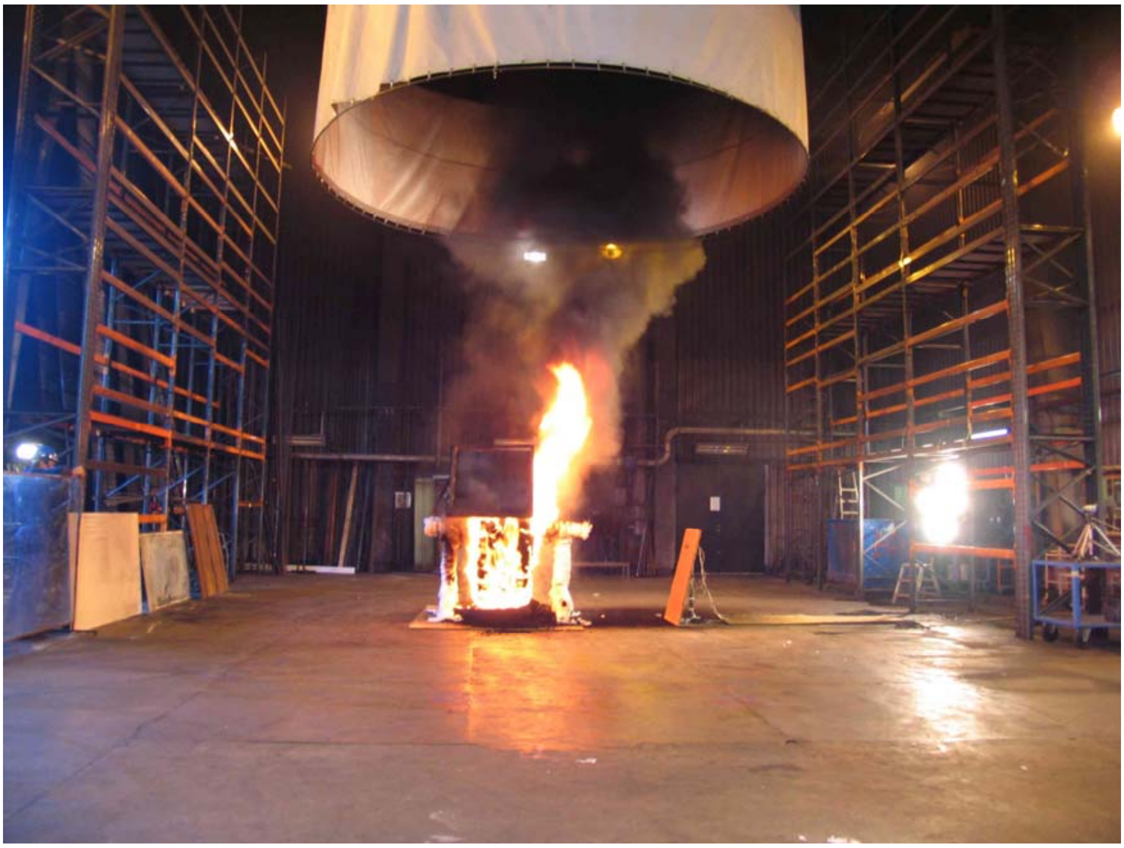

Figure 12 A photo taken 70 minutes from ignition. The heat release rate is about 2 MW.

Figure 13 A photo taken 80 minutes from ignition. The heat release rate is about 2 MW.

Figure 14 A photo taken 90 minutes from ignition. The heat release rate is about 3 MW. Notice that the tire is burning on two sides, i.e. on the inside and outside of the tire. This may explain the sudden increase in the peak heat release rate.

Heat flux

The heat flux from the fire was measured 1.5 m from the tire. The measurements were carried out by a Smidth-Boelter heat flux meter. It was located 0.9 m above floor level and centred to the tier. The results are shown in Figure 15. The heat flux curve follows very well the heat release rate curve shown in Figure 7.

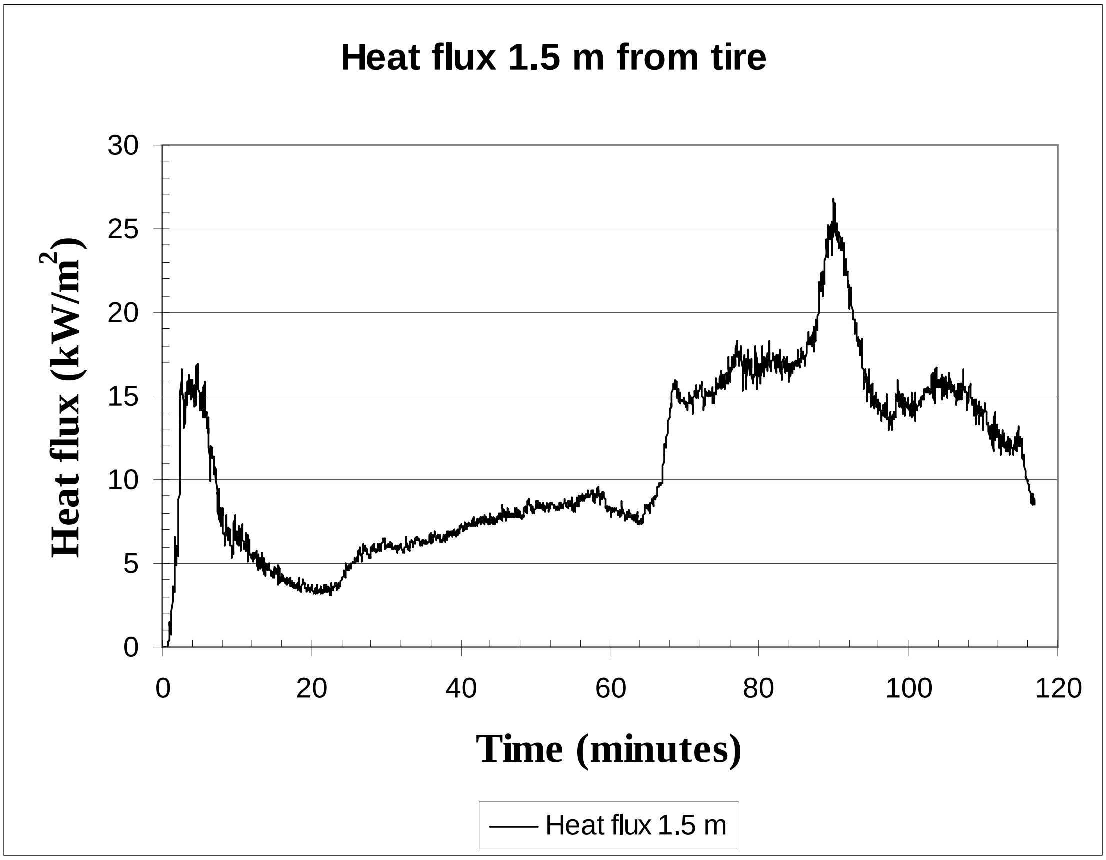

Figure 15 Heat flux measurements 1.5 m from the centre of the tire. The height from the floor and up to the heat flux meter was 0.9 m.

It is possible to calculate roughly the radiation from a burning object by using the following equation:

$$q'' = \eta \frac{Q}{4\pi x^2} \tag{1}$$

where q'' is the radiation in kW/m^2, Q is the heat release rate in kW and x is the distance in metre and η is the ratio of radiative heat flux of the total heat release rate. This ratio is usually about 0.3 but can vary depending on fuel type and fuel configuration. In Figure 16, a comparison of the measured and calculated heat fluxes using equation (1) is shown. The value of η =0.25 gives a very good correlation between the measured and the calculated value. Equation (1) appears to give a good correspondence for prediction of risk for fire spread between two adjacent vehicles.

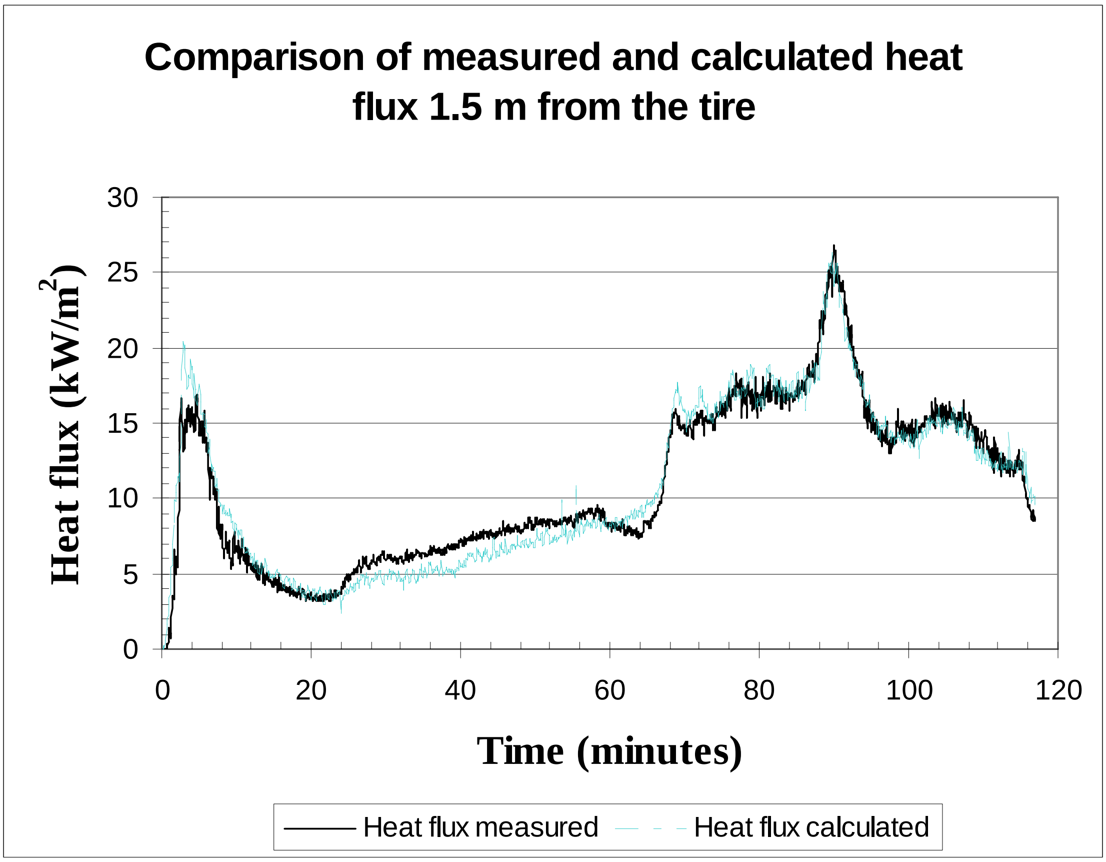

Figure 16 Comparison of measured Heat flux at 1.5 m from the centre of the tire and calculated heat flux according to equation (1). The hight up to the heat flux meter was 0.9 m.

Discussion

Diesel test

Prior to the test with the tire, some pre-tests were carried using diesel oil with and without a gravel in a pan that had a diameter of 1.25 m. The diesel oil was used to ignite the tire. The first test was done under the calorimeter with 25 litre of diesel in the fuel pan and no gravel. The second test was done by putting a 50 mm thick gravel bed with stones sized between 0 and 18 millimetre into the pan and pour it with 25 litre of diesel oil. The difference in measured heat release rate turned out to be rather large. The reason is mainly due to the heat feedback from the flames towards the fuel surface and the amount of freely exposed diesel fuel. Without a gravel the highest heat release rate was measured to be 1.8 MW and with gravel it was 1.1 MW. Further, the characteristic behaviour was very much different. In the beginning of the test, the diesel which was freely exposed above the gravel surface burned off quickly. After a short time the heat release rated peaked and then started to reduce in size. Both the growth rate and the maximum heat release rate were found to be considerably lower than in the test with freely exposed diesel fuel. This test show that the road surface, especially if it is made of gravel, can influence the size of the initial fire considerably. This must be considered when trying to estimate the fire size and fire growth for vehicles of this type.

Rubber tire

The test with the tire was carried out by igniting a pan with gravel which was placed under the tire. After ignition the diesel fuel started to burn and flames very soon reached up to the top of the wheel house. A first peak heat release rate of 2.3 MW was measured after 2 minutes and 56 seconds. The first heat release rate peak can only be explained as a combination of a burning rubber tire (surface layer) and burning diesel. At this time mainly the sidewall (the side seeing the heat flux meter) and the lower parts of the tread were burning. A rough estimation of the burning area when the peak occur is 5.9 m^2. If we subtract the contribution from the diesel fire of about 1.1 MW, we have about 1.3 MW from the tire (see Figure 8). This means that the heat release rate per exposed fuel surface at this time is 0.20 MW/m^2. This is in line with the results obtained from other studies mentioned in the introduction. The fire intensity reduces again and the next abrupt increase occur after about 70 minutes, when both sides of the tire are fully involved in the fire and certain amount of gases are coming from the inside of the tire. The total exposed exterior fuel surface area of an intact tier is about 8 m^2, meaning that the heat release rate per unit fuel surface are is about 0.25 MW/m^2. This is slightly higher than mentioned earlier and can be explained by pyrolysis gases pouring from inside of the tier due to openings close to the rim. The third and last peak occur after about 90 minutes from ignition. The maximum heat release rate is about 3 MW. It is very difficult to estimate the exposed burning area under these conditions.

The measurements were turned off before the tire was totally burned out. After 150 minutes from ignition the heat release rate was still about 0.3 MW. A reasonable estimation is that the fire duration was well over 2.5 hours. The total integrated heat content under the measured heat release rate curve is 9.6 GJ. If we use the heat of combustion of 27 MJ/kg [3] and we know that the rubber was 413 kg, then the total heat content is 11.2 GJ. This difference can be related to the fact that the measurements were turned off before all combustion had taken place and also due to uncertainty in the assumption of a heat of combustion value of 27 MJ/kg for this type of tier. It is clear, however, that the fire duration was well over 2.5 hours, but the rate of heat release is very low during this period.

Heat flux

The simple correlation given by equation (1) appears to give a very good correspondence with the experimental data. This encourage one to use this formula to estimate the risk for fire spread between vehicles.

Conclusions

- A front wheeler loader tire can give a maximum heat release rate of 3 MW.
- The maximum heat release rate is related to a collapse situation of the tier, and when the combustion gases heritage from both exterior and interior sides of the tire.
- The value of 0.2 MW/m^2 is a good design value to employ when one needs to estimate the maximum heat release rate of a large tier. This value was found to be reasonable when the exposed fuel surface area was definable.
- The fire duration was well over 2.5 hour.
- Equation (1) yields a reasonable values when using the fraction of radiative heat release rate to total heat release rate of 0.25.

SP Technical Research Institute of Sweden
Fire Technology - Fire Dynamics

Tommy Hertzberg	Haukur Ingason
Section Manager	Technical Officer

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Appendix 1

Figure 17 A test with diesel pool without gravel

Figure 18 A test with diesel pool with gravel , early in the test

Appendix 1

Figure 19 A test with diesel pool with gravel, late into the test