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TITLE

TESTING OF DIFFERENT PORTABLE FIRE EXTINGUISHERS AGAINST FIRES IN TWIN TYRES

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ABSTRACT

According to the ADR regulations (Section 8.1.4) vehicles transporting dangerous goods shall have as minimum a 6 kg dry powder portable fire extinguisher suitable against fires in brakes, tyres or in the goods. Due to the fact that there is a doubt in whether a 6 kg dry powder portable fire extinguisher will be sufficient to extinguish a severe fire in a twin tyre, the Directorate for Fire and Explosion Prevention in Norway has initiated a test programme at Norges branntekniske laboratorium as (NBL) for testing of different types of portable fire extinguishers against tyre fires. In addition, a literature study is carried out in order to obtain updated information concerning fire fighting of tyre fires.

The objective of the test programme has been to achieve reliable information concerning the fire extinguishing efficiency of different fire extinguishants or agents and to select the best-suited portable fire extinguisher or agent agianst tyre fires. The experience gained from the project will be used in connection with a forthcoming revision of the ADR regulations.

This report describes the experimental set-up, the expermental procedure and the results from the test series involving 22 tyre fire trials as well as the literature study. Finally, the report concludes which agent/fire extinguishers are best suited against fires in twin tyres and the needed amount of agent.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Fire	Brann
GROUP 2	Extinguish	Slokke
SELECTED BY AUTHOR	Portable Fire Extinguishers	Håndslokkere
	Twin tyres	Tvillingdekk

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SUMMARY

THE TEST PROGRAMME

A series of trials involving testing of different portable fire extinguishers against fires in twin tyres has been carried out at Norges branntekniske laboratorium as (NBL) (Norwegian Fire Research Laboratory). The test programme included in all twenty-two tests with fourteen different portable fire extinguishers as well as some preliminary trials. The following five different types of agents were tested in order to determine the best suited fire extinguisher or agent against fires in tyres of dimension 295/80R 22,5 (with the number of experiments in parenthesis):

A Dry powder (12)
B Foam (6)
C Water mist (1)
D IFEX Impulse Fire Extinguisher (2)
E Wet chemical (1)

The tyre fire trials were carried out under as realistic and equal conditions as possible. Consequently, tests with twin tyre fires were carried out under a mock-up of a fender built in accordance with the ADR regulations. All tyres were second hand tyres and of the same size, but not of the same make of tyre. A heat release rate of the tyre fire of 500 kW was used as a criterion for starting the fire extinguishment. At a heat release rate of 500 kW, which was achieved after 9-15 minutes, huge flames of 2-3 m of length emerged from the top of the twin wheel (see photo). Because tyre fires are not very repeatable, the criterion of 500 kW was achieved at highly different times.

The tests were carried out in NBL's test hall, in which varying conditions with respect to wind or draft were prevented. Hence, the fire extinguishing efficiency of the fire extinguishers was tested independently on varying wind and draft conditions. However, due to the fact that the cost budget was limited, some simplifications in relation to the real situation were carried out. For example, instead of using inflated tyres on a felly, deflated tyres were mounted on a Ø545 mm x 2 mm thick x 970 mm long steel pipe with a significantly larger weight than a felly. Further, the number of experiments was limited to 22 tests. Hence, not all the fourteen fire extinguishers were tested twice.

RESULTS

A Dry Powder

Already during the preliminary tests for determination of a suitable heat release rate at which fire fighting should start, it was experienced that the dry powder fire extinguishers were rather effective against tyre fires. This was the main reason for the extensive and thorough testing of the dry powder fire extinguisher (12 tests). The heat release rate has to be increased as much as to 500 kW, i.e. after a preburn time of 9-15 minutes, before some of the dry powder fire extinguishers were incapable of extinguishing the tyre fire permanently.

The fire was extinguished rather efficiently in all the tests by applying dry powder onto the fire until the fire extinguisher was emptied. However, in some tests the fire reignited after a certain time (4-11 min.). This was probably because the fire had burned through the walls of the tyre. Thus, there was a fire inside the tyre, which was hidden for the agent. Hence, the main reasons for the occurrence of a reflash was not insufficient cooling of the tyre by the agent, but because the fire was not accessible for the agent.

In six of twelve tyre fire trials with dry powder fire extinguishers the extinguisher succeeded in extinguishing the tyre fire permanently. In the other six tests a reflash of the tyre occurred 4 - 11 minutes after fire extinguishment. None of the dry powder fire extinguishers were clearly different form the other with respect to fire extinguishing efficiency or preventing a reflash of the tyre. Different percentages of MAP (MonoAmmoniumPhosphate) appeared not to affect the fire extinguishing efficiency of dry powder fire extinguishers very much.

B Foam

The *foam fire extinguishers* had not as good fire extinguishing properties as the dry powder fire extinguishers. In only two of six tests with foam fire extinguishers the tyre fire were extinguished permanently after an average extinguishing time of 77 seconds, compared to 22 seconds for dry powder. Reflash of the tyre occurred in three of the six tyre fire trials. In one test the foam fire extinguisher was not capable of extinguishing the fire. Both trials in which the fire fighting of the tyre fires were successful, the *Amerex Tyre Fire* 9,5 litre foam fire extinguisher was used. This fire extinguisher was the only fire extinguisher tested twice which succeeded in extinguishing the fire in both trials. Most of the foam fire extinguishers had a weight above 14 kg, which may be somewhat too heavy for effective fire fighting. Due to freezing of the foam liquid, the foam fire extinguisher will not work in severe cold, apart from *Amerex Tyre Fire*, which can be used down to –40 ° C. The Niagara, Forexpan and Imprex foam fire extinguishers can be used down to 0°C.

C Water based fire extinguishers

The *IFEX 3035* Impulse Gun and *Amerex Water Mist* fire extinguishers were both effective in the fire fighting of the tyre fires and preventing reflash. Of these two types of fire extinguishers Water Mist was the fire extinguisher that had the best fire extinguishing performance. The *Amerex Water Mist* fire extinguisher had a fire extinguishing efficiency close too that of dry powder. However, preventing reflash is a far more important property of a fire extinguisher, because it is of no help at all that a fire is extinguished efficiently, if a reflash of the tyre fire occurs.

Further, the *Amerex Water Mist* fire extinguisher was considerably more handy and easy to use than the *IFEX impulse gun*. In addition, *IFEX 3035* requires a disproportionately large storage space. However, there exists also a smaller backpack version of IFEX, i.e. *IFEX 3012*. Neither of these fire extinguishers will work in severe cold because they are not prepared for use in connection with ant-freeze solutions.

D Wet Chemical

In the single tyre fire trial carried out with the *Amerex Wet Chemical* fire extinguisher, the fire was extinguished almost as effective as in the test with the *Amerex Water Mist* fire extinguisher, but there was a reflash in the tyre after a relatively short time. Table I shows a ranking of the most important properties of different agents/fire extinguishers, while Table II shows the main advantages and disadvantages for the main types of fire extinguishers/agents.

*Table I: A ranking of the most important properties of different agents/fire extinguishers based on the tests (*** = good, ** = average, * = bad).*

Agent	Transport/ usage/ storage (weight, volume)	Usage/ needed skill of fire-fighter	Fire extinguishing efficiency	Probability of reignition	Applicability in severe cold	Applicability at high wind speeds
Dry powder	***	***	***	**	***	*
Foam	**	***	**	*	*	*
Water Mist	**/***	***	**/***	**/***	*	*
Water Impulse (IFEX 3035)	*	*	**	***	*	**
Wet chemical	**	***	**	*	*	*

Table II: The main advantages and disadvantages for the main types of fire extinguishers.

Type of fire extinguisher	Advantages	Disadvantages
Dry powder	• The highest fire extinguishing efficiency of all types of fire extinguishers tested. • Effective even in severe cold. • Easy to operate. • Low weight (9-10 kg). • Easy to store on the vehicle.	• Medium to high probability of reignition in case of severe tyre fires.
Foam	• Average to high fire extinguishing efficiency. • Easy to operate. • The *application wand* for the Amerex fire extinguishers, which made it easier to approach the fire and it caused improved safety.	• High probability of reignition in case of severe tyre fires. • May be useless in severe cold (apart from Amerex Tyre Fire, which may be used down to –40 °C).
IFEX 3050 Water Impulse Gun	• Probably the most effective fire extinguisher to prevent reignition. • Probably the only effective fire extinguisher against severe fires in tyres due to the large quantity of water (35 litre). • Average extinguishing efficiency.	• Useless in severe cold. • Not easy to operate. • Too heavy (50 kg) and unhandy.
Water Mist	• Effective in preventing reignition. • High fire extinguishing efficiency. • Easy to operate. • Low weight (12 kg). • Easy to store on the vehicle.	• Useless in severe cold.
Wet Chemical	• Average to high fire extinguishing efficiency and easy to operate. • The application wand made it easier to approach the fire and it caused improved safety for the fire fighter. • Prepared for anti-freeze additives.	• May be useless in severe cold; i.e. below –40 °C.

MAIN CONCLUSIONS AND RECOMMENDATIONS

On the basis of Table I and II one may conclude that *all* the fire extinguishers/agents have evident advantages and disadvantages. The most important property of a fire extinguisher is that it provides a permanent fire extinguishment. That is, when the twin tyre is extinguished, a reflash of the tyre must not take place.

Dry powder in general as well as the *'Amerex Water Mist'* and *'Amerex Tyre Fire'* extinguishers showed in all the best properties. Dry powder fire extinguishers have the best fire extinguishing performance, but in case of large tyre fires (i.e. above 4-500 kW) there may be a certain probability of reflash of the tyre fire after extinguishment.

All the six different dry powder fire extinguishers were tested twice. All the extinguishers had one test with successful and permanent fire extinguishment and one test in which reflash occurred. Consequently, none of the fire extinguishers tested were clearly different from the other with respect to fire extinguishing efficiency or in preventing reflash of the tyre. Hence, NBL is not in the position to recommend a special quality of the dry powder fire extinguisher with respect to for example type of dry powder or percentage of MAP (MonoAmmoniumPhophate). Different percentages of MAP seemed to have no effect on the efficiency of the fire fighting.

Due to the fact that a tyre fire will probably not have a heat release rate higher than 4-500 kW when the fire fighting starts, a dry powder fire extinguisher will in most cases extinguish the fire permanently. However, the driver must have accessible at least *two* 6 kg dry powder fire extinguishers on the vehicle. The driver should have instructions in bringing both fire extinguishers to the fire scene. Two dry powder fire extinguishers should be sufficient to extinguish the fire permanently.

Dry powder fire extinguishers should be equipped with an *application wand*, which will improve accessibility to the fire and the safety of the fire fighter. Inflated tyres can in case of an explosion of the tyre have a much stronger probability of launching embers and burning parts of the tyre, which may represent a threat to the fire fighter. Consequently, the fire fighter should also wear a *face guard* and *protective clothing* during the fire fighting.

The *'Amerex Water Mist'* and *'Amerex Tyre Fire'* extinguishers were also effective in extinguishing tyre fires and in preventing reflash of the fire. The main reason for not recommending the water mist fire extinguishers is that it may be useless in severe cold, because this fire extinguisher is neither approved nor prepared for anti-freeze solution additives.

A main conclusion from the tyre fire trials is that two dry powder fire extinguishers most likely are sufficient to extinguish tyre fires on vehicles transporting dangerous goods. The *'Amerex Fire Tyre'* is a good alternative to dry powder because it has good qualities with respect to extinguishing the fire permanently, and it is applicable down to –40 °C. However, it is not yet approved for use in Norway.

1 INTRODUCTION

According to the ADR regulations (Section 8.1.4), vehicles transporting dangerous goods shall have as a minimum a 6 kg dry powder portable fire extinguisher suitable for fire fighting of fires in brakes, tyres or in the goods. In addition, the vehicle shall also have a 2 kg portable dry powder fire extinguisher suitable for fire fighting in the motor and the cabin of the vehicle.

A fire in a tyre may break out under driving, either in case of overheating of the brakes and the felly due to a brake blockage, or due to frictional heat created by one or two deflated tyres of a twin wheel. These situations may result in heating of the tyre to a temperature at which the tyres may ignite spontaneously; i.e. solely due to the increased temperature of the tyre. Spontaneous ignition temperatures of tyres as low as 200 °C have been reported /7/.

However, there is a doubt in whether a 6 kg dry powder portable fire extinguisher will be sufficient to extinguish a severe fire in a twin tyre. Even though the dry powder fire extinguisher has succeeded in extinguishing the fire, at least temporarily, the tyre may reflash due to the fact that the temperature of the tyre or the felly is still above the spontaneous ignition temperature. Dry powder has no real cooling capabilities, i.e. to temperatures below the spontaneous ignition temperature of the tyre. Without cooling the tyre sufficiently down, a reflash may occur. If the fire extinguisher has been completely emptied during the first fire extinguishing effort, the driver of the vehicle has no other fire extinguishers than the additional 2 kg portable dry powder fire extinguisher. This fire extinguisher will hardly be of any help at all.

The Directorate for Fire and Explosion Prevention in Norway has initiated a test programme at Norges branntekniske laboratorium as[1] (NBL) for testing of different types of portable fire extinguishers against tyre fires /1/. In addition, a literature study shall be carried out in order to obtain updated information concerning fire fighting of tyre fires.

The objective of the test programme and the literature study has been as follows:

1. To achieve reliable information concerning the fire extinguishing efficiency of different agents.
2. To select the best-suited portable fire extinguisher or agent against tyre fires.
3. To establish the requirement with respect to the necessary amount of the best suited agents.

This experience gained from the project will be used in connection with a forthcoming revision of the ADR regulations.

[1] Norwegian Fire Research Laboratory.

2 TEST PROGRAMME

2.1 The Test Conditions

Apart from the agent the following parameters will affect the efficiency of the portable fire extinguisher:

- *The heat release rate* of the tyre fire when starting the fire fighting. The higher the heat release rate of the tyre fire is, the more difficult it will be to extinguish the fire.
- *The preburn time,* i.e. the time delay from ignition of the tyre fire to the start of the fire fighting. The longer the preburn time is, the more difficult it will be to extinguish the fire.
- The *preheating* of the tyre prior to ignition of the tyre. The stronger the preheating of the tyre is, the more difficult it probably will be to extinguish the tyre fire.
- The *distance* from the fire fighter to the front face of the outermost tyre. The larger the distance is, the more difficult it will be to extinguish the tyre fire.
- *Firefighting tactics*. The more skilled the firefighter is, the easier it will be to extinguish the fire.
- The *size* or the *dimensions* of the tyre. The larger the dimension of the tyre is, the more difficult it will be to extinguish the tyre fire.
- *Type of tyre*, i.e. the *type of rubber* of the tyre. Some type of tyres may be more combustible than other types and create a more severe fire after a certain time.
- *Single* or *twin tyres*. Fire in twin wheels will be considerably more difficult to extinguish than single tyres due the fact that large parts of the fire may be hidden between the tyres of a twin wheel. Thus, these parts will be more difficult to hit the fire with the agent.
- *Presence of a fender* above the twin wheels or not. A fender above the twin wheels will restrict the access of the fire fighter to hit hidden parts of the fire, e.g. between the tyres of a twin wheel.
- *Inflated/deflated tyres*. Inflated tyres can in case of an explosion of the tyre probably have a much stronger probability of launching embers and burning parts of the tyre, which may represent a threat to the fire fighter.
- *The ambient temperature*. If the ambient temperature is below the freezing point of the agent, the agent may be of no use for extinguishers with temperature range between 0-60 °C.
- *The wind velocity*. A high wind velocity may make it impossible for the agent to hit the fire sufficiently. Varying wind conditions during the tyre fire trials may cause rather different test conditions and test results of the tyre fire trials.

It is a necessary prerequisite for the tyre fire trials that the test conditions are as equal as possible for all the tests if the best suitable fire extinguisher shall be selected.

2.2 Agents

In all, five different contractors of portable fire extinguishers in Norway were invited to submit fire extinguishers suitable for fighting tyre fires to the experimental series. This invitation resulted in that a total of thirteen different portable fire extinguishers with different agents were delivered to NBL for testing. Table 2.1 shows the main data of these fire extinguishers.

Table 2.1: The main data of the 13 different fire extinguishers that were delivered to NBL for testing. (See Appendix B for more detailed information about these fire extinguishers.)

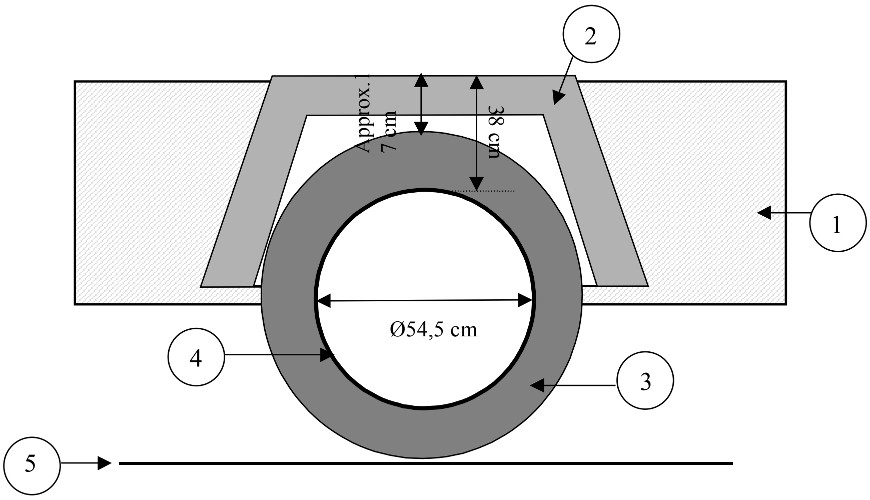
The Name of the Portable Fire Extinguisher	Agent	Size	Contractor
NOHA BC dry powder	BC Karate	6 kg	NOHA /2/
NOHA ABC dry powder	ABC Favorit	"	"
NOHA 9 litre foam	NIAGARA Foam (AR-FPPP)	9 litre	"
NOHA 9 litre foam	FOREXPAN Synthetic foam	"	"
Amerex Water Mist MODEL 272	Distilled water	"	Alf Lea & Co. /3/
Amerex Wet Chemical MODEL 262	Potassium acetate mixed with water	9,5 litre	"
Amerex TYRE FIRE	Foam	"	"
Brandstop 6G	ABC Tropolar Forte dry powder	6 kg	If… Shop NUF /4/
Pyrostop PC6	ABC dry powder	"	"
GLORIA F6 Ni	Imprex Foam	6 litre	Hellanor /5/
IFEX 3035	Water/200 bar pressurised air	35 litre	Lux Fire Technology /6/

2.3 The Test Arrangement

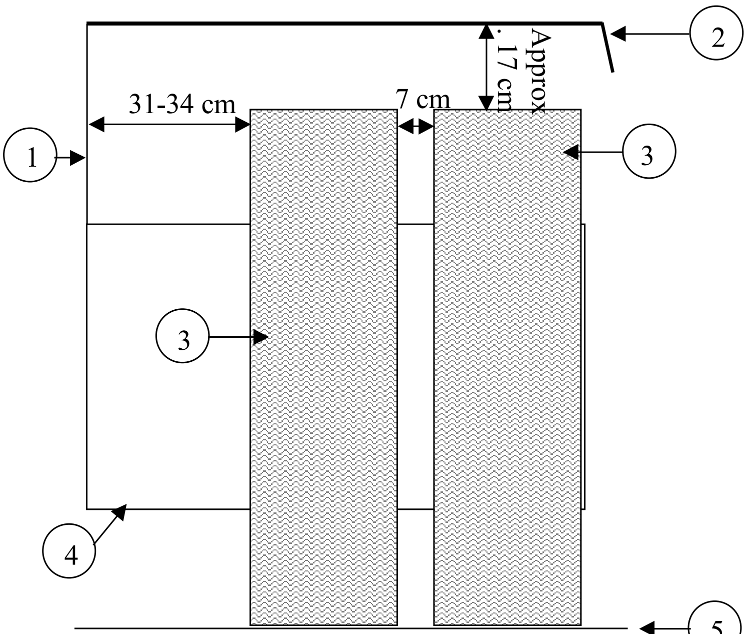
Figure 2.1 shows the test arrangement of the tyre fire trials, which were carried out during June 2001 in NBL's laboratory at Tiller in Trondheim, Norway. The main intention of the test arrangement was to simulate a real twin tyre fire on a vehicle as realistic as possible, but within the cost limit of the project. Based on this, some simplifications from the real situation were carried out. An example of such a simplification was not to use inflated tyres on a felly because it was both too time consuming and too difficult to change tyres on the felly, or to obtain the necessary number of tyres on a felly.

Tyres with the dimensions 295/80R 22.5 were mounted on a Ø545 mm x 22 mm thick x 970 mm long steel pipe instead of on a felly. A Ø545 mm x 2 mm thick steel plate was welded to the front end of the pipe (see Figure 2.1 and Figure C.4) and the steel pipe was welded to a support frame. The total weight of steel to be heated was then much greater than in a felly. Hence, a felly will achieve a higher temperature than the steel pipe and reignition of the tyre would probably not occur so easily in the tests (i.e. with the tyre on a felly) as in the real situation.

Due to the fact that tyre fires primarily arise in twin wheels and a fire in twin tyres are considerably more severe and considerably more difficult to extinguish than fires in a single tyre, trials with twin tyres were executed only. The tyres were mounted on the steel pipe rather loosely. Another feature that will affect the fire fighting of a tyre fire to a high degree, is the presence of a fender above the tyres. A fender will restrict the access of fighting the fire, especially between the tyres. Consequently, a full-scale fender with a construction and dimensions according to the ADR regulations was purchased and mounted above the twin tyre with correct distances between the tyre and the fender (see Figure 2.1).



No.	Detail	Dimension
1	Cover plate	180 cm x 66 cm (wxh)
2	Wing	
3	Tyre	295/80R22,5
4	Steel pipe	Ø545 x 22
5	Floor	



No.	Detail
1	Cover plate
2	Wing
3	Tyre
4	Steel pipe
5	Floor

Figure 2.1: The test arrangement used for the testing of the efficiency of different fire extinguishers against twin tyre fires.

2.4 Establishment of a Criterion for the Start of Fire Fighting

It is important that the state of the tyre fires is the same in the tests when starting the fire fighting. Either a certain *preburn time* or a certain *heat release rate* can be used as a criterion for starting the fire fighting of the tyre fires. The preburn time can be used only if the tyre fire development is approximately the same in all the tests. However, as already stated in the chapter dealing with the review of the literature of tyre fires (Appendix A), fire tests with equal tyres and under equal fire conditions were not particularly repeatable /7/. Thus by using the same preburn time for the start of fire fighting, the state of the tyre fire may be rather different when starting the fire fighting. That is, the heat release rate may vary a lot at equal time delays, which may cause rather unequal test conditions for the portable fire extinguishers.

On the other side, by using the same *heat release rate* as a criterion for starting the fire fighting, the state of the fires will be rather equal for all the tyre fire trials at the start of fire fighting. Thus, the test arrangement shown in Figure 2.1 was placed under a hood, which constitutes the exhaust system of the 'Full-scale room test for surface products' test method (ISO 9705). The exhaust system is capable of collecting broadly speaking the entire smoke production of the tyre fires. By means of calometry[1] the heat release rate of the tyre fires were calculated rather accurately and displayed on the screen of a monitor during the tests.

2.5 Preliminary Tyre Fire Trials

Some preliminary tyre fire trials were carried out in order to select a suitable heat release rate for starting the fire fighting. A heat release rate at which an ordinary dry powder fire extinguisher was facing problems in fighting a tyre fire, was expected to be a good criterion for starting the fire fighting.

The aim of the preliminary test series was to find this criterion. Based on previous tyre fire trials carried out at NBL in 1995 /8/ the heat release rate history of a twin tyre fire without a fender has been recorded (see Figure A.1 in Appendix A). According to these tests a maximum heat release rate of slightly less than 900 kW was recorded after approximately 30 minutes fire in the tyre. The heat release rate was 300 and 600 kW after 17 and 25 minutes, respectively. The heat release rate developed somewhat more rapidly in the current tests compared to the trials in 1995. The main reason for this was the presence of a fender above the tyres, which caused a strong radiative feed-back to the twin tyre. This resulted probably in a more rapid fire development.

The preliminary tyre fire trials started with a heat release rate of 300 kW as a criterion for the start of the fire fighting. However, the dry powder fire extinguisher put out the fire permanently rather effectively. The same occurred at a heat release rate of 400 kW. At a heat release rate of 500 kW, which occurred after 10-15 minutes, the dry powder fire extinguisher also fought the fire effectively. However, in some tests one could still see some smoke production and hear some crackling from the tyre for a long time. At last the tire reignited 10-15 minutes after fire extinguishment. Hence, a heat release rate of 500 kW was used as a criterion for starting the fire fighting.

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[1] That is, by measuring the concentration of oxygen and carbon dioxide in the ambient atmosphere as well as in the exhaust gases in addition to the exhaust flow rate, the heat release rate can be predicted.

2.6 Preheating of the Tyres

As mentioned in the literature review in Appendix A an extensive test series carried out in England in 1991. These tests have shown that preheating of the tyres appeared not to significantly affect the extinction performance compared with the results achieved with non-preheated tyres. Due to the fact that preheating by a propane gas burner is a very time consuming activity related with high costs /8/, it was decided not to include preheating of the tyres prior to the tests.

2.7 Test Procedure

An overview of the test conditions of tyre fire trials is shown in Table 2.2.

Table 2.2: An overview of the test conditions of tyre fire trials.

Test parameter	Value	Comments
Heat release rate at start of fire fighting:	500 kW	Due to the fact that it was rather difficult to achieve 500 kW, the fire fighting started at a somewhat lower heat release rate in some tests.
Preheating:	No	No preheating of the tyres.
Preburn time:	Varying	Dependent on the time when a heat release rate of 500 kW was achieved in the test (from 9 - 15 min).
Distance between fire fighter and the tyre:	1 m	That is, the standing distance between the fire fighter and the tyre (see figure 2.2).
Dimension of the tyres:	295/80R 22.5	
Make of tyre:	Varying	Different makes of tyres were used, e.g. Michelin, Goodyear, Toyo, Semperit, Dunlop
Tyres on a felly:	No	The tyres were mounted on a Ø545 mm x 22 mm thick x 970 mm long steel pipe, which had a significantly higher weight than a felly.
Single or twin tyres:	Twin tyres	Simulated by mounting two tyre side by side on the pipe at a certain distance between the tyres.
Inflated tyres:	No	Deflated tyres were used.
Location of the tyre in a paddle box/fender:	Yes	A mock-up of a fender according to the ADR regulations was used.
Location of the tests:	Indoors	The tests were carried out in the large test hall.
Ambient temperature:	Approx. 15 °C	The temperature of the large test hall of NBL
Wind or draft velocity:	Approx. 0 m/s	All doors and gateways to the test hall were closed.
Waiting time for reignition of the tyres:	15 minutes	If a reflash has not occurred within 15 minutes, the fire was defined as extinguished permanently
Ignition source:	-	The ignition source was a rags soaked with hepthane liquid, which were located under the front tyre and then ignited (see Figure C.5).
The skills of the fire fighter:	Normal	The experience the fire fighter had in fighting tyre fires was the preliminary tyre fire trials in addition to experience gained through other experiments involving fire fighting.
Emptying of the fire extinguisher during the first attempt:	Yes	If the fire reignited, the fire fighter could not use the fire extinguisher anymore.

2.8 Execution of the Tests

The tests started by igniting rags soaked in hepthane placed under the tyre (see Figure C.5). At this time the exhaust system was running in such a way that all the produced smoke gases from the tyre fires were collected by the exhaust hood and transported to the external atmosphere above the roof of the test hall. In the exhaust system there was a sampling station where among other things the temperature, flow-rate and the concentrations of O_2 and CO_2 of the exhaust gas were measured continuously.

The heat release rate of the fire was logged and shown on a screen monitor every 5 seconds during the test. When the heat release rate reached a value equal to approximately 500 kW, the fire fighting of the tyre fire started. The fire fighter was allowed to move within the marked area on the floor in front of the tyre as shown in Figure 2.2. The closest point of this area was horizontally 1 m from the front of the tyre. In practice, this rather close distance made it possible for the fire fighter to attack the fire almost as close as required only restricted by the thermal stresses from the emerging flames of the tyre fire.

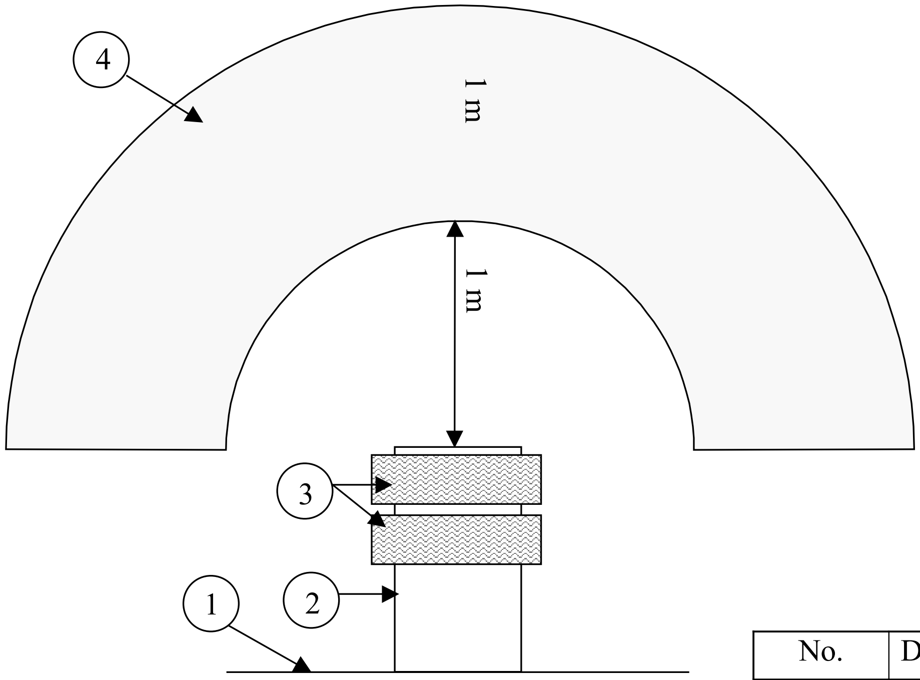
If the fire fighter succeeded in extinguishing the fire in the tyre and if the fire had not reignited within 15 minutes from the time when the fire was put out, the actual test was reported as successful, i.e. fire extinguisher had succeeded in extinguishing the tyre fire.

The following parameters were recorded during the experiment:

- Type and nominal weight/volume of fire extinguisher.
- Initial weight of the fire extinguisher.
- The weights after fire extinguishing.
- Used amount of agent.
- The preburn time.
- Fire extinguishing time.
- The time to a possibly reflash of the tyre. That is, the time from the start of the fire fighting to a possible reignition of the tyre.

Figure 2.3 shows three typical heat release rate histories of different tyre fire trials when using three different fire extinguishers, i.e. a) Dry Powder (NOHA T6CN), b) AFFF Foam (NOHA Niagara) and c) Water Mist (Amerex 272). These curves show clearly that the tyre fire trials were not particularly repeatable due to the fact that the heat release rate developed rather differently from test to test. The time when the heat release rate attained a value of 500 kW varied as much as between 630-900 seconds (i.e. 10,5 to 15 minutes) for these three tests.

A feature, which to a certain extent may be seen from the curves b) and c) in Figure 2.3, is that the heat release rate had a tendency to decrease temporarily after some time. However, this feature was much more evident in some other tests. If the heat release rate did not show any tendency to increase after approximately 10 minutes from ignition, the fire fighting was carried out at the actual heat release rate, which was lower than 500 kW. The heat release rate could be as low as slightly below 300 kW, even though the fire intensity seemed to be as severe as in the other tests when the heat release rate attained a value of 500 kW. This deviation in the measured heat release rate might also be due to a measuring error of the heat release rate.



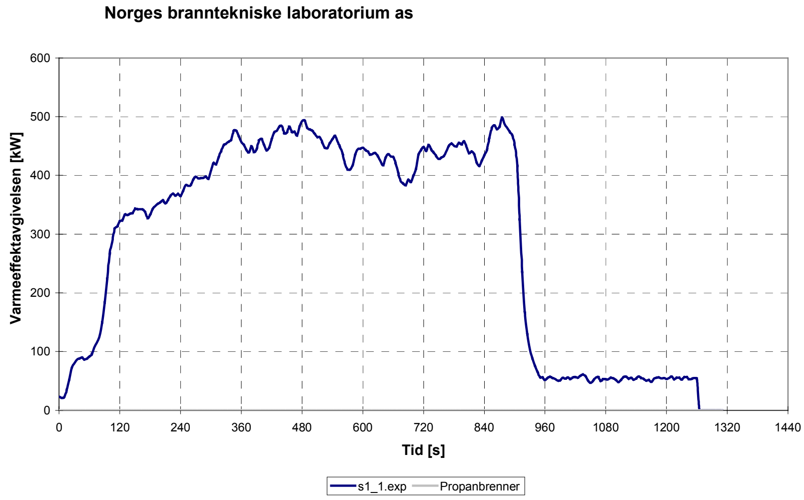
No.	Detail
1	Cover plate
2	Pipe
3	Tyre
4	Fire fighting sector

Figure 2.2: A sketch showing the marked area in which the fire fighter was allowed to move within on the floor in front of the tyre.

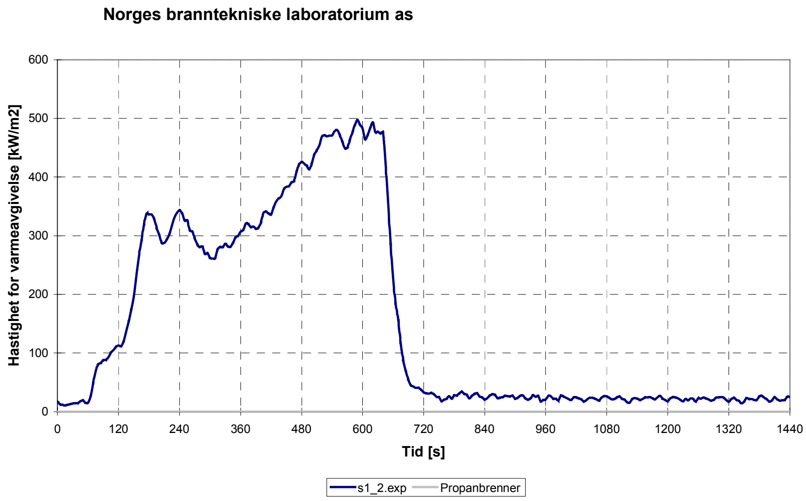
If the preburn time was too long, the fire might have burned through the rubber of the tyre. If this occurred, it was far difficult to put out the fire completely because the agent could not sufficiently hit the fire inside the tyre. After the fire was evidently extinguished, at least as observed for the fire extinguisher, one could still see some smoke production and hear crackling from the tyre for a long time (4-11 min.) until the tyre suddenly reflashed. Tyres with a slow fire development might have burned through the tyre wall before the criterion of 500 kW was reached due to the long preburn time. These fires might be hard to extinguish completely because a reflash of the tyre fire occurred after some time.

2.9 Test Results

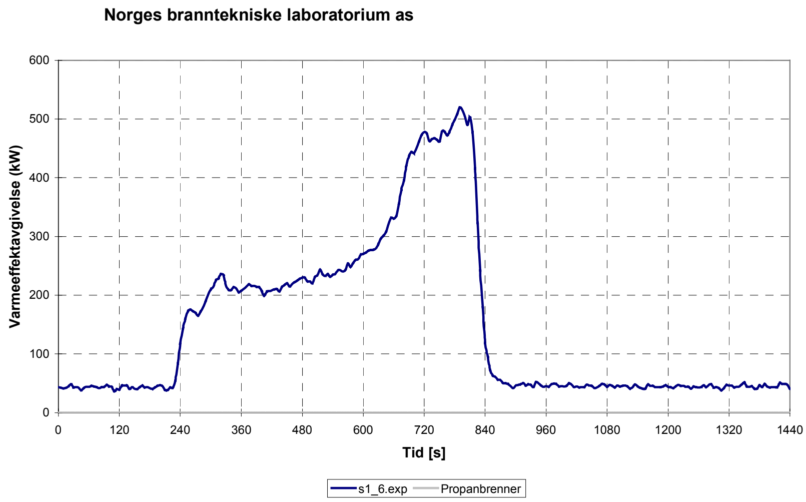
Table 2.3 shows the experimental results with respect to among other things the fire extinguishing time and the time to a possibly reignition of the tyre.



a) Dry Powder (NOHA T6CN)



b) AFFF Foam (NOHA Niagara)



c) Water Mist (Amerex 272)

Figure 2.3: Heat release rate histories of tyre fires extinguished with three different fire extinguishers.

Table 2.3: The test results with respect to the type, the most important characteristics and the fire extinguishing results of the fire extinguisher tested. (For more detailed information concerning these experiments see Table B.1 in Appendix B).

Supplier/type of portable fire extinguisher	**Initial weight (kg)**	**Weight after fire exting-uishing (kg)**	**Used amount of agent (kg)**	**Measured heat release rate at start of fire fighting (kW)**	**Time to start of fire exting-uishing (sec.)**	**Fire exting-uishing time (sec.)**	**Time to reignition* (min:sec)**
NOHA: Favorit 111 – 6 kg ABC *Dry Powder*	9,673	3,678	5,995	500	14:58	21	No reigni-tion
NOHA: Favorit 111 – 6 kg ABC *Dry Powder*	9,704	3,666	6,038	455	13:33	24	6:08
NOHA: Favorit 111 – 6 kg BE *Dry Powder*	9,452	3,233	6,219	554	9:49	12	6:35
NOHA: Favorit 111 – 6 kg ABC *Dry Powder*	9,362	3,156	6,206	326	6:48	23	No reigni-tion
NOHA: BC KARATE 6 kg *Dry Powder*	10,36	3,200	6,836	500	9:05	19	No reigni-tion
NOHA: BC KARATE 6 kg BC *Dry Powder*	10,265	3,242	7,023	480	13:45	25	4:00
NOHA: BC KARATE 6 kg *Dry Powder*	10,472	4,376	6,096	500	10:00	28	10:08
NOHA: BC KARATE 6 kg BC *Dry Powder*	10,492	4,961	5,531	350	6:31	38	No reigni-tion
If Shop: Pyrostop - 6 kg ABC *Dry Powder*	9,204	3,184	6,020	500	8:50	13	6:35
If Shop: Pyrostop - 6 kg ABC *Dry Powder*	9,152	3,205	5,947	334	5:14	9	No reigni-tion
If Shop: Bavaria Brandstop 6 kg ABC *Dry Powder*	9,684	3,669	6.015	297	12:08	27	No reigni-tion
If Shop: Bavaria Brandstop 6 kg ABC *Dry Powder*	9,650	3,687	5,963	500	11:08	27	10:42
NOHA: Niagara 9 litre AFFF *Foam*	14,216	5,282	8,934	500	9:45	37	3:35
NOHA: FOREXPAN 9 litre *Foam*	14,141	5,274	8,867	401	14:54	55	10:15
Alf Lea & Co.: Amerex Tyre Fire 9,5 litre f*oam*	14,227	3,677	10,550	500	11:23	56	No reigni-tion
Alf Lea & Co.: Amerex Tyre Fire 9,5 litre f*oam*	14,359	3,671	10,688	500	13:19	97	No reigni-tion
Hellanor: Gloria F6 - 9 l *Foam*	11,269	5,169	6,100	329	13:52	38	4:46
Hellanor: Gloria F6 - 9 l *Foam*	11,412	-	-	500	16:00	Not ex-ting-uished	-
Alf Lea & Co.: Amerex 262, 9,5 l Amerex *Wet Chemical*	14,299	3,821	10,478	500	10:00	35	3:33

Supplier/type of portable fire extinguisher	Initial weight (kg)	Weight after fire exting-uishing (kg)	Used amount of agent (kg)	Measured heat release rate at start of fire fighting (kW)	Time to start of fire exting-uishing (sec.)	Fire exting-uishing time (sec.)	Time to reignition* (min:sec)
Lux Fire Technology: IFEX 3035, *Water Impulse Gun*	-	-	-	500	15:44	Not exting-ui-shed[1]	-
Lux Fire Technology: IFEX 3035, *Water Impulse Gun*	87,60	58,55	29,05	445	13,00	82	No reigni-tion
Alf Lea & CO: Amerex 272, 9,5 l *Water Mist*	12,126	7,891	4,235	525	9:55	33	No reigni-tion

* *Given in minutes from start of the fire fighting, i.e. when the heat release rate of the tyre fire achieved a value of 500 kW = 0,5 MW.*

2.10 Discussion of the Results Dependent on the type of Agent

2.10.1 Requirements to the portable fire extinguisher

A fire extinguisher used in vehicles transporting dangerous good should satisfy the following requirements:

- *Permanent fire extinguishment* of the tyre fire.
- *Fire extinguishing efficiency*: High fire extinguishing efficiency.
- *Transport*: Easy to transport to the fire scene.
- *Usage*: Easy to use at the fire scene without requiring extensive training and practising.
- *Ambient conditions*: Effective under the following varying ambient conditions:
  - *Ambient temperatures*
  - *Wind speeds.*
- *Storage*: Easy to store on the vehicle and the fire extinguisher requires a comparatively small storage volume.
- *Malfunction*: A low probability for malfunctions of the fire extinguisher.

Table 2.4 shows a ranking of the fire extinguishers with respect to the most important requirements listed above. Of the fire extinguishment characteristics listed in Table 2.3, the probability of reignition is the most important, because it will be of no help at all that a fire extinguisher puts out the fire efficiently, if the fire reignites. Another important characteristic of the fire extinguisher is that it can be used under all ambient condition, e.g. in severe cold and at high wind velocities.

[1] This test should strictly speaking have been omitted from the test results because the fire fighter did not have sufficient skill to operate the fire extinguisher. In addition, the pressurised air accumulator was emptied relatively early during the test due to the fact that the fire extinguisher was used for training purposes prior to this test.

*Table 2.4: A ranking of the most important properties of different agents/fire extinguishers - (*** = good, ** = average, * = bad).*

Agent	Transport/ usage/ storage (weight, volume)	Usage/ needed skill of fire-fighter	Fire extinguishing efficiency	Probability of reignition	Applicability in severe cold	Applicability at high wind speeds
Dry powder	***	***	***	**	***	*
Foam	**	***	**	*	*	*
Water Mist	**/***	***	**/***	**/***	*	*
Water Impulse (IFEX 3035)	*	*	**	***	*	**
Wet chemical	**	***	**	*	*	*

2.10.2 Dry Powder Fire Extinguishers

Already in the preliminary tests for determination of a suitable heat release rate when starting the fire fighting, it was experienced that the dry powder fire extinguishers were rather effective against tyre fires. The heat release rate was increased to as much as to 500 kW, i.e. after a preburn time of 9-15 minute, before the dry powder fire extinguishers were incapable of extinguishing the fire permanently. The rather severe fires were all extinguished rather efficiently by applying dry powder onto the fire in 10-40 seconds. However, in some of the tests a reflash in the tyre occurred after some time. In six of twelve tyre fire trials with dry powder fire extinguishers the dry powder fire extinguisher succeeded in extinguishing the tyre fire permanently. In the other six tests the tyre reignited after 4 - 11 minutes.

The rather excellent fire extinguishing performance of dry powder fire extinguishers provided, however, a rather close access to the fire. When the fire fighter was very close to the huge flames emerging from the space between the tyre and the fender (see figure C.7 in Appendix C), the fire fighter could feel pain on his hands due to the thermal stresses from the fire. The gloves used by the fire fighter were not firemen gloves, but ordinary working gloves.

From Table 2.4 it appears that the dry powder fire extinguisher has an excellent fire extinguishing efficiency, but there was a certain probability of reignition if the preburn time was so long that the fire has burned through the walls of the tyre. An important characteristic of dry powder fire extinguishers is that they can be used in severe cold. All other agents may freeze during the night in sever cold if not stored in a hot cabinet. Due to this reason the dry powder fire extinguishers were tested more thoroughly than the other agents in order to be certain whether this fire extinguisher is sufficient or not against tyre fires.

All the four different types of dry powder fire extinguishers tested reflash occurred in 50 % of the trials. Different percentages of MAP (MonoAmmoniumPhosphate) did not seem to affect the fire extinguishing efficiency of dry powder fire extinguishers. However, no fire extinguishers had a MAP below 70 %.

2.10.3 Foam Fire Extinguishers

Six different foam fire extinguishers were tested as shown in Table 2.2. As it appears from the table the fire was effectively and permanently extinguished in two of the six tests, while reignition occurred in three tests and in one test the foam fire extinguisher was incapable of extinguishing the fire. The reason for the latter was probably due to an extremely long preburn of 16 minutes, which probably were caused by the fact that the fire had burned through the walls of the tyre. The two trials, in which a reflash did not take place, were both with the *Amerex Tyre Fire*.

The average extinguishing time of the five tests that succeeded at least temporarily in extinguishing the fire was almost 57 seconds, compared to only 22 seconds for the dry powder fire extinguishers. It seems as if the dry powder had a far better fire extinguishing efficiency than foam, not only with respect to extinguishing efficiency, but also in preventing reignition.

All the foam fire extinguishers had a weight of 11-14 kg, which may be a little bit too heavy during the fire extinguishing activity. Further, the foam fire extinguishers may not work in severe cold unless an antifreeze solution is applied to the foam. If an antifreeze solution is added to the foam, the fire extinguisher may usually be used down to -20 °C. However, the Amerex Tyre Fire, which is prepared for anti-freeze additives, can be used down to –40 °C. None of the fire extinguishers were tested with anti-freeze additives.

2.10.4 Fire Extinguishers Based on Water

2.10.4.1 IFEX

The IFEX 3050 consists of a 50 litre trolley and IFEX 1301 Impulse Gun. The trolley consists of a 50 litre (of total weight of 98 kg when filled with water) water/agent cylinder and a 6 litre 300 bar air cylinder. The water/agent cylinder is pressurised to 6 bar, and the impulse gun to 25 bar. A 15 m co-axial hose for water and air connected the trolley and the impulse gun.

Actually, the first trial with IFEX, in which the fire was not extinguished, should not have been included due to reasons already explained. The lack of practise and training of the fire fighter may explain the rather long fire extinguishing time of 82 seconds of IFEX compared to an average fire extinguishing time for the dry powder fire extinguishers of 22 seconds. The fire extinguisher was anything but easy to use for an untrained person.

A drawback of this fire extinguisher was that after some shots, the gun has to be refilled with water, which lasted for some seconds. During this time the fire might have become almost as severe as before the shots. This discontinuous fire fighting resulted in the rather bad fire extinguishing efficiency of IFEX compared to dry powder fire extinguisher. Further, this fire extinguisher was rather dramatic in use due to the powerful recoil of the shots.

In addition, this fire extinguisher was both heavy and voluminous (see Figure C.1), which made it unhandy and caused most likely storage problems. However, this fire extinguisher was probably the best extinguisher with respect to preventing reignition of the tyre due to the relatively large amounts of water applied to the tyre fire for a long time (i.e. 50 litre of water and the 2 litre air cylinder which allows for 17 minutes of operation /6/). A smaller backpack version of the fire extinguisher exists (i.e. IFEX 3012). This backpack consists of a 13 litre water/agent cylinder and a 2 litre 300 bar air cylinder.

2.10.4.2 Amerex 272 Water Mist

Only one test was carried out with the Water Mist fire extinguisher. This fire extinguisher uses distilled water in a 6,6 or 9,5 litre container, which was pressurised to 6,9 bar with nitrogen. This fire extinguisher, as well as the Amerex Tyre Fire, was equipped with an 30 cm long *application wand* (see Figure C.3), which was very useful during the fire fighting. It allowed the fire fighter to reach closer to hidden parts of the fire, e.g. between the tyres of a twin wheel.

The water mist fire extinguisher had a better fire extinguishing efficiency than IFEX and no reignition occurred. It managed to put out the fire permanently with the use of only 4,2 litre of water and there was still 5,3 litre left when the fire was extinguished. The fire extinguisher tested had approximately 2 kg less weight than the most of the foam fire extinguishers. Thus, it was somewhat easier to transport and operate during fire fighting. However, this fire extinguisher had the same disadvantage as the other water and foam based fire extinguishers in that it will not work in severe cold. This may be a big disadvantage in the wintertime in several European countries. The Water Mist fire extinguisher was neither approved nor prepared for anti-freeze additives.

2.10.5 Wet Chemical

Only one test was carried out for this fire extinguisher. It extinguished the tyre fire almost as efficient as the water mist fire extinguisher, but the fire reignited after 3,33 minutes. This fire extinguisher has the same disadvantages at severe cold as foam and water based fire extinguishers. However, the Amerex Wet Chemical is prepared for anti-freeze additives in such a way that it can be used down to –40 °C. Table 2.5 shows the main advantages and disadvantages for the main types of fire extinguishers.

Table 2.5: The main advantages and disadvantages for the main types of fire extinguishers.

Type of fire extinguisher	Advantages	Disadvantages
Dry powder	• The highest fire extinguishing efficiency of all types of fire extinguishers tested. • Effective even in severe cold. • Easy to operate. • Low weight (9-10 kg). • Easy to store on the vehicle.	• Medium to high probability of reignition in case of severe tyre fires.
Foam	• Average to high fire extinguishing efficiency. • Easy to operate. • The *application wand* for the Amerex fire extinguishers, which made it easier to approach the fire. which led to improved safety of the fire fighter?	• High probability of reignition in case of severe tyre fires. • May be useless in severe cold (apart from Amerex Tyre Fire, which may be used down to –40 °C).
IFEX 3050	• Probably the most effective fire extinguisher to prevent reignition. • Probably the only effective fire extinguisher against severe fires in tyres due to the large quantity of	• Useless in severe cold. • Not easy to operate. • Too heavy (50 kg) and unhandy.

Type of fire extinguisher	Advantages	Disadvantages
	water (35 litre). • Average extinguishing efficiency.	
Water mist	• Effective in preventing reignition. • High fire extinguishing efficiency. • Easy to operate. • Low weight (12 kg). • Easy to store on the vehicle.	• Useless in severe cold.
Wet Chemical	• Average to high fire extinguishing efficiency. • Easy to operate. • The application wand made it easier to approach the fire and it caused improved safety for the fire fighter. • Prepared for anti-freeze additives.	• A comparatively fast reflash of the tyre fire occurred.

2.11 Concluding Remarks

As it appears from Table 2.4 and 2.5 no agent/fire extinguisher has a top score for all the main properties of a fire extinguisher. All have both obvious advantages and disadvantages. As already stated the most important property of the fire extinguisher is not how efficient the tyre fire is extinguished, but that it ensures permanent fire extinguishment of the tyre fire. As regards to this important property the water based fire extinguishers are very suitable, i.e. Amerex Water Mist and the IFEX system. However, these fire extinguishers are useless in severe cold.

Of these two fire extinguishers the Amerex Water Mist is preferable due to all the disadvantages of the IFEX system, even though this fire extinguisher is probably the best to fight large tyre fires and to prevent a reflash in the tyre. However, the IFEX 3050 is the only fire extinguisher which is applicable against large fires in the vehicle, e.g. in twin tyres, battery case, engine room etc.

The Amerex Tyre Fire was the only fire extinguisher tested twice, which managed to extinguish the fire permanently in both trials. Further, by using anti-freeze additives it may be used down to –40 °C.

Dry powder is the most efficient fire extinguisher, but a reflash may occur if the fire has been too severe or the preburn time is too long so that the walls of the tyre have been burned through. However, the likelihood of having such a large fire before the start of fire extinguishment (i.e. above 500 kW), is probably not very high. It is anticipated that most tyre fires should be fought effectively by means of a 6 kg dry powder fire extinguisher. If large tyre fires shall be fought, there have to be available at least two 6 kg dry powder fire extinguishers. The driver must have instructions in bringing two fire extinguishers to the fire scene.

The conclusion with respect to the best suited fire extinguisher based on 22 tyre fire trials, is that a dry powder fire extinguishers is still recommended in vehicles transporting dangerous goods. Two fire extinguishers should be sufficient to fight even large fires in twin tyres. The Amerex Tyre Fire seems also to be well suited against tyre fires, but this fire extinguisher is not yet approved for use in Norway.

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APPENDIX A: A LITERATURE REVIEW

2.12 General

A brief review of the available literature on the extinguishment of tyre fires has been carried out. Most of the literature deal with fires in large piles of tyres, which is not of current interest to this project.

2.13 Interesting Information from the Literature Review

The following information was obtained on the basis of the literature review:

- NBL[1] has measured the heat release rate (in kW) from a free and unrestricted tyre fire in twin wheel, i.e. without a fender above the tyres /8/. The heat release rate as function of time is shown in Figure A.1.

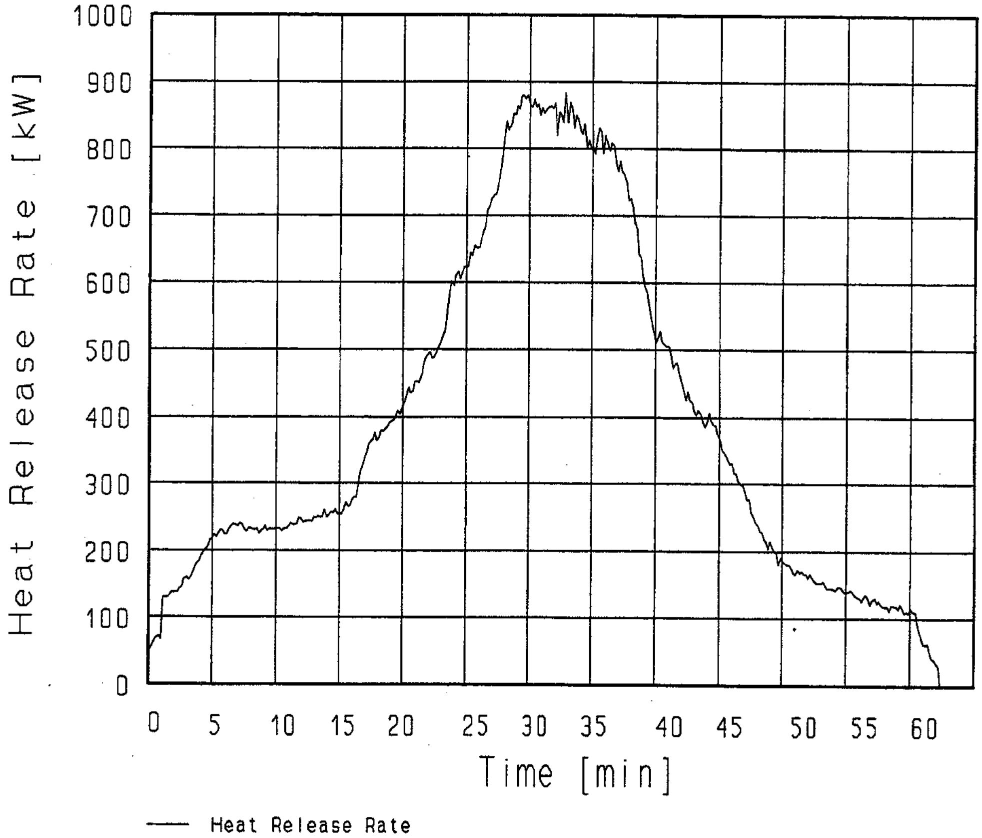

Figure A.1: The heat release rate (in kW) during a twin tyre fire. Maximum heat release rate was 878 kW. The time is given from pilot ignition of the tyres /8/.

- Spontaneous ignition of tyres may occur at temperatures between 200 and 428 °C dependent on the type of tyre /7/.
- In connection with spontaneous ignition of tyre fires, there may be an explosion hazard, which may be a threat to the fire-fighters. Hence, tyres should not bee preheated to a higher temperature than 160-190 °C in tyre fire trials /7/.

[1] Norwegian Fire Research Laboratory (a company in the SINTEF group)

- There may be parts of a burning tyre that is hidden and inaccessible for the agent /9/.
- A tyre fire will lead to heating of the steel felly, which may be difficult to cool sufficiently, especially if dry powder or foam fire extinguishers are used. If not sufficient cooling of the tyre is achieved, reflash of the tyre may occur /8/.
- Water may in certain cases be ineffective against tyre fires. However, by close access to the tyre fire water is as effective as other fire extinguishers. However, by remote access some aspirated foam fire extinguishers showed better fire extinguishing performance than water /9/.
- Preheating of the tyres to 160 °C did not affect the fire extinguishing performance of aspirated foam fire extinguishers compared no preheating of the tyre. Preheating to higher temperatures may cause a major threat to the fire fighters by the fact that the tyre may explode and throw out a lot of glowing particles and embers /7/.
- An explosion in a tyre may occur even though there is not any visible fire in the tyre /7/.
- Preheating of the tyre in connection with tyre fire trials should not cause higher temperatures than 180 °C /7/.
- Due to the fact that inflated tyres may explode, one should keep a safety zone between the tyre and the fire fighter /7/.
- By means of aspirated foam fire extinguisher the **agent** may be supplied directly on the fires even by remote access and at high wind speeds /7/.

APPENDIX B: Main Data and Test Results of Tested Portable Fire Extinguishers

B.1 Main Data

B.1.1 NOHA

Specifications	NOHA	NOHA	NOHA	NOHA
Agent	6 kg BC 101 Karate***	6 kg ABC Favorit* 111	9 l foam Niagara** AR-FFFP	9 l foam Forexpan S
Main Components	96 % potassium bicarbonate	85 % ammonium phosphate	-	Synthetic
Fire rating acc. NS-EN-3	No	34A, 183B, C	No	No

* Original container with agent: ABC E Favourite Tertia. Stability in the temperature range –80-80 °C

** Original container with agent: 9l water + foam, foam charge ref. NO3068.

*** Stability in the temperature range –80-120 °C.

B.1.2 Alf Lea & Co.

Specifications	Water Mist, Model 272	Wet chemical, Model 262**	Tire Fire**
Agent	Distilled water	Potassium acetate mixed with water	NN mixed with water
Type	9 litre stored pressure	9,5 litre stored pressure	9,5 litre stored pressure
Fire rating acc. NS-EN-3	13A	No*	No

* U/L Rating: 2A:1B:C:K

** Can be used down to –40 ° by adding an anti-freeze solution.

B.1.3 If Shop NUF

Specifications	Brandstop 6G-90*	Pyrostop PC6**	
Agent	6 kg Tropolar Forte ABC powder	6 kg Furex 70 ABC powder	
Main Components	82 % ammonium phosphate, ammonium sulphate	70 % ammonium phosphate	
Fire rating acc. NS-EN-3	34A 233B,C	34A, 233B, C	

* Stability in the temperature range –80-130 °C

** Stability in the temperature range –60-85 °C

B.1.4 Hellanor

Specifications	Gloria F6 Ni*		
Agent	Foam with Gloria Imprex		
Type	6 litre foam		
Fire rating acc. NS-EN-3	21A 144B		

- CO_2 is used as propellant gas. The time to empty the fire extinguisher is 29 seconds and the operating temperature is 0-60 °C.

B.1.5 Lux brannteknologi

Specifications	IFEX 3035*		
Agent	Water		
Type	Water impulse gun		
Fire rating acc. NS-EN-3	No		

A35 litre water cylinder on a trolley is used together with a 6 litre 200 bar air cylinder. The IFEX 3001 impulse gun is used in combination with the IFEX 3035. The overall weight of IFEX 3035 water filled is 76 kg.

A 50 litre version with a 6 litre 300 bar air cylinder, i.e. IFEX 3050, does also exist. The overall weight of IFEX 3050 water filled is 98 kg.

IFEX 301/S Backpack is a backpack version of IFEX with an overall weight of 23,3 kg. The backpack consists of a 13 litre water/agent cylinder, a 2 litre 300 bar air cylindre.

B.2 Test Results

Table B.1 in the subsequent pages shows the test result from the 22 tyre fire trials.

Table B.1: Results from the first test series of 13 different portable fire extinguishers. The fire fighting activity started when the fire in the twin tyres achieved a heat release rate of 500 kW. All points of time (in minutes) are given after the fire fighting activity started. It was defined that the tyre fires were extinguished permanently if no reflash had occurred within 15 minutes.

Supplier/type of portable fire extinguisher	**Type of tyre**	**Initial weight (kg)**	**Weight after fire extinguishing (kg)**	**Used amount of exting. medium (kg)**	**Time to start of fire extinguishing**	**Fire extinguishing time (sec.)**	**Time to reignition[1] (min:sec)**	**Comments**
1. **NOHA T6C-N** 6 kg ABC Dry Powder Fav 111)	Toyo & Michelin	9,673	3,678	5,995	14:58	21	No reignition	The waiting time for reignition was in this test only 9 min.
2. **NOHA Niagara** AFFF Foam	Goodyear & Semperit	14,216	5,282	8,934	9:45	37	3:35	After the fire fighting has terminated sparks are still emitted from the tyre. Embers lie on the floor between the tyres. A reflash of the tyre fire occurs in the space between the tyres.
3. **NOHA Fav 111** BE	Dunlop	9,452	3,233	6,219	9:49	12	6:35	Embers lie on the floor between the tyres. A reflash of the tyre fire occurs in the space between the tyres. The dry powder fire extinguisher was emptied during the first fire extinguishing effort.
4. **J.O. Nilssen Pyrostop** PC 6 6 kg ABC Dry Powder (70 %)	Otsu & Pirelli	9,204	3,184	6,020	8:50	13	6:35	
5. **A. Lea & CO** Amerex **262** Wet Chemical	Michelin & Dunlop	14,299	3,821	10,478	10:00	35	3:33	After the fire fighting has terminated sparks are still emitted from the tyre. The dry powder fire extinguisher was emptied during the first fire extinguishing effort.
6. **A. Lea & CO** Amerex **272** Water Mist	Dunlop & Uniroyal	12,126	7,891	4,235	9:55	33	No reignition	After the fire fighting has terminated sparks are still emitted from the tyre.
7. **A. Lea & CO TIRE FIRE** (Amerex)	Toyo	14,227	3,677	10,550	11:23	56	No reignition	The state of the fire seemed to be more severe than the previous fires at the time of fire extinguishing. When the fire was extinguished, there was still an ember by the floor. 11 min. after fire extinguishment there is still

[1] Given in minutes from the time when the fire fighting activity started, i.e. when the heat release rate of the tyre fire achieved a value of 500 kW = 0,5 MW.

Supplier/type of portable fire extinguisher	Type of tyre	Initial weight (kg)	Weight after fire extinguishing (kg)	Used amount of exting. medium (kg)	Time to start of fire extinguishing	Fire extinguishing time (sec.)	Time to reignition[1] (min:sec)	Comments
9 litre Foam								a certain smoke production from the tyre. At 15:20 after fire extinguishment there is a sort of reignition of the fire, but the fire self-extinguish after some time.
8. **J.O. Nilssen Bavaria Brandstop** GG-90 90 % ABC 6 kg Dry Powder	Otsu	9,684	3,669	6.015	12:08	27	No reignition	The HRR was only 297 kW at start of fire extinguishing, but the intensity of the fire seemed to be at least 500 kW. An ember at the tyre both at 5:30 and 13:00
9. **Hellanor GLORIA F6** Foam AB	Kuhmo & Michelin	11,269	5,169	6,100	13:52	38	4:46	HRR was 329 kW at start of fire extinguishing, but the intensity of the fire seemed to be at least 500 kW.
10. **NOHA FOREXPAN** Foam	Michelin & Otsu	14,141	5,274	8,867	14:54	55	10:15	HRR was only 401 kW, but the fire seemed greater than 500 kW. Reignition of the tyre occurs as a flash fire of the tyre.
11. **NOHA** 6 kg Dry Powder (Faw 111)	Toyo & Otsu	10,472	4,376	6,096	10:00	28	10:08	The fire extinguishing. started after 10 min. at a HRR of 500 kW.
12. **NOHA BC KARATE** 6 kg Dry Powder	Dunlop & Michelin	10,36	3,200	6,836	9:05	19	No reignition	Fire extinguishing. started at 9:05 and HRR of 500 kW. Embers on the inner side of the tyres, i.e. between the tyres.
13. **A. Lea & CO TIRE FIRE** (Amerex) 9 litre Foam	Otshu & Michelin	14,359	3,671	10,688	13:19	97	No reignition	This tyre seemed to be pretty much burned due to approx. 2 min. longer preburn time. The fire extinguisher was emptied. Embers are still falling from the tyre at 16:00.
14. **Hellanor GLORIA F6** Foam	Nokia & Goodyear	11,412	-	-	16:00	Not extinguished	-	Malfunction of both fire extinguishers used in the test.

Supplier/type of portable fire extinguisher	Type of tyre	Initial weight (kg)	Weight after fire extinguishing (kg)	Used amount of exting. medium (kg)	Time to start of fire extinguishing	Fire extinguishing time (sec.)	Time to reignition[1] (min:sec)	Comments
15. **J.O. Nilssen Bavaria Brandstop** GG-90 90 % ABC 6 kg dry powder	Tuarus & Sempirit	9,650	3,687	5,963	11:08	27	10:42	Fire extinguishing started at 11:08 at a HRR of 500 kW.
16. **Lux brannteknologi IFEX 3000** Water Fog	Dunlop	-	-	-	15:44	Not extinguished	-	The fire extinguishing activity was terminated because the fire extinguisher was empty of pressurised air. After each shot one had to wait for water filling some seconds. During this time the fire has increased again.
17. **Lux brannteknologi IFEX 3000** Water Fog	Michelin & Continental	87,60	58,55	29,05	13,00	82	No reignition	The HRR was 445 when the fire extinguishing started
18. **NOHA BC KARATE** BC Dry Powder 6 kg	Michelin & Goodyear	10,265	3,242	7,023	13:45	25	4:00	The HRR was 480 when the fire extinguishing started. Sparks are emitted from the tyre after the fire has been extinguished and there are some embers at the top of the tyre. A lot of white smoke is produced from the tyre. The fire extinguisher is emptied. The reignited fire is extinguished by means of a fire hose.
19. **NOHA** 6 kg ABC Dry Powder (Fav 111)	Goodyear & Bridgestone	9,704	3,666	6,038	13:33	24	6:08	The HRR was 455 when the fire extinguishing started. The fire was reignited on the inner side of the front tyre. The reignited fire is extinguished by means of a fire hose.
20. **NOHA FAW 111** ABC Dry Powder	Goodyear	9,362	3,156	6,206	6:48	23	No reignition	The HRR was 326 kW when the fire extinguishing started. No sparks were observed, but some crackling can be hear from the tyre. 7 min. after fire extinguishing almost no smoke, sparks or crackling can be observed or heard from the tyre

Supplier/type of portable fire extinguisher	Type of tyre	Initial weight (kg)	Weight after fire extinguishing (kg)	Used amount of exting. medium (kg)	Time to start of fire extinguishing	Fire extinguishing time (sec.)	Time to reignition[1] (min:sec)	Comments
21. **J.O. Nilssen Pyrostop** PC 6 6 kg ABC Dry Powder (70 %) (34A 233B C)	Nokia	9,152	3,205	5,947	5:14	se video!	No reignition	The HRR was 334 kW when the fire extinguishing started, i.e. at 5:14.
22. **NOHA** BC Dry Powder (Fav 111)	Goodyear	10,492	4,961	5,531	6:31	38	No reignition	The HRR was 350 kW when the fire extinguishing started.

APPENDIX C: Photos from the tyre fire trials

Figure C.1: The IFEX 3050 (red) trolley and the IFEX 1301 (glossy) impulse gun.

Figure C.2: Typical 6 kg dry powder fire extinguishers.

Figure C.3: Four fire extinguishers from AMEREX (Alf Lea & Co). The useful and handy application wand is shown on the right side of the fire extinguishers. The glossy fire extinguisher on the picture is the AMEREX Water Mist (model 272).

Figure C.4: The area in which the fire fighter was allowed to move within during the fire fighting activity.

Figure C.5: Ignition of the hepthane soaked rags under the tyres.

Figure C.6: In the early phase of the tyre fire.

Figure C.7: The state of the tyre fire when the heat release rate approaches 500 kW and it is immediately before fire fighting starts.

Figure C.8: The start of fire fighting with a dry powder fire extinguisher.

Figure C.9: At the end of fire fighting with a dry powder fire extinguisher.

Figure C.10: After the fire is permanently extinguished with a dry powder fire extinguisher.

Figure C.11: After the fire is not permanently extinguished with a dry powder fire extinguisher. There is still a certain smoke production from the tyre and one can hear crackling from the tyre. After some time there was a reflash in the tyre.

Figure C.12: Two tyres after a tyre fire trial.