SINTEF REPORT

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TITLE

An Experimental Study of the Self-ignition Tendency of Different Wood Coating Oil Products

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ABSTRACT

According to Directorate for Civil Protection and Emergency Planning (DSB) wood coating oil products (wood oils) are causing several fires each year in Norway.

DSB has inquired SINTEF NBL to investigate the liability of self-heating and self-ignition from the use of wood oils. According to the DSB's statistics with respect to the causes of building fires many residential fires are caused by self-ignition of rags soaked with wood oils.

The investigation includes the following aspects of the problem:

- A survey of the fire hazard of different wood oil products with respect to their tendency to cause self-heating and self-ignition.
- A survey of which wood oil products available on the Norwegian market that may cause self-heating and possible ignition of the oil soaked material (rags, brushes etc.).
- Evaluate the possibilities of self-ignition in connection with different application clothing (rag, brushes etc.).
- Recommend actions for safe use, storage, disposal or destruction of equipment in connection with the use of wood oils.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Safety	Sikkerhet
GROUP 2	Fire	Brann
SELECTED BY AUTHOR	Self ignition	Selv antennelse
	Wood coating oil	Treoljer

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MAIN CONCLUSIONS AND RECOMMENDATIONS

Main conclusions

- Wood coating oil products (wood oils) containing drying oils may along with other commonly used products cause self-ignition by *oxidation* of the product. Oxidation is by far the main chemical process causing self-ignition.
- Wood oils soaked in porous rags will only cause self-ignition and fire under special circumstances.
- This fact is also confirmed by the rather low number of registered fires each year due to self-ignition by chemical processes (approximately 10 fires in residential buildings and 10 fires in other buildings), compared to the very high consumption of products that are capable of causing this specific type of self-ignition in addition to wood oil products.

- All 33 experiments have been carried out in order to find out the tendency of different wood oils to cause self-heating and self-ignition.
- Eight different wood oils, including boiled linseed oil, one penetration oil and one anti-rust oil, as well as two types of rags (i.e. cotton rags and waste wool or ‘Twist’ rags) have been tested in two different experimental setups.
- Real spontaneous combustion was achieved in only 5 of the 33 tests carried out. Most of the tests resulted in self-heating and a sub-critical temperature development, i.e. the temperature increased to a maximum temperature, which was not high enough to cause self-ignition, followed by a temperature decrease down to the ambient temperature. The main reasons for this fact might be as follows:
  a) A too small size of the experimental setup (causing high transmission heat loss)
  b) A too high packing density of the rags (causing low ventilation (oxygen supply) and a corresponding low heat generation rates).

- The following main requirements have to be fulfilled if self-ignition of oil soaked rags shall take place, provided that the oil is prone to cause self-ignition:
  - *Insulation*: The rags soaked with wood oil have to be located at a place at which the heat loss by transmission is minimized. The rags have to be stored in for example a waste container of certain minimum size filled with other waste with good insulation properties. However, under optimum ventilation conditions of the rags and elevated temperatures on hot summer days, the necessary size of the container to cause self-ignition may be strongly reduced.
  - *Ambient temperature*: The spontaneous heating is favoured by high ambient temperature. By increasing the ambient temperature from 24 °C to 44 °C in tests with ‘Faxe’ wood floor oil a sub-critical temperature development was changed to a critical temperature development, which caused almost complete spontaneous combustion of the 3 x 1 m^2 rags.
  - *Minimum ambient temperature*: Based on the experiments carried out, it can be concluded that it is not expected that ordinary wood oils in ordinary waste containers will self-ignite at temperatures below 10-15 °C.
  - *Ventilation*: If the ventilation rate is too high, the heat will dissipate. If the ventilation rate is too restricted, the oxidation and the heat generation will be too small. The ventilation rate is probably the single most critical factor for self-ignition.

    A too high packing density of the rags will restrict the ventilation of the rags. Restricted ventilation of the rags was probably the case more often than the opposite during the tests carried out. Not even 0.3 litre of the highly pyrophoric *boiled linseed oil* absorbed in 3 m^2 cotton rag caused self-ignition at high packing density.

- *Amount of wood oil*: It seems as if the needed amounts of *boiled linseed oil* and *cotton rags* to cause critical temperatures and self-ignition under normal indoor conditions have to be 0.075-0.1 litre evenly distributed in a 1 m^2 cotton fabric. For the *wood oils* the needed quantity was 0.3 litres. However, more optimal ventilation conditions, increased ambient temperature and increased size of the waste container may reduce the needed amount of wood oil.
- *Oil loading*: If the oil loading (in l/m^2) is larger than the optimum content, the temperature increase of the oil is restrained due to too much heat is used to increase the temperature of the excess oil. The optimum oil loading area densities seemed to be in the range 0.1-0.15 l/m^2.

- Waste wool or *'Twist' rags* seemed to be more prone to self-ignition than *cotton rags*. This is indisputable due to the fact that the twist rags have a larger surface area than the cotton rags.

- Even though *sub-critical temperature development* was achieved in the far most of the 33 tests (primarily due to the small insulation thickness and too high packing density of the rags), the tendency to cause self-ignition may also be deduced from these tests. The most hazardous oils are those oils with the most rapid and highest temperature increase of the oils with sub-critical temperature development, provided the experimental conditions were equal.
- The oils tested can be divided into three classes with respect to fire hazard:
  - Class I - Extremely Hazardous oils:
    - *Linseed oil.*
  - Class II - Hazardous Oils (ranked, i.e. the oil listed first is most hazardous):
    1. *Faxe* wood floor oil,
    2. *Owatrol* anti-rust oil,
    3. *Trip trap* wood floor oil and
    4. *Butinox* wood oil
  - Class III - Non-hazardous or less hazardous oils:
    1. *Junker Rustic oil*
    2. Wood oil from *'Norsk Trepleie'*
    3. *Faxe* oil care
- By examination of the comments made by the police investigators in statistics from DSB with respect to the cause of fire, *Faxe wood oil* and *linseed oil* were mentioned in 27 and 26 of 268 cases of ignition by chemical processes, while the other wood oils were hardly mentioned.
- Among the five wood oils that were characterized as hazardous, it was only *Trip trap wood floor oil* that did not have any safety marking or warning tag against the risk of self-ignition and fire.

- **Recommendations for safe handling and disposal of equipment for wood oil**.
  The following procedures are recommended:
  - Put application equipment in a container filled with water
  - Burn application equipment in a fire place or oven
  - Storage of the rags in an *air tight metal container* intended for fire hazardous waste in case of short time storage or transport.

- **Final Conclusion**
  On the basis of this experimental series it can be concluded that wood oil products do represent a risk of self-ignition and fire, even though self-ignition occurs only under certain circumstances. Due to the fact that these circumstances may occur rather frequently, especially indoors as well as outdoors in the summer time, we recommend a clearly visible warning label on such products. That is, with respect to the fire hazard and how to treat application equipment after use.

1 INTRODUCTION

According to Directorate for Civil Protection and Emergency Planning (DSB) wood oil products are responsible for a significant number of fires each year in Norway.

DSB has inquired SINTEF NBL to carry out a project in order to investigate under which circumstances wood oil products can lead to spontaneous heating and ignition. According to DSB's statistics with respect to the causes of building fires, a significant number of residential fires are caused by self-ignition of rags soaked with wood oils /2/.

DSB's objective for the investigation is to establish documentation on the liability of self-heating and self-ignition from the use of wood oils.

According to DSB the investigation shall include the following aspects of the problem /1/:

- A survey of the fire hazard of different wood oil products with respect to their tendency to cause spontaneous combustion.
- A survey of which wood oil products available on the Norwegian market that may cause spontaneous heating and possible ignition of the oil soaked material (rags, brushes etc.).
- Evaluate the possibilities of self-ignition in connection with different application clothing (rag, brushes etc.).
- Recommend actions for safe use, storage, disposal or destruction of equipment in connection with the use of wood oil products.

The surveys and the evaluations shall primarily be based on experiments with the wood oil products most commonly available in the Norwegian marked. A brief review of the theory of spontaneous heating and ignition will also be essential in order to obtain necessary theoretical basis for the experiments.

2 SELF-IGNITION

2.1 The Frequency of Self-ignition in Norway

2.1.1 General

Table 2.1 shows statistics from the Directorate of for Civil Protection and Emergency Planning (DSB) /2/ regarding the percentage portion of fires in buildings due to *spontaneous ignition* or *self-ignition* in Norway during the 2002-2004 period. It appears that of all building fires in Norway, which are investigated by the police, roughly 3 % of the fires got self-ignition as the cause of the fire. There are mainly three different processes causing self-ignition, i.e. *chemical processes, physical processes* and *biological processes*.

Table 2.1: Number of building fires, and in percent of all building fires in Norway, during the 2002 – 2004 period caused by the different processes causing self-ignition /3/.

Process causing self-ignition	**2002**		**2003**		**2004**	
	Number of cases	**%**	**Number of cases**	**%**	**Number of cases**	**%**
Chemical:						
▪ All buildings:	18	0,91	21	1,09	20	1,22
▪ Residences:	9	0,77	12	1,05	10	1,02
Physical	27	1,37	14	0,73	19	1,16
Biological	6	0,30	5	0,26	4	0,24
Other	16	0,81	17	0,88	9	0,55
Sum:	67	3,39	57	2,95	52	3,18

2.1.2 Wood Oils

The statistics concerning the number of fires due to self-ignition do not specifically point out the different substance such as wood oils. From the table above it appears that *chemical processes*, which are the process causing self-ignition of wood oils in rags, were the cause of the fire in roughly 1 % or approximately twenty fires in buildings in Norway each year during the three year period 2002-2004. It appears also from the Table 2.1 that approximately half of these fires occur in residences, while the other half occurs in other buildings, e.g. office and industrial buildings.

The number of cases in Table 2.1 is the number of fires which the police in Norway investigate and report to DSB each year. The police in Norway are by a directive from the Director of Public Prosecutions obliged to investigate *all* fires with respect to finding the cause of the fire.

In addition to oxidation, chemical processes may also include a few cases involving exceptional reactivity, like for instance *white phosphorus, cellulose nitrate and alkali metals in contact with water*, etc. However, oxidation may include other commonly used products than wood oils, such as: oil paint, sealer, animal and vegetable oils, cotton, linen and foam rubber (the three latter materials at somewhat elevated temperatures), etc. These materials may also undergo exothermic reactions due to oxidation, which may cause self-heating and self-ignition.

When we take into account the wide use of wood oils as well as animal and vegetable oils, including many other both liquid and solid substances that may undergo exothermic oxidation, the number of fires each year due to wood oils seems not to be very high - at least not according to the numbers in Table 2.1.

However, there may be fires, which erroneously are attributed to other causes of fire or they are categorised as unknown cause of fire due to the lack of knowledge among fire investigators concerning the processes and materials causing self-ignition. Roughly 15 % of the fires in Norway each year have an *unknown* cause of fire.

In addition there are a lot of minor fires that are not investigated by the police and not reported to DSB, which may be caused by self-ignition. Hence, the total number of fires caused by self-ignition due to oxidation may be significantly higher than 20 fires each year.

2.2 Factors Affecting Self-ignition of Wood Oil

A lot of factors will affect the self-heating and the possibility of self-ignition of wood oils. The following factors are believed to be the most important factors:

- *The type of oil*
- *Insulation thickness (i.e. the total size and the shape of the pile of waste including the rags soaked with wood oil)*
- *The ambient temperature*
- *The temperature of the oil*
- *Ventilation rate of the rag*
- *The porosity of the rag in which the oil is absorbed*
- *The oil loading of the rags (litre oil per* m^2 *area of rag)*
- *The type of other waste contained in the waste container (i.e. the insulation properties of the waste in the waste container)*

In additions, other factors will also have some influence on the self-heating, as for example the *shape* of the pile and the *absorptivity* of the rags.

Many organic and inorganic materials will oxidize and produce some heat, but it is only certain materials and storage conditions of the materials that may result in self-ignition. A certain self-heating will almost always take place, but the heating will usually not be sufficient to lead to spontaneous combustion of the material.

Drying oils (e.g. linseed oil) soaked in rags are well known to cause self-ignition. However, pyrophoric oils soaked in rags will not always cause self-ignition. Only subtle combinations of the parameters listed above may result in self-ignition and fire.

2.2.1 The Type of Oil

Of the physical properties, the *volatility* of the oil has shown to be the most important property. Liquids of high volatility are liquids with low flash points[1] (e.g. below 80 °C), they evaporate readily and have consequently little or no tendency to cause self-ignition. Slow oxidative self-heating is favoured by liquids of *low volatility* and *high flashpoints*, will not evaporate quickly from the hot regions of the oily rags.

Saturated hydrocarbons oils, such as those found in petroleum products, are susceptible to neither self-ignition nor any noticeable spontaneous heating at normal temperatures. This is either because the flash points of these oils are too low or that their oxidation is extremely low.

Barbrauskas /4/ explains this phenomenon as follows: "*The mechanism involved in self-ignition is fundamentally different from ignition of solids from external heating. When a solid is externally heated, ignition occurs due to a gas-phase oxidation reaction. However when a substance goes into spontaneous combustion, the chemical reactions involved are those of the solid phase, which are exothermic pyrolysis or surface oxidation reactions. Hence, there is no correlation between ease of ignition from external heating and propensity to spontaneous combustion*".

Liquids that are prone to ignite spontaneously are those which have a high flash point (FP) and a low auto ignition temperature (AIT). Liquid fuels that have a high FP, will always have a low AIT. However, *wood oils* may have a flashpoint in the range 20-40 °C. The flashpoint is this low because the drying oil is suspended in solvents in order to make them usable as well as allowing mixing with various additives that constitute the product. Once the wood oil[2] has been applied to the substrate using different application clothing, the solvent will evaporate leaving only the drying oil in the application clothing.

In modern coatings, the raw linseed oil is modified by the addition of chemical drying agents or catalysts. These chemicals can accelerate the oxidation process much more than boiling. Thus, modified linseed oil can self-heat at a faster rate than boiled linseed oil.

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[1] A self heating criterion has been proposed by Lindner and Seibring /6/ in connection with fires in insulation materials due to leakage of oil into the insulation. The tendency of a liquid fuel has to ignite spontaneously in insulation materials was expressed by the spontaneous heating parameter 'Z' given by the following equation:

$$Z = \frac{AIT}{AIT - FP}$$

where AIT and FP are the 'Auto Ignition Temperature' and the 'Flash Point' of the oil, respectively (both in degrees Celsius). The Z parameter gives some indication of liquids that will spontaneous heat and those that will not, i.e. those that will rather evaporate (continued at the lower part of next page).

According to Britton 1991 /8/ self-ignition occurred for all liquid fuels having Z > 1.61, while evaporation occurred for liquid fuels having a Z < 1.35, except in cases where exceptional reactivity could be identified.

Of 36 different liquids tested the criterion the Z parameter was in the range 0.46-2.77. Twenty of the 36 liquids resulted in self-ignition of the liquid soaked in the insulation. All liquid fuels having a relatively low AIT and a high FP had a tendency to ignite spontaneously below AIT. When the AIT was above 500 °C, no spontaneous heating was observed.

For example, mineral oils like white spirits, turpentine, diesel, motor oil or lubricating oil are not prone to spontaneous heating and will not cause self-ignition at normal temperatures. White spirits, with AIT = 232 °C, FP = 44 °C, has a Z-value of 1.2, which is smaller than the criterion Z > 1.61. Linseed oil (with an AIT and a FP of X and Y °C), which is well known to cause self-ignition, has a Z-value of 3.25.

[2] The "pure" wood oil without the solvents (i.e. linseed oil) has however a FP in the range 200-250 °C and an AIT in the range 300-350 °C, which yields an average value of Z_{avg} = 325/(325-225) = 3.25, which is high above the criterion for self-ignition (i.e. Z > 1.61).

2.2.2 The Oil Loading of the Rags

Between the extremes of zero and 100 % filling of the rags with oil, there is an optimum concentration for self-ignition. If the oil content is larger than the optimum content, the temperature increase of the oil is restrained, because too much heat is used to increase the temperature of the excess oil.

The excess oil in the rags acts then as a *heat sink* since the oil that is in excess of what is needed for the exothermic decomposition. This oil has to be heated in such a way that it evaporates before the spontaneous heating can become critical. Since the heat capacity of liquids commonly is rather high, a substantial amount of energy is needed to heat the excess wood oil.

2.2.3 The Type of Rag and Other Waste

The Rag

Since oxygen reacts with oxidizing material at the surface and porous materials has a high surface to volume ratio, it is easy to understand why the self-heating and self-ignition commonly arise in porous materials like agricultural products such as grain or hay and in oiled rags. In all these situations, there is a large surface area over which oxygen may contact the oil.

Different application clothing for wood oils is also rather porous with a high surface to volume ratio. The area of the oil exposed to oxygen is then dramatically increased compared to in a can with a correspondingly increased rate of oxidation and heat generation.

Other Waste

A single rag contaminated with wood oil will not ignite spontaneously, but when several rags are thrown into a waste container among other waste (paper, fabrics, food etc.), the other waste comprise an excellent “insulation material”.

The rags together with other waste may constitute the necessary insulation material to prevent heat dissipation. The waste material must have low thermal conductivity. Most waste like paper, cardboard, plastic material, food stuff etc. have generally good insulation properties. In a waste container with rags contaminated with wood oil together with other waste, the entire content acts as insulation. The oily rags alone constitute rarely sufficient insulation.

Consequently, the size of the pile is not that of the rags alone, but all the trash surrounding the rags makes up the pile size. The rate of heat loss may then be lower than the rate of heat generation of the system. Consequently, there will take place a local and slow accumulation of heat within the rag, which ultimately may result in self-ignition.

2.2.4 The Critical Size of the Waste Container

As stated above it is well known that a single rag contaminated with wood oil will not self-ignite, but when they form a huge pile, self-ignition is a common problem. The larger the pile is the easier spontaneous heating and ignition may occur. This is because heat generation is proportional to the volume of the pile (or the third power of size of the pile), while the heat loss is proportional to the surface area of the pile or to the second power of the pile size. Hence, when the pile becomes bigger, the heat generations rate grows faster than the heat loss rate.

There exists a critical size, above which self-ignition can occur and below which self-ignition does not occur. This size is called *"critical size"* or *"critical diameter"* of the pile. It has been shown that the self-ignition temperature, which may be considerably lower than the autoignition temperature, decreases as the thickness of the insulation material increases.

2.2.5 The Critical Ambient Temperatures of the Rags

High temperatures of the oil will favour spontaneous heating. The oxidation and the spontaneous heat release rate will increase dramatically with increased temperature of the oxidized material as well as with the ambient temperature. These temperatures are usually roughly identical.

The possibility of self-ignition is greater if the surrounding air is warm and dry. The effect of ambient temperature is twofold. Firstly, high surrounding temperatures provide favourable conditions for exothermic oxidation reactions and spontaneous heating to take place, and secondly the temperature difference between the reaction zone and the surroundings is smaller, which will restrict the heat loss.

2.2.6 The Combined Effects of Ambient Temperature of the Oil and the Pile Size

There is a theoretical relation between critical ambient temperature and critical radius of material shown for some materials in Figure 2.1. The higher the ambient temperature is the smaller is the needed critical radius or pile size for self-ignition and vice versa. If the ambient temperature is just slightly lower than the critical temperature, the material spontaneous heats but does not ignite. When it is slightly higher, self-ignition may occur after a long period. The higher the ambient temperature is above the critical temperature, the shorter is the time to self-ignition.

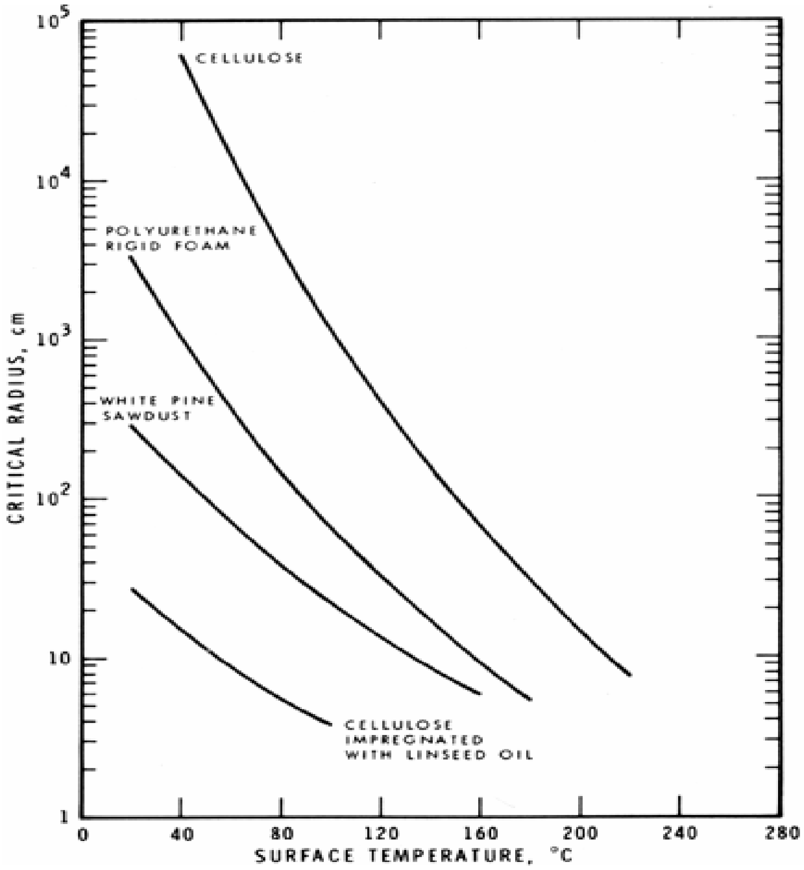


Figure 2.1: Surface temperature vs. critical radius in self-ignition.

Preheating of the material can initiate oxidation reaction that leads to self-ignition, or can accelerate ignition by adding even more heat to the combustible material. Additional heat may initiate self-ignition of some combustible materials which would not be subject to this process at normal temperatures. In these cases, the increase in temperature of the surroundings leads to an increased rate of oxidation. The rate of oxidation and heat generation may increase so much that the heat is being produced more rapidly than it can be lost. Examples of this are *foam rubber* and *cotton textiles*, which have been heated in a dryer.

Self-ignition of paint loaded filters from paint booths is studied by G. Jomaas /5/. At normal room temperatures (20-25 °C) it was found that the necessary size of a full waste container (including a trash bag of paint-loaded filters (60-90 cm in diameter together with other waste) was approximately 1.65 m in order to achieve self-ignition.

It is reasonable to anticipate that wood oils need a similar thickness of the insulation in order to cause self-ignition at normal room temperatures, since both wood oil and oil paint presumably contain roughly the same quantity of drying oils.

The fact that a much smaller pile size is needed to cause self-ignition at elevated ambient temperatures is utilized in many test methods for testing the propensity of different materials to cause self-ignition. At elevated temperatures the materials can be tested at a much smaller size. From Figure 2.1 it appears that for self-ignition of white pine sawdust the pile size at 20 °C have to be 2 x radius = 2 x (3 x 10^2) = 600 cm = 6 m. At 160 °C the size has to be only 2 x 6 cm = 12 cm. Such test are usually are carried out at a temperature around 200 °C.

2.2.7 Ventilation/Air Supply

Ventilation of the combustion zone is necessary to cause oxidation and subsequent smouldering or flaming combustion (dependent on the ventilation rate). However, ventilation provides also for effective dissipation of heat if the ventilation rate is too high. Self-ignition is a balance between the two factors *heat generation* and the *removal of heat by ventilation*. The air supply is important in that there must be enough oxygen present to permit the oxidation process, but not so much that the heat produced by the oxidation is carried away by ventilation as rapidly as it is formed.

Self-ignition of the cotton rags can be prevented by restricting the amount of oxygen reaching the rags (placed in sealed metal container) or by providing sufficient ventilation to quickly dissipate the heat. Due to the antagonism between the comparatively low ventilation rate needed for sufficient spontaneous heating and minimized heat loss by ventilation and the several orders of magnitude higher ventilation rate needed for a fire to develop in the oily rags, self-ignition will not take place in many cases due to:

a) *lack of oxygen* or due to or due to
b) a too *high ventilation rate*.

If a fire shall develop, it may be essential that the ventilation conditions change during the spontaneous heating, i.e. from a very low ventilation rate during the spontaneous heating process, to significantly higher ventilation when the oily rags burst into fire. This may occur due to a smouldering reaction within a material propagates slowly outwards. This may lead to flaming combustion when smouldering fire breaks through the surface. In such a way sufficient oxygen is supplied to the material in order to sustain a flaming fire in the material. During the self-heating process, the increased temperature may also increase the ventilation by increased draft or stack effect inside the material

G. Jomaas /5/ have shown that the packing density of paint loaded filters affects the ventilation rate and ease of self-ignition of the rags loaded with wood oil. Increasing packing density of the filters decreased the critical size for a given ambient temperature or the critical ambient temperature for a given size. However, on the other hand loosely packed pile of oily rags may undergo spontaneous combustion, whereas a tightly packed pile will result in limited heat generation due to too restricted air supply.

Since the balance of oxygen flow and heat loss needs to be carefully balanced, there is often a large element of 'bad luck' involved if self-ignition and a critical fire shall break out. Thus, some businesses may have had unsafe practises for many years before they have a fire caused by self-ignition.

2.3 Concluding remarks

- The two most necessary conditions for self-ignition of wood oils are oil that is prone to self-heat (i.e. containing a drying oil) and that the oil is absorbed in a porous material, e.g. a porous rag.
- While ignition of solids from external heating involves oxidation in the *gas phase*, the chemical reactions involved in self-ignition are those of the *solid phase*, which are exothermic pyrolysis or surface oxidation reactions. Thus, the mechanism involved in self-ignition is fundamentally different from ignition of solids from external heating.
- Oils that are prone to self-ignition are oils with high flash points and low auto ignition temperatures. Hence, oils that are prone to self-ignition are those that are not easily ignitable with an external heat source and vice versa.
- It is the drying oil in wood oils that cause self-heating and possible self-ignition. Since the drying oil is suspended in solvents, the solvents have to evaporate before the oil can oxidize and produce heat.
- Rags soaked with wood oil will not self-ignite in any case; they will only self-ignite under special circumstances.
- Providing that the oil has a tendency to self-heat and the oil is absorbed in a porous material, it is the *ventilation rate* of rags, the *size* of the waste container in which the rags were disposed after use and the *ambient temperature* that are the most important factors for self-ignition.
- Of these variables the *ventilation rate* of the rag seems to be the single most important factor.
- Since spontaneous heating is a very slow process, the needed ventilation rate for self-heating is usually very small. Thus, the ventilation rate needed to sustain a fully developed flaming fire in oil soaked rags will be much higher than the optimum ventilation rate causing self-heating and self-ignition of the rags.
- If a fire shall develop it is often required that the ventilation rate of the rags changes during the spontaneous heating process. That is, from a rather modest ventilation rate during the spontaneous heating, to a significantly higher heat loss when the spontaneous combustion and a fire breaks out in the rags.
- For a given temperature and ventilation conditions of the rags there is a minimum pile size of oil soaked rag (together with other waste) under which no self-ignition will take place. This pile size is called the *critical pile size*. If the temperature is increased, the critical pile size necessary for self-ignition will decrease and vice versa.
- For a given pile size (i.e. insulation thickness) and ventilation conditions of the rags there is a minimum temperature under which no self-ignition will take place. This temperature is called the *critical temperature*. If the pile size is increased, the critical temperature necessary for self-ignition will decrease and vice versa.

3 EXPERIMENTS

3.1 The Experimental Setup

3.1.1 Test Setup I

In order to study the effects of insulation thickness two experimental setups were used, i.e. the test setups shown in Figure 3.1 and Figure 3.2. Figure 3.1 shows Experimental Setup I, which include a 25 litre bucket internally insulated with 100 mm class A Rockwool insulation both along the sidewall and in the bottom of the bucket. Thus, a cavity or air space of approximately 5 litres (150 mm diameter and 295 mm depth) was left in the bucket, in which the oily rags were placed.

a) b)

c) d)

Figure 3.1: The Test Setup I: a) The 25 litre bucket with 100 mm thick Rockwool 'Class A' insulation both in bottom and along the inside of the bucket. The insulation in the bucket created a cavity with a volume of approximately 5 litres. b) 13 x Ø10 mm holes were made in the bottom of the bucket in order to increase the ventilation of the rags. c) If the bucket was placed directly on the floor of the closet, no ventilation effect was achieved. d) However, when the bucket was placed upon some logs, a certain ventilation effect of the rag was achieved. This increased ventilation of the rags was tested in only one test, i.e. in test 1.10.

3.1.2 Test Setup II

Figure 3.2 shows the Experimental Setup II with increased insulation thickness. It comprises five 'Class A' Rockwool insulation mats of dimension 600 mm x 600 mm x 100 mm placed upon each other as shown in Figure 3.2a. In the centre of the mat in the middle a quadric hole was created in such a way that a cavity of dimensions 200 mm x 200 mm x 100 mm (= 4 litre cavity) was formed. Within this cavity the oily rags were placed. The temperature of the oils and the ambient temperature were regulated by placing an oven in the closet as shown in Figure 3.2a and 3.2d.

a) b) c) d)

Figure 3.2: a) The Test Setup II consisted of 5 x 600 mm x 600 mm x 100 mm thick Rockwool 'Class A' insulation mats placed upon each other. b) In the mat in the middle there was made a square cavity. c) The rag was placed upon a metal surface and the oil was distributed as evenly as possible over the surface of the rag. d) The rag was placed into the square cavity of dimensions 200 mm x 200 mm x 100 mm high (i.e. a volume of 4 litres). Two thermocouples were placed within and/or between the rags.

Test Setup II was designed in order to obtain good insulation conditions for the cotton rags soaked with wood oil, while Test Setup I was designed in order to obtain a more realistic experimental setup. This setup may represent a small waste container in the kitchen in which oil soaked rags may be thrown into among other domestic waste. Test Setup II is comparable with a rather large waste container stored in a refuse storage area indoors or outdoors. The size of the experimental setups corresponds to a considerably larger size than 0.5-0.6 m due to the much better insulation properties of Rockwool compared to most domestic waste, probably an effective size of 1-1.5 m.

3.2 Tested Oils

The tested wood oils[3] are described in Table 3.1:

Table 3.1: Description of the tested wood oils (from the label on the pail).

Name of Oil	Area of Application	Content	Labelling with warning against self-ignition?
Boiled linseed oil	Additive to paints and fillers and wooden boats	~15 % linoleic acid , ~20-25 % oleic acid, ~50 % linolenic acid	Yes (contains drying oils)
Owatrol anti-rust oil	Against rust, wood surfaces and, replaces thinner	Naphtha, hydrogen desulphurized (17-22 % aromatics)	Yes (contains linseed oil)
Trip Trap wood floor oil	Wooden floors	Vegetable-oil components – isoparaffin, white pigments, dry solid matter (60 %)	No
Faxe Prestige Nataural & White	All untreated or lye-treated wood	High content of processed vegetable and wood oils, isoparaffin <15 %, siccative and titanium dioxide	Yes (contains drying oils)
Faxe oil care	Wooden floors	Acrylic wax, bi- and palm wax, water	No
Junckers Rustic Oil	For maintaining internal oil-treated floors, solid timber kitchen work surfaces	Solvent-borne, impregnating urethane hardening oil (Butanonoxim)	No
Butinox wood oil	Special oil for impregnated wood	Mineral turpentine (17-22 % aromatics) Adhesive: 24,4 % alkyd based on soybean oil, 9 % alkyd based on tall oil	No, but rags should be wetted with water after use.
Wood Oil[4] Natuarl/White	Wooden floors	Low aromatic hydrocarbon 60-100 %	No

The oils were distributed evenly in the rags by dripping/spraying carefully the oil on the rags which were lied down on a metal surface (see Figure 3.2c). Excess oil on the metal surface was wiped up by the dry part of the rags. In this way the oils were distributed rather evenly in the rags as shown in Figure 3.2c. In all almost 8 litres of different type of wood oils were used during the 33 tests.

The eight wood oil products shown in Table 3.1 were partly selected on the basis of requests from DSB and which oils which were available in shops in the city of Trondheim. The selected oils do represent all oils available on the Norwegian market, but these oils are definitely among the most common wood oils. The number of oils that should be tested was limited by the budget of the project.

3.3 Tested Rags

The following types of rags were used in the tests:

- Cotton curtain rags (30 tests)
- Waste wool or ‘Twist’ rags (3 tests)

Due to the fact that cotton rags are more often used in connection with wood oils, cotton rags were primarily tested in the experimental series, i.e. in 30 of 33 tests. Three different types of pure

3 All the oils are termed as ‘wood oils’ in spite of the fact that not all the oils were strictly speaking ‘wood oils’.
4 From ‘Norsk Trepleie’

cotton curtains were used during the tests, but with approximately the same quality and area density. A total cotton curtain area of almost 60 m^2 was used during the 30 tests involving cotton rags.

3.4 Experimental Series

Due to the large set of parameters that might have an influence on the spontaneous heating and ignition of the rags as listed in Section 2.2, it is hard to design the experiments as long as the knowledge of which combination of conditions that may cause self-ignition is rather limited. Some preliminary experiments had to be carried out in order to find these conditions. Thus, the tests had to start with a lot of trial and error tests.

According to the suggestions to the content of the project from DSB, it was desirable with a general survey of the fire hazard of wood oil products as well a ranking of the types of wood oils that are prone to self-ignition. While the former suggestion requires highly varying fire conditions in order to find which fire conditions that may cause self-ignition for some selected oil products, the latter suggestion requires that the fire conditions are unchanged for all the eight wood oils tested (listed in Section 3.2). Because of the many variables influencing self-ignition, it seems obvious that a lot of experiments are needed to give a satisfactorily answers to all these suggestions.

Due to the limited budget of this project, the numbers of tests within the scope of this project were restricted to 20-30 tests. Thus, the experimental series will not be a scientific study of the problem of self-ignition of wood oils, but rather *indicative tests*, which may give us a better understanding of which fire conditions and which types of wood oils that might have a tendency to cause self-ignition and spontaneous combustion.

The experimental series were divided into four parts as shown in Table 3.1.

Table 3.1: Description of the four experimental series of the tests carried out.

Experimental series no.	**Description of experimental series**	**Experimental setup no.**	**Test no**	**Number of experiments**
1	Tests involving cooked linseed oil absorbed in cotton rags in a small waste container, i.e. the 25 litre bucket.	1	1.1-1.10	10
2	Tests with different drying oils in cotton rags in the 25 litre bucket.	1	2.1-2.14	14
3	Tests with wood oils in 'Twist' in the 25 litre bucket.	1	3.1-3.3	3
4	Tests with different drying oils in a "large pile", i.e. within a 600 mm x 600 mm x 500 mm high block of Rockwool insulation.	2	4.1-4.6	6
Total numbers of experiments:				33

As already mentioned, wood oils usually comprise a drying oil and a solvent (to make them at a usable consistency plus allows the mixing of oils with various additives that constitute the finished product). Before the drying oil can be oxidized and cause spontaneous heating, the solvent has to evaporate. This evaporation will usually take some time. Hence, the oxidation and maximum temperature increase during the tests will be rather delayed. The test results show that for some oils this could take considerably time, i.e. up to 20-25 hours.

The test time of the 33 the experiment varied from a minimum of 17 hours and 38 minutes to a maximum of 121 hour and 33 minutes. The total test time of the experimental series was almost 1037 hours, i.e. in all more than 43 days. The average test time was more than 31 hours per test. Hence, a lot of data (i.e. three temperatures as well as the elapsed test time) had to be recorded, processed and presented in the project.

Due to the fact that both experimental setups were rather fire resistant, the tests were also run when no persons were in the laboratory. The reason for the rather long test times was that the experiments were run over night and in some tests even also over the weekend. Thus, most of the tests were run longer than strictly speaking necessary.

4 DISCUSSION OF TEST RESULTS

4.1 General

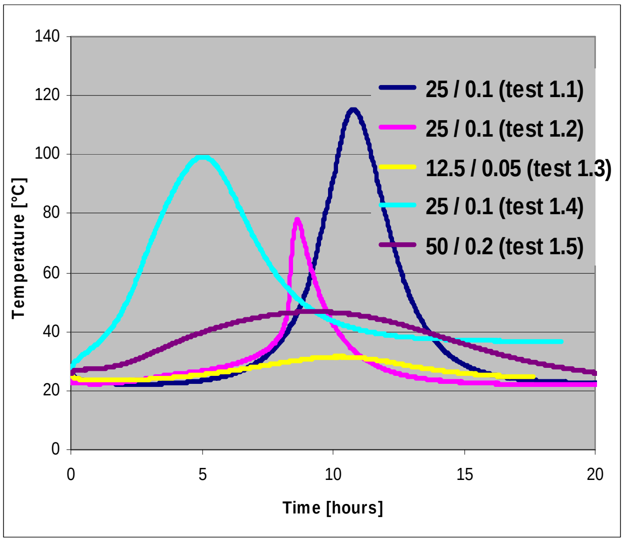
As already stated a total of 33 experiments have been carried out in order to investigate the tendency to self-heating, self-ignition and spontaneous combustion of eight different wood oils, which were suspected to have self-heating properties. In Appendix A the experimental setups are described. All the experiments are described separately with respect to experimental conditions and measured temperatures within the rags as function of time during the experiment. In cases where decolourization, charring or burning of the rags occurred during the test, photos of the rags are also shown in Appendix A.

4.2 Amount of Wood Oil Needed to Cause Significant Spontaneous Heating

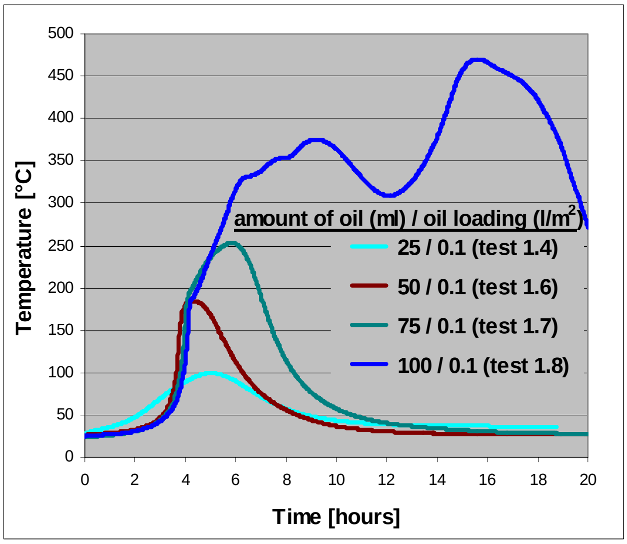
4.2.1 Linseed Oil

In Experimental Series I only *boiled linseed oil* was tested. Figure 4.1a shows the temperature development for eight of the ten tests in this series (i.e. Test 1.1-1.8). It appears from the yellow curve (Test 1.3) in Figure 4.1a that l2.5 ml boiled linseed oil in a 0.25 m^2 cotton rag, together with two dry 0.25 m^2 cotton rags above and beneath the oily rag, resulted in a temperature increase of only 30 °C during the 18 hour long test.

Neither twice as much linseed oil (Test 1.1 shown by the black curve of Figure 4.1a) was sufficient to cause critical temperatures in the rag, even though a maximum temperature of a maximum temperature of 115 °C was achieved after 11 hours. However, more favourable ventilation conditions might have caused higher maximum temperatures during these tests.



a) In all the tests, apart from Test 1.2, the cavity in the bucket was lined with an open plastic bag in which the rags were placed.



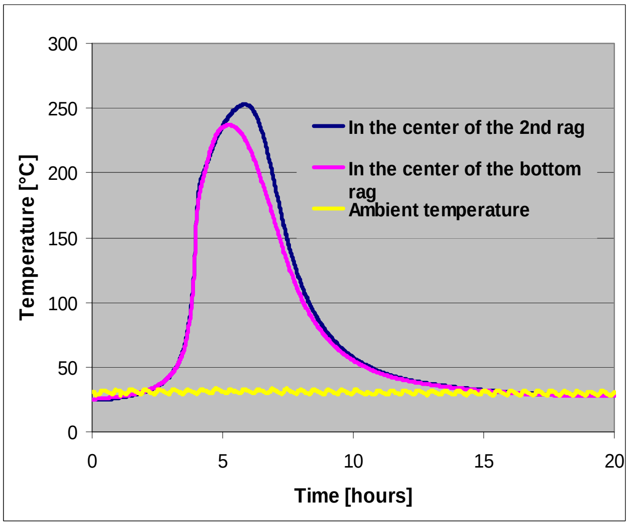
b) No plastic bag was used during Test 1.6 – 1.8. In Test 1.4 the ambient temperature was 36 °C.

Figure 4.1: The temperature within the oily rags of Test 1.1-1.8 of Experimental Series 1 in which only linseed oil was tested (The numbers of the legends show the amount of oil (in ml)/ the oil loading density (in litre/m^2).

The cavity was lined with a plastic bag in Test 1.1, which was completely open in the top. Test 1.2 (the red curve of Figure 4.1a) shows that without the plastic bag the maximum temperature achieved after approximately 9 hours was 78 °C, while 115 °C was achieved in Test 1.1. Since a plastic bag will restrict the ventilation of the rag, this should indicate that the ventilation rate was more than sufficient without the plastic bag. By comparing the graphs of the Test 1.1, 1.3 and 1.5, in which the oil loading was 0.1, 0.05 and 0.2 l/m^2, respectively, oil loading of 0.1 l/m^2 caused the highest temperature increase within the rag.

It appears from the Test 1.6 (the brown curve) in Figure 4.1b that a doubling of the both amount of boiled linseed oil and the rag area (50 ml of linseed oil and 2 x 0.25 m^2 of cotton rags compared to Tests 1.4 (the turquoise curve) but the same oil loading of 0.1 l/m^2), a maximum temperature of 185 °C was achieved after 4 ½ hour. A slight semicircular decolourization of the rag of Test 1.6 could be observed at the lower edge of the rag, as shown in Figure A.2a in Appendix A.

The temperature development of Test 1.7 in Figure 4.1b shows that a threefold amount of boiled linseed oil and area of cotton rags compared to Test 1.4 (i.e. 0.075 litre of linseed oil in 3 x 0.25 m^2 of cotton rags with the same loading area density of 0.1 l/m^2), a maximum temperature of slightly above 250 °C was achieved. It appears from Figure 4.2b that the middle and the upper rag in the cavity were strongly charred, but the temperature development was scarcely sub-critical, resulting in no thermal runaway.



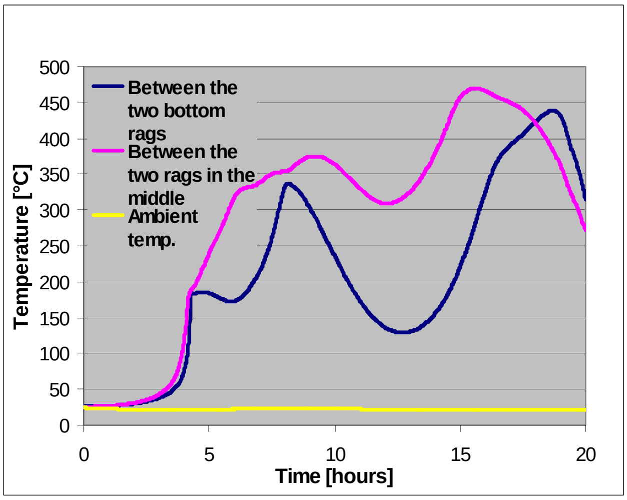
a)

b)

Figure 4.2: a) The temperature development in the rags and b) a photo of the highly charred cotton rags after Test 1.7.

Figure 4.3 shows that a fourfold amount of linseed oil (i.e. 0.1 litre evenly distributed in a 4 x 0.25 m^2 rags and the same oil loading of 0.1 l/m^2) resulted in critical temperatures and thermal run-away after about 4 hours. The four rags were strongly burned and the residues comprised only highly charred remains. Hence, it seems as if the amounts of boiled linseed oil and cotton rags in order to cause self-ignition in a rather small waste container of 25 litres have to be in the order of 0.075-0.1 litre evenly distributed over an area of cotton fabric of 0.75-1.0 m^2. The optimal loading area density of linseed oil seems to be approximately 0.1 l/m^2.

However, the above-mentioned amounts of linseed oil and cottons rags apply to the prevailing conditions of the tests. If the size of the container had been bigger (with thicker insulation), the ambient temperature had been higher or the oil loading and ventilation conditions had been optimal, probably a far smaller amount of linseed oil might have caused critical temperatures and spontaneous combustion with a similar almost complete burning of the rags.



a)

b)

Figure 4.3: a) The temperature development in the rags and b) a photo of the highly burned cotton rags after Test 1.8 (22 °C ambient temperature).

Figure 4.4 shows the temperatures in the rags when the amount of boiled linseed oil and area of cotton rags in Tests 1.9 and 1.10 were threefold as high as in Test 1.8, but with the same loading of linseed oil per area of cotton rags of 0.1 l/m^2. It appears that the temperature increases of Tests 1.9 and 1.10 were far less than in the test with one-third of both the amount of linseed oil and area of cotton rags (i.e. in Test 1.8).

This is an evidence of the fact that the degree of self-heating will not increase in any case by increasing amounts of linseed oil. There are also other parameters that govern the oxidation and self-heating process, as for instance the ventilation or air supply to the rags. In this specific case it is probably the ventilation of the rags that becomes too restricted. A threefold area of cotton rags (from 1 m^2 to 3 m^2) in a 5 litre cavity causes a high packing density and, thus, restricted ventilation of the rags. As shown in Figure A.4c in Appendix A the packing density of the rags in the cavity was pretty high, resulting in restricted air supply for oxidation of the linseed oil.

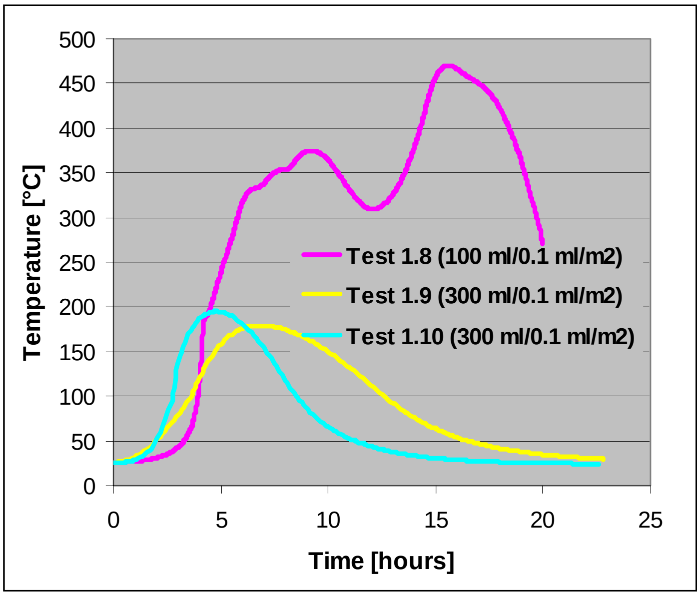


Figure 4.4: The temperatures in the rags when the amount of boiled linseed oil and area of cotton rags in Tests 1.9 and 1.10 were threefold as high as in Test 1.8.

4.2.2 Wood Oils

Figure 4.5 and Table 5.1 (on the next page) show that of the seven wood oils tested in Test Setup I (apart from boiled linseed oil) only *Owatrol* penetrating anti-rust oil, *Faxe* wood floor oil, *Trip trap* wood oil and *Butinox* wood oil achieved maximum temperatures well above 100 °C. For *Faxe oil care*, *Junker Rustic oil* and 'wood oil' from '*Norsk Trepleie*' almost no temperature increase was recorded during the 13-30 hours long tests. The reason is probably that these oils do not contain any components prone to spontaneous heating, i.e. drying oils.

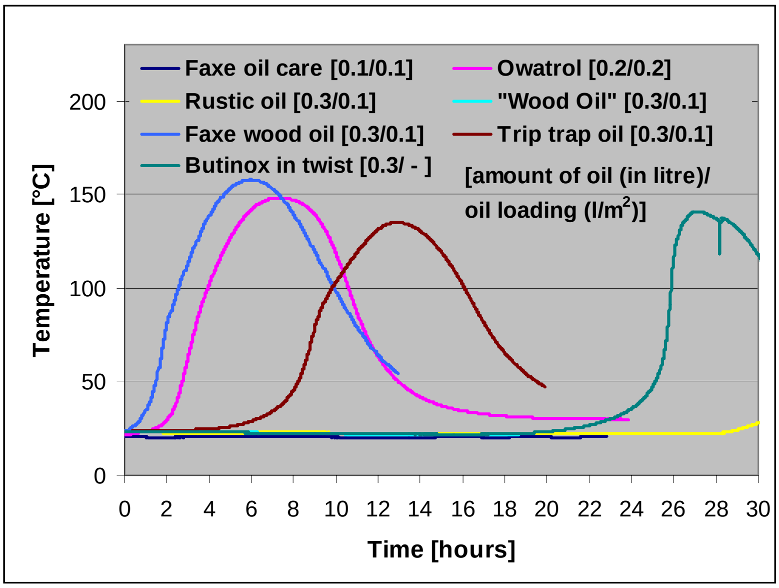


Figure 4.5: Spontaneous heating of different wood oils in Test Setup I (the numbers in brackets: [the amount of oil (in litre)/oil loading area density (l/m^2)]).

Based on the temperature development of the tests with oily rags in the 25 litre bucket, it can be concluded that the *size* of the test setup was too small to ensure sufficient insulation and minimized heat loss. After a while the heat loss from the bucket exceeded the heat generation due to the oxidation of the wood oil. Consequently, the temperature increase ceased and the temperature within the rags started to decrease, i.e. a typical development of a *sub-critical self-heating* with no thermal runaway.

Another explanation to the sub-critical temperature developments shown in Figure 4.5 may also be that the oil in the rags dried up after some hours. The rags were usually rather dry after the test, although the weight loss of the rag was small (5-25 %). Dried up wood oil will oxidize at a much slower rate than in the liquid state, resulting in a lower heat generation rate. A combination of the desiccation of the rags and a too small size of the waste container was probably the reasons for the sub-critical temperatures shown in Figure 4.4. However, the small size of the waste container was probably the main reason.

The tendency of wood oil to cause spontaneous combustion should also been shown by the degree of temperature increase even in cases where the size or the ambient temperature is too low to cause critical temperatures (as shown in Figure 4.5). The higher and faster the temperature increase under sub-critical conditions is, the more prone the oil should be to cause spontaneous combustion at larger pile sizes or ambient temperatures.

It appears from Table 5.1 that the necessary amount of wood oil needed to achieve the maximum temperatures and the times of the maximum temperatures varied strongly with the type of wood oil and experimental conditions.

Table 5.1: Spontaneous heating of different wood oils and the resulting maximum temperatures (shown by the bolded numbers) during the tests in Test Setup I.

Type of oil in Test Setup I	Amount of oil (litre)	Cotton area (m2)	Oil loading (l/m2)	Ambient temperature (°C)	Max. temp. (°C)/at time (hrs.:min.)	Test no.
Boiled linseed oil	0.05	0.5	0.1	31	**183**/4:20	Test 1.6
	0.075	0.75	0.1	29	**253**/5:81	Test 1.7
	0.1	1	0.1	23	**470**/15:36	Test 1.8
	0.3	3	0.1	24	**179**/6:55	Test 1.9
	0.3	3	0.1	22	**195**/4:50	Test 1.10
Faxe oil care	0.1	1.0	0.1	22	**22/ -**	Test 2.1
Owatrol anti-rust oil	0.1	1	0.1	22	**33**/14:48	Test 2.2
	0.15	1	0.15	23	**156**/4:11	Test 2.5
	0.2	1	0.2	23	**148**/7:14	Test 2.6
	0.3	2	0.15	25	**133**/7:57	Test 2.7
	0.26	Twist	-	24	**200**/ -	Test 3.1
Junkers Rustic oil	0.1	1	0.1	22	**25**/1:36	Test 2.3
	0.3	2	0.1	23	**30**/50:25	Test 2.11
Wood oil[5]	0.3	3	0.1	23	**23**/ -	Test 2.10
Faxe wood floor oil	0.3	3	0.1	22	**158**/6:00	Test 2.12
	0.3	3	0.1	22	**65**/26:50	Test 2.13
	0.3	3	0.1	45	**146**/8:35	Test 2.14
Trip Trap	0.45	3	0.15	21	**109**/16:21	Test 2.8
	0.3	3	0.1	22	**135**/12:56	Test 2.9
Butinox wood oil	0.1	1	0.1	38	**44**/27:40	Test 2.4
	0.3	Twist	-	22	**141**/27:20	Test 3.2
	0.3	Twist	-	22	**139**/27:15	Test 3.3

For Owatrol anti-rust oil an amount of 0.15 litre was sufficient to cause a maximum temperature of almost 150 °C, while for the other oils twice as large amount of wood oil was needed, i.e. 0.3 litre. However, small differences in the experimental conditions (e.g. ventilation conditions of the rags due to different packing density of the rags) may show larger effects on the temperature increase than the type or the amount of wood oil.

It appears from Table 5.1 that only two of the tests in the Experimental Series 1, 2 and 3 with Test Setup I achieved self-ignition and spontaneous combustion. That is, in Test 1.8 and to a certain extent in Test 1.7, both with *boiled linseed oil*. In the tests 1.6, 1.9 and 1.10 (all with *boiled linseed oil* in cotton rags), 2.12 (*Faxe wood oi*l in cotton rags) and 3.1 (*Owatrol* in Twist) and 3.2 (*Butinox* in Twist) the rags were only more or less decolourized and scorched (see Figure A2-A.4 and A.7 in Appendix A). In all the other 19 tests of Test Setup I with wood oils no signs or patterns of spontaneous heating or combustion of the rags could bee observed.

4.3 Ambient Temperature and Insulation Thickness

The reason for the modest temperature increase in Test Setup I was as stated in the previous section a too small insulation thickness or size of the test setup, resulting in a too high heat loss

5 From 'Norsk Trepleie'.

and sub-critical temperatures development. Figure 4.6 shows the temperature development of six oils tested with a twice as high insulation thickness as used in Test Setup I. Table 4.2 shows the main conditions of the tests as well as the maximum temperatures achieved during the test. Figure 4.7 shows photos after the tests of the rags, which were decolourized or highly burnt due to self-heating and spontaneous combustion.

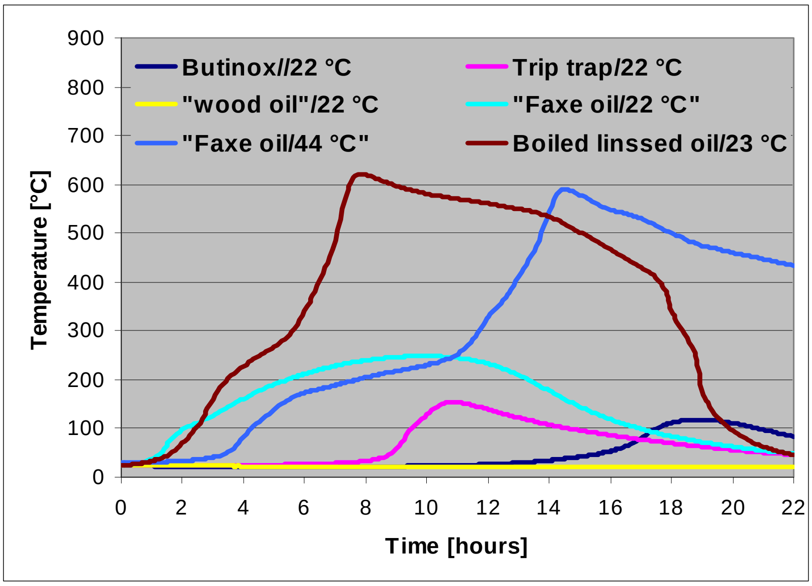


Figure 4.6: Spontaneous heating of different wood oils in Test Setup II (0.3 litres in 3 m^2 cotton rags resulting in oil loading of 0.1 l/m^2). The indicated temperatures after the name of the wood oil are the prevailing ambient temperatures during the test, i.e. the temperature inside the closet in which the tests were carried out.

At an insulation thickness or size of the waste container corresponding to Test Setup II (probably corresponding to a size of a waste container of least 1-1,5 m due to the ideal insulating properties of Rockwool insulation), the needed amount of wood oil to cause significant degree of self-heating has to be 0.3 litre over a cotton area of 3 m^2 for linseed oil.

If spontaneous combustion of ordinary wood oil, i.e. *Faxe Prestige Oil*, shall take place at this size, the ambient temperature of the wood oil has to be increased by 20 °C, i.e. from 24 °C to 44 °C. Optimum ventilation conditions and liquid loadings of the rags may reduce the amount of wood oil and cotton rags.

Table 5.2: Spontaneous heating of different wood oils in Test Setup II.

Type of oil in Test Setup II	**Amount of oil (litre)**	**Cotton area (m^2)**	**Oil loading area density (l/m^2)**	**Ambient temperature (°C)**	**Max. temp. (°C)/at time (hrs.:min.)**	**Test no.**
Trip Trap	0.3	3	0.1	22	**153**/10:50	Test 4.1
Wood oil[6]	0.3	3	0.1	23	**23/ -**	Test 4.2
Butinox	0.3	3	0.1	25	**118**/18:55	Test 4.3
Faxe Prestige oil	0.3	3	0.1	24	**248**/10:00	Test 4.4
“	0.3	3	0.1	44	**591**/14:30	Test 4.5
Boiled linseed oil	0.3	3	0.1	23	**622**/7:50	Test 4.6

6 Wood oil from 'Norsk Trepleie'.

a) Experimental setup of *Experimental Series 4*. Three 1 m^2 rags were placed in the centre of the 200 mm x 200 mm hole cut out in the 100 mm thick Rockwool mat in the middle mat (of the five mats).

b) Test 4.4: The three rags with *Faxe Prestige* wood oil (24 °C ambient temperature) after the test. The outer surface of the rags was slightly decolourized. The three rags were highly glued together in a massive clump.

c) Test 4.5: The residues of the 3 m^2 rags with *Faxe Prestige wood* oil elevated temperature (44 °C).

d) Test 4.6: The residues of the 3 m^2 rags with *Boiled Linseed oil* at room temperature (i.e. 23 °C).

Figure 4.7: Photos of the rags or residues of the rags after the three tests of Experimental Series 4 (i.e. Tests 4.4, 4.5 and 4.6) in which the rags were decolourized or completely burnt.

It appears from the curves in Figure 4.6 that *Faxe Prestige wood oil* at 20 °C elevated temperatures and *boiled linseed oil* an increased thickness resulted in thermal runaway and almost complete combustion of the 3 m^2 cotton rags. However, the ambient temperature of *Faxe* wood oil had to be raised by 20 °C, i.e. from 24 to 44 °C (in Test 4.4 and 4.6), to achieve self-ignition. At 24 °C ambient temperature the rags were only decolourized and slightly scorched as shown in Figure 4.7b.

None of the rags with the wood oils (apart from linseed oil) in the 25 litre bucket, not even at elevated temperature, were burnt apart from one test (i.e. Test 2.12), in which the rag was slightly decolourized. This should clearly indicate that that the size of the waste container, in which the oil soaked rags are contained, has to be of rather large dimension if self-ignition and spontaneous combustion shall take place. The equivalent size of a waste container with ordinary waste must probably be at least 1-1.5 m. This is accordance with the reported tests with paint loaded filters /5/ in Section 2.2.6, which had to be of size 1.65 m in order to cause spontaneous combustion at room temperature. Oil based paint is here assumed to have roughly the same propensity to spontaneous heating as wood oils.

Elevated ambient temperature may however reduce the necessary size of the waste container. Hot summer days, where the waste container is heated by the sun for a rather long time, may probably reduce the necessary size of the waste container considerably.

4.4 Ventilation/Air Supply

4.4.1 Test Setup I

In Test 2.13 (shown in Figure A.6) three 1 m^2 cotton rags with *Faxe Prestige* wood oil were placed into a 5 litre plastic bag, which was tied up by a string. No temperature increase was observed until the bag was completely opened after more than 17 hours. This indicates that the air within the plastic bag is not sufficient to support spontaneous heating. Thus, a constant and restricted air supply to the oily rags is needed.

From the three tests with linseed oil in Figure 4.4 (Test 1.8-1.10) it is not at all the case that the higher the amount of oil and cotton rag is (for constant oil loading) the higher is the resulting temperature within the rags. For Test 1.9 and 1.10 the amount of linseed oil and rag area were three times as large as in the Test 1.8, but the resulting maximum temperatures were only in the range 179-195 °C compared to 470 °C in Test 1.8.

The large amount of rags (3 x 1 m^2) in the 5 litres free space in the bucket in Test 1.9 and 1.10 caused, as mentioned above, a too restricted air supply. In test 1.8 there were only one-third as large area of cotton rags (i.e. 4 x 0.25 m^2 = 1.0 m^2) rags and one-third the amount of linseed oil.

The large difference in the maximum temperature (i.e. almost 300 °C) and in the resulting damage by fire of the rags were clearly due to the increased packing density of Test 1.9 and 1.10 compared to test 1.8.

4.4.2 Test Setup II

Since, 3 x 1 m^2 rags were placed in a somewhat smaller cavity in the test setup (i.e. 200 mm x 200 mm x 100 mm = 4 litre cavity of Test Setup II compared to 5 litre in Test Setup I), it is evident that the packing density of in this setup was at least as high as in Test Setup I. However, there was some ventilation between and within the mats, i.e. through cracks between the mats and within the mats. This applies especially for the mat in the middle with the quadratic 200 mm x 200 mm hole. In order to make this hole, this mat was cut into four separate pieces.

The four pieces of Rock wool insulation were put together in order to create the quadratic hole. Thus, there were created cracks for leakages of air. The thermocouple wires were also guided through these cracks caused also increased opening space in the cracks.

There has certainly been some ventilation through all these cracks and within the mats. As the temperature of the rags increased due to the spontaneous heating, a draft or stack effect was created. This draft effect within the test setup ensured the increased demands for oxygen supply for the increased oxidation with increasing temperature, until self-ignition ultimately occurred after several hours.

In this way the Test Setup II was probably a far more ideal test setup for causing spontaneous combustion than Test Setup I, where the air supply or ventilation of the rags was probably far more restricted due to the rather air tight 25 litre bucket.

4.5 Type of Rag

Two types of rags were used during the four experimental series, namely cotton rags (in Experimental Series 1, 2 and 4) and 'Twist' or waste cotton rags in Experimental Series 3. Even though only three tests were carried out in Experimental Series 3, it appears clearly from Table 5.1 that *Owatrol* anti-rust oil and *Butinox* wood oil were more prone to self-heating in the 'Twist' rags than in the cotton rags.

While the cotton rags with *Owatrol* attained temperature in the range 33-156 °C, the only test with a 'Twist' rag achieved a temperature of approximately 200 °C. While the test with *Butinox* in cotton rags achieved a maximum temperature of 44 °C, the two tests with 'Twist' rags achieved a temperature of around 140 °C.

These increased temperatures with 'Twist' rags compared to cotton rags must indisputable be due to the larger surface area of the 'Twist' rags compared to the cotton rags. Thus, the contact surface area between the wood oil and the oxygen is larger in twist rags than in cotton rags, which should ensure increased oxidation and heat generation.

4.5.1 Oil Loading

The *oil loading area density* or simply the *oil loading* (in ml/m^2 or l/m^2) was not varied very much during the 33 tests, i.e. between 0.05, 0.1, 0.15 and 0.2 l/m^2. It has already been concluded in Section 4.2.1, based on the eight tests of Experimental Series I, that for boiled linseed oil an oil loading of 0.1 l/m^2 seemed to be optimal. By adding this amount of oil to the rags (1 dl to a 1 m^2 cotton rag), the rag was rather wet. Consequently, this oil loading area density was also used in the wood oil tests.

However, Figure 2.5, which shows the achieved temperatures of the rag for different loadings of Owatrol anti-rust oil in cotton rags, it appears that an oil loading of 0.1 l/m^2 (the red curve) resulted in definitely the smallest temperature increase of the oil loadings of 0.1, 0.15 and 0.2 l/m^2.

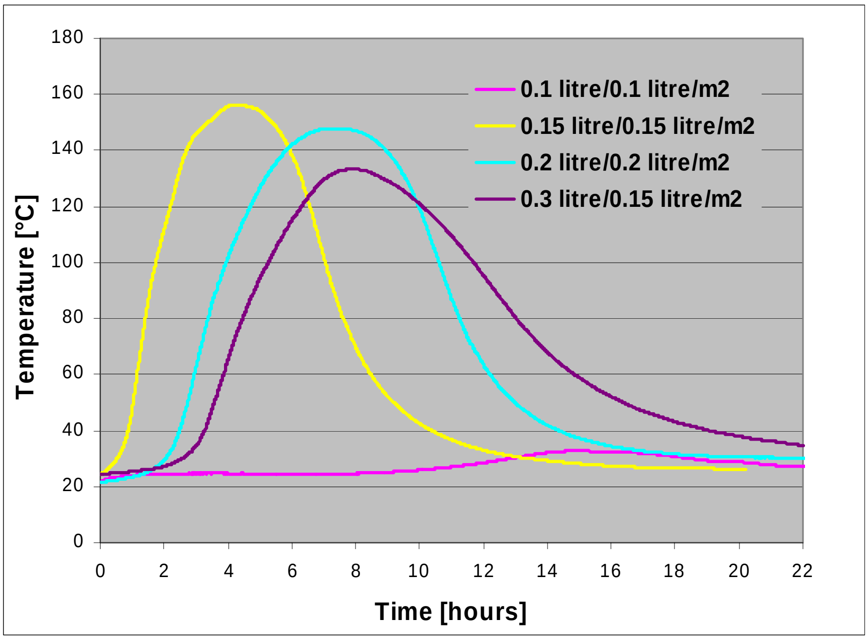


Figure 4.8: The achieved temperatures of the rag for different loadings of Owatrol anti-rust oil.

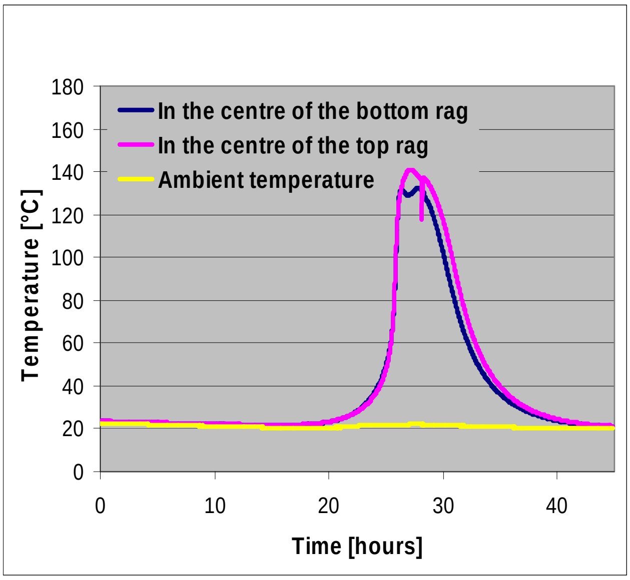
The low temperature increase of the oil loading of 0.1 l/m^2 may also be due to other effects as for example the ventilation rate, which might have been more restricted in this specific test. This hypothesis is supported by comparing the maximum temperatures achieved by the tests in Table 5.1. From these numbers it appears that an oil loading of 0.1 or 0.15 l/m^2 resulted in the highest maximum temperatures.

Consequently, it can be concluded that in spite of the above mentioned results for Owatrol oil, oil loadings in the range 0.1-0.15 l/m^2 seems to be most critical.

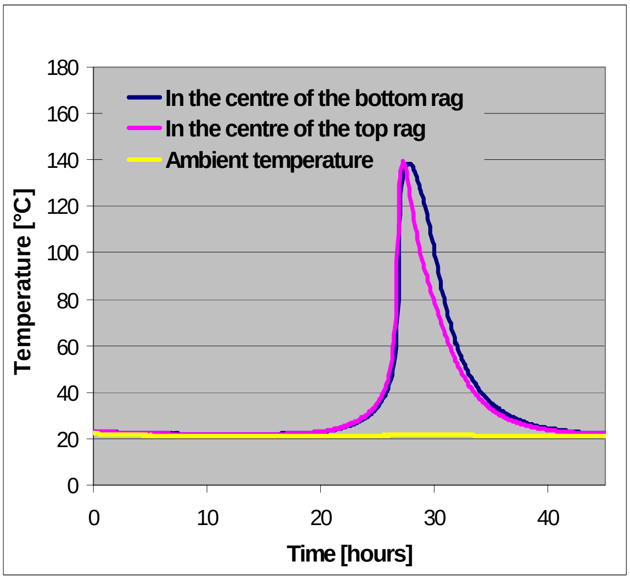
4.6 The Repeatability of the Tests in Experimental Setup I

Figure 4.8 shows the temperature development in two experiments with 50 % twist and 50 % (by weight) Butinox wood oil in Experimental Setup I (25 l insulated bucket). The Twist rag was almost filling up the 5 litre space completely.

From figure 4.8a and b it appears that the repeatability of these two tests was rather good, but the data basis (only two tests) is too small to draw a definite conclusion that the repeatability of the tests was good. On the other hand, it is not for certain that the repeatability of the tests with cotton rags would have been as good as shown in Figure 4.9. This probably because the ventilation conditions of the rags will be more dependent on the placing of the cotton rags than the twist rags.



a) Test 3.2: 249 g Butinox wood oil in 250 g Twist and 22 °C ambient temperature



b) Test 3.3: 243 g Butinox wood oil in 250 g Twist and 22 °C ambient temperature

Figure 4.9: The two only tests with approximately the same experimental conditions.

4.7 The Fire Hazard of Different Wood Oil Products

It might be difficult to rank different wood oil products with respect to the fire hazard on the basis of the 33 experiments carried out because only 3-5 experiments resulted in real spontaneous combustion. However, as already stated the tendency to cause self-heating and self-ignition may also be deduced from sub-critical tests. The oils with the most rapid and highest temperature increase in sub-critical tests should also be the oils that are most hazardous with respect to self-ignition and spontaneous combustion.

It can be concluded that boiled *linseed oil* falls into an own category with respect to fire hazard compared to other oils. It is far more prone to cause spontaneous heating, ignition and combustion than all the other oils evaluated. In ordinary wood oils the linseed oil is suspended in a solvent, which will delay the oxidation because the solvent has to vaporise before the oxidation can start.

Among the other wood oils products *Faxe Prestige* wood floor oil at 20 ° C elevated ambient temperature (of 34 °) showed almost the same tendency to cause spontaneous heating as boiled linseed oil (cf. Figure 4.6). However, linseed oil attained a slightly higher maximum temperature twice as fast as Faxe wood floor oil.

Owatrol anti-rust oil seems to be slightly more hazardous then *Trip Trap* wood oil. *Butinox* wood oil attained almost the same maximum temperatures than the two last-mentioned oils. However, the time of the maximum temperatures was extremely long (more than 24 hours), while the other wood oils needed from 4-18 hours to reach the maximum temperature.

The oils tested can be divided into three classes with respect to the fire hazard (cf. Table 5.1):

- **Class I. Extremely Hazardous oils:**
  - *Linseed oil.*

- **Class II. Hazardous Oils (ranked, i.e. the oil listed first, is most hazardous):**
  1. *Faxe oil wood floor oil,*
  2. *Owatrol anti-rust oil,*
  3. *Trip trap wood floor oil and*
  4. *Butinox wood oil*

- **Class III: Non-hazardous or very little hazardous oils (the oil listed at first, is most hazardous)**
  1. *Junker Rustic oil*
  2. *Wood oil from 'Norsk Trepleie'*
  3. *Faxe oil care*

However, the numbers of tests carried out with equal experimental conditions were not sufficient to draw reliable conclusions with respect to the ranking of the self-ignition tendency of the eight wood oils.

Among the five wood oils that were characterized as hazardous, it was only *Trip trap wood floor oil* that did not have any safety marking or warning tag against the risk of self-ignition and fire.

On the basis of this experimental series it can be concluded that wood oil products do represent a risk of self-ignition and fire, even though this occurs only under certain circumstances. Due to the fact that these circumstances may occur rather frequently, especially indoors and outdoors in the summer time, there is a need for better labelling of such products. That is, with respect to the fire hazard and how to treat application equipment after use.

5 SAFE HANDLING AND DISPOSAL OF EQUIPMENT FOR WOOD OILS

SINTEF NBL will recommend the following safety actions in connection with wood oils:

1. **Soaking of application equipment with water**
   - Place permanently a filled water tank of suitable size, i.e. a water tank which has the capacity to store all the application equipment submerged in water after use.
   - Directly after submerge all application equipment into the tank, which should have a floating lid that will ensure application equipment submerged in the tank.
   - This should be carried out at least at the end of the working day.
   - At regular intervals and at least before the water tank is filled up to a point where the water is close to overflowing, remove application equipment and hang out to dry before disposal in regular waste containers.
2. **Burn application equipment a fireplace or oven.**
3. **Storage of the rags in a sealed metal container intended for fire hazardous waste.** Method 2 should only be used for short time storage or transport. Afterwards they should be handled according to method I.

6 EXAMINATION OF DSB's STATISTICS ON SELF-IGNITION

6.1 General

SINTEF NBL has received statistics from DSB involving fires with self-ignition as the cause of fire. The statistics cover all fires with self-ignition by *chemical* and *biological processes* separately for the ten year period 1995-2004. The statistics are based on among other things information from the police with respect to the cause of the fire.

The total number of cases of self-ignition in connection with chemical processes during the ten year period was 265 cases; while in connection with biological processes there were 90 cases. Thus, in average there are 26-27 cases each year of self-ignition in connection with chemical processes and 9 cases each year with biological processes.

6.2 Cause of Fire

The statistics mentioned above was received in an Excel spreadsheet. A column in a worksheet was termed as 'Comments to the cause of the fire'. The police write down short notes with respect to the main reasons for categorizing the fire as self-ignition. Table 6.1 shows the number of cases where words as for example: 'oil', different trademarks of wood oils, 'grinding dust' or 'grinding', 'pyrophoric', 'gasoline' etc were mentioned as the main reason for categorizing the cause of the fire as self-ignition due to both chemical and biological process.

Table 6.1: The frequency of selected words included in the arguments for categorizing the cause of fire as self-ignition.

Searched words in the comments to the cause of the fire	Number of cases		
	Chemical processes	Biological processes	Total
Oil:	94	12	106
Linseed oil	24	2	26
Faxe wood oil:	26	1	27
Owatrol wood oil:	2	0	2
Trip Trap wood oil:	0	1	1
Butinox wood oil:	0	0	0
Gasoline:	8	0	8
Grinding:	18	2	20
Grinding dust:	11	2	13
Pyrophoric:	5	0	5

It has to be pointed out that in 72 of the 265 cases (i.e. 27 % of the cases) in connection with chemical processes there were no comments with respect to the cause of the fire. Likewise in 27 of the 90 cases (i.e. 30 % of the cases) in connection with biological processes there were no comments with respect to the cause of the fire from the police.

From Table 6.1 it appears that self-ignition of 'oil' occurred in 106 of the 196 cases where the police had written comments to the case of the fire. Of the oils, *Faxe wood* oil and *linseed oil* were the oils in which self-ignition occurred by far most frequently, i.e. in 27 and 26 cases, respectively. The other wood oils as for instance *Owatrol*, *Trip Trap* and *Butinox* wood oil were almost not mentioned at all.

6.3 Defects in the Statistics

It also appears from Table 6.1 that there are a lot of errors with respect to the reporting of the cause of the fire and the process causing self-ignition.

6.3.1 Processes Causing Self-ignition

As explained in Section 2.1 there is mainly the following three processes that can cause self-ignition: *physical, biological* and *chemical processes*. It appears from Table 6.1 that under *biological processes* there are defined 12 cases involving self-ignition of 'oil' soaked in rags. These cases are evidently defined in a wrong category. The same applies to the two cases under biological processes involving self-ignition of 'grinding dust' or 'grinding' from floors treated with wood oils. The correct category for both self-ignition of oily rags and grinding dust is *chemical processes*.

In Table 6.1 there are also five cases of self-ignition of 'pyrophoric' wood, which are defined under chemical processes. These five cases come actually under *physical processes*. By examining all the comments to the cause of fire there are many equivalent cases with a wrong placing of the process causing self-ignition. This may be due to either writing errors (wrong number on category) or due to lack of knowledge regarding these processes causing self-ignition among the police.

6.3.2 Erroneously Definition of the Cause of Fire as Self-Ignition

The Excel spreadsheet received from DSB contained also a worksheet with examples of fires categorized as self-ignition in 2003 and 2004, including all three processes causing self-ignition. By a review of the comments on the cause of the fire there are also surprisingly many examples of fires which erroneously are categorized as self-ignition.

Many fires are obviously due to other causes of fire. One has to bear in mind that in connection with self-ignition, the heat necessary to cause ignition has to come from the ignited *material* itself, not externally supplied heat.

Examples of fires which are categorized as self-ignition are fires due to: sawing (friction), externally supplied sparks, hot ash with glows from fire places, combustible liquid on a hot surface (e.g. a leakage of gasoline or diesel in a car engine), oils in a hot deep-fryer or fat in a hot frying pan, ignition of pyrophoric wood due to heat transfer from different fireplaces or heaters, burning-glass effect, textiles or paper in contact with a luminous lamp, dust in a television set, chimney fires, etc. In Table 6.1 there are 8 cases where self-ignition of gasoline. Common for all these cases is that the heat necessary for ignition is externally supplied to the ignited material.

In other cases it seems as if a can with wood oil, linseed oil or even petroleum products were found near the origin of the fire, the cause of fire was right away defined as self-ignition.

This should indicate that the knowledge of self-ignition among the police is often rather low. Many fires are either placed in wrong category of self-ignition or fires are erroneously categorized as self-ignition. However, it is also expected that many fires which are due to self-ignition, the cause of fire are never revealed as self-ignition due to the same reasons.

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APPENDIX A: TEST RESULTS

Table A.1 shows data with respect to number of tests as well as the test number and the number of experiments carried out in four experimental series carried out during the project.

Table A.1: Description of the experimental series within the test program.

Experimental series no.	Description of experimental series	Experi-mental setup no.	Test no	Number of experi-ments
1	Preliminary tests involving cooked linseed oil absorbed in cotton rags.	1	1.1-1.10	10
2	Tests with different drying oils in cotton rags in a small "pile", i.e. a 25 litre bucket.	1	2.1-2.14	14
3	Tests with wood oils in Twist in a "small pile", i.e. a 25 litre bucket.	1	3.1-3.3	3
4	Tests with different drying oils in a "large pile", i.e. within a 600 mm x 600 mm x 500 mm high block of Rockwool insulation.	2	4.1-4.6	6
Total numbers of tests carried out:				33

The varying parameters during the tests were as follows:

- *Eight different types of wood oils* (Boiled linseed oil, Faxe oil care, Faxe wood floor oil, Wood floor oil from 'Norsk trepleie', Butinox wood coating oil, Owatrol penetration/anti-rust oil, Trip trap wood penetration oil and Rustic oil from Junker).
- *Two types of rag* (Cotton and waste wool or 'Twist' rags).
- *Amount of oil* (in litre (l) or ml)
- *Oil loading*, i.e. quantity of oil per surface area of the cotton rag (litre/m^2)
- *Ambient temperature*
- *Temperature of the oil*

When the quantity of oil evenly distributed over the rag and the area of rag were known, the average loading of oil in the rag was known by dividing the quantity of oil by the rag area. However, an oil loading parameter for the Twist rags could not be calculated because the 'area' of the Twist rags was not known or could not be predicted. The cotton rags used in the test were curtains of roughly the identical quality.

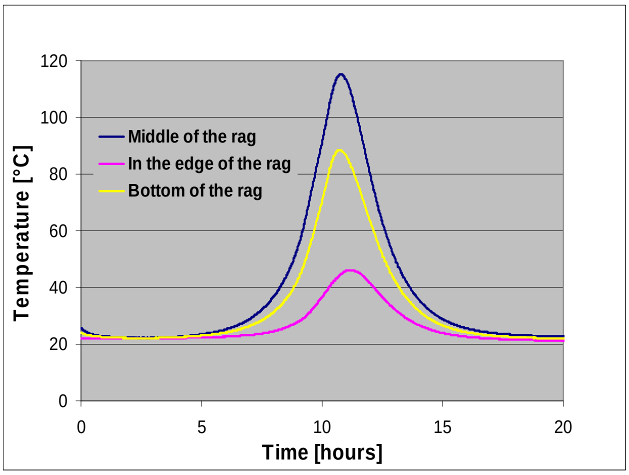
The cotton rag area in the cavity varied from 0.5 – 3.0 m^2. The volume of the cavities was approximately 5 litres in Experimental Setup I and approximately 4 litres in Experimental Setup II. The larger the area or the quantity (in kg) of cotton rags or Twist rags was, the more tightly the rags were packed. Consequently, the higher packing density the lower was the ventilation rate of the rags.

When starting the experiments, we did not have any idea of which quantities of oil and rags that were needed to generate or produce spontaneous heating sufficient for self-ignition of the oily rags. Hence, the experiments were carried out by varying the parameters mentioned above, trying to find the right combinations that caused spontaneous ignition.

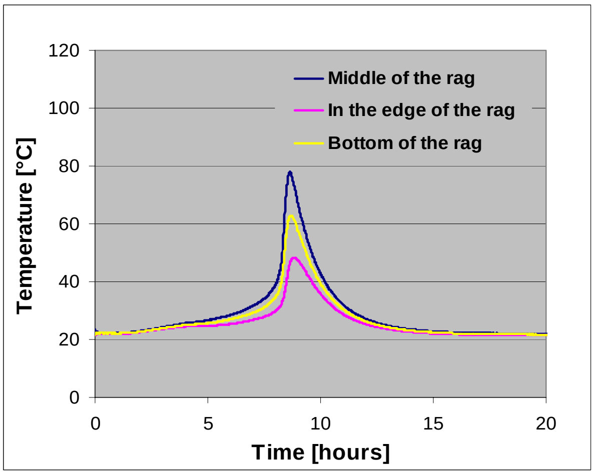
Table A.1: The test parameters of experimental series 1 with Experimental Setup I where boiled linseed oil was the only oil tested.

Name of test	Test set-up no.	Type of oil	Amount of oil	Rag: Type of fabric	Rag: Area of cotton rag/ weight of waste wool	Oil loading (litre/m^2)	Start oil temp./ average ambient temp. (°C)	Test duration (hrs.:min.)	Max. temp. (°C) at time (hrs.:min.)	Comments to the test
Test 1.1 (01)	I	Boiled linseed oil	25 ml	cotton rag	1 x 0,25 m^2 + 2 similar dry rags	0.1	22	23:06	*115 °C* at 10:48	The rags were put into a 5 litre open plastic bag with two similar, but dry cotton rags at bottom and top of the oily rag. The plastic bag was completely open.
Test 1.2 (02)	I	“	”	”	“	0.1	22	27:33	*78 °C* at 10:39	Same as above, but no plastic bag was used.
Test 1.3 (03)	I	“	12.5 ml	”	“	0.05	22	17:38	*32 °C* at 10:18	Same as Test 1.1, but half the amount of oil (12.5 ml) was used.
Test 1.4 (04)	I	“	25 ml	”	“	0.1	28/36	18:43	*99 °C* at 05:03	Same as Test 1.1, but elevated ambient temperature, i.e. approx. 36 °C.
Test 1.5 (05)	I	“	50 ml	”	“	0.2	23	23:14	*47 °C* at 09:09	Same as Test 1.1, but twice the amount of oil (50 ml) was used.
Test 1.6 (06)	I	“	50 ml	“	2 x 0.25 m^2 = 0.5 m^2	0.1	27/29	20:47	*183 °C* at 04:20	Same as Test 1.1, but 2 rags on the top of each other with 25 ml oil in both and with the third dry rag on the top (no plastic bag). After the test the rags were stuck together. A rag was slightly brown discoloured (see Fig. A.2a).
Test 1.7 (07)	I	“	75 ml	“	3 x 0.25 m^2 = 0.75 m^2	0.1	25/31	20:00	*253 °C* at 05:81	3 rags on the top of each other with 25 ml oil. All three rags were more or less burned, but the rag in the middle was burned most.
Test 1.8 (08)	I	“	100 ml	“	4 x 0.25 m^2 = 1.0 m^2	0.1	24/22	20:00	*470 °C* at 15:36	4 rags on the top of each other, 25 ml oil in each rag. The rags were highly burnt (see Fig. A.2c).
Test 1.9 (31)	I	“	300 ml	“	3 x 1.0 m^2 = 3.0 m^2	0.1	26/23 °C	22:50	*179 °C* at 6:55	The cotton rags were somewhat decolourized at the contact surface between the rags (Fig. A.3c).
Test 1.10 (33)	I	“	“	“	“	0.1	25/23 °C	22:30	*195 °C* at 4:50	Increased ventilation through holes in the bottom of the bucket. The rags were burned at the contact surface between the rags (Fig. A.4d).

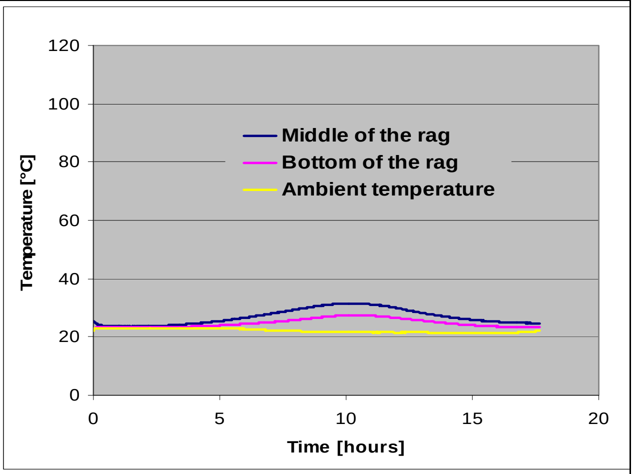
Experimental setup of the tests Test 1.1 – Test 1.10.



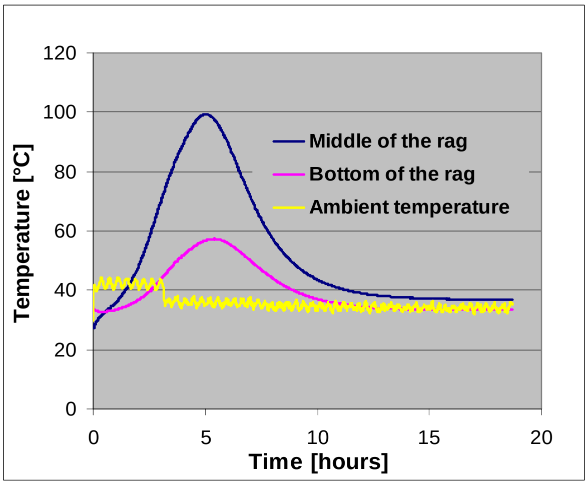
Test 1.1: 25 ml boiled linseed oil in a 500 mm x 500 mm cotton rag contained in a plastic bag - ambient temperature: $T_{amb.}$ = 22 °C (loading: 0.1 l/m^2).



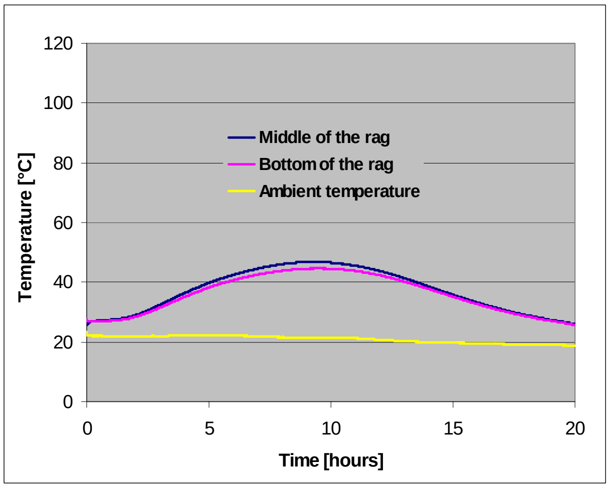
Test 1.2: 25 ml boiled linseed oil in a 500 mm x 500 mm cotton rag without a plastic bag and perforations of the bottom of the waste container - $T_{amb.}$ = 22 °C (loading: 0.1 l/m^2).



Test 1.3: 12.5 ml boiled linseed oil in a 500 mm x 500 mm cotton rag contained in a plastic bag - $T_{amb.}$ = 22 °C (loading: 0.05 l/m^2).

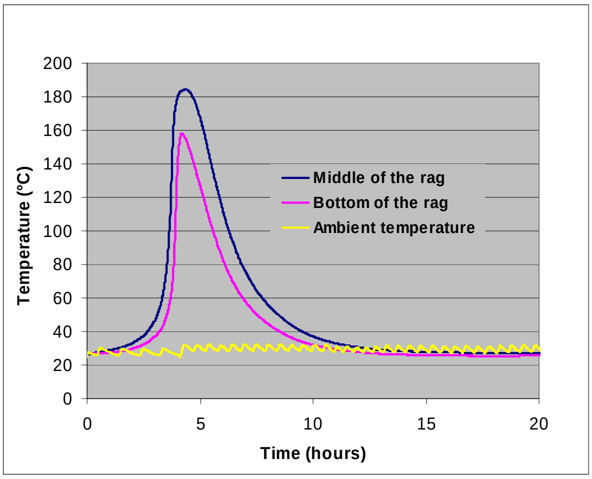


Test 1.4: 25 ml boiled linseed oil in a 500 mm x 500 mm cotton rag contained in a plastic bag at 36 °C elevated ambient temperature (loading: 0.1 l/m^2).



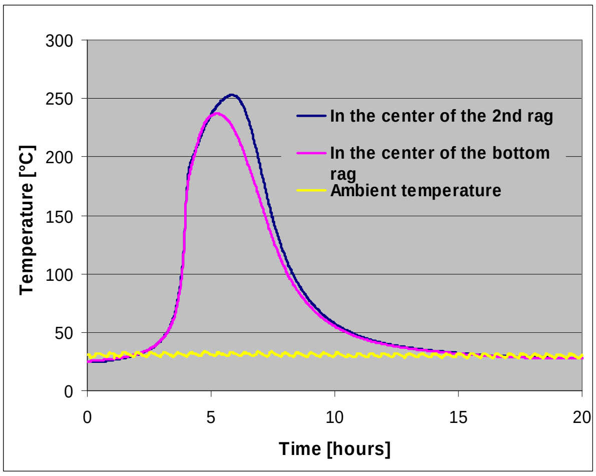
Test 1.5: 50 ml boiled linseed oil in a 500 mm x 500 mm cotton rag contained in a plastic bag - $T_{amb.}$ = 23 °C (loading 0.2 l/m^2).

Figure A.1: Test 1.1-1.5 with boiled linseed oil in a 500 mm x 500 mm cotton rag both contained in a plastic bag and without a plastic bag ($T_{amb.}$ is the ambient temperature).



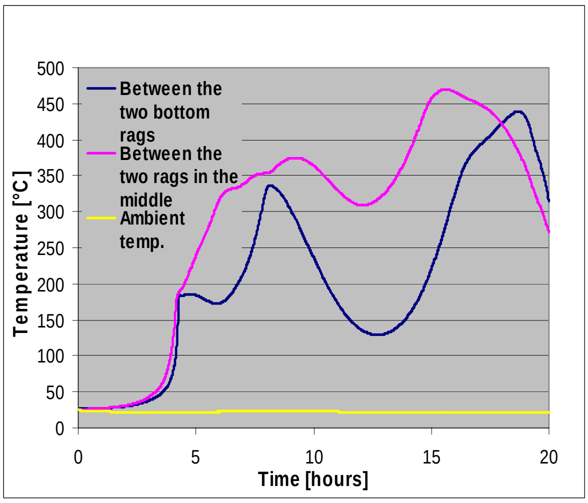
a) <u>Test 1.6:</u> 2 x 25 ml *boiled linseed oil* in 2 x 500 mm x 500 mm cotton rags - $T_{amb.}$ = 29 °C (loading: 0.1 l/m^2). ($T_{amb.}$ is the ambient temperature)

The picture shows the bottom rag in the bucket after the Test 1.6 was finished. Parts of the rag are somewhat brown and slightly burned (see the brown semicircle at the lower edge of the rag).



b) <u>Test 1.7:</u> 3 x 25 ml *boiled linseed oil* in three 500 mm x 500 mm cotton rags, i.e. a total amount oil of 75 ml - $T_{amb.}$ = 31 °C (loading: 0.1 l/m^2).

The three rags after Test 1.7. It appears that the rag in the middle (the rag located in the middle) is clearly most burned.



c) <u>Test 1.8:</u> 4 x 25 ml *boiled linseed oil* in four 500 mm x 500 mm cotton rags- $T_{amb.}$ = 22 °C (loading: 0.1 l/m2).

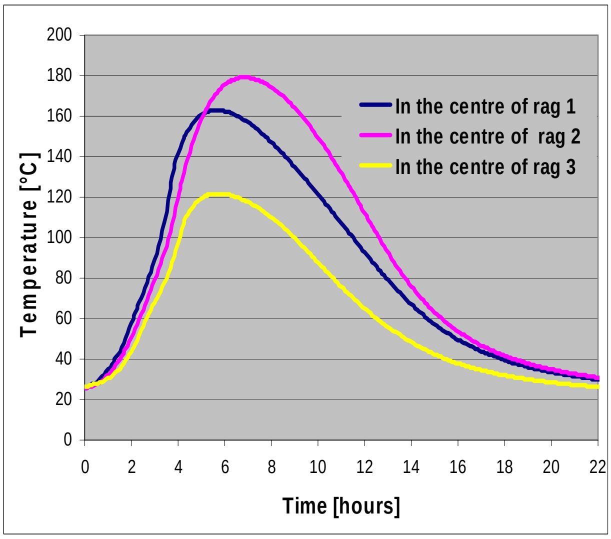
The highly charred residues of Test 1.8 in which four 500 mm x 500 mm large cotton rags (total of 1 m^2) were evenly contaminated with a total of 1.0 dl of boiled linseed oil.

Figure A.2: Test 1.6-Test 1.8 with boiled linseed oil evenly distributed in cotton rags.

a) One of the three 1 m^2 rags after 100 ml *boiled linseed oil* had been evenly distributed in the rag.

b) The experimental setup of Test 1.9.

c) The three cotton rags after the 22 hrs long test with 0.3 litre *boiled linseed oil*.



d) The temperature in the centre of the three rags during the test.

Figure A.3: *<u>Test 1.9:</u> 3 x 100 ml boiled linseed oil evenly distributed in 3 x 1 m^2 cotton rags (liquid loading: 100 ml/m^2) at approximately 22 °C ambient temperature placed in 25 litre bucket insulated with Rock wool insulation.*

a) The test setup of Test 2.16 with 0.3 litre *boiled linseed oil* in 3 x 1 m^2 cotton rag and with increased ventilation of the rags.

b) 13 holes were made in the bottom of the bucket and in the insulation above in order to improve the ventilation of the bucket.

c) The three rags cotton rags filled the free space in the bucket completely.

d) The rags after the test. They were rather burned in the contact surface between the rags but the opposite surface of the bottom and top rag were not burned. The rags were somewhat wet after the test.

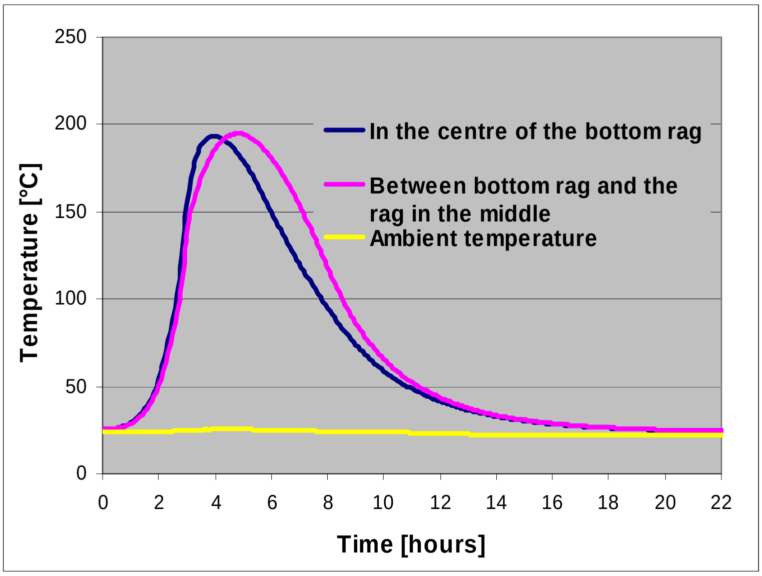


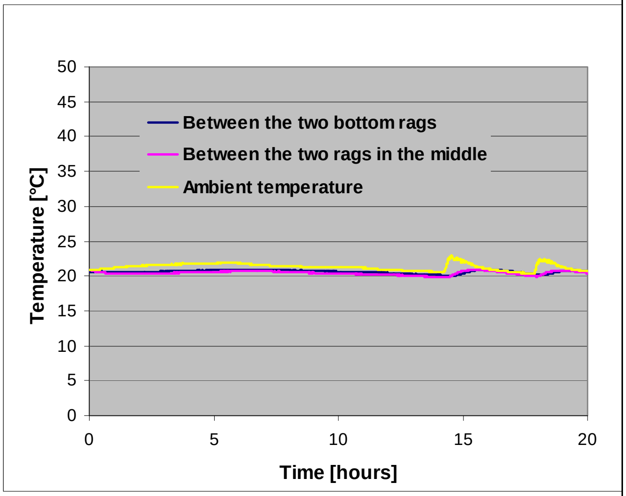
Figure A.4: Test 1.10: 3 x 100 ml boiled linseed oil evenly distributed in 3 x 1 m^2 cotton rags (liquid loading: 100 ml/m^2) at approx. 22 °C ambient temperature placed in 25 litre bucket insulated with increased ventilation through hoes in the bottom of the bucket.

Table A.2: The test parameters of experimental series 2.

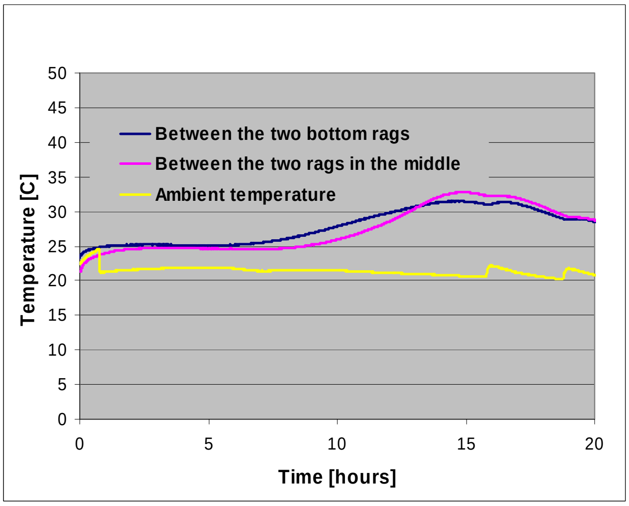
Name of test	Test set-up no.	Type of oil	Amount of oil	Rag		Oil loading (litre/m²)	Start oil temp./ average ambient temp. (°C)	Test duration (hrs.:min.)	Max. temp. (°C) at time (hrs.:min.)	Comments to the test
				Type of fabric	Area of cotton rag/ weight of waste wool					
Test 2.1 (09)	I	Faxe Oil Care	100 ml	"	4 x 0,25 m^2 = 1.0 m^2	0.1	22	22.42	*22 °C*	4 rags on the top of each other with 25 ml oil in all rags. No temperature increase.
Test 2.2 (10)	I	Owatrol Anti-Rust Oil	"	"	"	0.1	22/21	22:25	*33 °C* at 14:48	Same test conditions as in previous test. A maximum temperature increase of only 11 °C was observed after 14-15 hours.
Test 2.3 (11)	I	Rustic Oil	"	"	"	0.1	22/21	121:33	*25 °C* at 1:36	The temperatures in the rags were always above the ambient temperature during the test, at most 5 ° C.
Test 2.4 (12)	I	Butinox Wood Oil	"	"	"	0.1	22/28	40:40	*44 °C* at 27:40	When the ambient temperature was increased from 22 °C to 38 °C at 22:10 the maximum temperature increased from 28 °C at 20:10 to 44 °C to at 27:40.
Test 2.5 (13)	I	Owatrol Oil anti-rust	150 ml	"	2 x 0.5 m^2 = 1.0 m^2	0.15	25/25	20:09	*156 °C* at 4:11	2 x 0.5 m^2 cotton rags with 150 ml oil evenly distributed in the rags. The two cotton rags were rather dry and glued together.
Test 2.6 (14)	I	"	200 ml	"	"	0.2	22/27	23:42	*148 °C* at 7:14	The weight of the rags with 200 ml oil was 304.9 g, i.e. 51.4 % of oil and 48.6 % of cotton by weight. The rags were drenched with oil.
Test 2.7 (15)	I	"	300 ml	"	2 x 1.0 m^2 = 2.0 m^2	0.15	25/26	22:00	*133 °C* at 7:57	No data was recorded during this test, but a temperature of approx. 200 °C had been achieved during the test (shown by the data screen).
Test 2.8 (19)	I	Trip trap wood oil	450 ml	Cotton rags	3 x 1 m^2 = 3 m^2	0.15	23/21 °C	21:38	*109 °C* at 16:21	The three cotton rags were rather drenched with wood oil when they were put into the waste container and 77 % of the oil was still in the rags after the almost 22 hour long test.

Name of test	Test set-up no.	Type of oil	Amount of oil	Rag		Oil loading (litre/m²)	Start oil temp./ average ambient temp. (°C)	Test duration (hrs.:min.)	Max. temp. (°C) at time (hrs.:min.)	Comments to the test
				Type of fabric	Area of cotton rag/ weight of waste wool					
Test 2.9 (20)	I	"	300 ml	"	3 x 1 m² = 3 m²	0.1	23/22 °C	19:52	*135 °C* at 12:56	The three cotton rags were rather wet of oil when they were put into the waste container and they were still somewhat humid. 75.9 % of the oil was still in the rag after the test.
Test 2.10 (21)	I	Wood oil from Norsk trepleie	"	"	"	0.1	23/23 °C	18:39	No temp. increase	The three cotton rags were still as wet as before the 18.5 hour long test. 92.3 % of the oil was still in the rags.
Test 2.11 (22)	I	Rustic oil	"	"	"	0.1	23/22 °C	96:05	*30 °C* at 50:25	A maximum temperature increase of only 8 °C was achieved after more than 50 hrs.
Test 2.12 (27)	I	Faxe wood floor oil	"	"	"	0.1	24/22 °C	23:50	*158 °C* at 6:00	The three cotton rags were relatively dry after the test, but 90 % of the oil was still in the rags. The rags were somewhat difficult to tear apart and they were slightly decolorized at the contacts surface of the rags.
Test 2.13 (28)	I	"	"	"	"	0.1	24/22 °C	43:25	*65 °C* at 26:50	Same conditions as in Test 2.12, but the rags were put into a 5 litre plastic bag which was tied up by a string on the top. At 17:20 the plastic bag was untied and the plastic bag was opened due to no temperature increase.
Test 2.14 (30)	I	"	"	"	"	0.1	26/45 °C	23:05	*146 °C* at 8:35	No plastic bag. The cotton rags were rather dry after the test, but 83.4 % of the oil was still in the rags after the test.

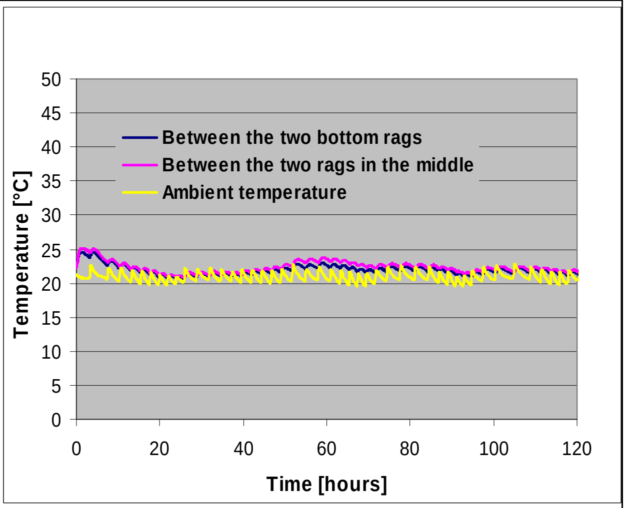

The test setup of experimental series 2, i.e. Test 2.1-2.14, were Twist rags were tested.



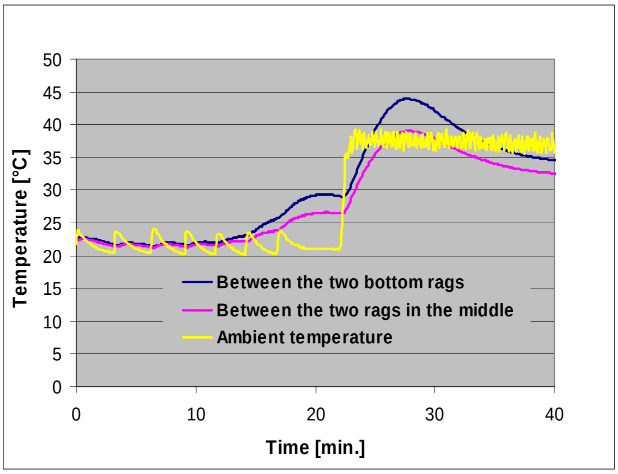
Test 2.1: 1.0 dl of *FAXE Oil Care* in four 500 mm x 500 mm evenly supplied to cotton rags.



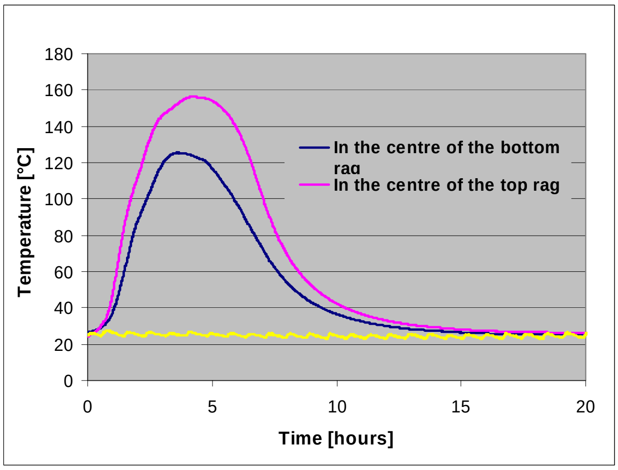
Test 2.2: 1.0 dl of *Owatrol Oil* (penetration, anti-rust oil) evenly supplied to four 500 mm x 500 mm cotton rags.



Test 2.3: 1.0 dl of *Junkers Rustic Oil* in 4 x 500 mm x 500 mm cotton rags. The somewhat jagged curves are due to the thermostat of the heating oven in the closet.

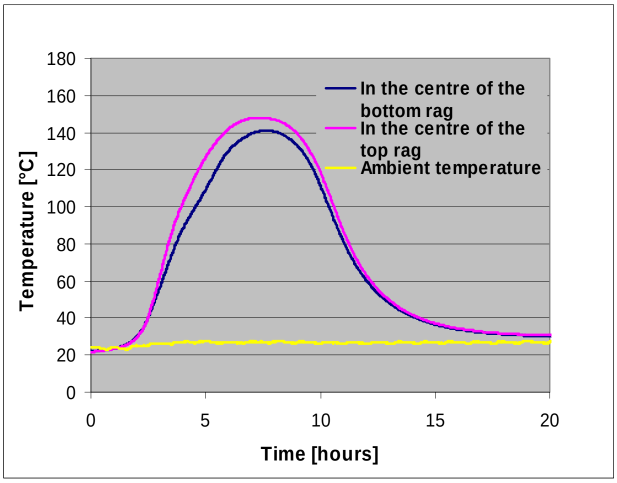


Test 2.4: 1.0 dl *Butinox Wood Oil* evenly distributed in four 500 mm x 500 mm cotton rags. When the ambient temperature was increased from 21-22 °C to 38 °C at 22:10, the temperature between the two bottom rags increased to maximum 44 °C at 27:40.

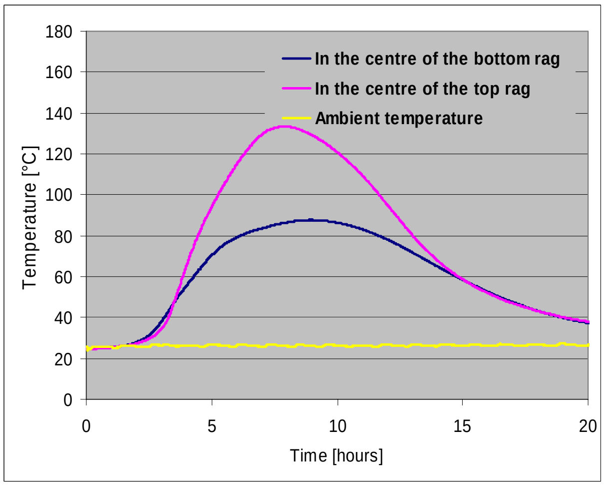


Test 2.5: 150 ml *Owatrol oil* in two 0.5 m^2 cotton rags (150 ml/m^2).

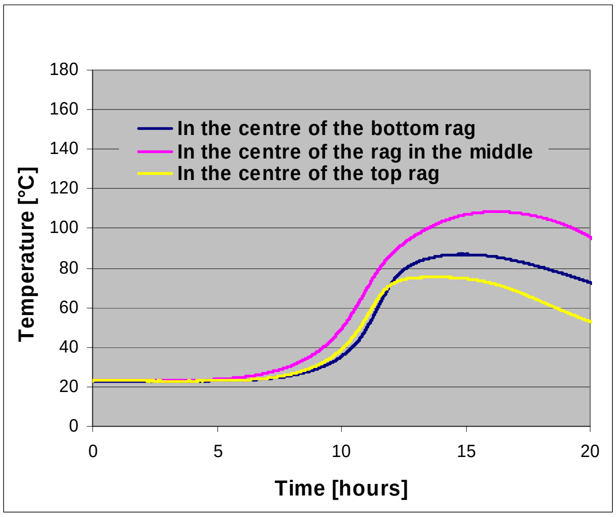
Figure A.5: Test 2.1-2.5 in Test Setup I with different wood oil products.



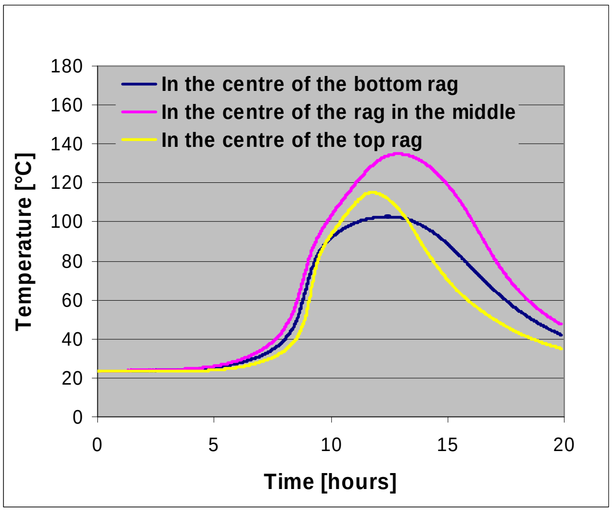
<u>Test 2.6:</u> 200 ml *Owatrol oil* in two 0.5 m^2 cotton rags (loading: 200 ml/m^2).



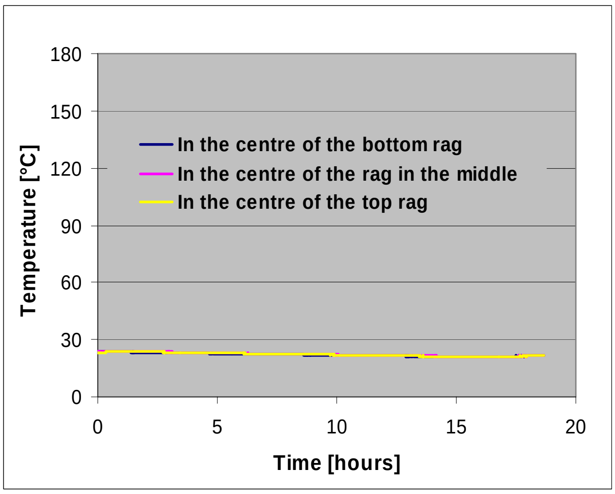
<u>Test 2.7</u>: - 300 ml *Owatrol oil* in two 1.0 m^2 cotton rags (loading: 150 ml/m^2).



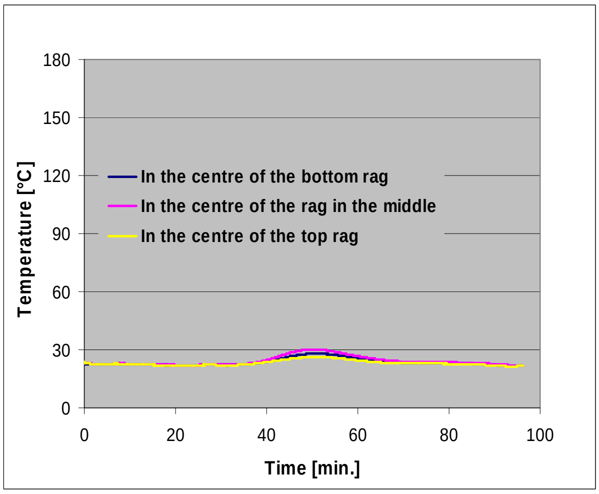
<u>Test 2.8:</u> 3 x 150 ml *Trip trap wood oil* in 3 x 1 m^2 cotton rags (loading: 150 ml/m^2). More than three-fourth (77.4 %) of the oil was still in the three rags when the test was terminated.



<u>Test 2.9:</u> 3 x 100 ml *Trip trap wood oil* in 3 x 1 m^2 cotton rags (loading: 100 ml/m^2). 75.9 % of the oil was still in the rag after the test, i.e. 24.1 % or 58.3 g was removed or oxidized.



<u>Test 2.10:</u> 3 x 100 ml *wood oil from Norsk trepleie* in 3 x 1 m^2 cotton rags (loading: 100 ml/m^2). The rags were still rather wet and 92.3 % of the oil was still in the rags.

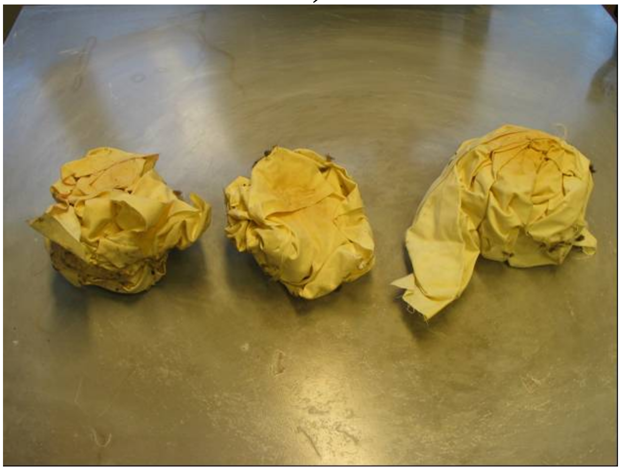


<u>Test 2.11:</u> 300 ml *Rustic oil from Junker* in 3 x 1 m^2 cotton rags (loading: 100 ml/m^2). The three cotton rags were rather wet of wood oil when they were put into the waste container.

Figure A.6: Test 2.6-2.11 in Test Setup I with wood oil products.

a)

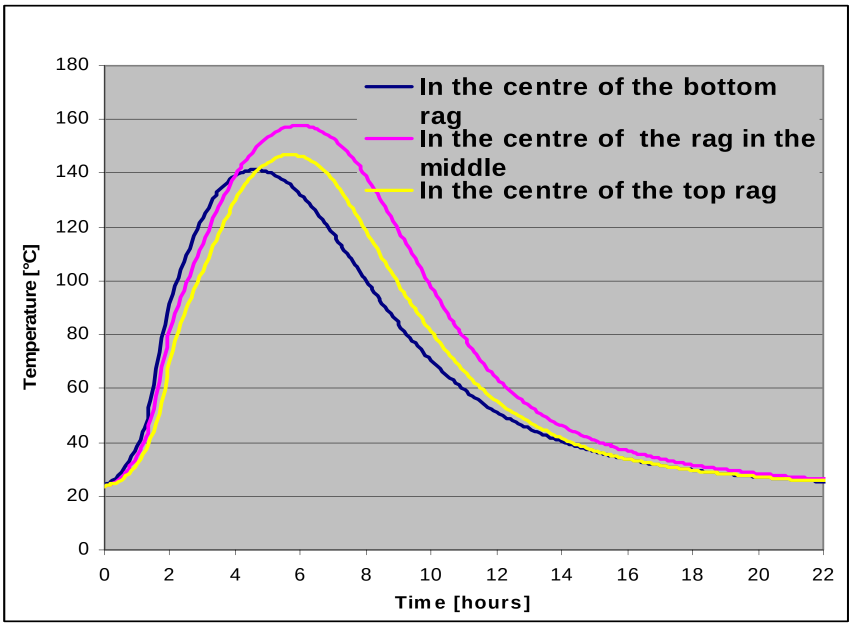
b)



c)

<u>Test 2.12:</u> The three cotton rags were stuck together in three parts. Each part was difficult to tear apart, but not far as much as in Test 26.

a) One rag of area 1 m2 with 100 ml *Faxe wood floor oil* before the test.
b) The rags were put into the bucket with insulation on the top of each other.
c) The three cotton rags after the test. The cotton was light brown of color at some places (primarily at the contact surface between each part). They rags were relatively dry, but 90 % of the oil was still in the rags. The reason that the exothermic oxidation ceases after about 5 hours is probably that the oil dry out within this time.



d) The temperature development in the centre of the three rags.

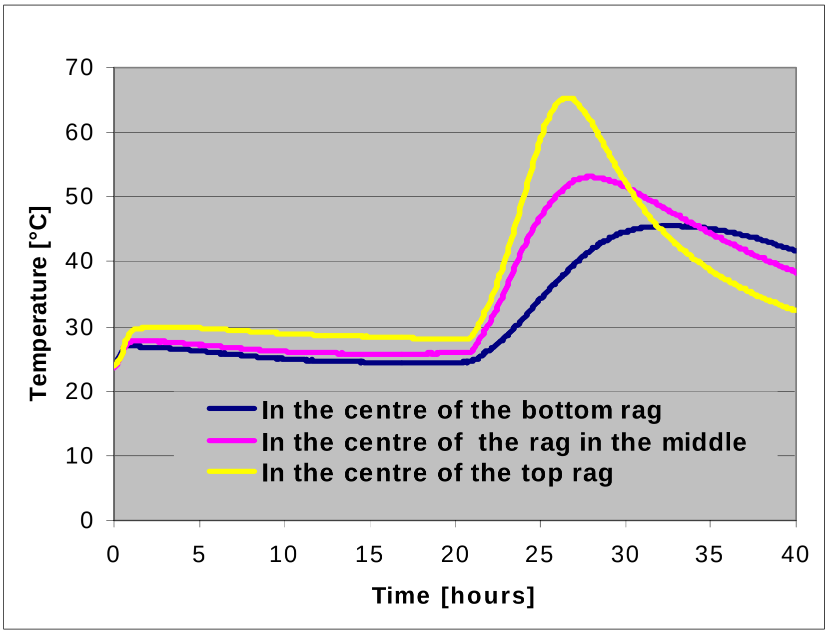
Figure A.7: Test 2.12 in which 3 x 100 ml Faxe wood floor oil was added evenly to 3 x 1 m^2 cotton rags (loading: 100 ml/m^2) in 25 litre bucket lined with 100 mm thick Rockwool insulation.

a)

b)

c)

Test 2.13: *Faxe Wood Floor Oil* (loading: 100 ml/m2) in 25 litre bucket lined with 100 mm thick Rockwool insulation.
a) The three cotton rags (3 x 1 m^2 with 3 x 100 ml FAXE oil evenly distributed in the rags) put into a 5 litre plastic bag.
b) The plastic bag was tied up by a string on the top of the bag (where the three thermocouples wires were guided out of the bucket).
c) The test setup during the test.
d) The temperature development as function of the test time. At 17:20 the plastic bag was untied and the plastic bag was opened at the top, but the metallic cover was placed on the top of the bucket again.



d)

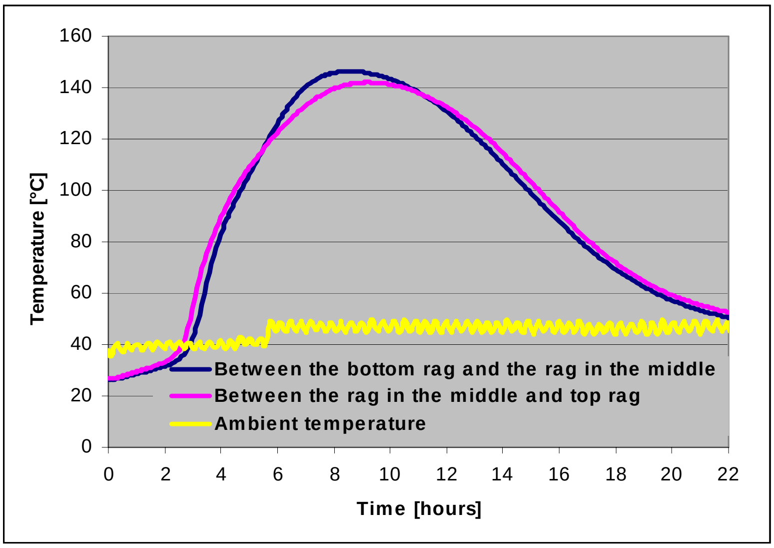
Figure A.8: Test 2.13 in which 3 x 100 ml FAXE wood floor oil (white) was added evenly to 3 x 1 m^2 cotton rags contained in a plastic bag in the 25 litre insulated bucket. The plastic bag was tied up by a string on the top of the bag. At 17:20 the plastic bag was untied and the plastic bag was opened at the top.

a) The test setup of the experiment.

Test setup of which was at elevated ambient temperature with *Faxe wood floor oil*:

- Average temperature: 45,2 °C
- Maximum temperature: 37,5 °C
- Minimum temperature: 49,8 °C

b) The cotton rags after the test. The rags were rather dry and slightly decolorized.



c) The temperature development at two locations as well as the ambient temperature.

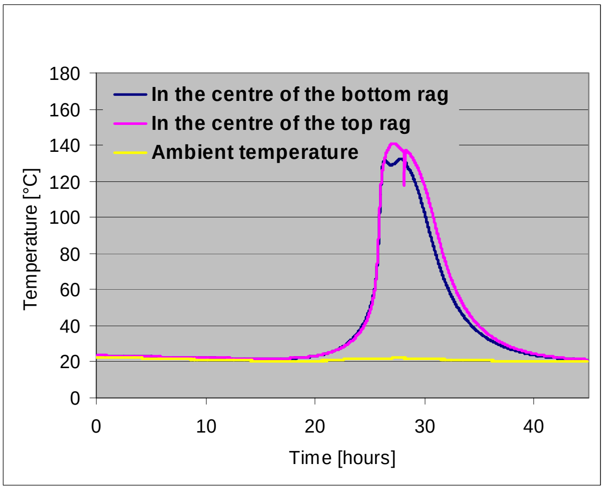
Figure A.9: Test 2.14: 3 x 100 ml Faxe wood floor oil in 3 x 1 m² cotton rags (liquid loading: 0.1 l/m²) at elevated ambient temperature. The cotton rags were rather dry after the test, but weighing of the rags prior to and after the test showed that 83.4 % of the oil was still in the rags after the test.

Table A.3: The test parameters of experimental series 3 in Test Setup I.

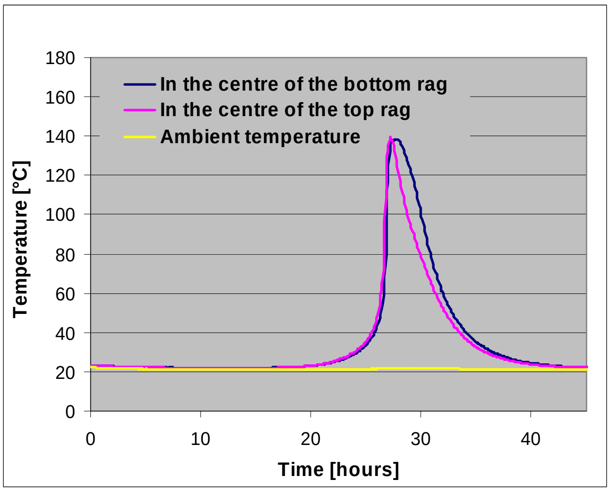
Name of test	Test set-up no.	Type of oil	Amount of oil	Rag: Type of fabric	Rag: Area of cotton rag/ weight of waste wool	Oil loading (litre/m^2)	Start oil temp./ average ambient temp. (°C)	Test duration (hrs.:min.)	Max. temp. (°C) at time (hrs.:min.)	Comments to the test
Test 3.1 (16)	I	Owatrol anti-rust oil	260 ml (215 g)	Waste wool/ Twist	250 g waste wool	46/54 %		-	Approx. 200 Data error!	Test setup 1: The oil was distributed evenly in two rags of total weight of 464,7 g which consisted of 46,2 % oil and 53,8 % waste wool.
Test 3.2 (17)	I	Butinox oil	300 ml	"	"	50/50 %	23/21 °C	44:53	141 °C at 27:20	Test setup 1: The oil was distributed more or less evenly in two rags of total weight of 498,6 g which consisted of 50 % oil and 50 % waste wool.
Test 3.3 (18)	I	"	"	"	"	50/50 %	23/21 °C	66:20	139 °C at 27:15	Repetition of Test 3.2.

The experimental setup of experimental series 3. The time-temperature curve of Test 3.1 is missing due to data error during the data recording.

Test 3.1: 260 ml *Owatrol oil* (218 g) in three Twist rags of total weight 250 g. The three rags were rather agglutinated and slightly burned. The max. temperature achieved during the test was ~ 200 °C.



Test 3.2: 250 g Twist and ~300 ml (248.5 g) *Butinox wood oil*.



Test 3.3: 250 g Twist and ~300 ml (243 g) *Butinox Wood Oil* without insulation material (Rockwool) on the top - only the metallic cover.

Test 3.2: The Twist rags supplied evenly with 0.3 litre *Butinox wood oil*.

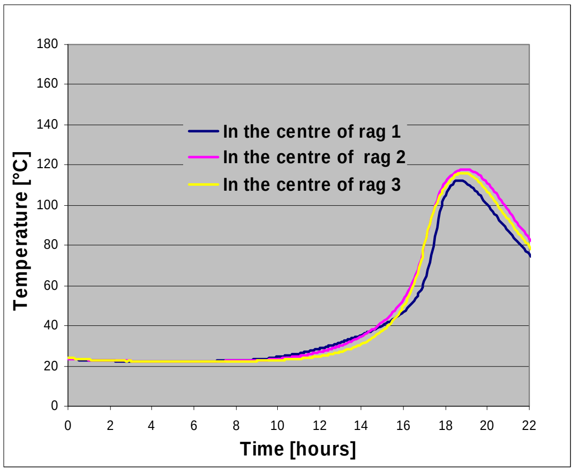
Test 3.2: The Twist rags after the test.

Figure A.10: Test 3.1-3.3 of experimental series 3: 3 x 100 ml boiled linseed oil evenly distributed in 3 x 1 m² cotton rags (liquid loading: 100 ml/m²) at approx. 22 °C ambient temperature placed in Test Setup I (25 litre bucket insulated Rockwool insulation).

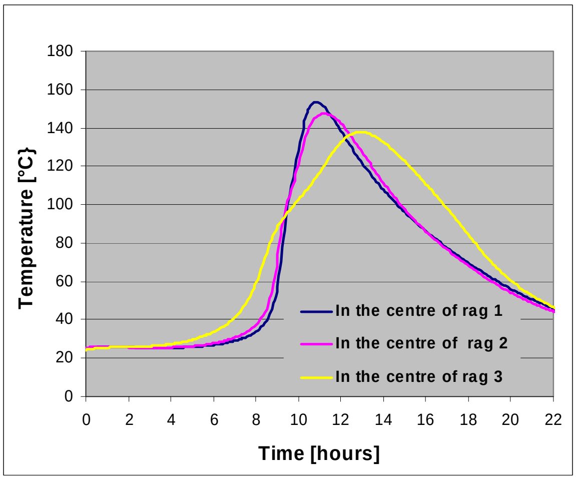
Table A.4: The test parameters of experimental series 4 in Test Setup II.

Name of test	**Test set-up no.**	**Type of oil**	**Amount of oil**	**Rag**		**Oil loading (litre/m²)**	**Start oil temp./ average ambient temp. (°C)**	**Test duration (hrs.:min.)**	**Max. temp. (°C) at time (hrs.:min.)**	**Comments to the test**
				Type of fabric	**Area of cotton rag/ weight of waste wool**					
Test 4.1 (23)	II	Butinox oil	300 ml	"	3 x 1 m^2	0.1	24/22 °C	22:20	118 °C at 18:55	More than 70 % of the oil was still in the three rags when the test was terminated.
Test 4.2 (24)	II	Trip trap wood oil	"	"	"	"	25/22 °C	31:45	153 °C at 10:50	More than 55 % of the oil was still in the three rags when the test was terminated.
Test 4.3 (25)	II	Wood oil from Norsk trepleie	"	"	"	"	24/22 °C	38:05	No temperature increase	99 % of the oil was still in the three rags when the test was terminated.
Test 4.4 (26)	II	Faxe wood floor oil	"	"	"	"	23/22 °C	21:55	248 °C at 10:00	Almost 74% of the oil was still in the three rags when the test was terminated.
Test 4.5 (29)	II	"	"	"	"	"	29/44°C	29:30	591 °C at 14:30	At elevated ambient temperature. The rags were completely burned after the test. Only a rather small amount grey ash was left after the rags (see Figure A.13d).
Test 4.6 (32)	II	Boiled linseed oil	"	"	"	"	25/23 °C	22:05	622 °C at 7:50	At ambient temperature. The rags were completely burned after the test. Only a rather small amount grey ash was left after the rags (see Figure A.14b).

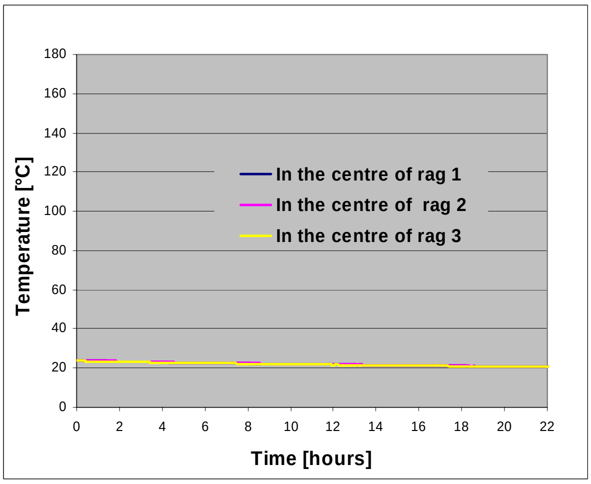
The test setup of the Experimental Series 4.



<u>Test 4.1:</u> 3 x 1 m2 cotton rags and 3 x 100 ml *Butinox wood oil* evenly distributed in the rags (i.e. 100 ml/m^2). 70,2 % of the oil still in the rags, i.e. 29,8 % or 47,1 g oil oxidized/evaporated



<u>Test 4.2:</u> 3 x 100 ml *Trip Trap wood floor oil* in 3 x 1 m2 cotton rags, i.e. 100 ml wood oil per m2 cotton rag. The liquid loading was different in the three rags. Least liquid load in rag 1 and the most in rag 3. 54.5 % of the oil still in the rag, i.e. 45.5 % or 102.6 g oxidized or evaporated.



<u>Test 4.3:</u> 3 x 100 ml *wood floor oil from Norsk Trepleie* in 3 x 1 m^2 cotton rags (i.e. loading: 100 ml/m^2). The rags were still rather humid after the more than 28 hour long test. 99 % of the oil was still in the rags after the test.

Figure A.11: The test setup of the experimental series 4 and the temperature in the cotton rags as function of time for Test 4.1-4.3.

Test 4.4: One rag of area 1 m2 with 100 ml *Faxe wood floor oil* before the test.

Faxe Wood Oil (loading: 100 ml/m^2) in 60 cm x 60 cm x 50 cm high block of Rockwool insulation.

The three rags after the test when the two upper insulation mats are removed. The insulation is slightly burned brown were the thermocouples wires have been located and where some air supply has supported some combustion.

The three cotton rags were glued together. The three rags were difficult to tear apart. The cotton was light brown of colour at some places (primarily at the contact surface between each part and it was dry, hard and brittle.

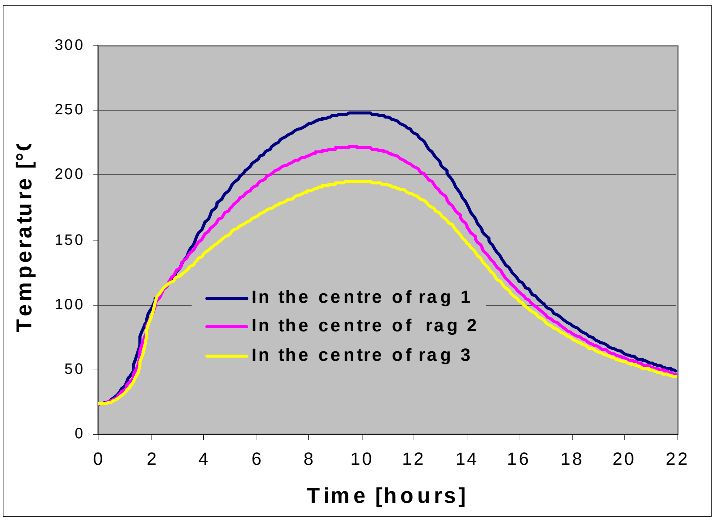


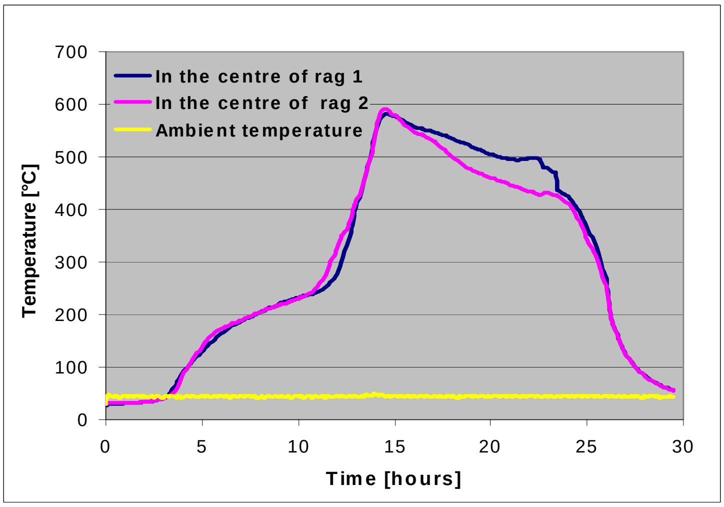
Figure A.12: Test 4.4: 3 x 100 ml Faxe wood floor oil in 3 x 1 m2 cotton rags. Almost 74% of the oil was still in the three rags when the test was terminated. $T_{amb.}$=22 °C ($T_{amb.}$ is the ambient temperature).

a) Test 4.5: The three cotton rags with *Faxe wood floor oil* were placed into the cavity before as shown.

b) The test setup after the almost 30 hour long test. The upper mat is slightly brown due to the heat generation during the test.

c) The fire damages of the Rockwool mat containing the cavity and mat above. The mats have become rather grey due to the fact that the cementing agent is lost due to the heat.

d) The residues of the oily cotton rags after the test.

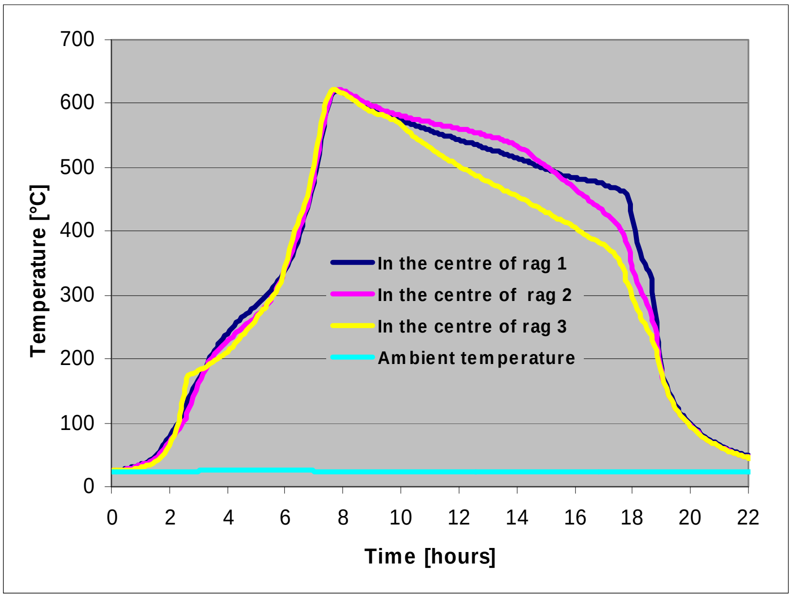


e) The temperature development during the test

Figure A.13: Test 4.5: 3 x 100 ml Faxe wood floor oil (white) was added evenly to 3 x 1 m² cotton rags at an elevated ambient temperature of 44 °C. The, maximum, minimum and average ambient temperature were 49.3, 41.7 and 44.1°C during the test.

a) Test 4.6: 5 hrs after the start of the test with *boiled linseed oil*. There was still some smoke from the test setup after 6 hrs, but after 7 hrs the smoke development has ceased.

b) The test setup after the test when the two upper Rockwool mats were raised. The picture shows the cavity in which the three rags were placed after the 22 hours long test.



c) The temperature in the centre of the three rags during the test

Figure A.14: Test 4.6: 3 x 100 ml Boiled linseed oil in 3 x 1 m^2 cotton rags (liquid loading: 100 ml/m^2) $T_{amb.}$=23 °C ($T_{amb.}$ is the ambient temperature)..