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RALF Project 97-1612

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Abstract

As part of a two year project supported by the Swedish Council for Work Life Research, two methods for the determination of the fire characteristics have been applied to a series of 8 hydraulic fluids in order to obtain data about the fire behaviour of these fluids. The results of this comparison show that both methods give a good indication of the fire behaviour of the fluids but that the small scale method (ISO 15029-2) is less dependent on the viscosity of the fluid than the large scale method (ISO 15029-3). This is due to the method of creating the spray of fluid for ignition. In the small scale test a very well defined, pre-mixed, spray of small droplets (with a narrow distribution of diameters) is created using an aspiration method with a flow of air pushing the fluid through the nozzle. This spray gives a worst case burning behaviour with even relatively inflammable fluids burning. In the large scale method a well defined spray of fluid is created using a swirl nozzle. The spray is not premixed and the distribution of droplet sizes is broader. This method is more sensitive to the viscosity of the fluid with highly viscose fluids producing larger droplets.

The large scale method is recommended for the resolution of any questions concerning the safety of the fluid should this not be clear from the results of the large scale test. This recommendation is based on the fact that the large scale method gives a better representation of what one would expect in real life. The fact that the large scale method is sensitive to the viscosity of the fluid, however, does leave the results open to manipulation through the addition of viscosity modifiers. These modifiers can at times be sensitive to shear and break down after a short period of use. Thus it is recommended that those fluids tested using the large scale method should be both as new fluids and after a given period of use. The large scale method has been crippled by the lack of a classification scheme. To remedy this a scheme is proposed.

The understanding of the fire behaviour of the hydraulic fluids gained through the comparison between the two test methods provides the backdrop for an indepth study of hot industrial applications of hydraulic fluids. Two hot industries have been studied (a Zinc and Aluminium Foundry and a Brass Foundry) in particular detail. A risk assessment has been made of the Foundries and placed in the context of the choice of hydraulic fluid. Both of the Foundries studied use Fire Resistant fluids which was found to be necessary considering the risk associated with their operations.

Key words: Hydraulic fluids, flammability, fire test methods, foundry, fire resistance, toxicity, environment.

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Foreword

The work presented in this report has been conducted as a part of a general effort to define and resolve real and perceived risks in the work place. The hope is that this work will show that while much has been achieved in the area of fire safety in hot industrial applications of hydraulic fluids in recent years more could be achieved by the definition of an internationally acceptable classification scheme for the fire characteristics of hydraulic fluids.

The financial support of the Swedish Council for Work Life Research is gratefully acknowledged as is the help of all those directly or indirectly involved in this project. In particular the two Foundries who provided us with access to their site and all necessary information are thanked.

1 Introduction

Many of the tasks undertaken by modern industry would be impossible without the use of fluid technology in the form of hydraulics. Dye casting for example requires extreme pressures in order to obtain a quality product. Many of these industrial processes place extreme constraints on the fire performance of the constituent parts of the hydraulic system due to the presence of high temperatures such as ovens or molten metal, or highly combustible material such as coal dust. Given the potential for loss of life and property should a fire occur in these processes every effort has been made to minimise the risks.

The basic requirements for a fire to occur are a fuel, a source of ignition and oxygen. Provided one of these components can be removed the fire risk can be greatly reduced. Oxygen is always present and in hot applications an ignition source is also readily available. In the case of hydraulic machinery the hydraulic fluid may provide the fuel. In some applications the hydraulic fluid cannot be entirely removed and likewise it is impossible to entirely ensure that no small leakage of the fluid can occur under pressure with the production of a spray of fluid. In the case of flammable hydraulic fluids, such as mineral oil, an extremely dangerous fire can result from the ignition of such a spray.

Historically a number of accidents both in mines and foundries have prompted the introduction of fire resistant fluids in hydraulic systems. However, no clear definition of a 'fire resistant' hydraulic fluid has been available. In lieu of a definition, national organisations responsible for worker safety have been forced to take a very narrow view of fire resistant fluids. In Sweden, the Swedish Board for Occupational Health and Safety have required hot industry to use 'water/glycol or similar mixtures'. A much more general view would be possible if there existed an internationally accepted classification scheme for the fire performance of hydraulic fluids. With proper fluid classification it would be possible to require a certain class of fluid in a given application rather than a certain type of fluid. This would open to way for producers to design new fluids with a well specified performance without compromising safety.

In order to reduce the risk associated with the use of hydraulics in hot industry we must be sure that the hydraulic fluids are fire resistant; but by establishing a classification requirement rather than a base fluid requirement all would benefit. The responsible ministry would be readily able to accept or reject new fluids as they are developed, fluid producers would be able to base fluid development research on well defined regulations, and industry would easily be able to choose new fluids.

Hydraulic systems using 'fluid power' represent a number of benefits over electromechanical drives or pneumonic power, including smaller size, higher energy efficiency and ease of adjustment. The removal of the fire risk associated with the fluid by the replacement of the hydraulic equipment with non-fluid technology is unacceptable and would lead to technically unreliable systems presenting new potential hazards. To minimise the risk in especially dangerous applications one must, therefore, influence the fire behaviour of the fluid itself.

This study has aimed at two things. Firstly, two test methods have been investigated and the fire characterisation of a variety of hydraulic fluids as measured using the two methods has been compared. These two methods are presently being forwarded as international standards and will hopefully provide the classification scheme we seek in the near future. Indeed one method has a well defined classification scheme associated with it today and it will probably gain international acceptance within the next 1-2 years. The results of this study have previously been presented in a preliminary report. The final report is given here in Chapter 2 and the work will also be presented at an international conference in 1999.

Based on the experience gained from this first part of the project, two case studies have been conducted using hot industrial applications of hydraulic fluids. In both cases foundries were investigated and the results of a risk analysis of both sites is summarised in Chapter 3. The risk associated with the industry is set in relation to the hydraulic fluid used and the risk it might represent depending on type. The classification scheme associated with the small scale test apparatus is used to define a 'fire resistant' fluid and a classification scheme is suggested based on the results of the large scale test rig. These methods are compared and classes of fluids suitable for use in hot industrial applications are proposed.

Finally, the importance of the results of this project for worker safety is discussed and recommendations for future work are given in Chapter 4.

2 Fire Behaviour and Classification of Hydraulic Fluids

The development of test procedures that give a reliable assessment of the fire behaviour of hydraulic fluids is necessary. A certain amount of research has already been done in this area but more effort is required in order to provide meaningful information concerning the relationship between small and large scale tests and that between various available tests and real life applications. Within this context a set of eight hydraulic fluids with varied fire behaviour have been tested according to the small scale method ISO 15029-2 and the large scale method ISO 15029-3. A comparison of the results shows that a correlation exists between the fire behaviour determined using these two very different methods.

2.1 Experimental description of ISO 15029-2

This test method is the third spray test presented in the 7th Luxembourg document (chapter 3.1.3) [1]. It has been developed as a part of a joint research effort at the Health and Safety Executive (HSE) and the University of Manchester in the United Kingdom [2]. It represents the first concerted effort to produce a small scale test method that reliably tests both the ignition and burning behaviour of hydraulic fluids. It is generally applicable to situations where finely dispersed sprays of hydraulic fluid could be produced as it tests inherent combustion characteristics of the fluid rather than some specific fire behaviour bound to a specific application.

The hydraulic fluid is sprayed inside a combustion chamber using a stainless steel pneumatic atomiser which produces an atomising spray consisting of the fluid and air under pressure. Further, a forced flow of air in the combustion chamber is used to ensure minimal disturbance of the spray by turbulent effects upon ignition. The temperature of the test fluid must be maintained between 13 and 20 °C. This spray is then exposed to a propane flame. The test rig is shown in Figure 1. The temperature of the test chamber, the fresh air and the exhaust gases are measured both with and without an ignition flame, in both cases with air coming through the nozzle. The temperature is recorded using a K-type thermocouple and is then used to calculated an ignitibility factor, *RI*. A burning spray is said to have been stabilised when its energy release, length and other properties are steady as a function of time and time averaged values of the ignitibility factor are calculated.

Discrimination of fluids with low ignitibility is facilitated by using two propane flow rates for the ignition source. The low flow rate (0.13 Nm^3/hr) is sufficient for discrimination of most fluids while only those that exhibit especially poor ignitibility (i.e., good fire resistance) are tested using a higher propane flow (0.4 Nm^3/hr). Provisions are made in the test apparatus for the calculation of smoke opacity and a flame length index, *RL*, although these results are not used explicitly in the primary classification scheme.

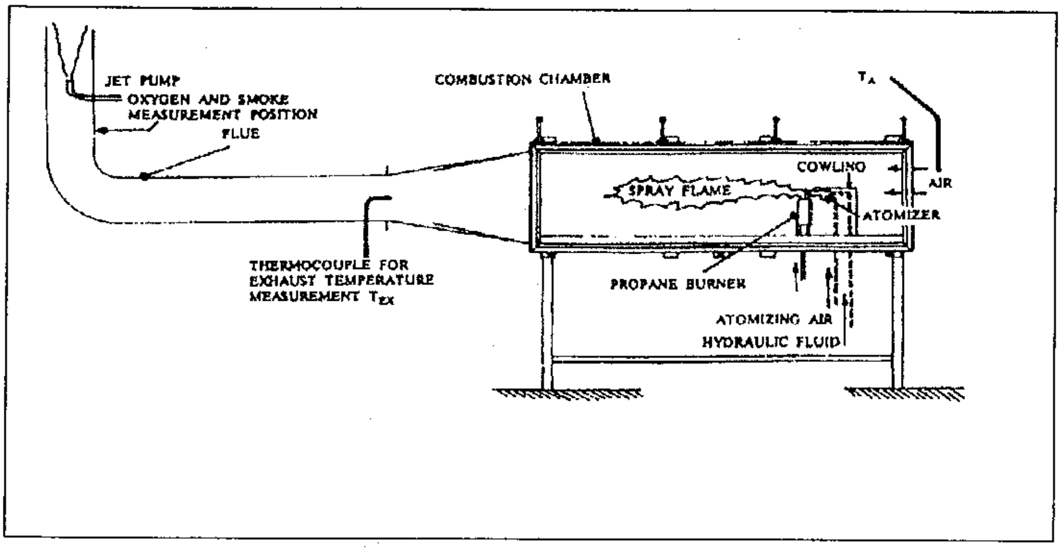


Figure 1 *Test apparatus for ISO 15029-2 (also know as the Buxton test). The test chamber is approximately 2 m long and 0,5 m high.*

The ignitibility factor is calculated based on the temperature measurements. In the case of the low propane flow rate the calculation is made using the following equation:

$$RI_w = \frac{500(T_p - T_{A1})}{7(T_{EX} - T_{A2})}$$

where RI_w is the 'raw' ignitibility factor (i.e., without a calibration correction), T_P is the exit temperature, T_{A1} is the air entry temperature without the jet spray, T_{EX} is the temperature of the combustion gases with the jet spray, and T_{A2} is the entry air temperature with the jet spray. All temperatures are measured in degrees Celsius. The value should be presented as an integer, rounded up or down as necessary. Should this value exceed 50 it is discarded and a new test is made with the high propane flow.

In the case of the high propane flow rate the calculation is made using the following equation:

$$RI_w = \frac{100(T_p - T_{A1})}{T_{EX} - T_{A2}} + 30$$

where all the parameters are defined as above.

An elaborate calibration procedure is described in detail in the Luxembourg document. A series of calibration tests are carried out using solutions of pure ethylene glycol and demineralised water. The results of these tests are fitted to a quadratic equation for each of the propane flow regimes and these equations are used to scale the RI_w obtained from the test fluids. This procedure is used to eliminate any problems associated with drift in the test apparatus and to ensure the repeatability of results obtained using this procedure in different testing laboratories.

The ignitibility factor, *RI*, provides a convenient means of ranking a fluid according to the ignitibility risk it presents. A primary grade ranging from A, safest, to H, most hazardous, can be given based on this factor. Secondary rating can be made based on the flame length index, *RL* (with grades ranging from A, safest, to F, most hazardous) or the optical density of the smoke, *D* (with grades ranging from A, safest, to D, most hazardous). This is summarised in Table 1. The secondary rating cannot be used to pass or fail a fluid but is meant to give extra guidance in choosing the best fluid for a given application. Classification of all types of hydraulic fluids is possible.

Table 1 Summary of classification schemes for the Buxton method. RI is the ignitibility factor, RL is the flame length index and D is the optical density of the smoke.

Classification Scheme	Classification Parameter	Safest grade	Most hazardous grade
Primary	*RI*	A	H
Secondary	*RL*	A	F
Secondary	*D*	A	D

2.2 Experimental description of ISO 15029-3

This test measures the combustion efficiency of a well-defined spray of hydraulic fluid, using three different ignition source intensities. The test is a down-scaled version of a large scale test rig that was designed to mimic the types of sprays one could expect from a rupture in hydraulic lines or connections [3].

The hydraulic fluid is forced through a swirl nozzle under pressure while maintained at a temperature that is representative of operating temperatures. Test pressures of approximately 50, 100, 150 and 250 bar are then used, the exact choice of pressures for testing being partially determined by manufacturers recommendations for the fluid in question. Three separate ignition sources are tested at each pressure and the heat release rate and mass flow of the fluid are measured. The ignition sources are composed of three open tube propane burners, with their size defined in terms of their heat release rate (10, 100 and 200 kW) and internal diameters. The test apparatus is shown in Figure 2.

The Heat Release Rate as measured in the experiments is corrected for the effect of the burner and then used to calculate a combustion efficiency, ϕ.

The results of this method are presented as a combustion efficiency. The combustion efficiency, ϕ, is calculated using the following equation:

$$\phi = \frac{(\dot{Q}_{O_2} - \dot{Q}_{O_2 ign})}{\dot{m}q}$$

where $\dot{Q}_{O_2}$ is the heat release rate as measured in the test (kW), $\dot{Q}_{O_2 ign}$ is the heat release rate of the ignition source (kW), $\dot{m}$ is the mass flow of the fluid as measured in the test (kgs^{-1}) and q is the net heat of combustion of the tested fluid (water in gas phase) determined using the ASTM D240-76 Bomb Calorimeter (MJkg^{-1}). Further, the analysis of the production of CO and CO_2 and the density of the smoke evolved were conducted as a part of the test.

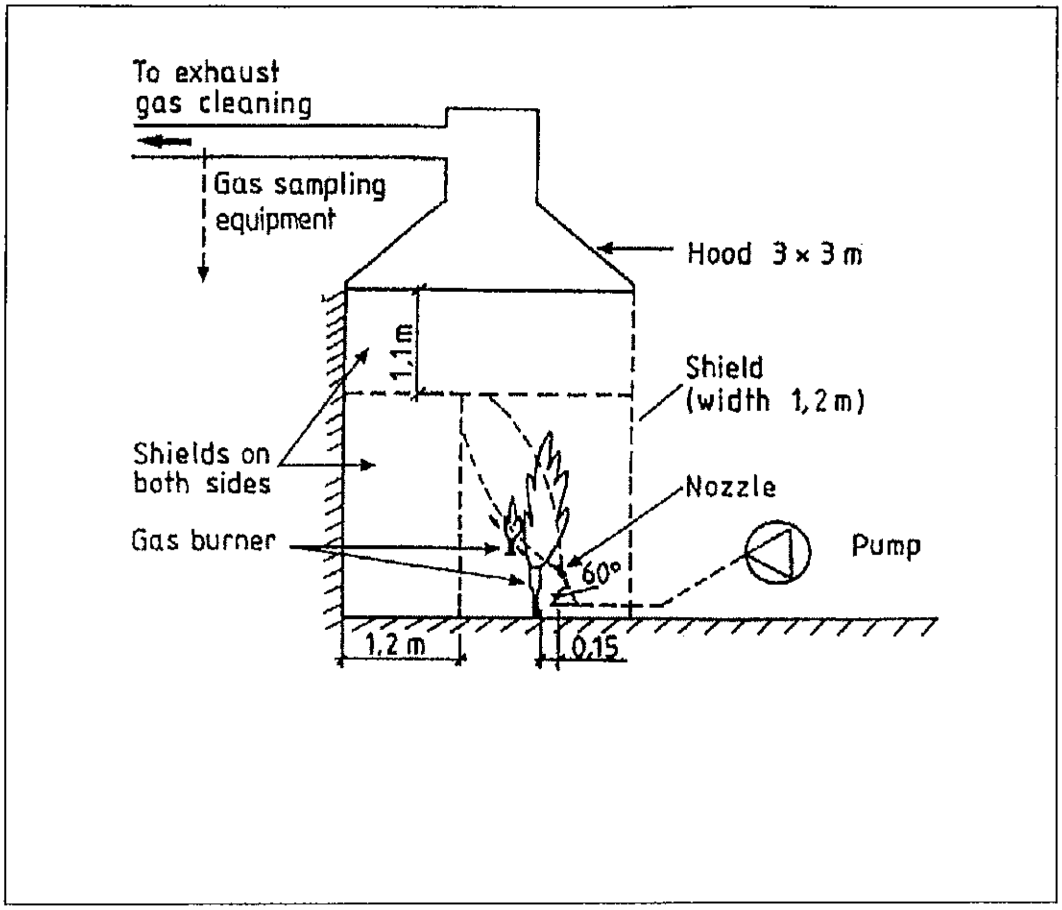


Figure 2 Test apparatus for ISO 15029-3 (also know as NT FIRE 031).

This test method contains no provisions for the classification of the tested fluid. It does not even suggest criterion for a pass/fail gradation. The method provides information concerning the intrinsic fire behaviour of the fluids tested, it gives a realistic result that can be related to real life applications and is not operator dependent (i.e., it has good reproducibility and repeatability). It is, however, somewhat crippled by the lack of a classification scheme which makes interpretation of the results difficult. The work presented in this report represents an effort to increase the utility of the method. Practical difficulties arise when testing fluids containing greater than approximately 70-80 % water. The test method itself places no constraints on which fluids may be tested. Special pump equipment would, however, be necessary to facilitate the testing of fluids containing very large amounts of water.

2.3 Fluids Tested

A set of eight (8) hydraulic fluids were included in the study. These fluids were selected such that they would exhibit a range of fire behaviours. The fluids are summarised in Table 2 below. The water content was determined using ASTM E 203-75, Karl-Fischer titration. The Heat of Combustion was determined using the ASTM D 4809-90 bomb calorimeter.

Table 2 *Summary of hydraulic fluids included in the tests, their water content, and Effective Heat of Combustion*

Code	Type	Water content	Heat of Combustion*
I	Oil-in-water	97%	Not Measured
II	Water-glycol	34%	13,00 MJ/kg
III	Water-glycol	48%	9,41 MJ/kg
IV	Glycol	5%	26,70 MJ/kg
V	Phosphate ester	<0,1%	29,99 MJ/kg
VI	POE	<0,1%	36,90 MJ/kg
VII	PAO	<0,1%	41,34 MJ/kg
VIII	mineral oil	<0,1%	42,85 MJ/kg

*Effective Heat of Combustion, i.e. corrected for the Heat of Vaporisation of water.

Note that fluid I was composed of 97% water and was not expected to burn using the ISO 15029-3. As this fluid was unsuitable for the pump in this apparatus it was not tested using this method and therefore no Heat of Combustion was determined for this fluid. It has been assigned a proposed Combustion Efficiency of <5%.

2.4 Results

ISO 15029-2

Multiple repeats of each test were carried out but not all tests were repeated the number of times laid out in the 7th Report due to time and resource constraints.

The propane burner at low flow rate (0.13m^3hr^{-1}) produces 3.07 or 3.29kW based on oxygen consumption or calorific value of fuel. The high propane flow rate produces 9.21 or 10.12kW based on similar ideas. The burner outputs have not been subtracted from the heat release rates given below. The oxygen consumption was averaged over the duration of the test with readings taken manually at the same times as the temperatures. The instrument used had a resolution of 0,05%. The results of the ISO 15029-2 are summarised in Table 3.

Table 3 *Results of ISO 15029-2 tests. The standard deviations are cited in parentheses.*

Fluid	C_3H_8 Flow	RI	RL	Smoke opacity	Q (kW)	Class
I	High	119,5 (6,7)	89,6 (9,0)	0,019 (0,003)	12,2 (3,1)	A
II	High	79,3 (5,2)	50,4 (0,79)	0	29,0 (2,6)	C
III	High	89,0 (2,0)	55,2 (5,2)	0,007 (0,010)	24,4 (3,1)	B
IV	Low	10,2 (0,8)	7,1 (0,1)	0	41,5 (2,4)	H
	High*	32,4	45,1	0	54,9	
V	Low	36,3 (5,9)	10,5 (1,1)	0,097 (0,010)	15,3 (3,1)	E
	High*	44,1 (2,8)	44,4 (4,4)	0,023 (0,004)	48,8 (4,3)	
VI	Low	9,7 (0,6)	5,0 (0,5)	0	48,8 (3,1)	H
VII	Low	7,7 (0,2)	5,1 (0,1)	0	54,9 (6,1)	H
VIII	Low	7,1 (0,4)	6,4 (0,8)	0	53,4 (7,9)	H

The results are given as means with the standard deviations cited in parentheses. The so called 'High*' tests in Table 5 were not a requirement of the procedure but done for interest and to see the results given. Smoke measurements do not seem very useful.

ISO 15029-3

The results of the ISO 15029-3 experiments are summarised in Tables 4 and 5. Graphical results from the large scale tests are summarised in Appendix 1.

Table 4 *Fluid flow rates as measured for each fluid and pressure. 'NA' indicates that the fluid was not tested at this pressure.*

Fluid	Flow rate at 50 bar (g/s)	Flow rate at 100 bar (g/s)	Flow rate at 150 bar (g/s)
I	NA	NA	NA
II	21	29	NA
III	20	28	NA
IV	20	28	34
V	19	29	38
VI	18	27	33
VII	19	26	32
VIII	19	27	33

Table 5 *Results of ISO 15029-3 tests. The Burner diameter of the three ignition sources, ∅, is cited in mm, the fluid pressure is in bar, and the combustion efficiency, ϕ, is a value between 0 and 1. A combustion efficiency of '0' indicated no ignition of the fluid. 'NA' indicates that the fluid was not tested using this combination of ignition source and pressure.*

∅	P	ϕ(I)	ϕ(II)	ϕ(III)	ϕ(IV)	ϕ(V)	ϕ(VI)	ϕ(VII)	ϕ(VIII)
10	50	<0,05	0	0	0,93	0	0,61	0,89	0,84
	100	<0,05	0	0	0,88	0	0,27	0,98	0,97
	150	<0,05	NA	NA	0,86	0	0	0,97	0,95
25	50	<0,05	0,45	0,37	0,95	0,74	0,66	0,95	0,81
	100	<0,05	0,62	0,11	0,95	0,89	0,90	0,99	0,94
	150	<0,05	NA	NA	0,85	0,84	0,93	0,98	0,95
100	50	<0,05	0,50	0,51	0,93	0,82	0,62	0,83	0,83
	100	<0,05	0,85	0,52	0,84	0,91	0,88	0,98	0,95
	150	<0,05	NA	NA	0,89	086	0,93	0,98	0,96

Those fluids that exhibit a combustion efficiency of ϕ>0,80 show the same fire behaviour for all ignition sources. Thus, provided ϕ>0,80 it would be sufficient to test the fluid using the medium sized ignition source only although it would be wise to use the smallest ignition source also to determine borderline cases. The 25 mm ignition source is more reliable than the hand held source while the largest burner represents an unnecessary expenditure of energy without providing additional information. Thus, this source provides the best information for later classification of the fluid.

Further, it was determined that those fluids which are difficult to ignite using the smallest burner should be tested at 50 and 100 bar only. This is because these fluids consistently extinguished the bunsen flame by virtue of the high flow of a marginally flammable fluid found at the 150 bar level. Those fluids do not ignite with the smallest ignition source should be ordered amongst themselves first and given a lower flammability than fluids which do ignite with this ignition source. However, due to the difficulty of sustaining a flame in these fluids, the medium sized ignition source at a pressure of 100 bar provides the best trade off between the volume of fluid available for combustion and droplet size thereby giving the broadest division of fire behaviour. Thus, test results from the 25 mm burner at 100 bar should be used for ordering of these fluid also. Similarly fluids which can be ignited using the smallest ignition source but have difficulty maintaining a stable flame should be ordered amongst themselves and placed after this first group, although once again the classification should be made based on the results of the 25 mm burner at 100 bar.

Even in the case of the more highly flammable fluids the combination of pressure and ignition source stated above seems suitable for fluid classification.

Based on the above discussion one can recommend a coarse classification of the hydraulic fluids using the ISO 15029-3 test method. The smallest ignition source could be used to break the fluids up into three groups: ‘a’ those readily ignited, ‘b’ those with unstable ignition and ‘c’ those with no ignition. Within each group the fluids could be ordered according to the combustion efficiency based on a single measurement at 100 bar using the 25 mm ignition source. This method has been used when ordering the fluids below.

2.5 Comparison of Results

There is a clear division of the fluids into those containing large amounts of water and those that were essentially free from water in terms of the fire behaviour determined using both methods. Fluids I, II, and III did not exhibit a high combustion efficiency using the large scale method and it was necessary to test all three fluids using the high propane flow in the small scale method. Ordering of all eight fluids based on combustion efficiency for the large scale method as described above, and according to the ISO 15029-2 as described in the Luxemburg document as the Buxton method, are compared in Table 6.

Table 6 *Comparison of ordering of the fluids according to flammability from least flammable (at left) to most flammable (at right). The value in parentheses is the classification according to each standard, as described above.*

ISO 15029-2	*Least.*	I (A)	III (B)	II (C)	V (E)	IV (H)	VI (H)	VII (H)	VIII (H)	*Most.*
ISO 15029-3	*flamm*	I (a)	III (a)	II (a)	V (a)	VI (b)	VIII (c)	IV (c)	VII (c)	*flamm*

A superficial comparison of the ordering of the fluids as found in Table 6 shows that the ordering is in agreement for the first four fluids but not for the last four. This is due to the fact that both methods have difficulty distinguishing between fluids which display a high spray flammability. All four of these fluids are in the same class according to ISO 15029-2 (i.e., 'H'). Similarly, all three of the four fluids would be placed in class 'c' as described above, based on the ISO 15029-3, while the fourth would be placed in class 'b' using this method (see Table 6 above). In other words, these fluids all exhibit similar behaviour and should be considered as representing a fire risk in an application containing even a small ignition source.

Relative to the ordering of the final four fluids, however, it is worth noting that the large scale method (ISO 15029-3) is more sensitive to the viscosity of the fluid tested. The more viscous the fluid tested the larger the droplet size using this method. In general one can say that as the droplet size increases the flammability decreases. The small scale method is not as dependent on viscosity as the spray is produced through an aspiration technique which consistently causes small droplets.

2.6 Conclusions

Both methods are able to provide an unambiguous grouping of the eight fluids present in the study. The viscosity of the fluid being tested is obviously an important parameter in the large scale test. This leaves the test open to manipulation in one sense in that additives can be used to increase the fluid viscosity in the hope of attaining a better fire rating. The large scale test does, however, realistically mirror a real scenario and therefore the increased fire rating would be acceptable provided the additives are not shear sensitive, i.e. are not degraded upon normal use of the fluid. This difficulty would indicate that testing of virgin and used fluid may be appropriate in the case of highly viscous fluids.

We suggest that fluids in classes 'A', 'B', 'C' and 'E' according to ISO 15029-2 be defined as 'fire resistant fluids'. Class 'A', 'B' and 'C' fluids are recommended for high temperature applications with surface temperatures above e.g. 500 °C, while class 'A', 'B', 'C', 'D' and 'E' fluids are recommended for high temperature applications with surface temperatures below e.g. 500 °C and where no open flame is present. Similarly class 'a' fluids according to ISO 15029-3 should be defined as 'fire resistant fluids'. Class 'a' fluids with a combustion efficiency of >80% (i.e., ϕ>0,80) according to this method measured using the 25 mm at 100 bar should, however, only be recommended for applications with surface temperatures below ca 500 °C and where no open flame is present. The choice of 500 °C is at present based on indications from the work conducted 15 years ago and should be confirmed by future investigations before being included in a standard.

3 Risk Assessment in Hot Industry

3.1 Case Study 1: Aluminium and Zinc Foundry

An aluminium and zinc foundry was investigated and fire risks were assessed , in particular those associated with any flammable fluid present in the machinery. The foundry has a total of 13 machines; 10 for aluminium casting and 3 for zinc casting.

The machines have a pump pressure of 160 bar in the hydraulic system, but can achieve up to 3,5 times this pressure in the casting cycle (which gives a maximum pressure of 560 bar). The mould is heated using a transistor oil at a pressure of approximately 2-3 bar. This oil is heated to 250 °C and the mould reaches a temperature of approximately 150 °C. A schematic picture of the layout is shown in Figure 3.

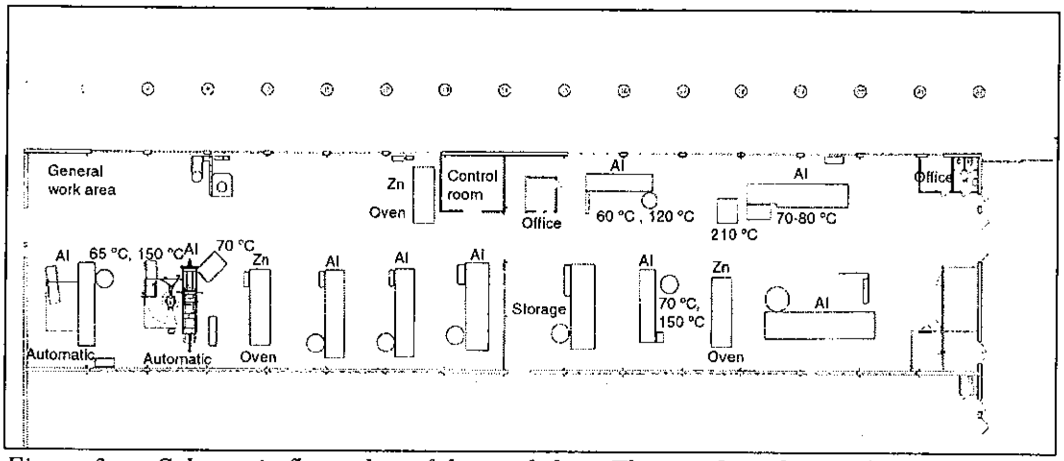


Figure 3 Schematic floor plan of the workshop. The metal used in each machine is shown as is the approximate surface temperature of the oven where such information was available.

There are a number of potentially flammable fluids in the machines. Some of these (such as the hydraulic fluid) are flexible and can be chosen according to the fire risk. In this particular application a so called 'fire resistant' hydraulic fluid is used (a water/glycol) and from the risk assessment one can see that a fire resistant fluid is necessary. Other fluids include the transistor oil described above, a release agent and a small volume of gear box oil. The release agent is an emulsion of oil in 97% water.

A number of accidents have occurred and it is expected that, due to the nature of the business, more may occur in the future. No fires have resulted from these accidents but had a flammable hydraulic fluid been used then an extremely dangerous situation could have developed. A generalised representation of the machinery is shown in figure 4. The arrow in the figure shows the position of a gasket where a number of leaks have occurred in the past. The so called accumulator tank (marked P_f) has a pressure of between 160 and 560 bar and in the case of a small breach of the gasket a spray of hydraulic fluid is released until the tank is empty (approximately 20-40 L of fluid). In the Aluminium machine the crucible containing molten metal was placed beside this end of the machine. In the Zinc machines, however, the so called accumulator was immersed in the molten metal. Despite the fact that a small open flame was associated with the Zinc moulding this machine was determined to be less hazardous because the gasket was below surface level.

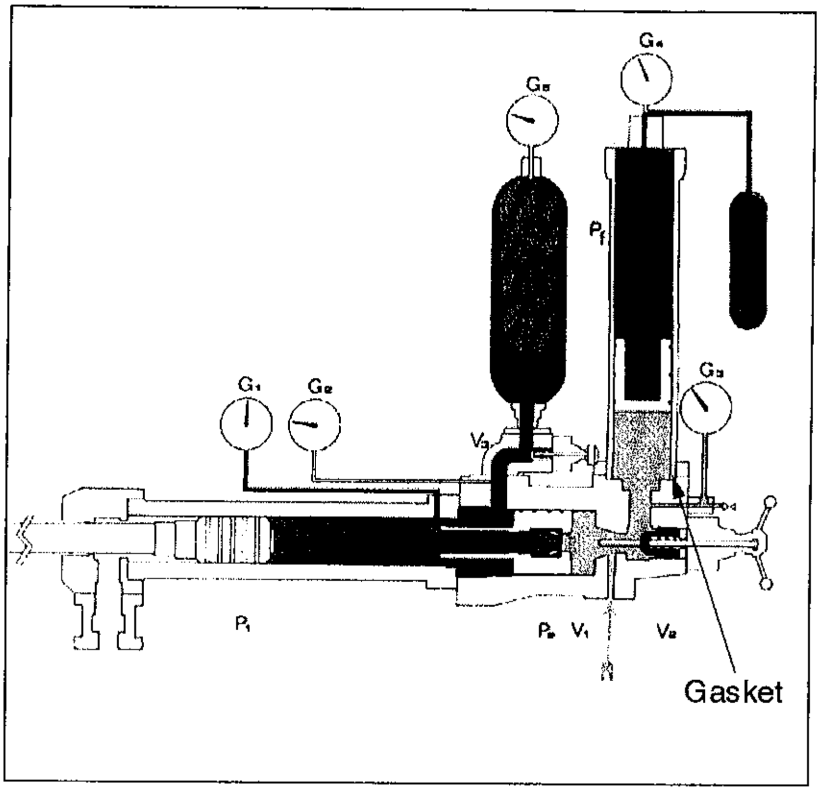


Figure 4 Generalised representation of hydraulics in founding machinery. The arrow marks the position of the gasket which was identified as a risk.

In the accidents in the Aluminium machines the hydraulic fluid sprayed directly into the crucible. In the case of Aluminium the molten metal has a temperature of 680–720 °C while the Zinc temperature is approx. 410 °C. In the case of the Aluminium melt ignition would occur should a spray of flammable hydraulic fluid impinge on the metal surface. In the case of the Zinc melt a more or less fire resistant fluid could be used, although a flammable fluid should not be used, partly because the gasket is immersed in molten metal and partly because of the lower melt temperature.

In this particular workshop the Zinc and Aluminium machines were placed in close proximity so that a spray from a zinc machine could conceivably impinge on a crucible containing Aluminium. Thus, it is important that all machines contain a hydraulic fluid with a very high fire resistance. Further, the surface temperature of the ovens containing the molten Aluminium was between 60–150 °C depending on where the measurement was made. A measurement was not made of the Zinc oven temperature but it is expected that it would be below that of the Aluminium melt.

Apart from the risk associated with this specific gasket there is always the possibility that a hydraulic join or flexible tube could spring a leak with the formation of a spray of hydraulic fluid. For the reasons outlined above it is important that a fire resistant hydraulic fluid be used in this application due to the inherent ignition sources present.

The machines had some fluid in a spill tray underneath the central moulding area. This contained varying amounts of fluid and was a combination of hydraulic fluid, oils and release agent. This fluid would consist of water to a large degree shortly after any spill. Due to the heat, however, it is probable that the water would evaporate and at some point the fluid could become a fire hazard. Regular removal of such fluid is important to reduce any possible fire risk.

In summary one can say that the workshop investigated has an obvious ignition source and a well documented history of accidents involving leaking hydraulic fluid under high pressure resulting in a spray of hydraulic fluid. The possibility that similar accidents may occur in the future seems great. Considering the fact that the majority of machines are manned (11 of 13) and the risk to life and property should a fire occur it is very important that a fire resistant hydraulic fluid is used that the fire risk is kept to an absolute minimum. In this case the ISO 15029-2 fluid classes of 'A', 'B' or 'C' would be suitable while class 'a' fluids according to ISO 15029-3, with a combustion efficiency of <0,8 measured using the 25 mm burner at 100 bar, would be suitable.

3.2 Case Study 2: Brass Foundry

An Brass foundry was investigated and fire risks were assessed , in particular those associated with any flammable fluid present in the machinery. The foundry has a total of 17 machines, all for brass casting.

The machines were similar to those described above in terms of the fluid technology. All machines were, however, semi-automatic and did not require manual removal of the casting. Three machines were fully automatic with partial dressing of the casting by a robot.

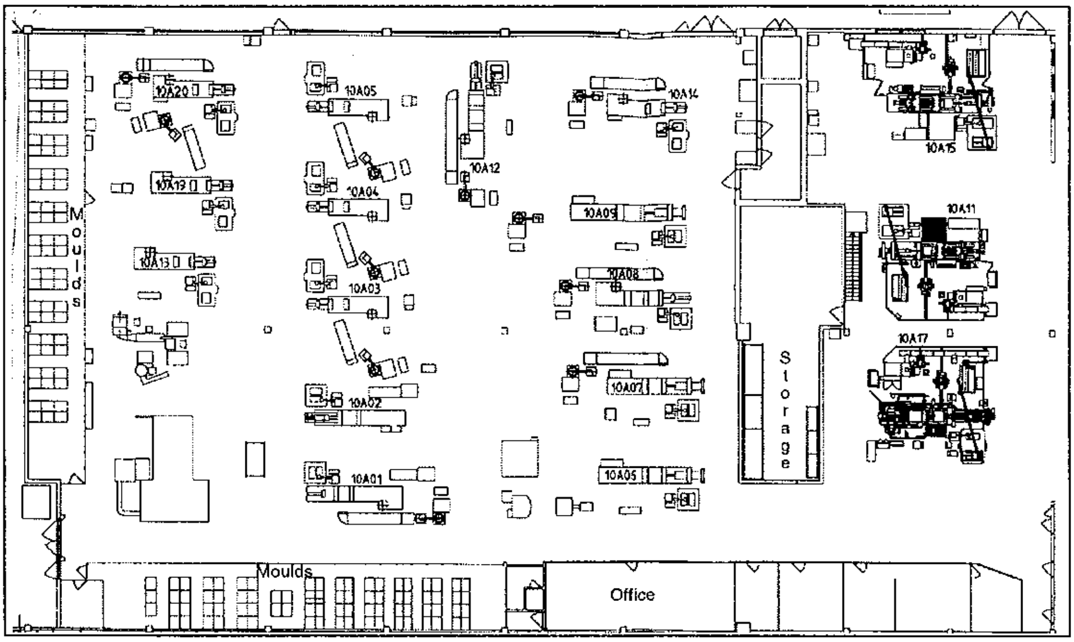


Figure 3 Schematic floor plan of the workshop.

There are a number of potentially flammable fluids in the machines. Some of these (such as the hydraulic fluid) are flexible and depending on the fire risk a more of less flammable fluid can be used.

In this particular application a so called 'fire resistant' hydraulic fluid is used (a water/glycol) and from the risk assessment one can see that a fire resistant fluid is necessary. Other fluids include the transistor oil described above, a release agent and a small volume of gear box oil. The release agent is a flammable powder but is used in very small amounts and as such represents a small risk.

No major accidents have occurred. No problems have been experienced with the gasket defined as the major risk at the other foundry. In this case the major risk was identified as all hydraulic connections and the hydraulic lines themselves. A minor accident occurred recently when an oven relay caused it to continue heating the molten metal beyond the limits otherwise set. The extreme temperatures involved gave rise to burn-off of the zinc portion in the metal which, in turn, gave rise to flaming. These flames were quite extensive due to the high temperature and caused a fire in the ventilation hood above the oven. The fire did not spread but there is an abundance of wooden material used for the construction of storage units in the workshop. The spread of the fire to such material does represent a risk and this material should be kept to a minimum.

In a number of cases small fires have resulted from the ignition of these wooden storage units by hot castings from the machinery. The fires have been easily discovered and extinguished but it would be advisable to use metal boxes for newly moulded material to avoid this risk. In one case such a wooden box was beside a line containing oil (at approximately 3 bar) if this were to spring a leak at the same time that the wooden box caught fire then ignition could result with dire consequences. This risk must be recognised as small but it is able to be avoided.

The moulding tools are separated by thin walls from the foundry. Further the ceiling in this storage area is wooden. In the case of a fire in the foundry hot fire gases could cause this material to ignite, thereby spreading the fire into this area. Thus, in the case of a fire in the foundry the tools could be damaged or destroyed. These tools represent a major capital investment by the company and should be placed in a separate area.

The machines are placed close together. Thus, should one machine begin to burn there is a definite risk that the fire could spread to nearby machinery. The crucible containing the molten metal (brass) is placed beside the end of the machine beside the hydraulics (as in the first case study). The ovens containing the crucible are all built in to a degree with the molten surface partially screen from any spray of hydraulic fluid. The surface temperature of the molten metal is approximately 975 °C and thus more than sufficient to ignite a flammable fluid. In this particular foundry the hydraulic fluid in all machines was a so called fire resistant fluid (a water/glycol). This choice is necessary due to the presence of such high temperature molten metal and associated high temperature surfaces (for the oven, the mould, and new castings). Were a spray of hydraulic fluid to be formed in this case there is very little danger of ignition. Were a flammable hydraulic fluid used and a similar spray formed then an extremely dangerous fire could easily result.

In summary one can say that the workshop investigated has an obvious ignition source an although they have had few accidents it is realistic to assume that accidents may occur in the future. Despite the fact that the machines do not require manual operation they do require observation and need to be checked regularly. The risk to life and property should a fire occur is great and in this application it is important that a fire resistant hydraulic fluid is used in order to keep the fire risk to an absolute minimum. In this case the ISO 15029-2 fluid classes of 'A', 'B' or 'C' would be suitable while class 'a' fluids according to ISO 15029-3, with a combustion efficiency of <0,8 measured using the 25 mm burner at 100 bar, would be suitable.

4 Work Safety Relevance and Future Work

At present there is no uniform, internationally accepted classification for hydraulic fluids according to their fire behaviour. Responsible bodies world-wide, such as the Swedish Board for Occupational Health and Safety, have been forced to take a very narrow view of what is acceptable in a number of hot industrial applications of fluid technology due to a lack of solid foundation for informed choices amongst the fluids presently available.

Ideally these organisations require a classification scheme based on the fire behaviour of the hydraulic fluids in order to facilitate the specific requirement of a given class of fluid rather that a given type. We believe that this study has been able to prove the suitability of both the small scale ISO 15029-2 and the large scale ISO 15029-3 in classification of the fluids. This classification has then been related to the surface temperatures present in a hot industrial environment. This recommended classification should open the way for the development of fluids with a better lubrication behaviour and good fire characteristics.

In cases where the surface temperature in the hot industry to exceed ca 500 °C at any time fluids of class 'A', 'B', or 'C' according to ISO 15029-2 are recommended while in cases where the temperature does not exceed 500 °C fluids of class 'A', 'B', 'C', 'D' or 'E' are suitable. Similarly, class 'a' fluids according to ISO 15029-3 are recommended in hot industry. In cases where the surface temperature may exceed 500 °C at any time the combustion efficiency should be below 0,8 when measured using the 25 mm burner at 100 bar.

The recommendation of a surface temperature of ca 500 °C to denote a boundary between different levels of fire hazard is presently based on experience of fire resistant fluids from work conducted almost 15 years ago. In order to confirm the choice of this temperature as a suitable safety level tests should be conducted using hot surfaces as ignition sources rather than open flames. Results of this type would complete the information needed to internationally promote the interpretation of the classifications schemes defined above.

It is recommended that this work be continued in the form of a Task Force of interested parties from SP, the Swedish Board for Occupational Health and Safety, the Swedish Foundry Association, and representatives from fluid manufacturers and distributors. This group would finalise the classification scheme and it's relationship to worker safety.

5 References

[1] 7th Luxemburg Document, "Requirements and tests applicable to fire-resistant hydraulic fluids used for power transmission and control (hydrostatic and hydrokinetic)", Doc. No. 4746/10/91 EN, Directorate General V (1994).

[2] A.J. Yule and K. Moodie, "A method for Testing the Flammability of Sprays of Hydraulic Fluids", Fire Resistance and Industrial Fluids, ASTM STP 1284, pp1-5 (1996).

[3] G. Holmstedt and H. Persson, "Spray Tests with Hydraulic Fluids", Fire and Safety Science - Proceedings of the 1st Int. Symp., pp 869-879 (1986).

Appendix 1: Results from ISO 15029-3 tests

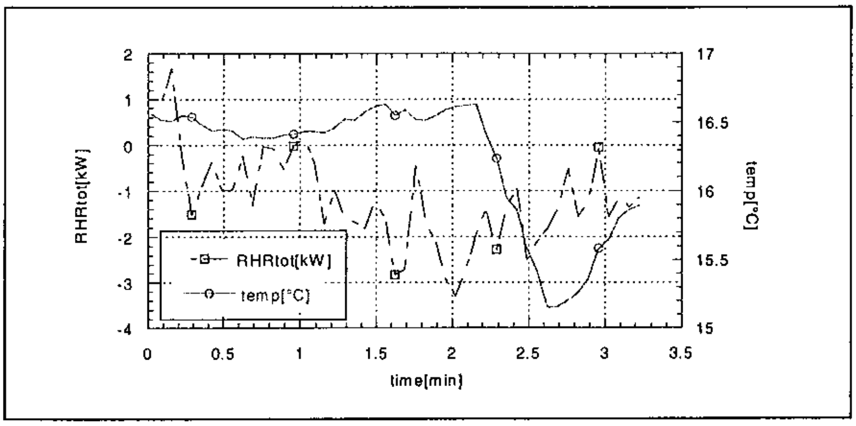
Fluid A

There are no large scale test results from fluid A. Due to the large amount of water in this fluid the pump in the large scale rig could not pump efficiently.

Fluid B

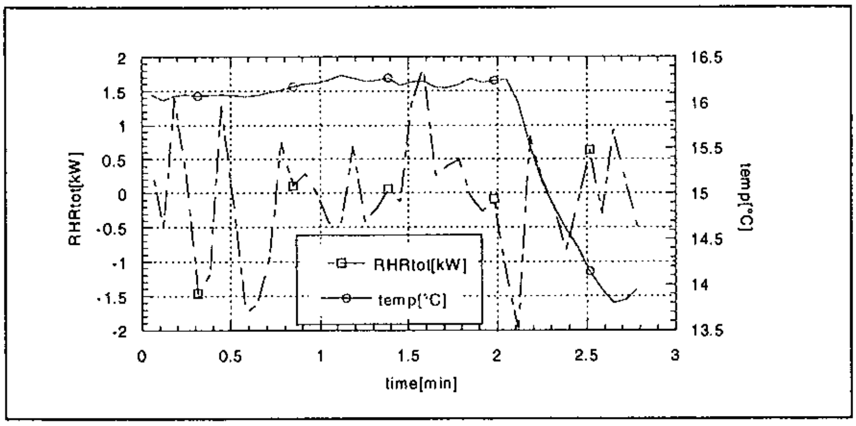
10 mm ignition source

50 bar



Fluid B - 10 mm burner

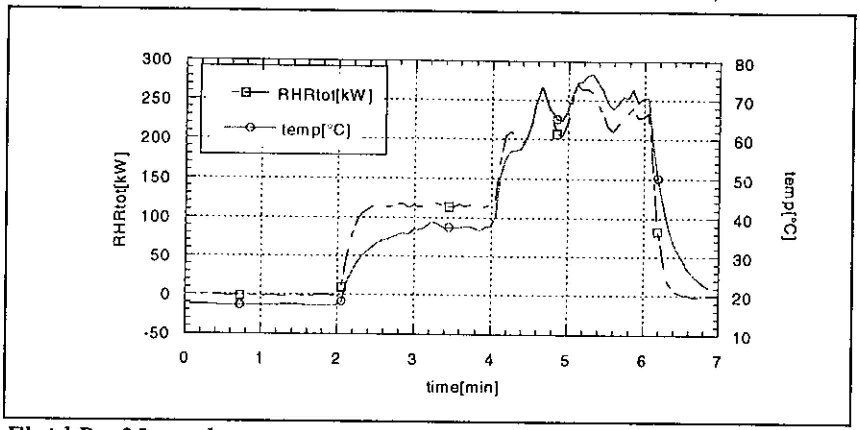
100 bar



Fluid B - 10 mm burner

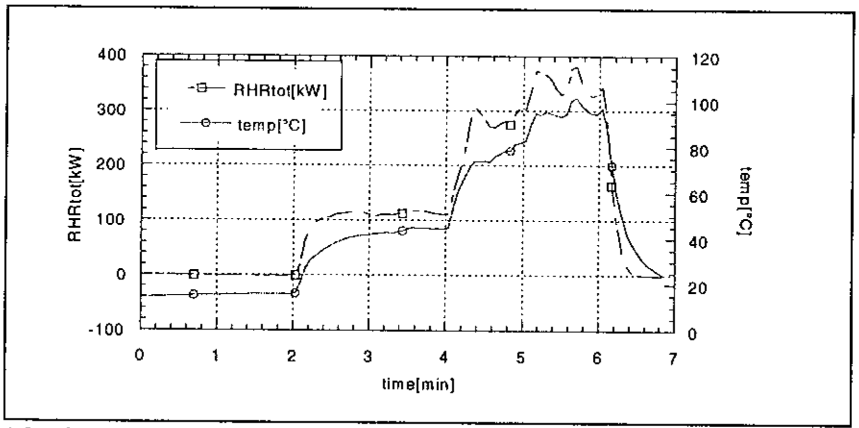
25 mm burner

50 bar



Fluid B - 25 mm burner

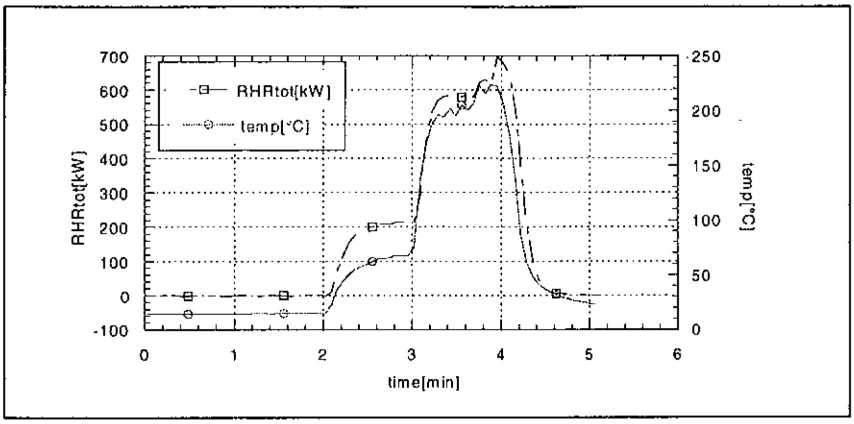
100 bar



Fluid B - 25 mm burner

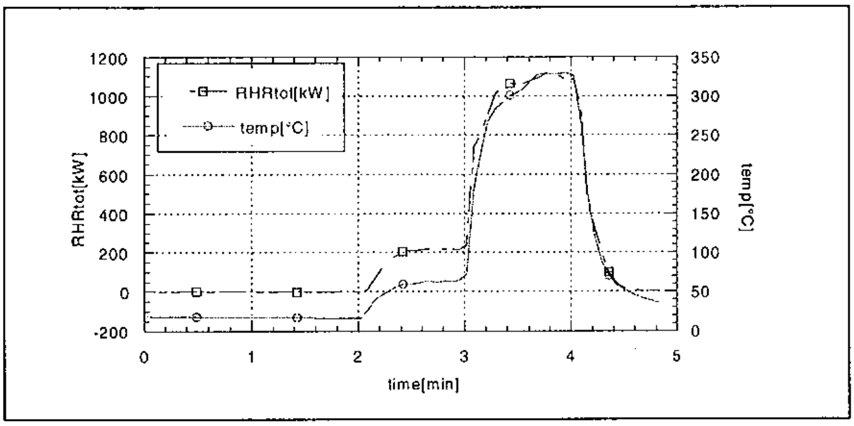
100 mm burner

50 bar



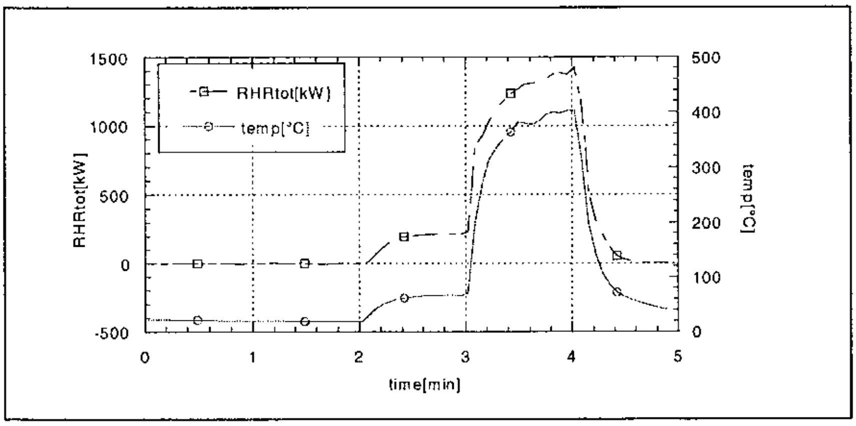
Fluid F - 100 mm burner

100 bar



Fluid F - 100 mm burner

150 bar

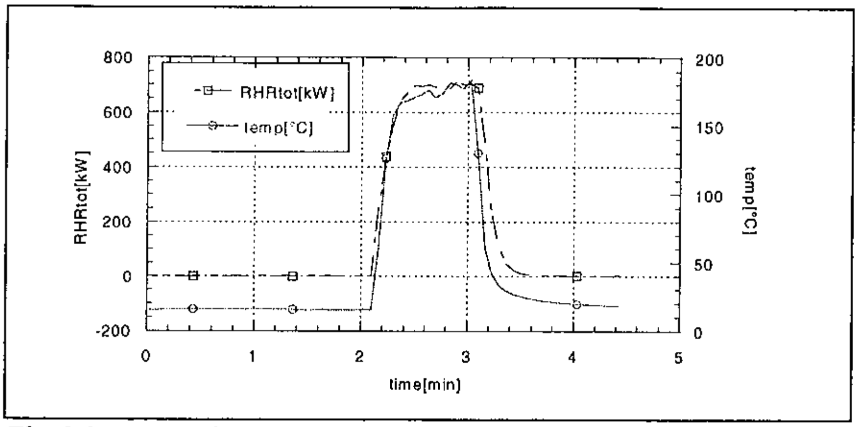


Fluid F - 100 mm burner

Fluid G

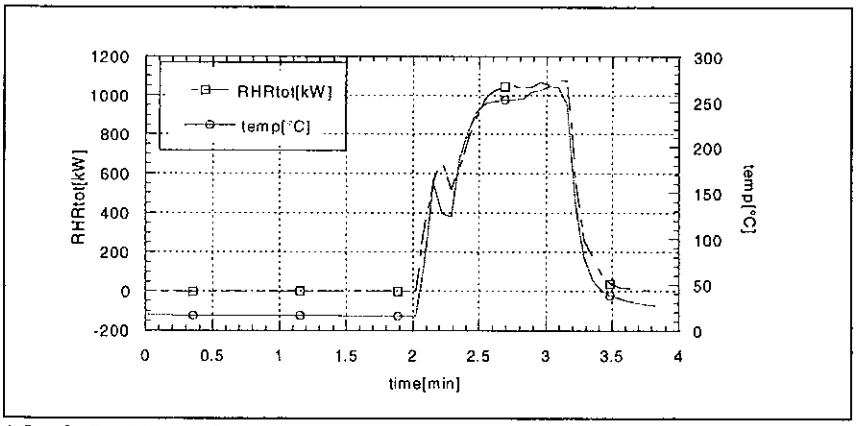
10 mm burner

50 bar



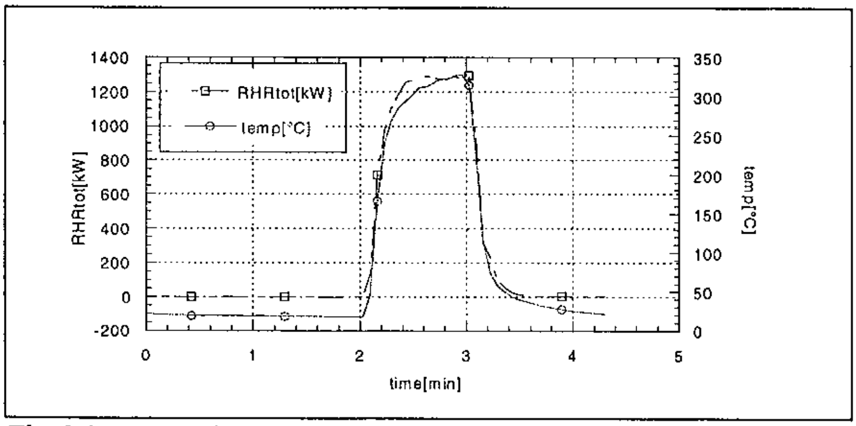
Fluid G - 10 mm burner

100 bar



Fluid G - 10 mm burner

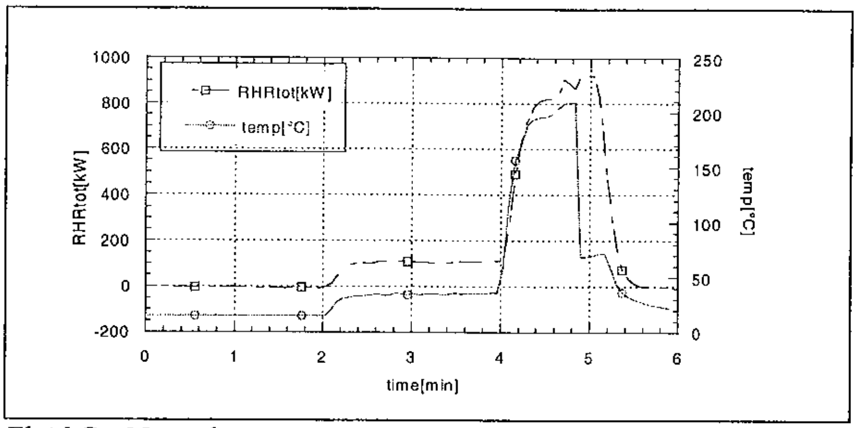
150 bar



Fluid G - 10 mm burner

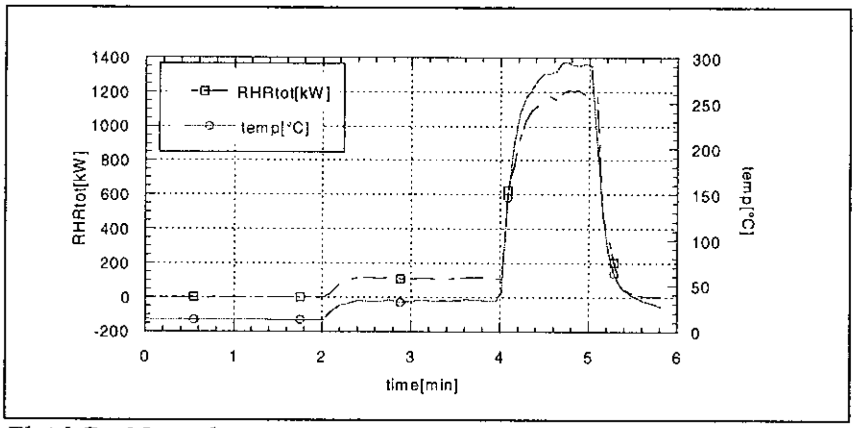
25 mm burner

50 bar



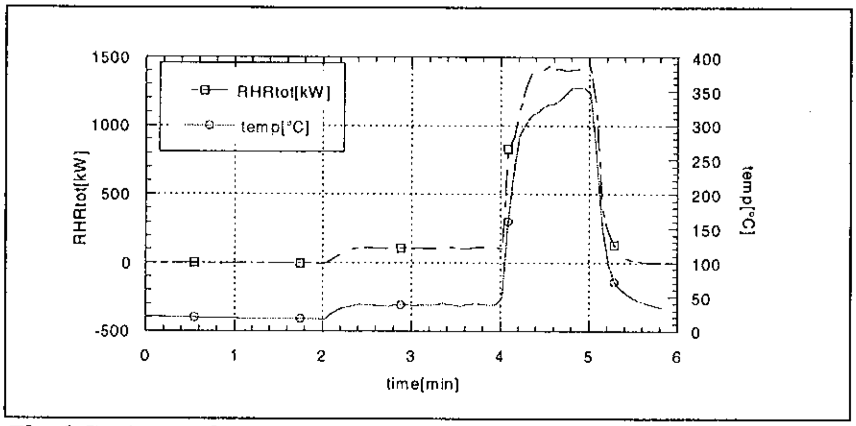
Fluid G - 25 mm burner

100 bar



Fluid G - 25 mm burner

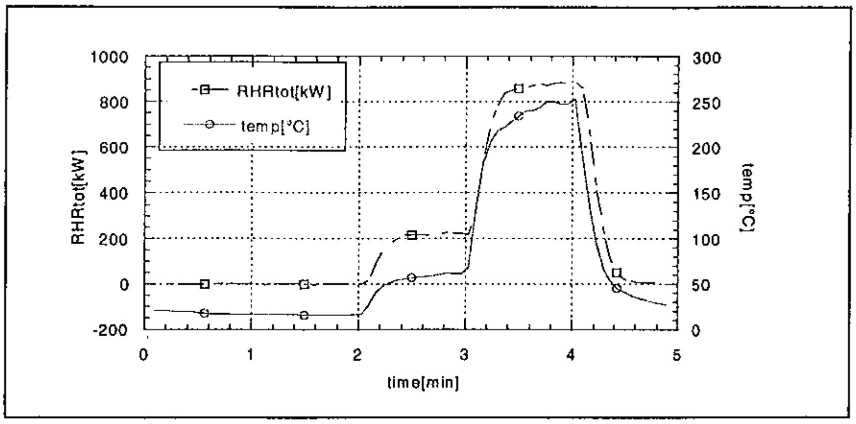
150 bar



Fluid G - 25 mm burner

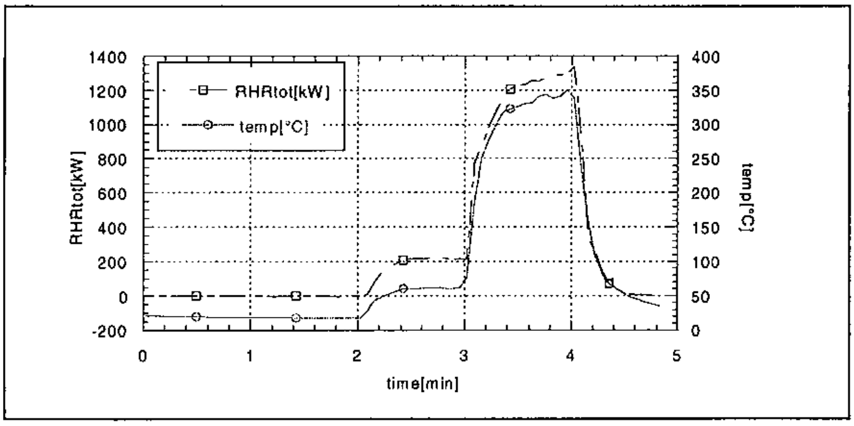
100 mm burner

50 bar



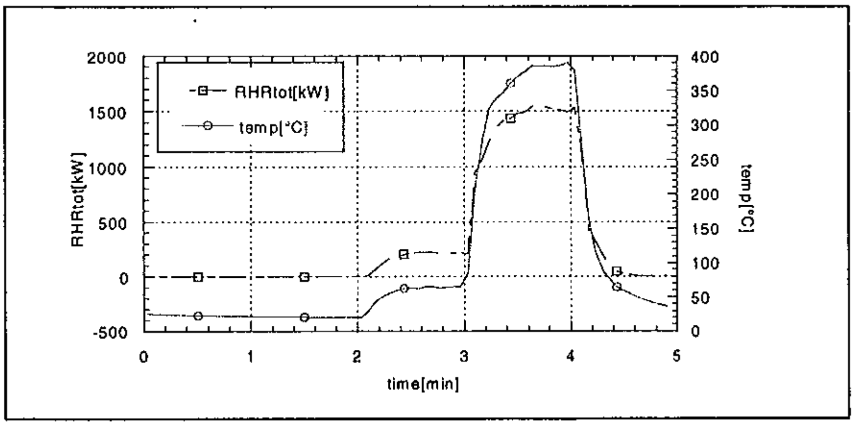
Fluid G - 100 mm burner

100 bar



Fluid G - 100 mm burner

150 bar

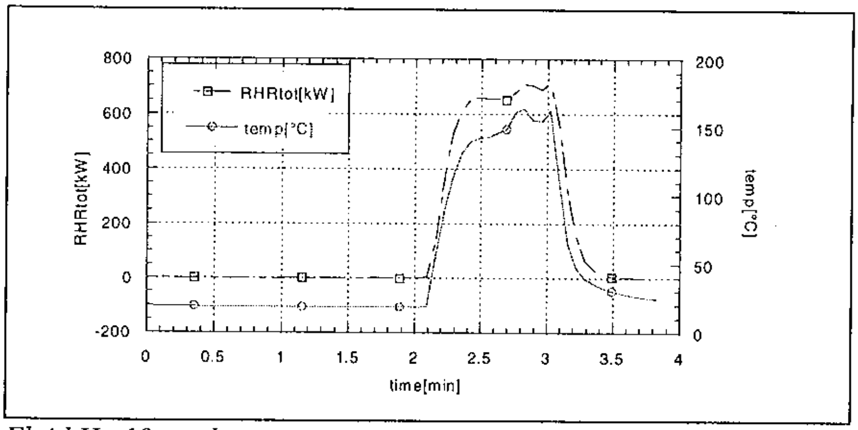


Fluid G - 100 mm burner

Fluid H

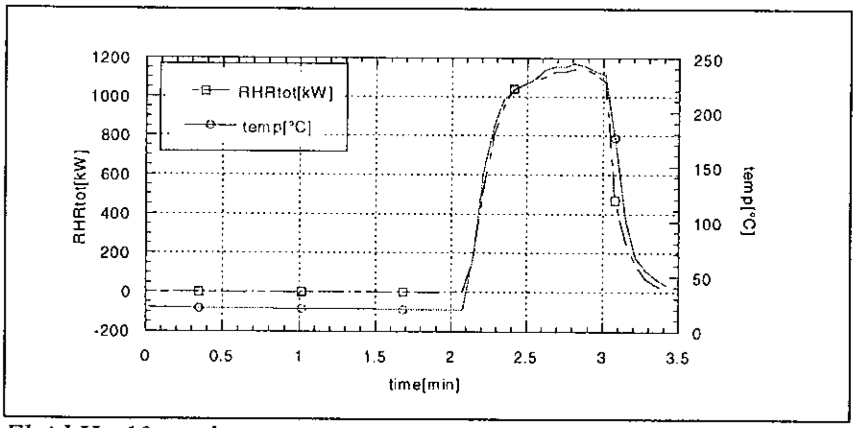
10 mm burner

50 bar



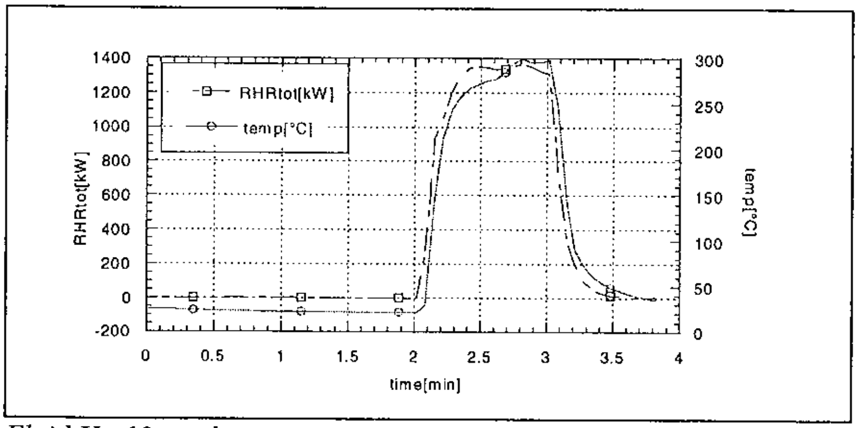
Fluid H - 10 mm burner

100 bar



Fluid H - 10 mm burner

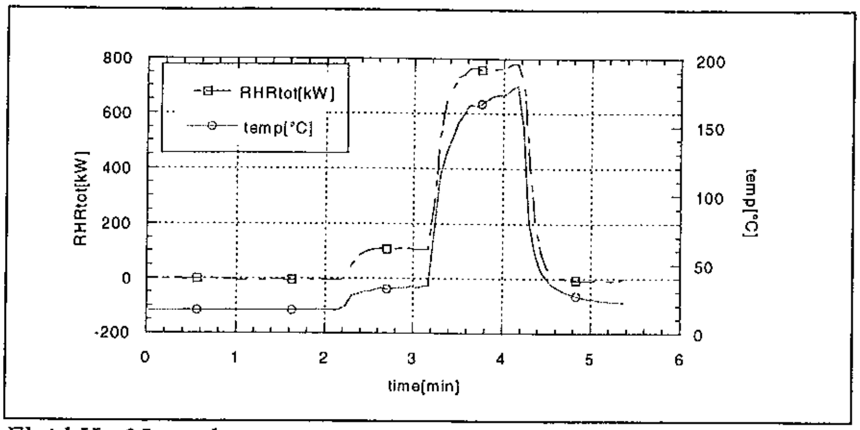
150 bar



Fluid H - 10 mm burner

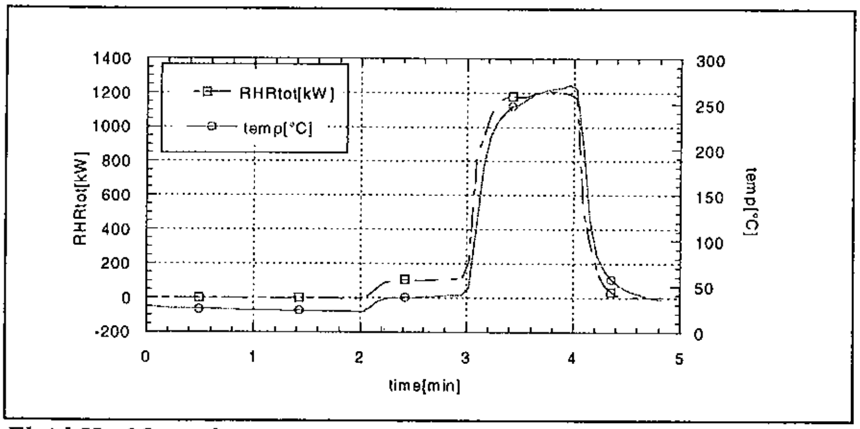
25 mm burner

50 bar



Fluid H - 25 mm burner

100 bar



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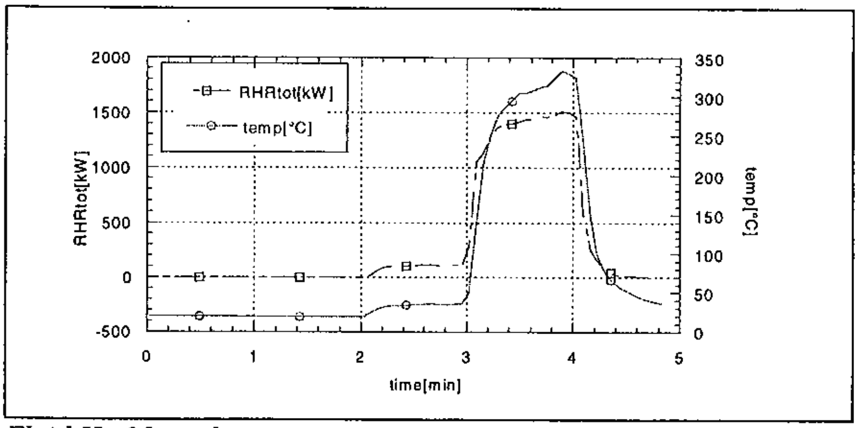
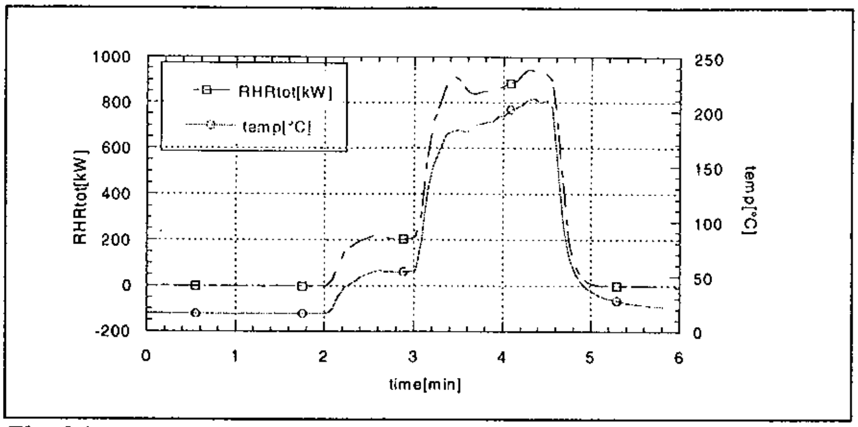
150 bar



Fluid H - 25 mm burner

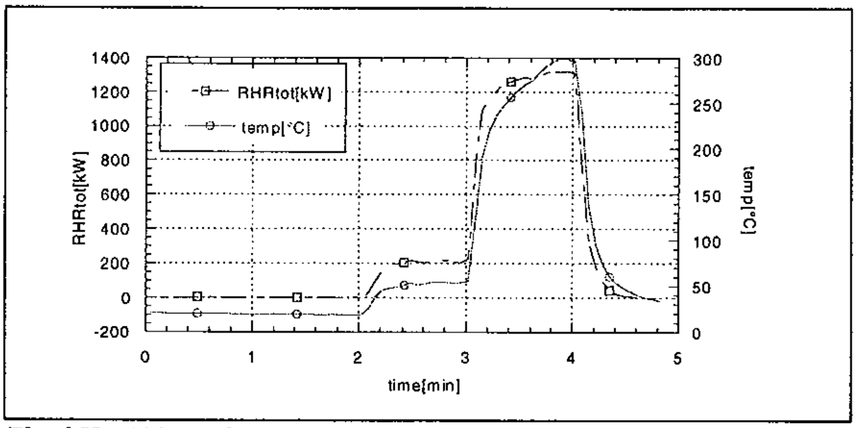
100 mm burner

50 bar



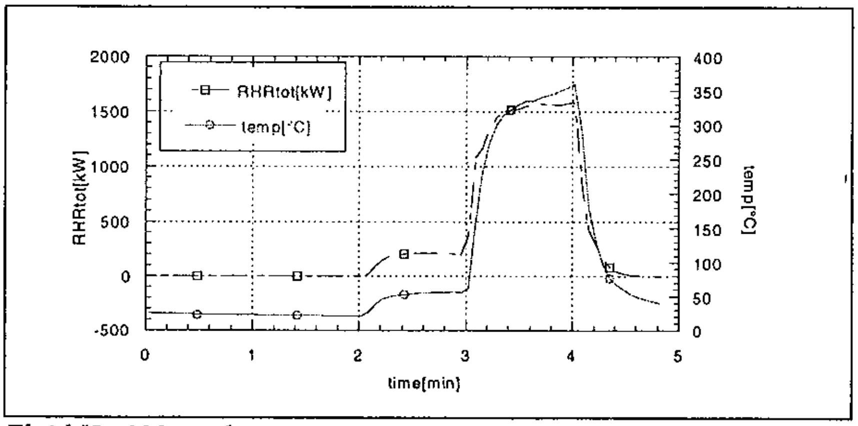
Fluid H - 100 mm burner

100 bar



Fluid H - 100 mm burner

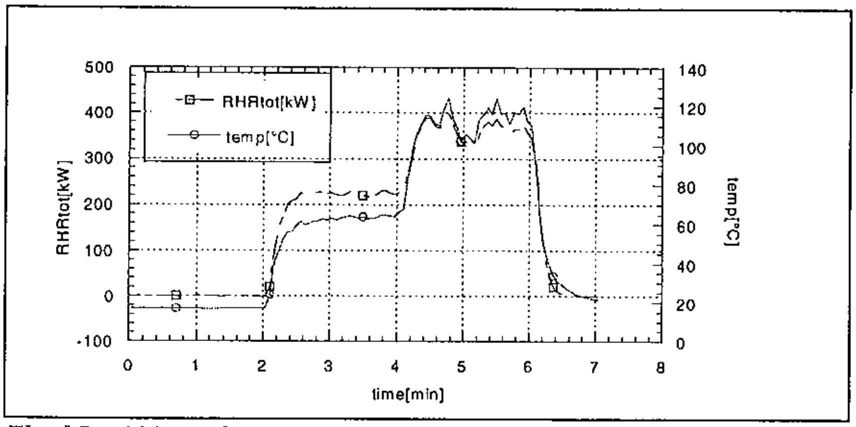
150 bar



Fluid H - 100 mm burner

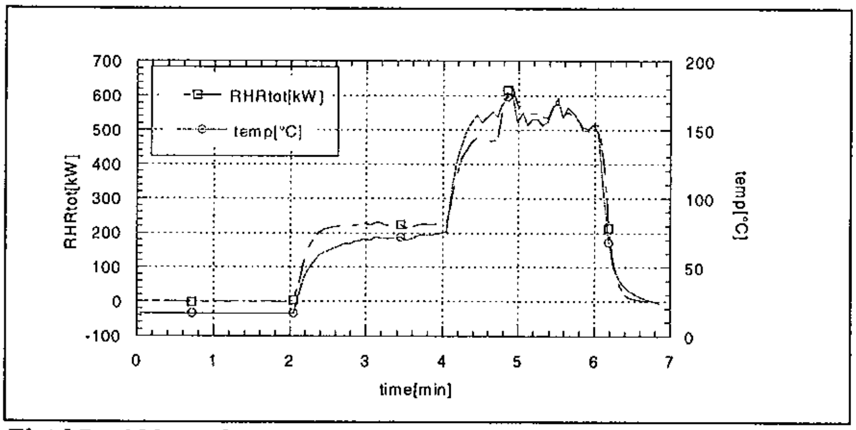
100 mm burner

50 bar



Fluid B - 100 mm burner

100 bar

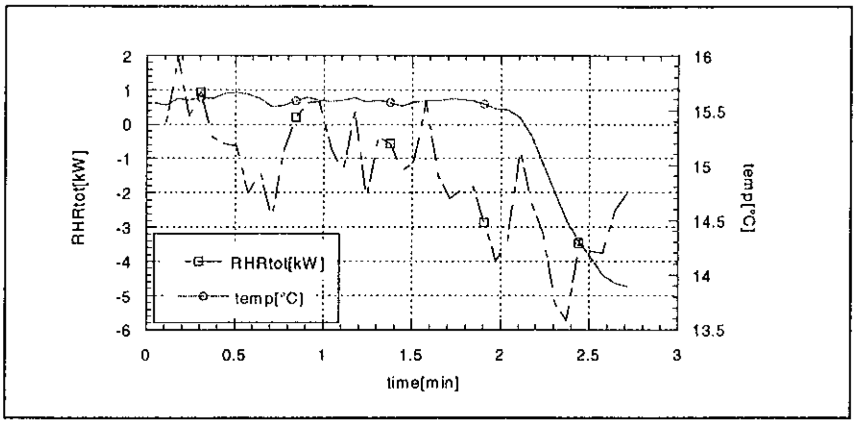


Fluid B - 100 mm burner

Fluid C

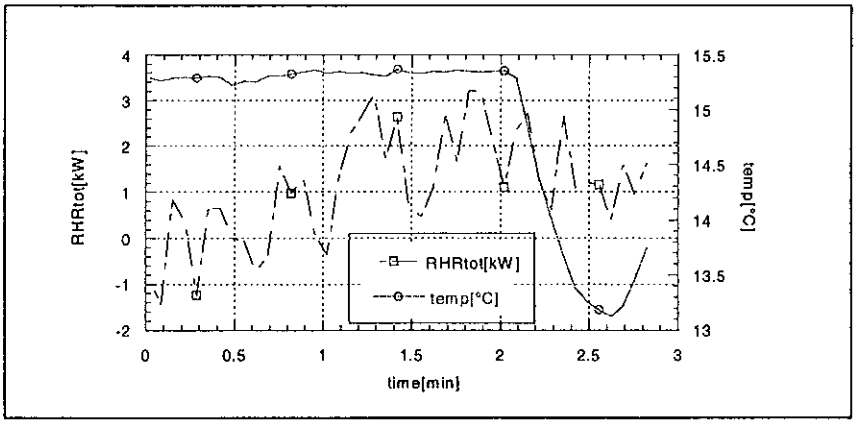
10 mm burner

50 bar



Fluid C - 10 mm burner

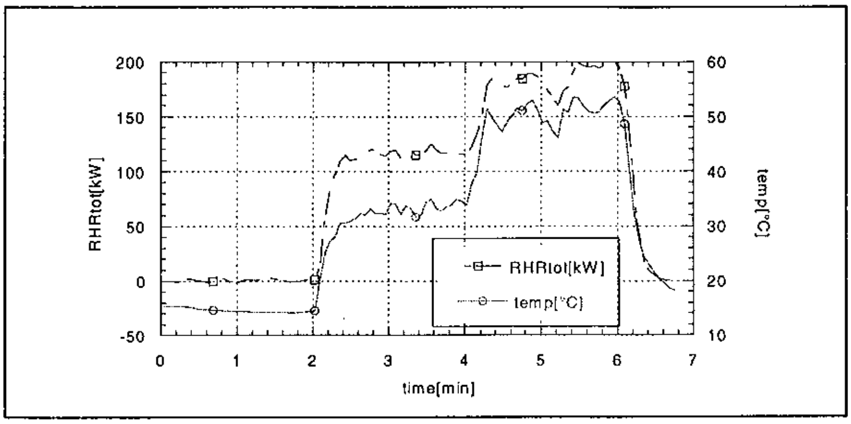
100 bar



Fluid C - 10 mm burner

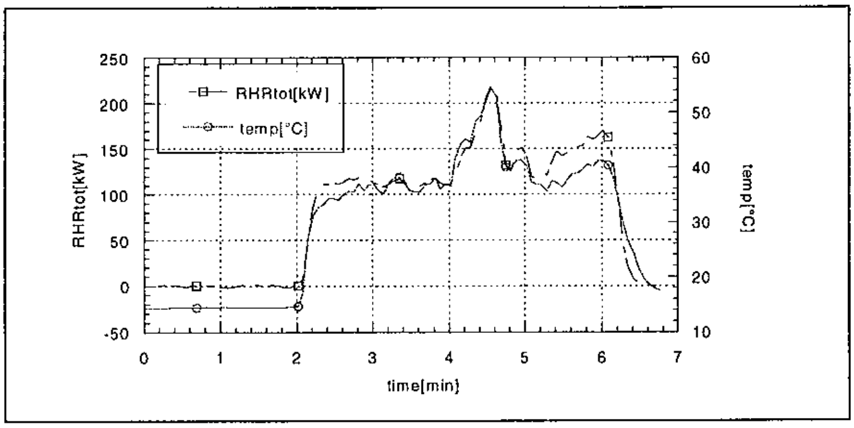
25 mm burner

50 bar



Fluid C - 25 mm burner

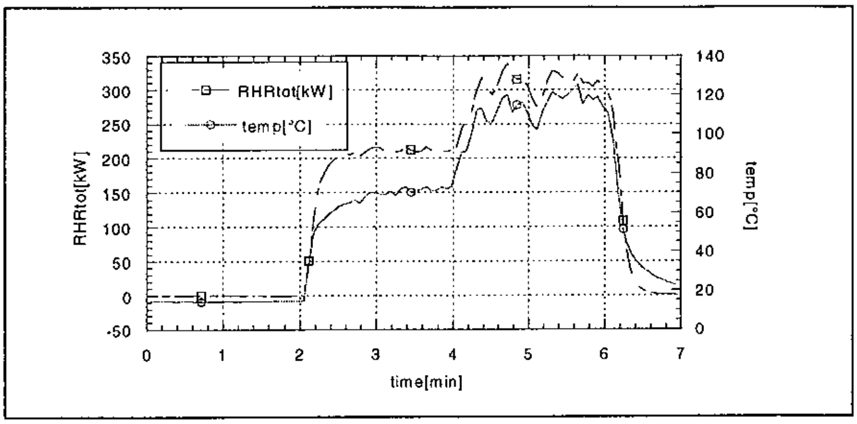
100 bar



Fluid C - 25 mm burner

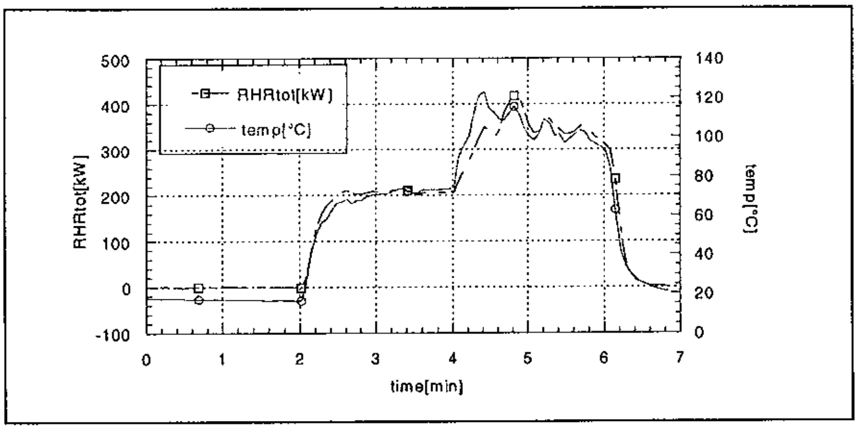
100 mm burner

50 bar



Fluid C - 100 mm burner

100 bar

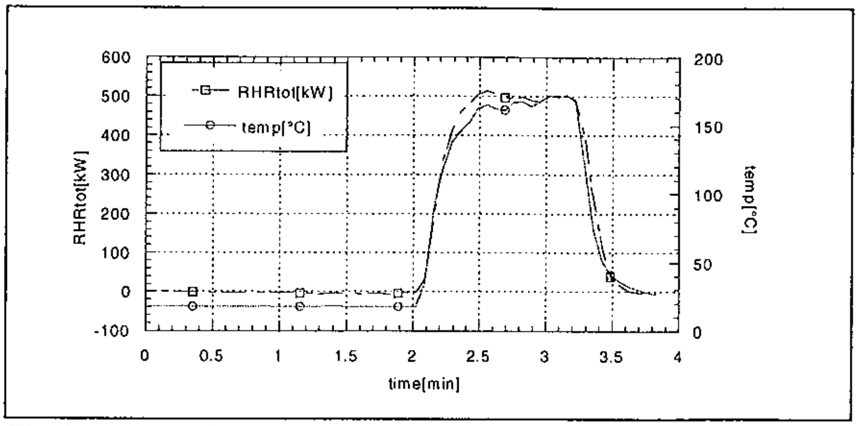


Fluid C - 100 mm burner

Fluid D

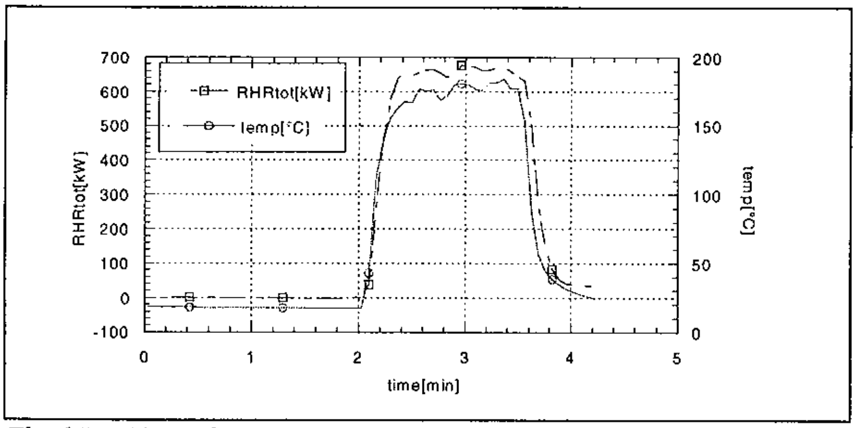
10 mm burner

50 bar



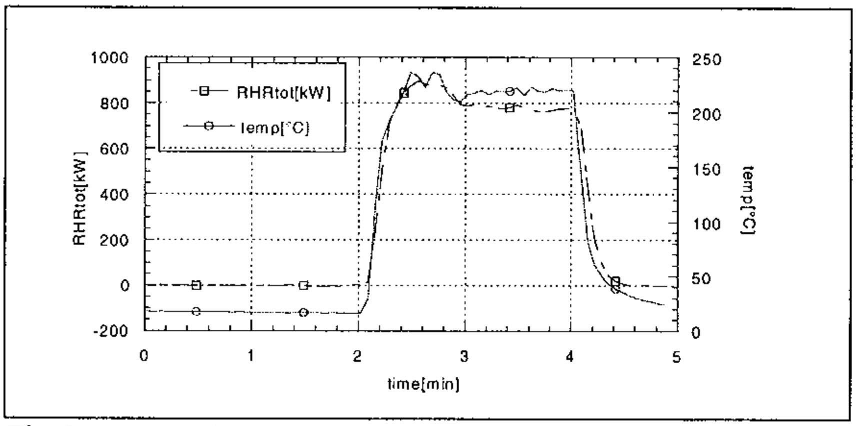
Fluid D - 10 mm burner

100 bar



Fluid D - 10 mm burner

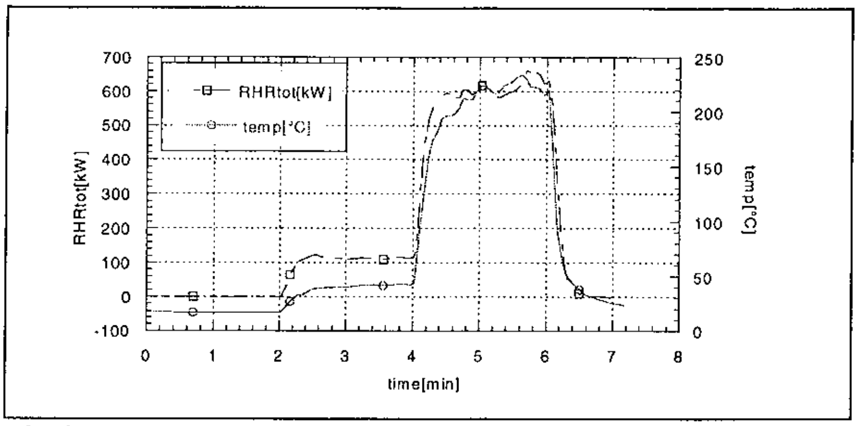
150 bar



Fluid D - 10 mm burner

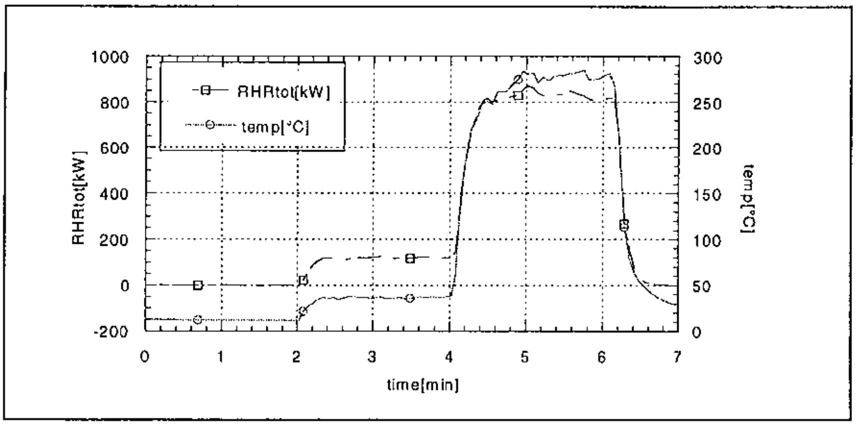
25 mm burner

50 bar



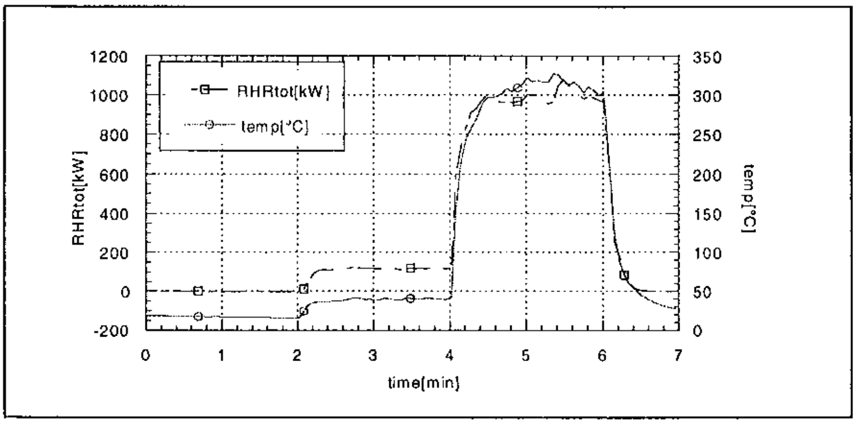
Fluid D - 25 mm burner

100 bar



Fluid D - 25 mm burner

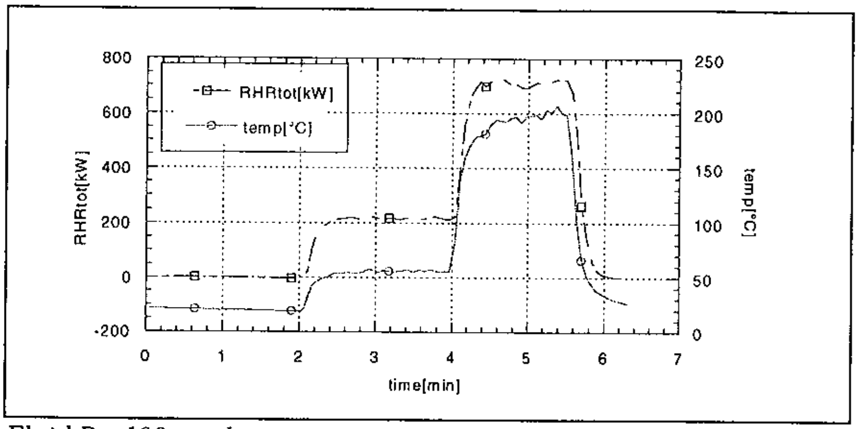
150 bar



Fluid D - 25 mm burner

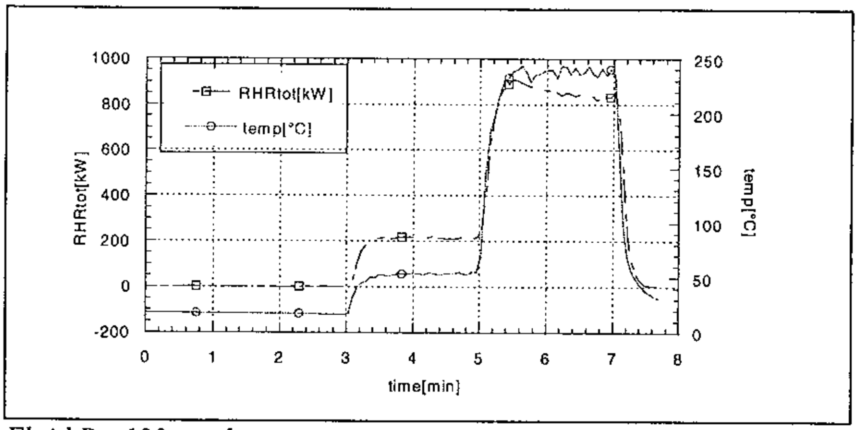
100 mm burner

50 bar



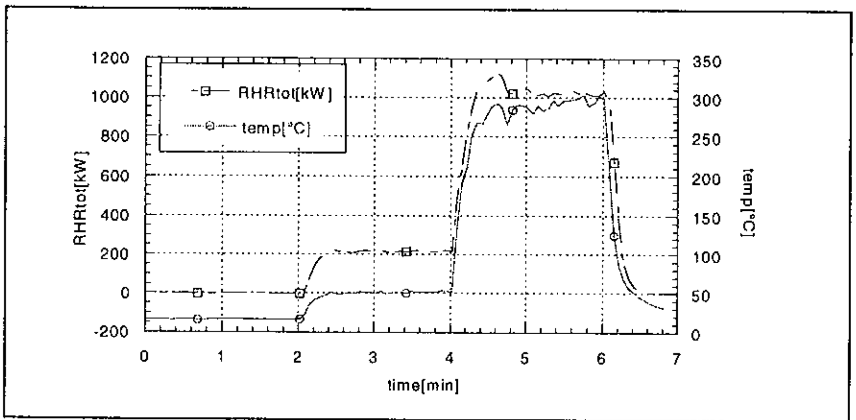
Fluid D - 100 mm burner

100 bar



Fluid D - 100 mm burner

150 bar

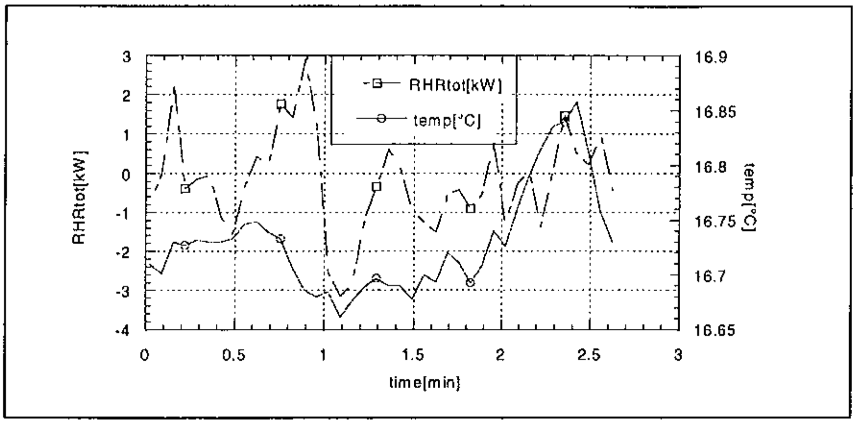


Fluid D - 100 mm burner

Fluid E

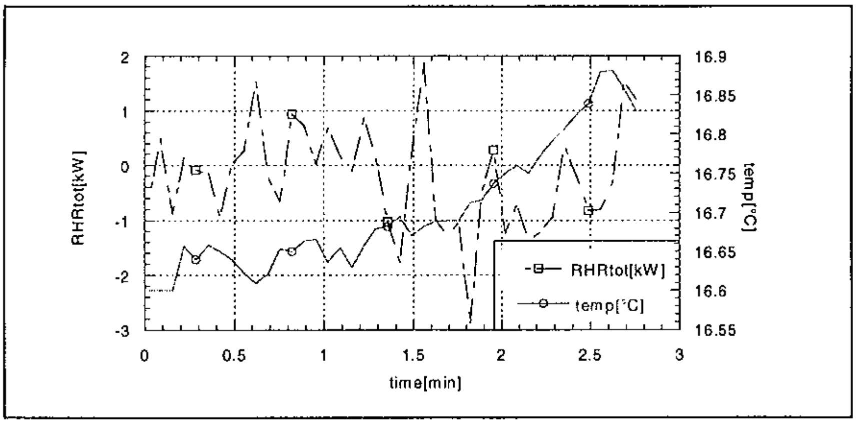
10 mm burner

50 bar



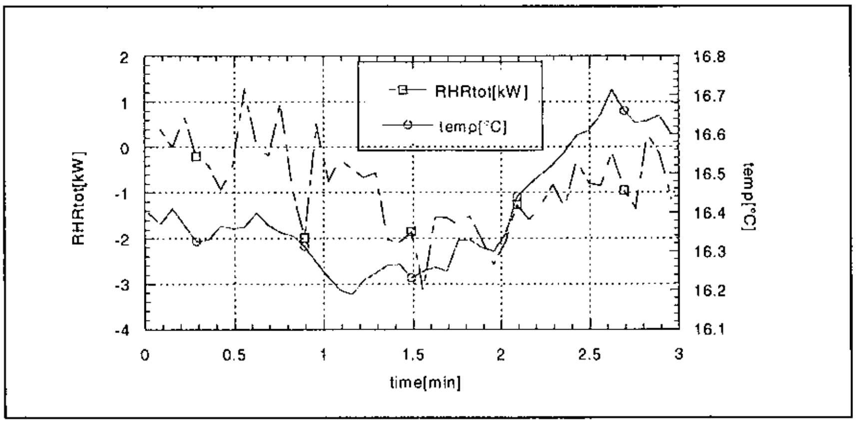
Fluid E - 10 mm burner

100 bar



Fluid E - 10 mm burner

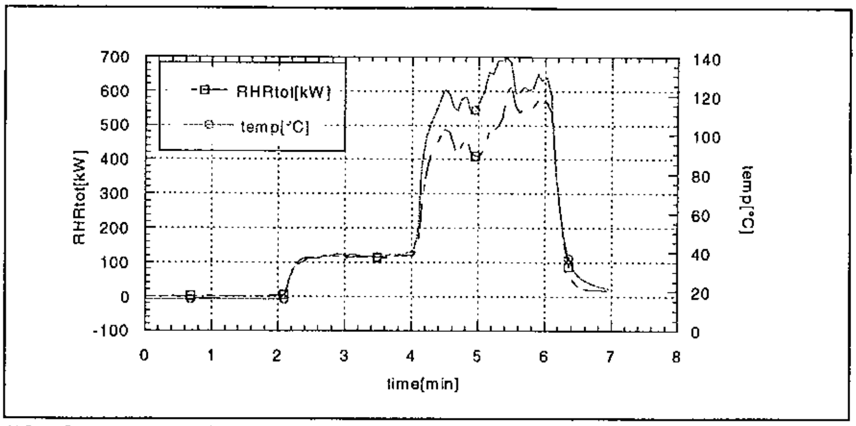
150 bar



Fluid E - 10 mm burner

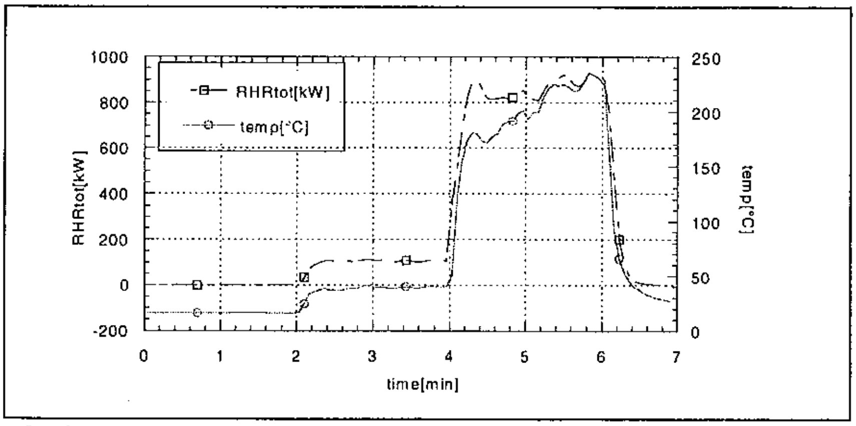
25 mm burner

50 bar



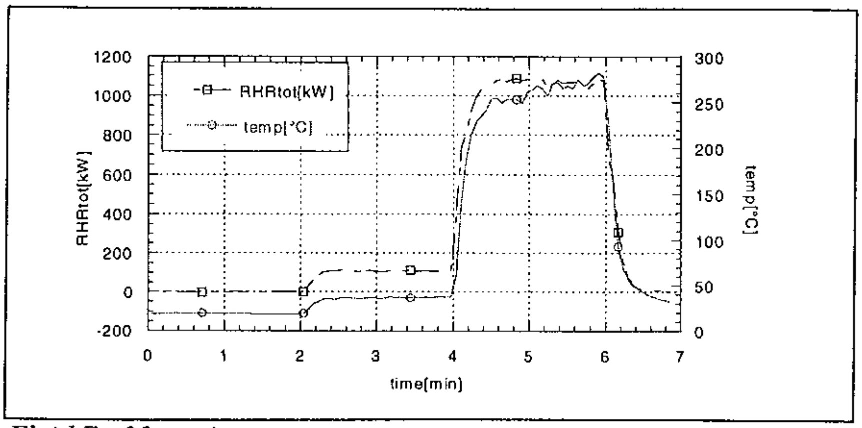
Fluid E - 25 mm burner

100 bar



Fluid E - 25 mm burner

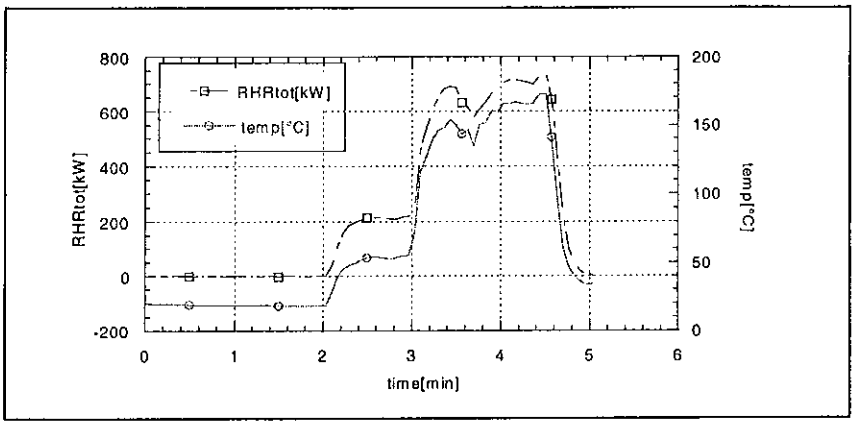
150 bar



Fluid E - 25 mm burner

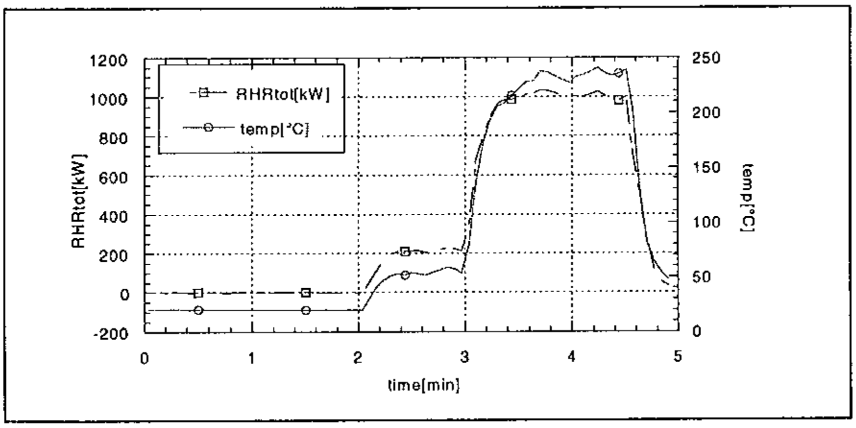
100 mm burner

50 bar



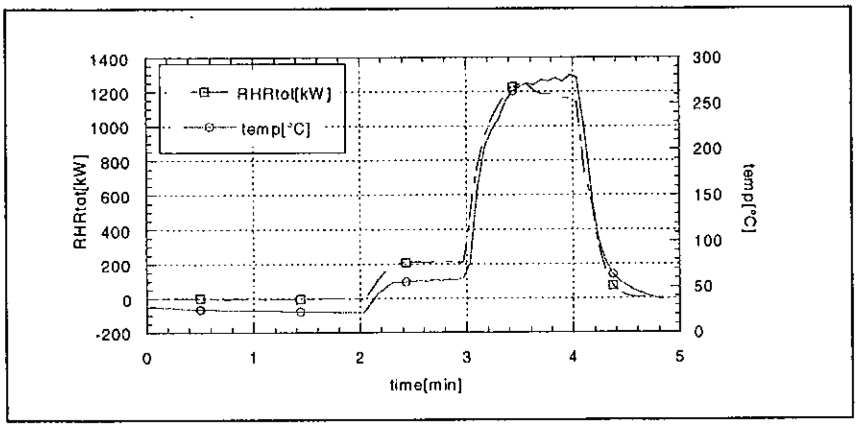
Fluid E - 100 mm burner

100 bar



Fluid E - 100 mm burner

150 bar

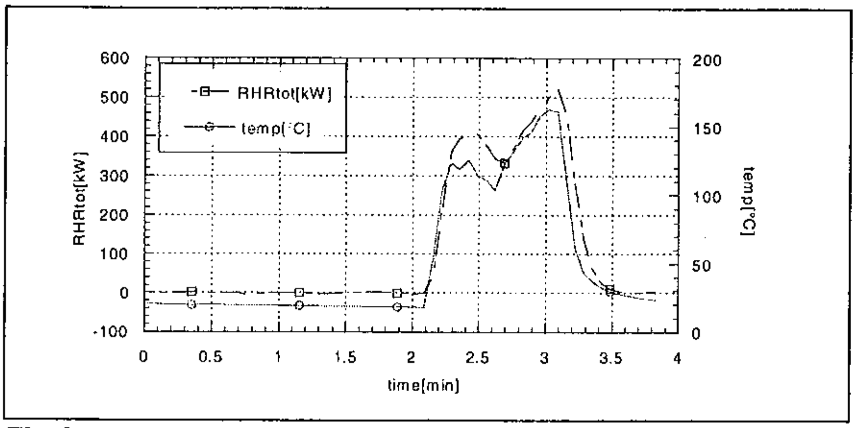


Fluid E - 100 mm burner

Fluid F

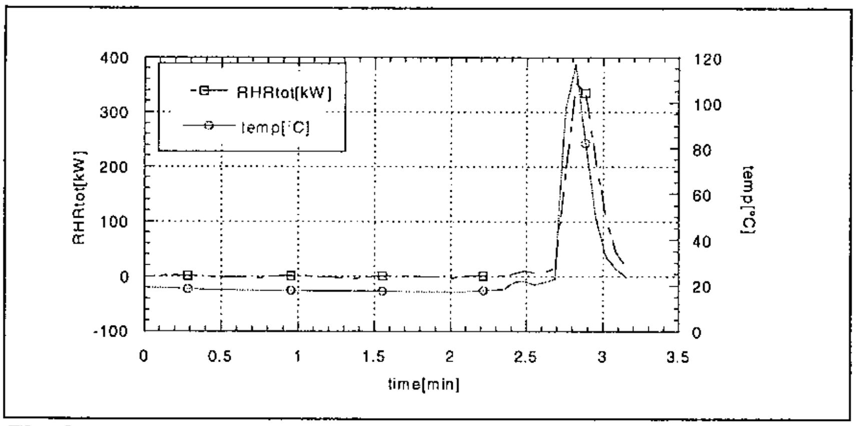
10 mm burner

50 bar



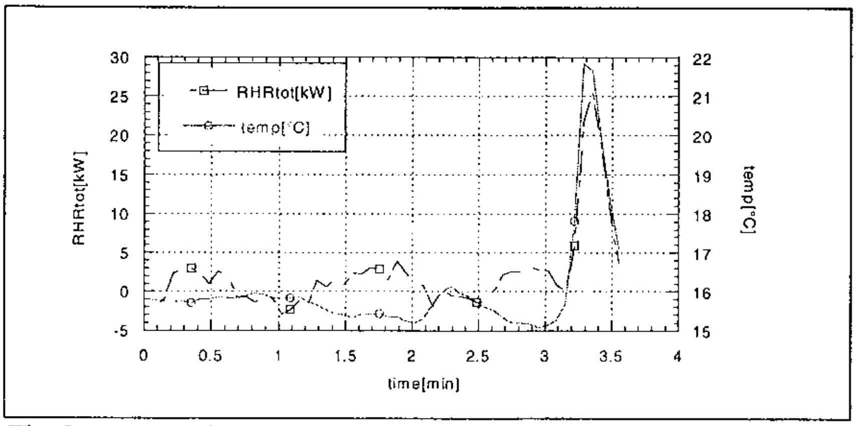
Fluid F - 10 mm burner

100 bar



Fluid F - 10 mm burner

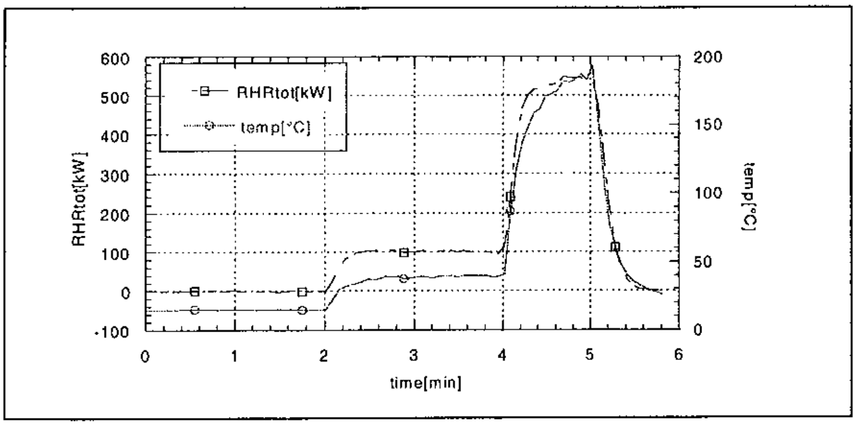
150 bar



Fluid F - 10 mm burner

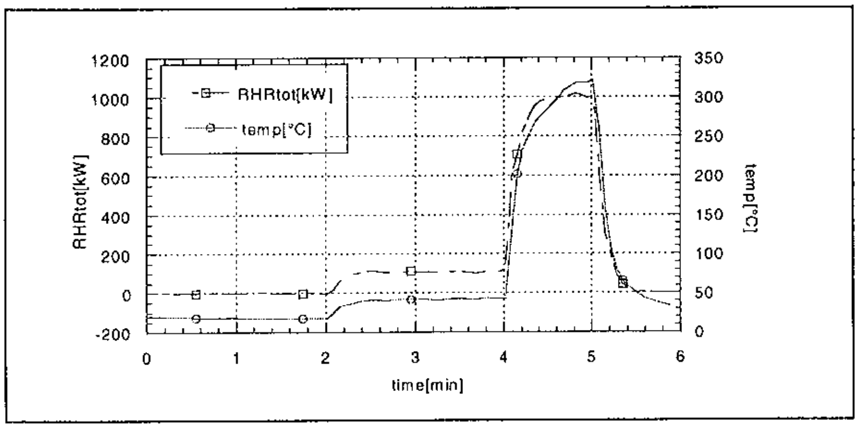
25 mm burner

50 bar



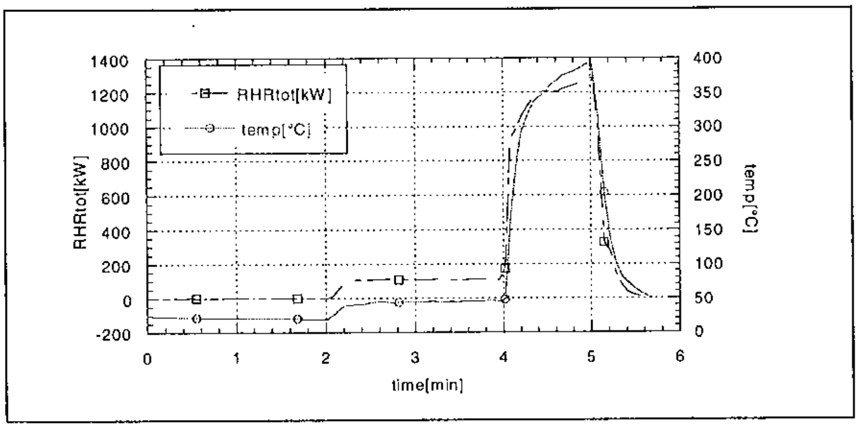
Fluid F - 25 mm burner

100 bar



Fluid F - 25 mm burner

150 bar



Fluid F - 25 mm burner

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