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Technical report

Per Walmerdahl, Per Werling

A Method for Smoke Spread Testing of Large Premises

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Report title
A Method for Smoke Spread Testing of Large Premises

Abstract (not more than 200 words)

A method for performing non-destructive smoke spread tests has been developed, tested and applied to several existing buildings.

Burning methanol in different size steel trays cooled by water generates the heat source. Several tray sizes are available to cover fire sources up to nearly 1MW. The smoke is supplied by means of a suitable number of smoke generators that produce a smoke, which can be described as a non-toxic aerosol. The advantage of the method is that it provides a means for performing non-destructive tests in already existing buildings and other installations for the purpose of evaluating the functionality and design of the active fire protection measures such as smoke extraction systems etc.

In the report, the method is described in detail and experimental data from the try-out of the method are also presented in addition to a discussion on applicability and flexibility of the method.

Keywords
Smoke spread, fire, optical density, visibility, smoke potential

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Rapportens titel (i översättning)

En Metod för Rökspridningsförsök i Stora Lokaler

Sammanfattning (högst 200 ord)

En metod för att genomföra oförstörande rökspridningsprov har tagits fram, testats och applicerats på ett antal befintliga byggnader.

Metanol förbränns i olika stora vattenkylda kärl och skapar härmed en värmekälla. Ett flertal olika storlekar på kärl innebär att brandstorleken kan varieras upp till närmare 1MW. Röken genereras med hjälp av lämpligt antal rökgeneratorer, vilka producerar en rök, enklast beskriven som en icke-toxisk aerosol. Fördelen med denna metod är att förutsättningar ges för oförstörande rökspridningsprovning av befintliga byggnader och anläggningar i syfte att utvärdera funktionaliteten och utformningen av det aktiva brandskyddet såsom rökevakueringssystem etc.

I rapporten beskrivs metoden i detalj och experimentella data från utprovningen av metoden presenteras i tillägg till en diskussion om användbarhet och flexibilitet hos metoden.

Nyckelord

Rökspridning, brand, optisk densitet, siktbarhet, rökpotential

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1 INTRODUCTION

1.1 Background

On many large premises, the event of fire outbreak and especially the subsequent smoke spread can be difficult to predict and control. This involves a large number of civilian buildings as well as military underground installations, hangars etc. In the former case, the change to performance-based building regulations has provided better possibilities to try out and apply new designs for fire protection measures. One area where this has been of special interest is in the design of fire protection and smoke extraction systems for large premises like atria in shopping malls, conference locations etc. In some cases there is a need to test the solutions in order to assure the correct operation and capacity of the chosen system.

Over the years, several experiments have been performed at FOI with focus on increased understanding of for example ventilation effects, smoke spread, development of smoke layers and how to most effectively evacuate smoke without means of mechanical ventilation. The main part of these experiments have been performed in model scale (see for example Hägglund *et al*, 1996a and 1996b and Walmerdahl *et al*, 2000).

1.2 Objectives

The purpose and hence objective of this study is basically threefold. First, the intention is to develop a concept for a *non-destructive hot smoke test method* (chapter 2), which as far as possible is to resemble a real fire scenario with subsequent smoke spread. Second, the *test smoke used should be characterised* (chapter 3) in an overview manner to get an idea of smoke potential. The reason for this is mainly to make it possible to make rough comparisons to smoke production during full-scale fire scenarios. Finally, some applied tests should be *performed in suitable facilities* (short discussion in chapter 4) in order to ensure applicability.

1.3 Limitations

Following report should be seen as an attempt to develop an approach to non-destructive testing of military installations and existing buildings. The method is to be considered a rough instrument to simulate full-scale fires rather than a precise instrument for this. Results from this kind of Hot Smoke Tests should therefore focus on qualitative aspects rather than quantitative.

Also, some practical aspects of the Hot Smoke Test are not elaborated on further here. For example, a number of safety measures are taken in connection with each experiment such as different possibilities for extinguishment of the fire or dilution of the inflammable liquid during a test.

2 SMOKE SPREAD METHOD AND APPLICABILITY

This chapter will mainly deal with the method applied for Hot Smoke Tests and the equipment used for performing them.

2.1 Fire source

Burning methanol in different size steel trays cooled by water generates the heat source. This will allow an even rate of burning. The combustion process itself can be considered relatively "clean" as only a very limited amount of soot is formed as a result of the high combustion efficiency (Karlsson *et al*, 2000).

Several container sizes are available in order to cover a wide range of fire sizes and generate flexibility for the method and a possibility to use in different size compartments. The sizes are to a large extent based on the method given for Hot Smoke Tests (Australian Standard, 1999) and table 1 gives details of the tray sizes used.

Size	Internal height [mm]	Internal length [mm]	Internal width [mm]	Tray area [m^2]
A1	130	841	595	0.50
A2	90	594	420	0.25
A3	65	420	297	0.125

Table 1 *Fire tray details.*

The fire trays are then placed in a water bath and the sizes of these are given in table 2. (In table 2 tray A1 is placed in B1 etc.) These trays are welded together in order to stay in place.

Size	Height [mm]	Length [mm]	Width [mm]
B1	180	990	700
B2	130	700	495
B3	105	495	350

Table 2 *Water bath details.*

Depending on the configuration of trays during a test, the heat release from a certain tray size will vary to some extent. However, a rough estimate of the heat released from pool fires can be done using the method described in (Karlsson *et al*, 2000). Using this method will give the following values (table 3) for burning rate and heat released, assuming the heat of combustion for methanol is 20MJ/kg and the combustion can be considered complete. Assumed is also the value for mass loss rate per unit area, a value taken to be $20g/m^2s$.

Tray size	Burning rate [g/s]	Fire size [kW]
A1	10.0	200
A2	5.0	100
A3	2.5	50

Table 3 *Calculated burning rates.*

A very steady burning rate is established for the tray configurations and an example of this is shown in figure 1 below. The diagram shows the burning characteristics for container A1, which has an area of $0.5m^2$.

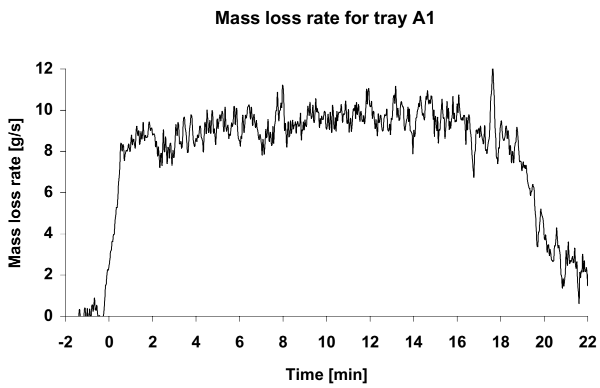

Figure 1 *Burning rate of container A1.*

The mass loss rate from the test is in good agreement with the calculated value given for tray size A1 in table 3. The average value for tray A1 is 9.1g/s compared to the calculated value 10g/s. Corresponding measured value for A2 is 4.4g/s and the calculated 5g/s.

2.2 Smoke production

The smoke is generated by means of a suitable number of smoke generators of the type JEM ZR-41 that have been used in the try-out of the method. Through all tests, the smoke generators were operated at maximum continuos smoke production rate. This was measured at several occasions and a mean value was established to about 2.3g/s, a value used in the determination of smoke potential in chapter 3. One of the smoke generators is shown in figure 2 along with the three fire tray sizes available.

Figure 2 *Smoke generator ZR-41 and fire trays A1-A3.*

The smoke itself is an aerosol that appears white to the observer and basically consists of polyglycols and distilled water. One of the major advantages of the smoke is that it is non-toxic at room temperature and does not contain soot or other particles that deposit on walls or ceiling of the tested facility. The contents of the smoke has been tested under ambient conditions (10-15°C) and it was concluded that any potentially hazardous materials are well below any short- or longtime exposure limits (Jonsson, 1988). However, it is known that when the smoke is exposed to temperatures in excess of 100°C, a considerable amount of smoke breaks down and in some cases small amounts of formaldehyde might be formed. For this reason, it is advantageous to let the smoke be entrained in the plume region at temperatures below 100°C during testing. Also, this will render less smoke (aerosol) to break down and a more confident prediction of smoke generation can be done.

3 SMOKE CHARACTERISATION

To be able to roughly compare the smoke produced during a Hot Smoke Test to a real fire situation, some comparative tests were performed at FOI´s test facilities at the Fire and Rescue School in Rosersberg. Principally, 24 tests were performed with different types of fuels and these are briefly outlined in the following and table 4. (The first five tests are not presented since these were done mainly to find the most suitable experimental set-up.)

Test No.	Fuel	Fire size [m]	Position of Fire source / Smoke generator	Art. smoke conc. or % dilution	Ambient conditions
6	Heptane	0,33*0,33	R1/-	-	Cloudy, 0-1m/s, 10°C
7	Heptane	0,33*0,33	R1/-	-	Cloudy, 0-1m/s 12°C
8	Kerosene	0,33*0,33	R1/-	-	Cloudy with sunny intervals, 0-1m/s, 12°C
9	Kerosene	0,33*0,33	R1/-	-	Sunny, 1-2m/s, 13°C
10	Methanol	0,50*0,50	R1/R2	Conc.	Hazy, 1-2m/s, 13°C
11	Methanol	0,50*0,50	R1/R2	Conc.	Cloudy, 1-2m/s, 12°C
12	Methanol	0,50*0,50	R1/R1	Conc.	Cloudy, 1-2m/s, 12°C
13	Methanol	0,50*0,50	R1/R2	50%	Cloudy, 1-2m/s, 14°C
14	Wood cribs	0,50*0,50	R1/-	-	Cloudy, 1-2m/s, 14°C
15	Heptane	0,33*0,33	Hall	-	Cloudy, 1-2m/s, 12°C
16	Heptane	0,33*0,33	Hall	-	Cloudy, 1-2m/s, 12°C
17	Kerosene	0,33*0,33	Hall	-	Cloudy, 1-2m/s, 12°C
18	Methanol	A1	Hall/Hall 2-2	Conc.	Cloudy, 0-1m/s, 11°C
19	Methanol	A2	Hall/Hall 2-2	Conc.	Cloudy, 1-2m/s, 12°C
20	Methanol	A2	Hall/Hall 1-2	Conc.	Hazy, 1-2m/s, 13°C
21	Methanol	A1	Hall	-	Hazy, 0-1m/s, 6°C
22	Methanol	0.50*0.50	R1/R2	Conc	Hazy, 0-1m/s, 6°C
23	Methanol	0.50*0.50	R1/R2	75%	Hazy, 0-1m/s, 6°C
24	Methanol	0.50*0.50	Hall/Hall 1-2	Conc	Hazy, 0-1m/s, 5°C

Table 4 *Test details for smoke characterisation experiments.*
(For further description, see experimental set-up in appendix A.)

In the following, results of the tests are given with the main objective of giving a rough estimate of smoke potential for the artificial smoke as compared to other fuels with better known characteristics.

3.1 Experimental set-up

The experimental set-up is illustrated in appendix A and here the locations for different measurements are shown. As shown in table 4, three different fuels are used beside the test smoke. During most tests, steel pans cooled with circulating water were used and only in test 18-21 the trays described in previous chapter were used (in test 14 wood cribs were used). For Hot Smoke Tests, table 4 also specifies where the fire and smoke source is placed in relation to each other and whether the smoke generating fluid (JEM Pro-Smoke High Density (Special)) was concentrated or diluted. In test 18-20 and 24, table 4 also gives the height above floor and distance away from the fire source for the smoke generator (e.g. 1-2 means 1m up and 2 m to the side of the fire source). Test 21 was merely conducted for evaluating mass burning rate of tray A1.

3.1.1 Instrumentation

The quantities measured during the tests includes mass loss rate of the burning fuel, gas temperature, optical density and velocity as well as temperature of the hot gases flowing through the horizontal ceiling opening. The experimental set-up is illustrated in figure 5 and 6 of appendix A, which also contains the different measurement locations.

A load cell (Nobel Elektronik U2D1) placed underneath the weighing platform, which in turn was protected by Promatek board and additional insulation, measured the mass loss rate during test 6-17 (in test 18-21 a load cell from Bofors Elektronik of type KIS (1kN) was used).

The gas temperature was measured on three heights in room R1 and R2 T-vert R1 and R2 in appendix A). Also, in the Hall thermocouples distributed over a vertical line on a 1.0m spacing were used. All thermocouples were welded and of type K with a wire diameter of 0.5mm.

Optical density was measured on two locations. One optical density meter (OD-meter) was positioned 2m below the ceiling in the hall and one measured the optical density of the smoke escaping through the ceiling opening. The measuring equipment used consisted of smoke extinction meters over a path length of 1.0m and 0.95m respectively. The device itself consists of a lamp, a lens, windows and a photocell. The lamp is of halogen type and the lens aligns the light to a parallel beam, which the photocell then measures the reduced intensity of. The windows protect the interior of the meter from heat and smoke. Air is also forced through the meter to prevent the deposition of soot on the windows during the tests. The optical density (D) per path length (or smokiness), D_L, is defined by:

$$D_L = \frac{D}{L} = \frac{1}{L} \cdot \log_{10}\left(\frac{I_0}{I}\right) = \frac{1}{L} \cdot \log_{10}\left(\frac{100}{T}\right) \quad (1)$$

where the initial light intensity of I_0 is reduced to a value of I over the path length L, resulting in T percent transmission. The unit for D_L is [1/m]. The advantage of measuring optical density is that it correlates with visibility. The OD-meter positioned 2m below the ceiling was also cooled by running water through all tests. The water-cooled meter is further described in (Jansson *et al*, 1985)

In order to establish the mass flow through the ceiling vent, the velocity and temperature of the hot gases flowing through the opening was measured. For this, a differential pressure probe and thermocouple mounted centrally in the opening was used. A bi-directional type probe was used, further described in (McCaffrey and Heskestad, 1976).

Finally, visual estimates of the smoke layer height were made throughout the experiments in order to get a rough estimate of the development of smoke layers in the different compartments during what could be referred to as "steady state" conditions.

3.2 Results and evaluation of test data

The results of the experiments presented are quantitative as well as qualitative and represent a set of data for an outline characterisation of the smoke. All quantitative data is gathered in appendix B and the values given in table 5 and 6 represent average values (generally 5^{th} to 9^{th} minute of each test). In appendix C, the full experimental data including diagrams is given for tests 11, 16, 17 and 24. In the following sections overall results as well as general observations are discussed.

3.2.1 General observations

Several observations were done during the tests that are of importance for the evaluation of the results. First of all, it was concluded that the influence of external wind effects on smoke evacuation could be considerable. This was proven especially for the case of wind gusts that disturbed the flow through the ceiling vent and also gave rise to dilution of the smoke, the latter giving rise to fluctuations in optical density measurements. However, in some cases the wind also disturbed the flame, which then tilted to one side and affected the burning rate somewhat.

In general, the smoke filling process of the different compartments was very similar between the tests and can be outlined as follows. For the case of heptane and kerosene burnt in compartment R1, a smoke free height of about one metre was established after less than one minute in compartment R1 and R2. In the Hall a smoke free height of 2.5-3m was reached after 2-3 minutes.

3.2.2 Temperatures

Considering only the temperatures in the fire room, it becomes obvious that the highest temperatures occur for the case of heptane fires. This is caused by the higher mass loss rate and energy content (44.6MJ/kg) compared to methanol (20MJ/kg) and kerosene (44.1MJ/kg) (NFPA, 1995). Also, the conversion to soot is evidently larger for the case of kerosene, which means heat radiation losses will increase. (Table 5 shows a temperature difference in the fire room between test 6 and 7 as well as between 8 and 9. This is due to the fact that in test 7 and 9 (also in 12), the thermocouples in the fire room (R1) were not shielded from heat radiation as during other tests.)

3.2.3 Mass flow through the ceiling vent

By measuring gas velocity and temperature of the gases flowing through the ceiling vent, the mass flow can be calculated. The mass flow is dependent on several factors such as velocity of the gas, vent size and density of the hot gases. Consequently, a higher velocity will be experienced when the area is small in order to accomplish the same mass flow. The mass flow can be calculated from the following relation:

$$\dot{m} = v \times A \times \rho \times C_d \qquad (2)$$

where v is the velocity of the hot gases [m/s], A is the ventilation area [m^2], ρ is the density of the hot gases [kg/m^3] and C_d is the flow coefficient, which was set to 0.6 for these experiments (Walmerdahl *et al*, 2000).

3.2.4 Mass burning rate of the fuel

The burning rate of the fuel varied depending on fuel type, fire size and location. In general the methanol showed a very steady burning rate as compared to heptane and kerosene, where the burning rate tends to vary more. In short, this means the instantaneous values are fluctuating but the time average stays relatively constant between the different tests.

3.2.5 Smoke properties

The following section aims at summarising the different properties of the smoke measured in the experiments. Focus is on smoke potential for the different fuels.

There are a few different approaches to make rough calculations of smoke potential, D_0 [m^2/g], and in this study the following approach has been used (see for example Rasbash *et al*, 1979 and Karlsson *et al*, 2000).

Based on the measurements done, the following relation for smoke potential is used:

$$D_0 = \frac{D_L \cdot \dot{V}_s}{\dot{m}} \qquad (3)$$

where $\dot{V}_s$ is the flow rate of outflowing air [m^3/s] corrected for ambient temperature, $\dot{m}$ is the burning rate of the fuel [g/s] and D_L was defined through equation (1).

For the case of heptane fires (tests 6-7 and 15-16), these were performed a bit differently. During the first two tests, the fire source was located in compartment R1 and in 15-16 it was in the Hall. This was done in order to evaluate if the results on smoke production would differ due to different ventilation conditions and geometry of the two compartments (soot deposition on walls etc.). The main observation included a difference between optical densities 2m below the ceiling for the case of placing the fire source in the Hall or in R1. This, however, is not of major concern for this study. Weighing in other factors, it is realised that the smoke potential given is relatively constant over an extended period of time and assumes a value of close to 0.020m^2/g. An example of the data collected from the tests with heptane is given in appendix C (test 16). As can be seen the optical density of the smoke seems to reach a rather steady value, which also means smoke potential reaches a value constant over the test period, since volume flow and mass loss rate can be considered constant.

Kerosene was used as a second test fuel and the mass burning rate of kerosene had a tendency to fluctuate more than during the heptane fires. The optical densities observed are about a factor 10 higher than for the heptane case due to the more pronounced soot formation and the smoke potential varied between 0.155 and 0.336m^2/g (an average of 0.23m^2/g correlates well to other values in for example (Jansson *et al*, 1988 and Rasbash *et al*, 1979)). A steadier burning situation was experienced when the fire source was located in a more open space (Hall) and not contained within a smaller volume (R1). One example of the experimental data is collected in appendix C and shows the results from test 17. Tests 8 and 9 show similar results even though the fluctuations in optical density are larger.

Wood cribs were also used in one test for comparison (25x25x500mm). As shown in figure 3, smoke potential varies considerably compared to the case of liquid fuels in water-cooled trays, where the production tends to be more even.

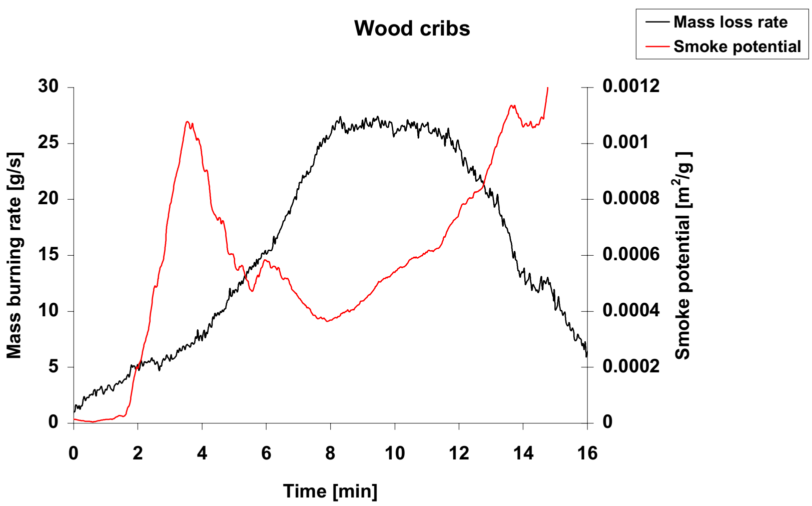

Figure 3 *Temperature and smoke potential for wood cribs.*

This can be attributed to several factors such as the fluctuating mass burning rate as well as the content of the pyrolysis gases. Similar behaviour can be observed during combustion of furniture and mattresses for example (e.g. Onnermark *et al*, 1985). The low value of smoke potential is to a large extent due to the low moisture content in the wood cribs used.

Methanol was used as fuel in the trials involving Hot Smoke Tests and the purpose of the variety of tests was mainly to see how the artificial smoke behaved under varying circumstances. A prerequisite is that the smoke (aerosol) not be exposed to temperatures in excess of 100°C because then a considerable amount of the produced smoke breaks down and the visibility in the produced smoke is notably increased. Also, there is the question of avoiding a possible production of formaldehyde around these temperatures (Jonsson, 1988). A further matter is the behaviour of the smoke as exposed to relatively "low" temperatures (about 60°C) for an extended period. It was shown in for example test 12 (fire source and smoke generator in the same compartment) that the smoke becomes notably thinner when exposed to these conditions. It is therefore preferred to feed the smoke into the plume region where the temperature is below 100°C and also not to conduct tests in to small compartments. Avoiding these conditions will result in a relatively well-predicted result when it comes to smoke production and visibility estimates.

There is always a possibility to dilute the smoke generating fluid with distilled water. This was done in two tests and some observations were made. First, the dilution generated what could be explained as a "less stable" smoke, which tended to break down more quickly. This was seen in test 13 and 23, where it was hard to establish an even smoke potential since the smoke tended to break down successively. This was mainly seen as a decreased optical density over the test period. This event was more pronounced for the case of 75% dilution of the smoke fluid and no mean value is presented in table 6 of appendix B.

In appendix B, (average) test data from test 11 and 22 is given as well as 20 and 24. Test 11 and 22 are performed under similar conditions and still show different results. This is applicable for 20 and 24 as well and this result could have several factors. Already mentioned is the dependence of external wind and how this fluctuates. Another important issue is the dependability of the smoke generators and how the capacity of these might vary. During the evaluated tests these are operated at a maximum continuous smoke production rate. Still, these rates seem to vary to some extent (from the average 2.3g/s). Finally can be said the full experimental data from test 11 and 24 is given in appendix C. Even though the time averaged value for test 11 and 22 as well as 20 and 24 differ somewhat, the resulting shape of all smoke potential curves roughly resemble those presented in appendix C.

3.3 Summary and conclusions from test data

The main result is that the smoke potential (in the Hot Smoke Tests) can be approximated constant over a test period of 10-15 minutes. After more than 15 minutes, the smoke tends to start breaking down and visibility increases.

The smoke potential of the artificial smoke is estimated to about $0.20 m^2/g$ (even though fluctuations were quite large between different tests). This value can be used to create a suitable smoke production to a fixed fire scenario. By adjusting fire size and number of smoke generators this can be achieved. Some corresponding smoke potential data for materials can be found in the literature given under "references" in the end of this report.

4 SUMMARY AND CONCLUSIONS

In order to simulate a realistic full-scale fire scenario, a method for non-destructive testing has been developed. A rough estimate of the smoke potential for the artificial smoke (under hot smoke test conditions) was done in comparison to liquid fuels and was estimated to 0.20m^2/g.

The method has been tested at several locations, where applicability has been assured. The results of these tests have mainly been of either a qualitative or secret character, which means they will not be further presented here. However, it can be concluded that along with suitable measurements (mass flows, temperatures, optical densities etc) and observations, the tests can be used to evaluate the smoke spread process in a more quantitative manner. Comparisons to CFD (Computational Fluid Dynamics) calculations are also possible.

One example of measurements that can be done during these field tests is given in below figure. Here the temperature at different heights above the fire source was measured and gives an indication to the actual conditions experienced. The "dip" in the temperature curves is a result of smoke vents being opened at ceiling level.

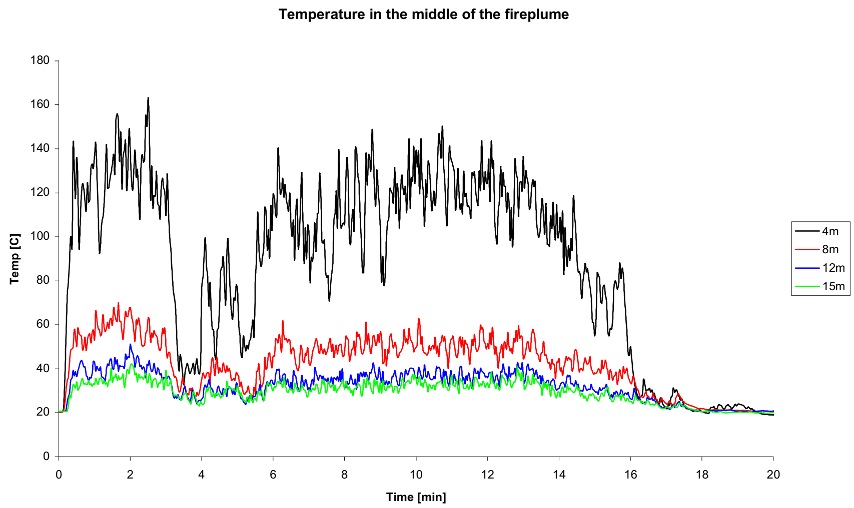

Figure 4 *Temperature at different heights above the fire source (four trays of type A1 are used).*

In the future, the method should be further applied to existing buildings/installations in order to evaluate smoke management systems. The method can be seen as a complement to other means of consequence analysis such as CFD calculations.

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Appendix A INSTRUMENTATION AND GENERAL LAYOUT

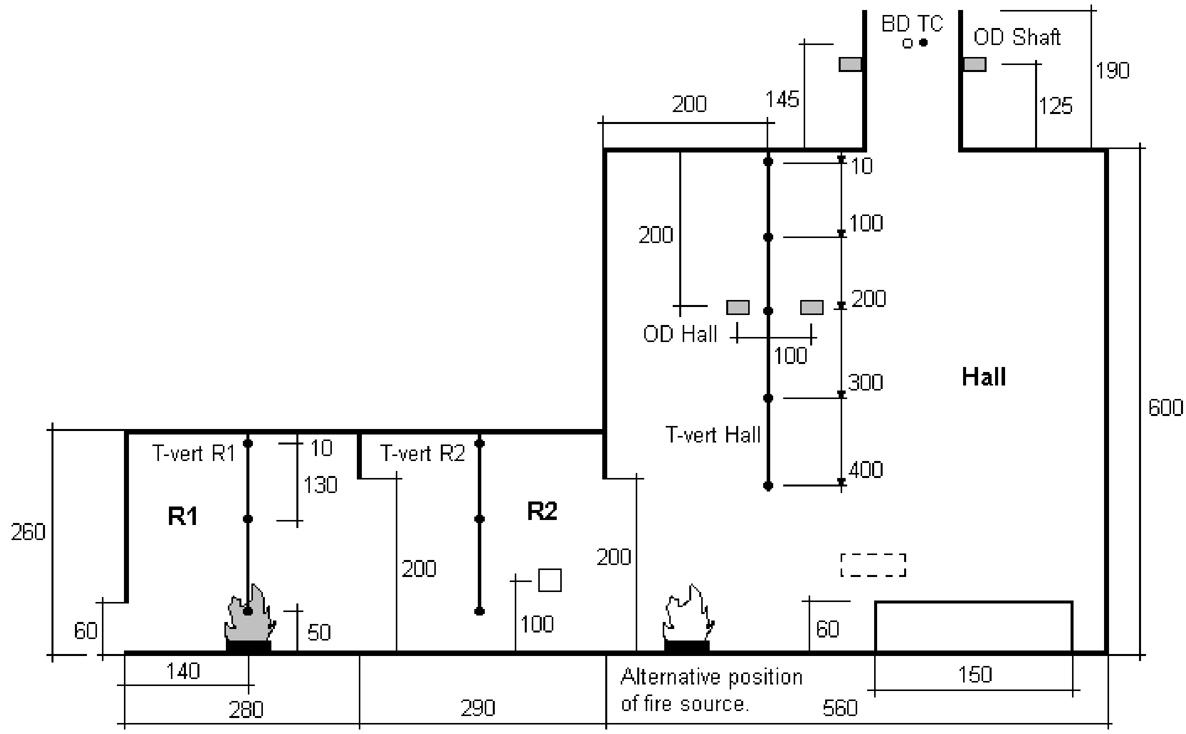

Figure 5 *Side-view of experimental set-up.*

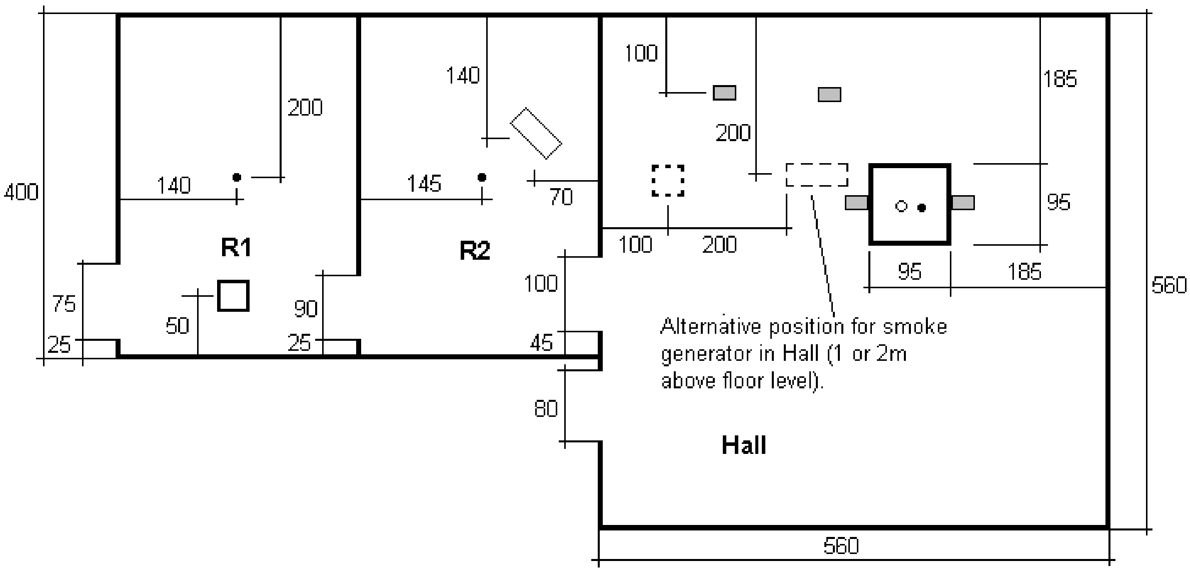

Figure 6 *Plane view of experimental set-up.*

Appendix B SUMMARY OF TEST RESULTS

TEST NO	6	7*	8	9*	10	11	12*	13	15	16	17	20
R1 10cm below ceil	109.7	113.8	77.1	81.3	76.6	78.1	85.1	84.8	-	-	-	-
R1 130cm below ceil	95.8	100.9	64.4	74.5	68.7	68.0	74.6	73.8	-	-	-	-
R1 50cm above floor	29.6	39.7	26.4	35.6	26.8	21.7	26.8	23.4	-	-	-	-
R2 10cm below ceil	75.3	76.5	53.8	55.4	55.6	58.0	60.7	62.6	-	-	-	-
R2 130cm below ceil	41.6	43.2	32.6	33.8	35.4	35.9	35.8	37.7	-	-	-	-
R2 50cm above floor	15.6	16.3	16.2	18.1	18.0	16.1	16.8	17.3	-	-	-	-
Hall 10cm below ceil	29.7	31.1	22.7	25.2	26.6	25.6	26.3	27.4	36.6	33.2	32.0	20.5
Hall 1m below ceil	11.2	12.2	12.7	13.4	13.1	12.9	13.4	14.1	15.5	28.3	29.7	17.7
Hall 2m below ceil	26.8	28.5	20.9	23.3	24.6	23.0	23.9	25.0	32.0	28.6	28.6	17.7
Hall 3m below ceil	24.1	25.4	18.8	21.8	23.2	21.5	21.9	22.9	26.4	23.6	25.0	15.4
Hall 4m below ceil	13.1	13.8	14.4	15.7	14.7	14.3	15.2	15.7	19.0	18.5	20.0	10.7
Temp BD-probe	31.6	33.1	23.6	26.0	27.2	26.6	27.5	28.7	39.0	35.7	34.7	19.0

- No average value available

Table 5 *Summary of temperature measurements. Tests denoted "*" had non-shielded thermocouples in the fire room (R1). No average data available for test 14 and for test 18, 19 and 21-23 no measurements were done.*

TEST NO	Hall 4m OD	Shaft OD	Smoke potential	Burning rate	Velocity	Mass flow
6	0.047	0.024	0.013	3.2	2.7	1.7
7	0.058	0.040	0.023	3.0	2.7	1.7
8	0.274	0.207	0.155	1.8	1.9	1.2
9	0.307	0.244	0.201	1.9	2.0	1.3
10	0.482	0.392	0.202	2.9	2.1	1.3
11	0.573	0.547	0.304	4.0	2.2	1.4
12	0.288	0.143	0.087	3.6	2.4	1.5
13	-	-	-	3.8	2.3	1.5
14	-	-	-	-	-	-
15	0.032	0.027	0.019	2.8	3.2	2.0
16	0.027	0.026	0.015	3.8	3.4	2.0
17	0.285	0.197	0.336	3.1	2.8	1.7
18	-	-	-	NA	3.7	2.2
19	0.439	0.247	0.182	4.3	2.9	1.8
20	0.584	0.304	0.237	4.4	3.0	1.8
21	NA	NA	NA	9.1	4.3	2.6
22	-	0.304	0.208	NA	2.7	1.8
23	-	-	-	NA	-	-
24	-	0.475	0.374	NA	2.8	2.0

- No average value available
NA No measurement done

Table 6 *Summary of measured average data.*

Appendix C EXPERIMENTAL DATA FOR SELECTED TESTS

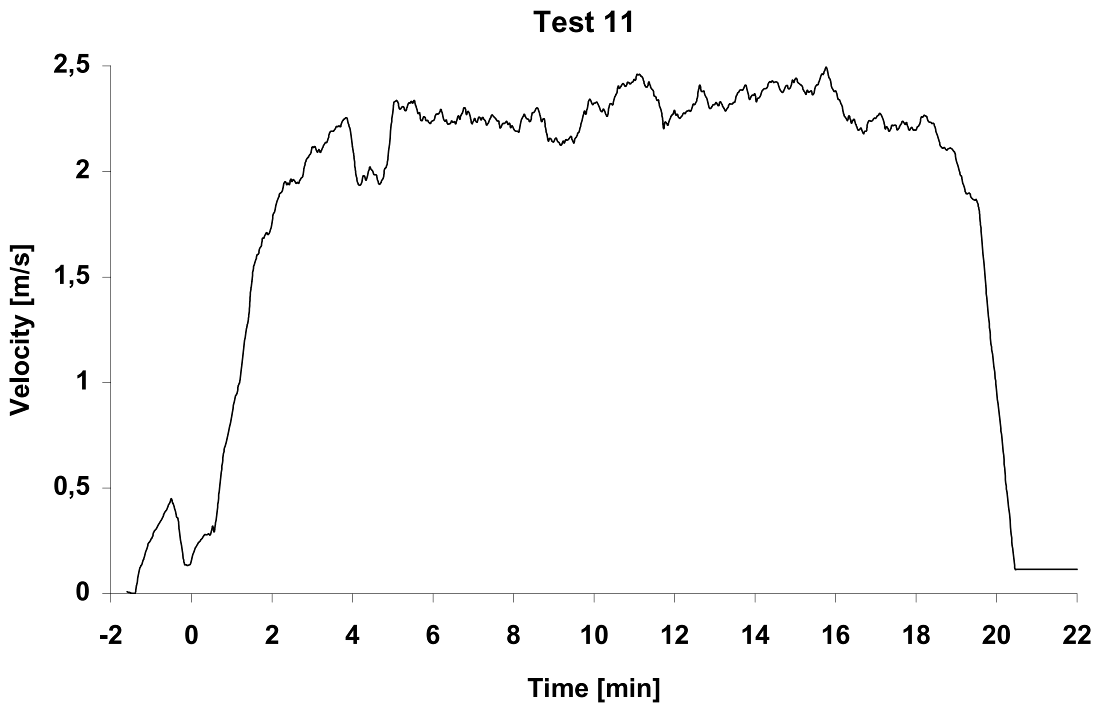

Diagram 1 *Gas velocity through the ceiling vent for test 11.*

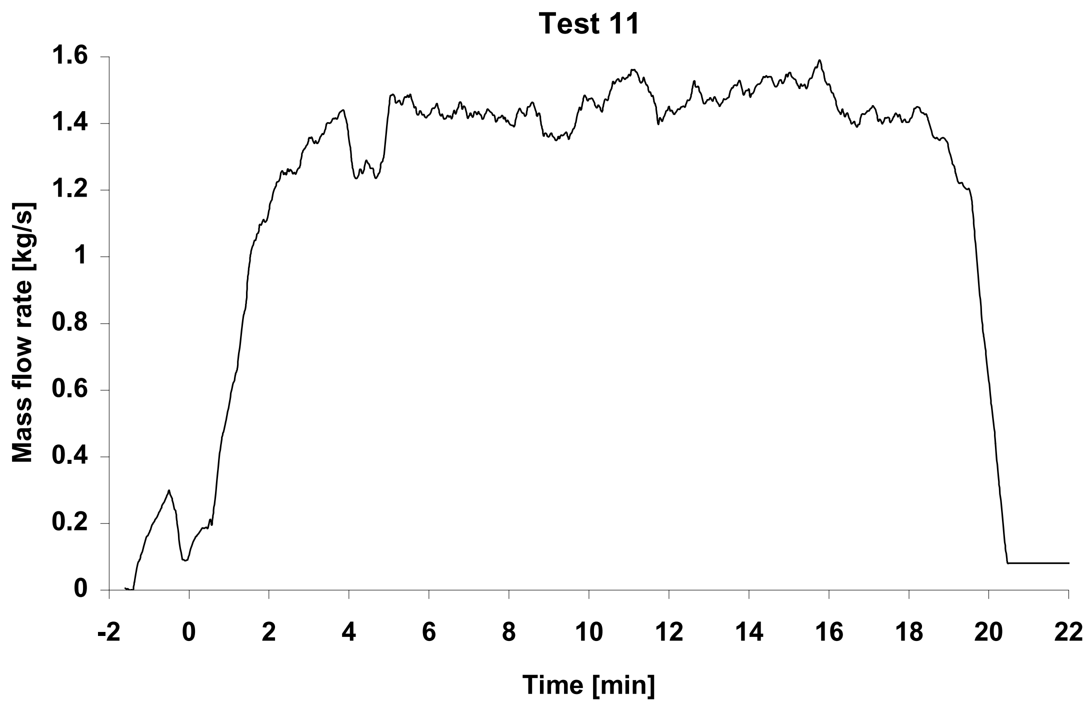

Diagram 2 *Mass flow rate through the ceiling vent for test 11.*

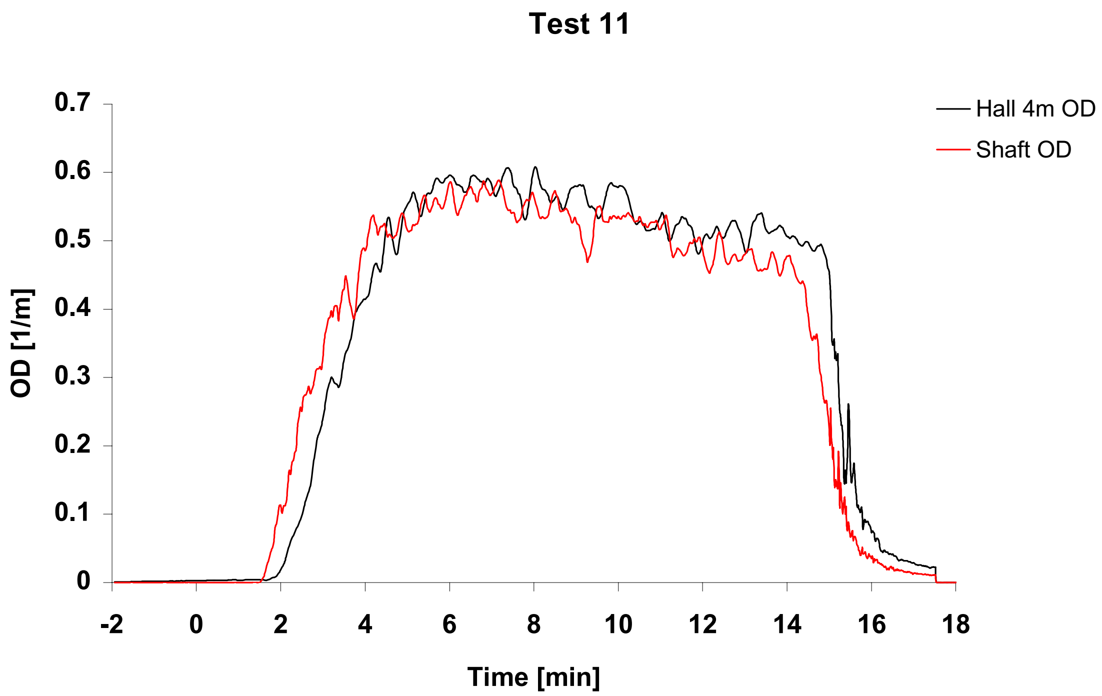

Diagram 3 *Optical density per path length for test 11.*

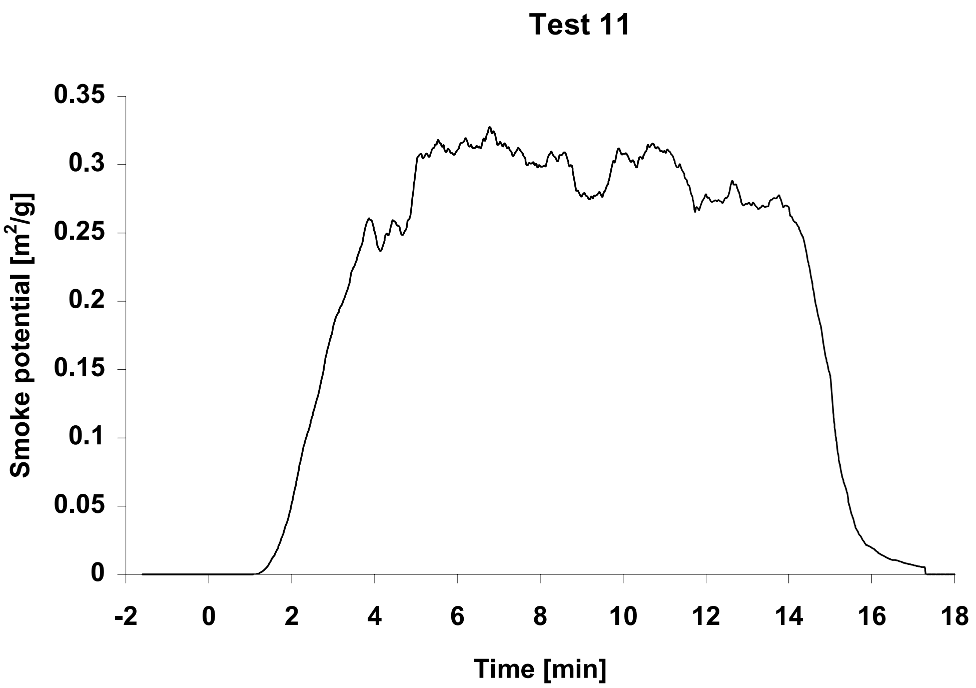

Diagram 4 *Smoke potential for test 11.*

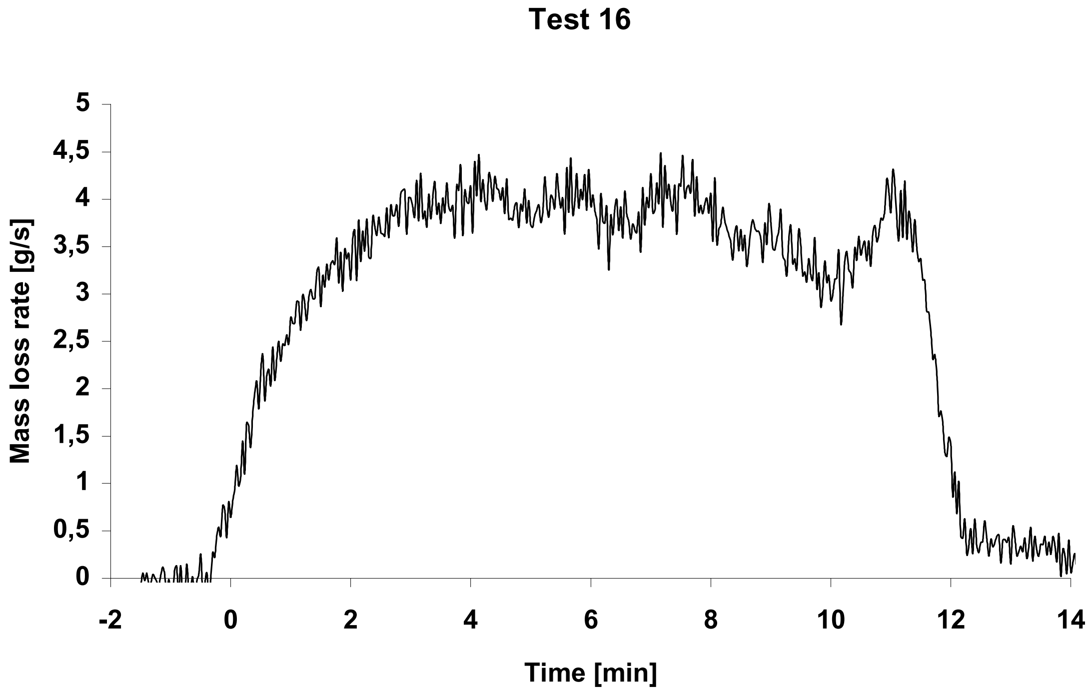

Diagram 5 *Mass loss rate for test 16.*

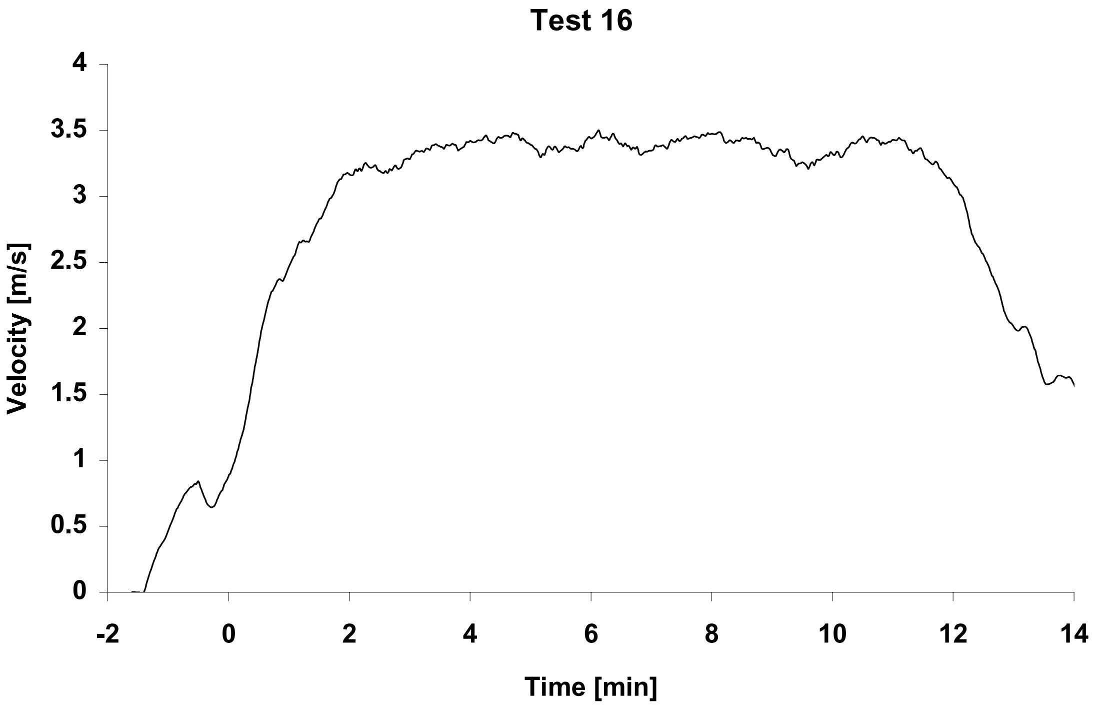

Diagram 6 *Gas velocity through the ceiling vent for test 16.*

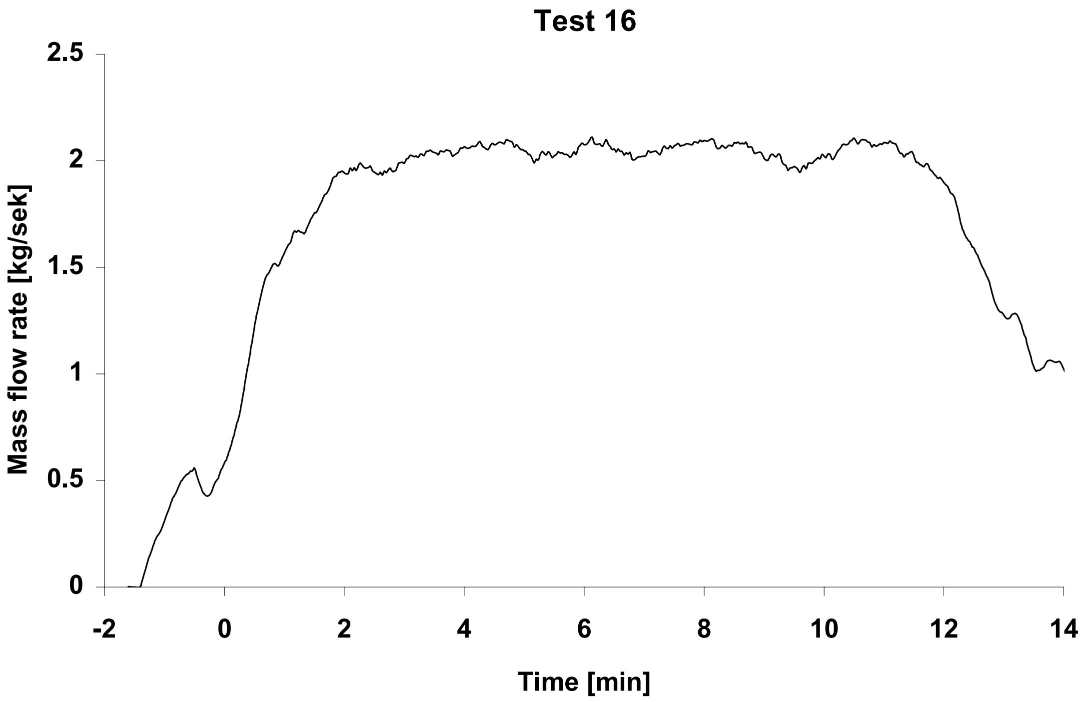

Diagram 7 *Mass flow through the ceiling vent for test 16.*

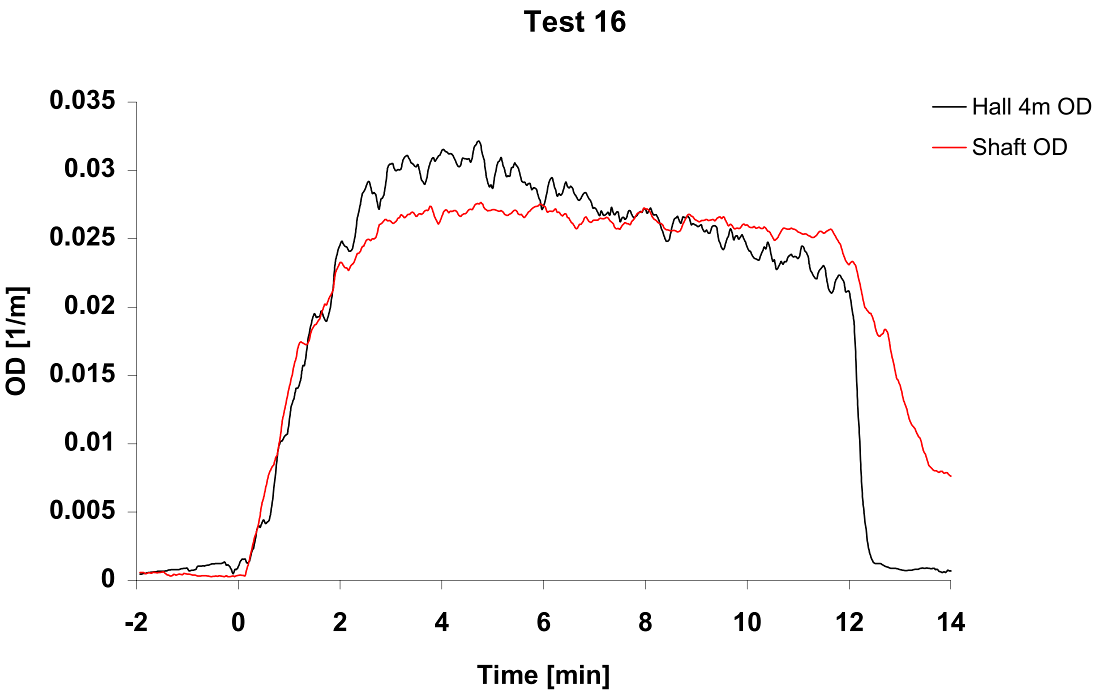

Diagram 8 *Optical density per path length for test 16.*

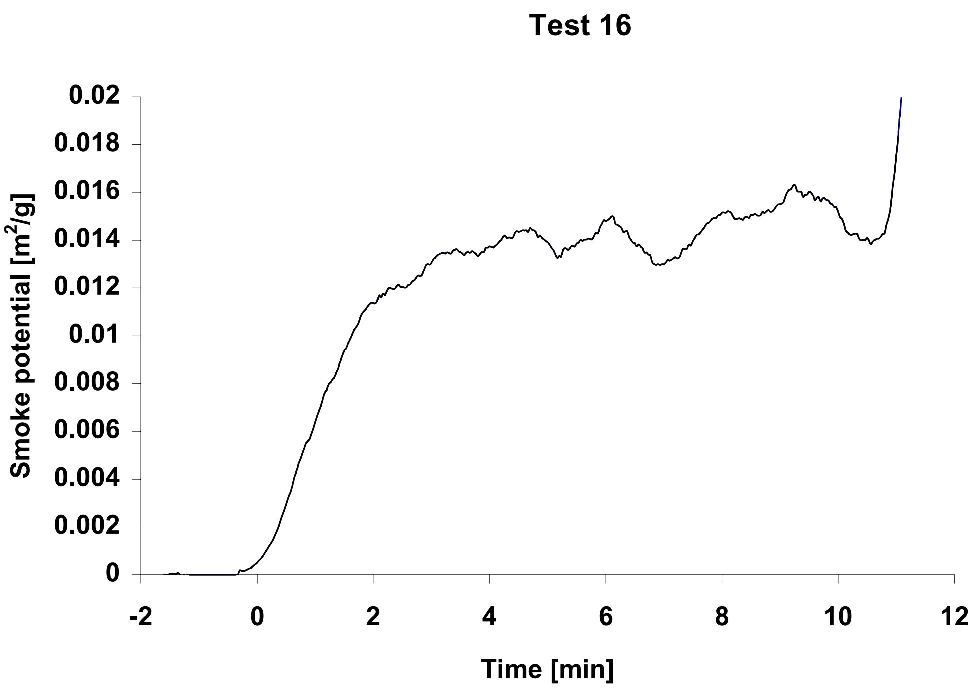

Diagram 9 *Smoke potential for test 16.*

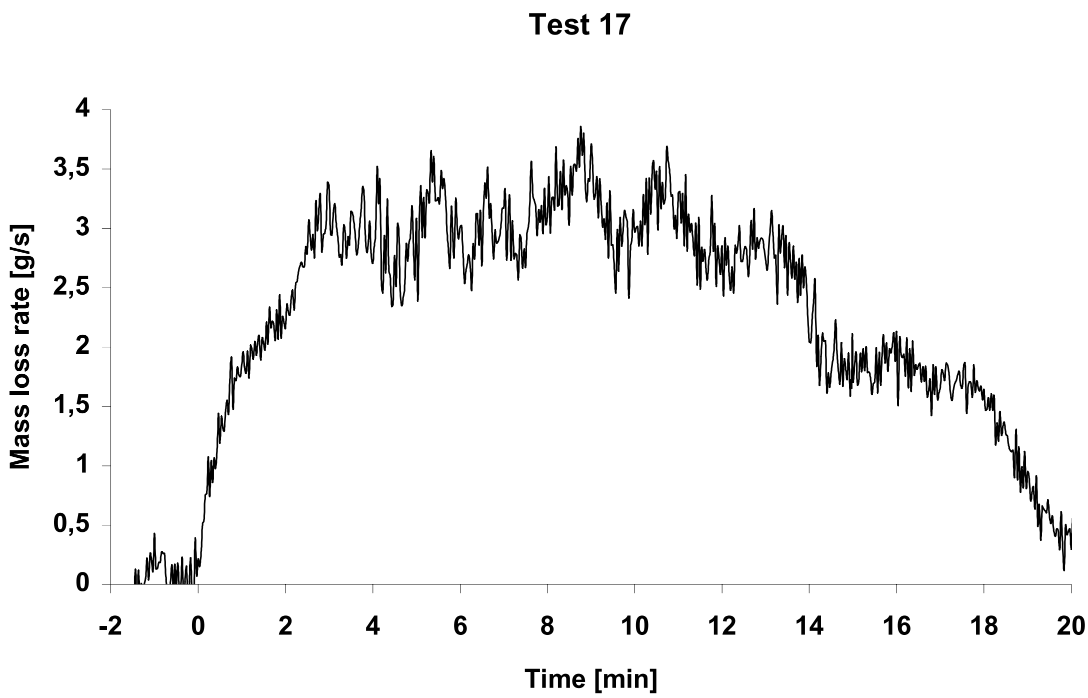

Diagram 10 *Mass loss rate for test 17.*

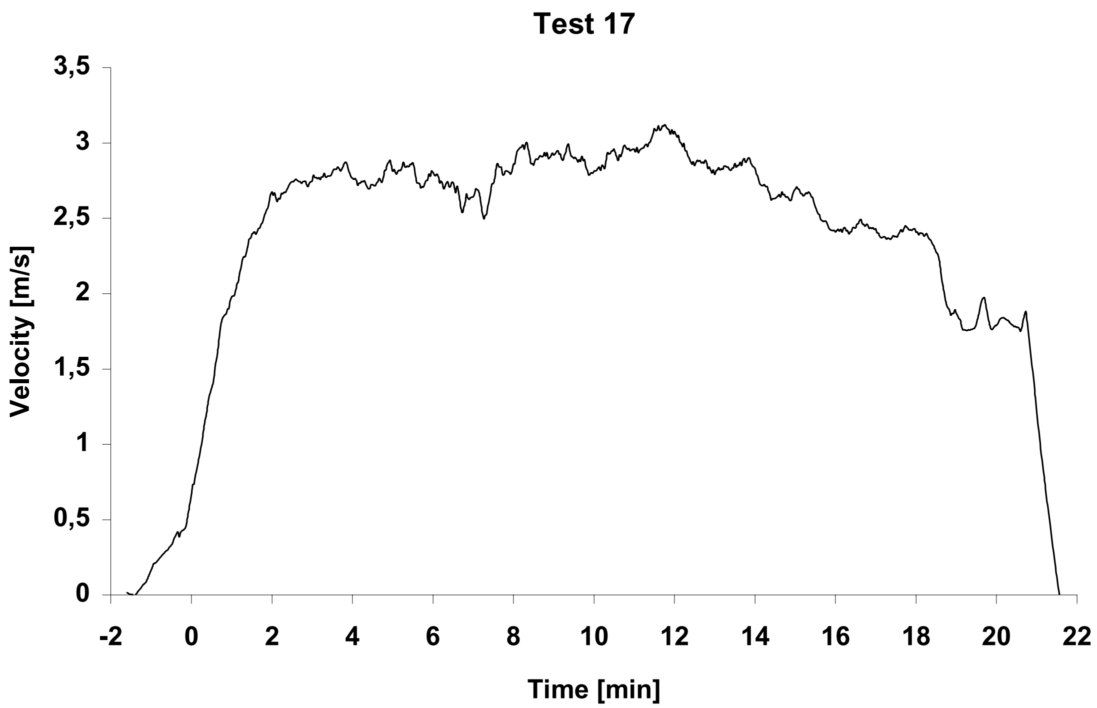

Diagram 11 *Gas velocity through the ceiling vent for test 11.*

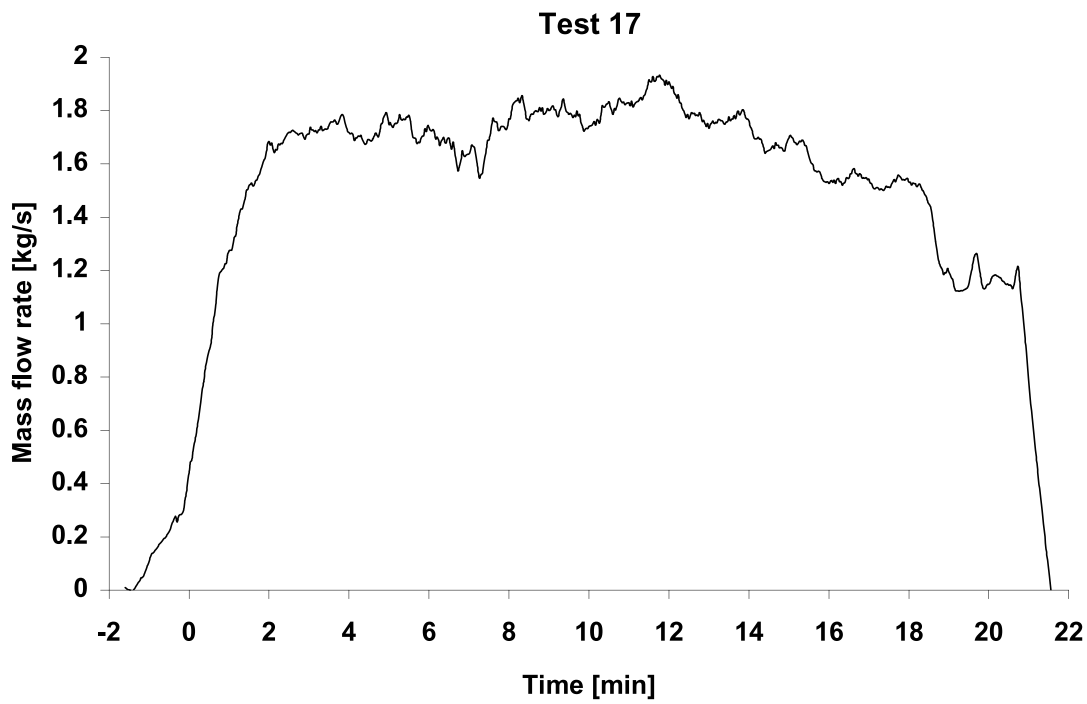

Diagram 12 *Mass flow rate through the ceiling vent for test 17.*

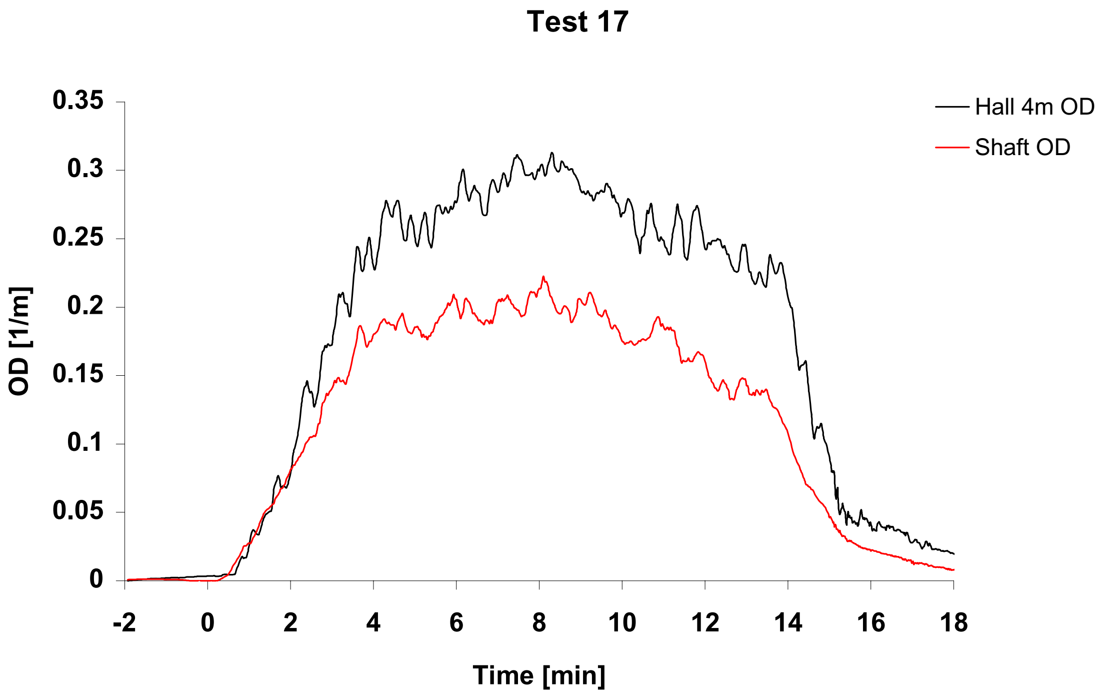

Diagram 13 *Optical density per path length for test 17.*

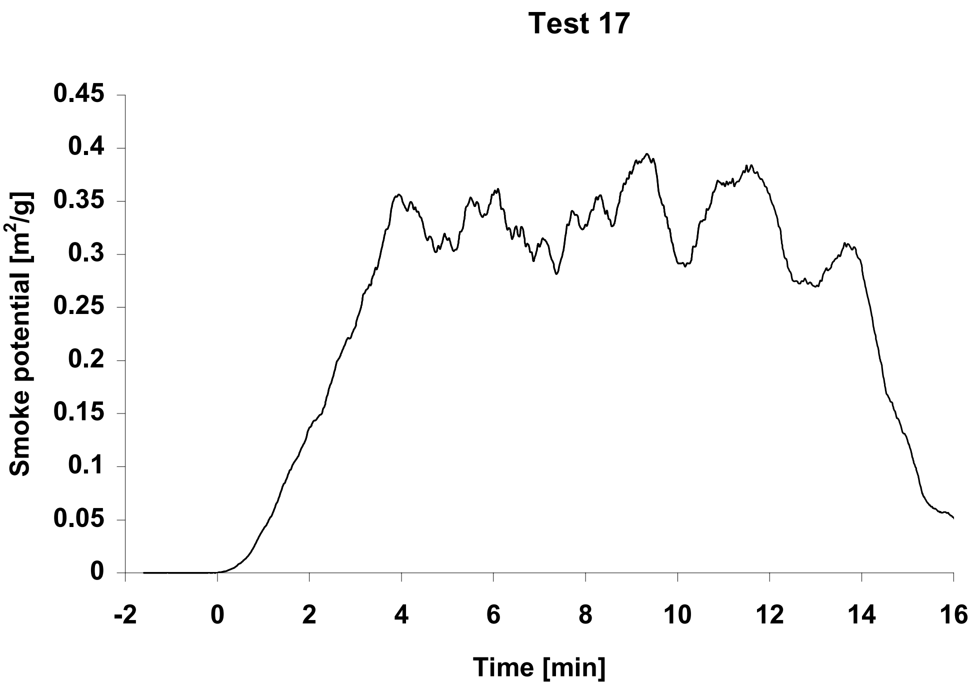

Diagram 14 *Smoke potential for test 17.*

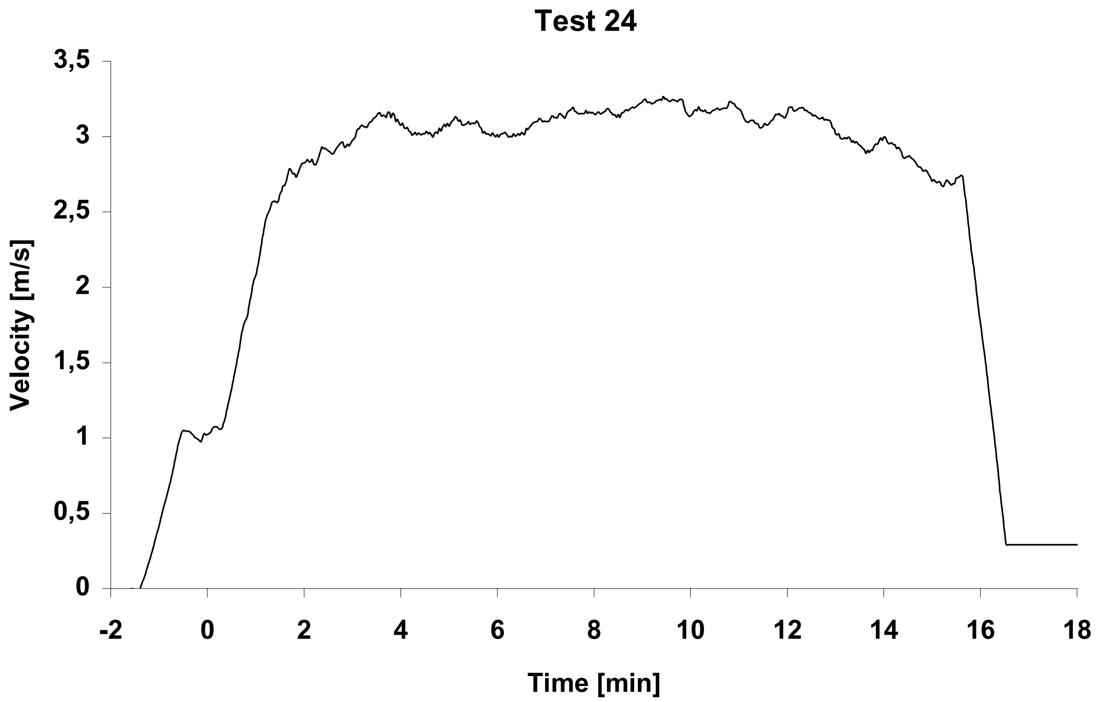

Diagram 15 *Gas velocity through the ceiling vent for test 24.*

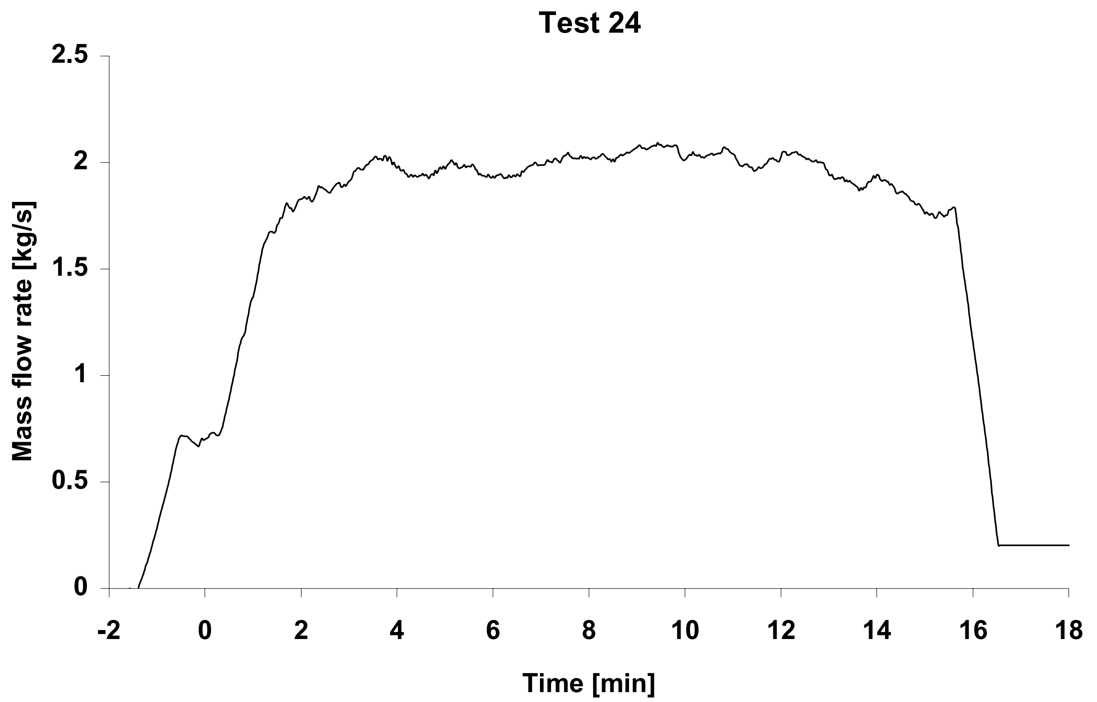

Diagram 16 *Mass flow rate through the ceiling vent for test 24.*

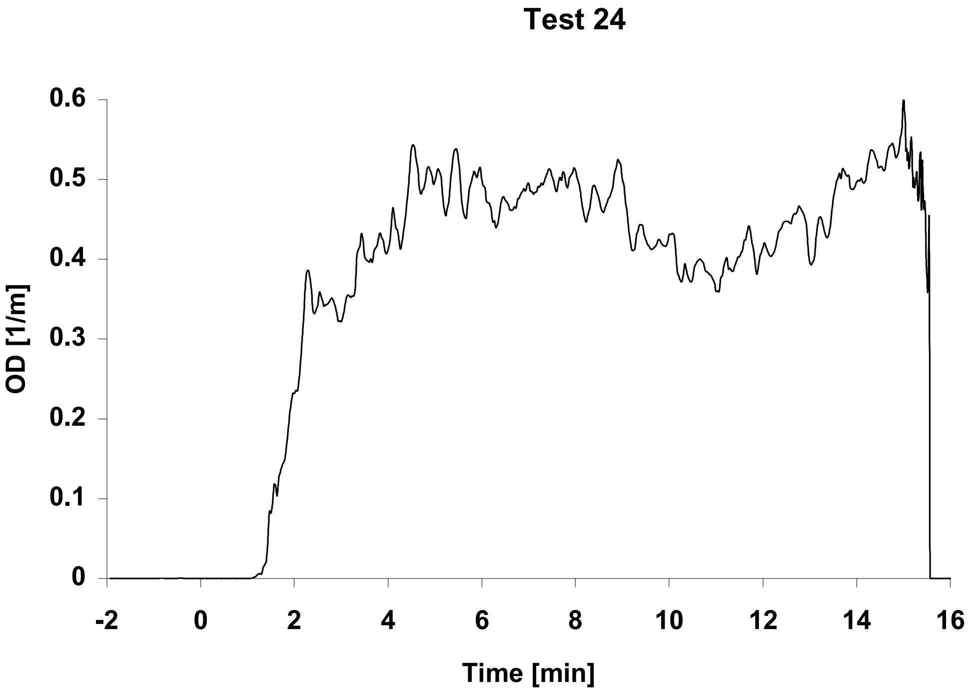

Diagram 17 *Optical density for test 24.*

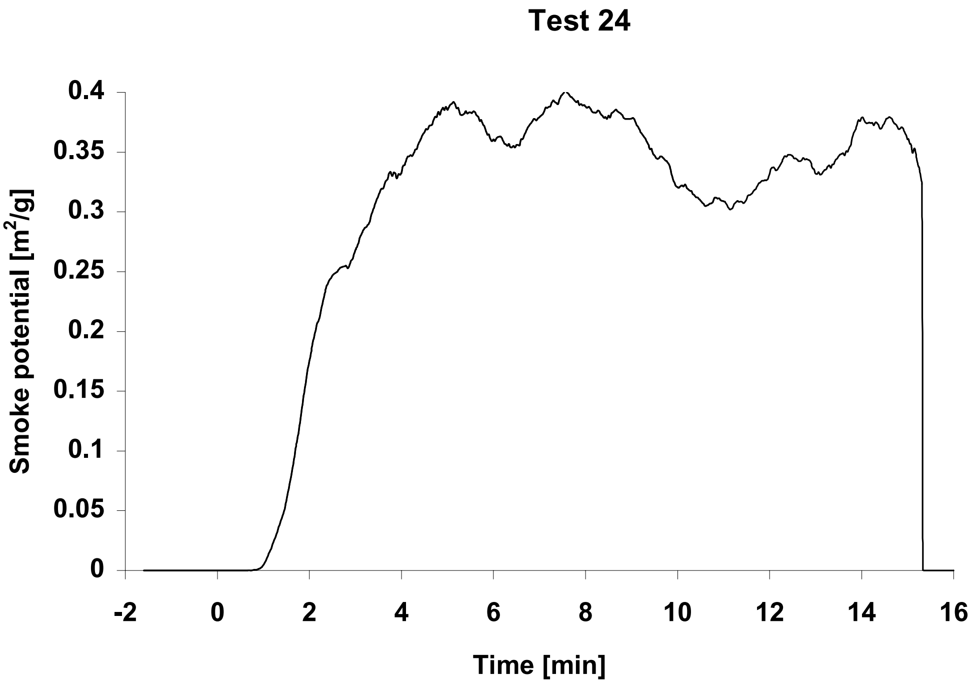

Diagram 18 *Smoke potential for test 24.*