Smoke Spread and Gas Temperatures during Fires in Retail Premises - Experiments and CFD Simulations

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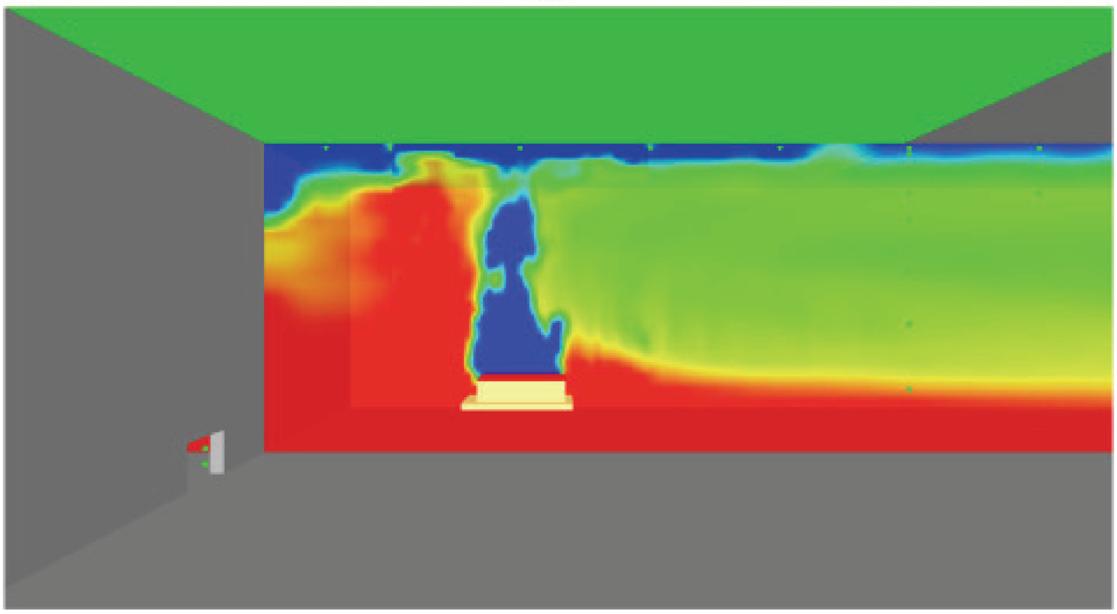
BRANDFORSK
Styrelsen för svensk brandforskning

Brandforsk projekt nr 308-071



SP Technical Research Institute of Sweden

Fire Technology

SP report 2008:55

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Abstract

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In analytical solutions, e.g. for evacuation design, the use of computer programs for simulating the smoke spread is common. In recent years a group of computer codes named CFD (Computational Fluid Dynamics) codes has emerged as an engineering tool for describing smoke spread. The CFD codes need to be compared against experimental data so that they can be fully validated.

To investigate how different configurations in a retail premises affect the smoke spread and temperatures during a fire, 11 tests were performed. The tests scenario was built in scale 1:2 and can be described as a large room with small ventilation openings near the floor. The configuration parameters were: different fire sizes, different fire positions and different shelf configurations. Heptane pools were used to represent the fires. Three different fire sizes were used and during the test with the largest fire size, 650 mm × 650 mm, the test conditions became under-ventilated, i.e., there was insufficient oxygen available to allow stoichiometric combustion of all evaporated fuel. For the simulations conducted as part of this work, the focus was on under-ventilated fires. However, the experimental results for all of the tests are presented and discussed

The fire tests were simulated using the CFD code FDS (Fire Dynamics Simulator). To see how well FDS simulates under-ventilated fires, both well ventilated and under-ventilated cases were selected for the validation. Gas temperatures and oxygen concentration for the experiments and the simulations, respectively, are compared. Different types of meshes for the simulations and different ways of modelling the fire were used. The results of the validation show that the combustion model (mixture fraction combustion model) with empirical amendments for when the fire is allowed to burn, is very sensitive to changes in the oxygen level. The comparison between the experimental data and the simulation indicates that FDS easily can underestimate the oxygen level and thereby the heat release rate which, in turn, creates an underestimation of the temperatures. The validation has shown that the simple empirical expression used for when the fire is allowed to burn is very sensitive and if used without proper understanding it may produce large differences between the experiments and the simulations. It is also clear that the temperatures for well ventilated cases may be overestimated and that the use of visibility and toxicity (soot and carbon monoxide yields) are related to uncertainties. It should also be noted that there are cases where the temperature from the simulations and the temperature measurements correspond relatively well with each other and yet other cases when the simulated temperature is higher than the measured temperature. This depends on the simulation case, the position in the set-up and the time period compared.

Key words: fire experiments, smoke spread, temperature, CFD simulations, FDS

SP Sveriges Tekniska Forskningsinstitut
SP Technical Research Institute of Sweden

SP Report 2008:55
ISBN 978-91-86319-16-8
ISSN 0284-5172
Borås

Contents

Preface

The experiments described in this report were performed within a project financed by the Swedish Rescue Services Agency, on the validation of performance based fire safety design with an emphasis on comparisons between predictions from different computational tools (CFD) and experiments. The experiments were performed at SP Technical Research Institute of Sweden.

These experiments have been further analysed within a project financed by the Swedish Fire Research Board (Brandforsk). This work also included simulations using a computational fluid dynamics (CFD) code. Comparisons between these simulations and the experiments are also included in the report. Part of the work was performed as a Master of Science thesis at Department of Fire and Safety Engineering and Systems Safety at Lund University.

The technicians at SP, Michael Magnusson, Lars Gustavsson, and Sven-Gunnar Gustafsson, are acknowledged for their valuable help in performing the fire experiments. Patrick van Hees and Göran Holmstedt at the Department of Fire and Safety Engineering and Systems Safety (Lund University) are also acknowledged for their help concerning FDS. We also want to thank Heimo Tuovinen at SP Technical Research Institute of Sweden for his help with the computer cluster at the University Collage of Borås.

A reference group was appointed for the project and the members of the reference group were:

Patrick Van Hees, Lund University
Erik Grahn, Bengt Dahlgren AB
Magnus Nordberg, Brandkonsulten AB
Per Blomqvist, SP Fire Technology

The members of the reference group are acknowledges for their comments and input throughout the project.

Nomenclature

CFD	Computational Fluid Dynamics
DNS	Direct Numerical Solution
FDS	Fire Dynamics Simulator
Fr	Froude number
g	Acceleration of gravity (m/s^2)
HRR	Heat release rate
HRRPUA	Heat Release Rate Per Unit Area
I	Light intensity
k	Extinction coefficient (m^{-1})
L	Length (m)
LES	Large Eddy Simulation
m	Mass (kg)
MLR	Mass loss rate
MLRPUA	Mass Loss Rate Per Unit Area
NIST	National Institute of Standards and Technology
Q	Energy (kJ)
$\dot{Q}$	Heat release rate (kW)
RANS	Reynolds Averaged Navier Stokes
SOFIE	Simulation Of Fires In Enclosures
t	Time (s)
T	Temperature (K)
TC	Thermocouple
u	Velocity (m/s)

Summary

To investigate how different configurations in a retail premises affect the smoke spread and temperatures during a fire, 11 tests were performed by SP Technical Research Institute of Sweden. The tests scenario was built in scale 1:2. The configuration parameters were: different fire sizes, different fire positions and different shelf configurations (i.e., with or without shelves).

The tests show that obstacles such as shelves, the size of the fire and the fire position all influence the conditions in the premises. The large heptane fires (650 mm × 650 mm fire area) included in the test series reach under-ventilated conditions while the small and medium fires not. The shelves affect the temperature in the enclosure where their presence increases the temperature in the top of the enclosure and decreases the temperature towards the bottom of the enclosure, compared to tests without shelves. The importance of the fire position is also investigated where a fire flush to the wall is compared to a fire out on the floor. The fire flush to the wall does have a slightly higher mass loss rate, although there is no significant difference in temperature in the room.

The recent years advancements in computer power, resulting in savings in terms of both time and money, has made CFD simulations of smoke spread more and more common. The most common CFD-program in Sweden is FDS (Fire Dynamics Simulator) which is developed by NIST (National Institute of Standards and Technology). To ensure the correctness of the program, however, it needs to be validated. In this report, FDS is compared to the a series of experiments with a focus on under-ventilated fire conditions.

The results of the validation show that the combustion model (mixture fraction combustion model) with empirical amendments for when the fire is allowed to burn, is very sensitive to changes in the oxygen level. This mostly affects the temperature, which can be underestimated by, e.g., around 30 %. There are cases where the temperature from the simulations and the temperature measurements correspond relatively well with each other and yet other cases when the simulated temperature is higher than the measured temperature. This depends on the simulation case, the position in the set-up and the time period compared.

One should keep in mind that both the simulations and experiments contain uncertainties and the temperature can easily be underestimated even more. The visibility and the carbon monoxide results from the simulations are linked with even larger uncertainties than the temperature measurements; but, due to limitations in the FDS code and lack of experimental data, these parameters have not been validated.

1 Background

The building legislation in Sweden has gone from following strict prescriptive building codes to include more analytical performance based codes. There is also a tougher climate in the building business where the constructor has to be as economically efficient as possible. To build smart can save much money and for fire safety design that often means analytical solutions. In the Swedish buildings codes (Boverkets byggregler) it is stated that analytical solutions have to have a higher degree of verification compared to simply following the building codes or recognised handbooks [1]. In analytical solutions, e.g. for evacuation design, the use of computer programs for simulating the smoke spread is common. In recent years a group of computer codes named CFD (Computational Fluid Dynamics) codes has emerged as an engineering tool for describing smoke spread. The CFD codes need to be compared to experimental data so that they can be fully validated.

In a research project on the validation and comparison of CFD codes [2, 3], retail premises was identified as an area where more experimental data for the validation of computer codes was needed. There is little data available for how retail premises affect the smoke spread and how different configurations affect the results. Some smoke spread data is available in the literature. Some concern properties of the smoke gas layer [4, 5], while others describe the development of the smoke in a more schematic way [6, 7]. In many test series there have not been measurements performed in as many positions as in the work presented in this report and most of the cases where extensive measurements have been performed represent other geometries than the one of interest. Those other geometries include small rooms (e.g. connections between rooms) [8-11], corridors (sometimes connected to different rooms) [12-14], tunnels [15-20], complex geometries in several floors [21-26], and premises with high ceiling height [27]. Söderbom performed smoke spread tests in large premises [28], but the geometry was not the same as the case in the present report. Further, the parameters studied were not exactly the same and the temperature measurements were not as detailed as those presented here.

Computer modelling is, as any modelling, associated with errors and uncertainty. The computer program that is used in this report, FDS [29], has to some extent been verified and validated (see section 5.1 for definition) by its developer (National Institute of Standards and Technology, NIST). Despite this, there are many functions and models in the program that still contain uncertainties and errors. In FDS one of the models used in this study, the mixture fraction combustion model, has been associated with both uncertainties and errors when used for under-ventilated fires. Further, there is always a need for validation of this kind of computer code when they are applied to new geometries.

Previous relevant validation work has been conducted for some different parts of this report. In the case of the validation of CFD, a large validation and verification study of most of the models included in FDS has been conducted under the auspices of the US Nuclear Regularity Commission [30]. The study is a series of 7 reports where one of them, volume 7, concerns FDS. The report covers most of the models included in FDS. The study includes some under-ventilated experiments and simulations but the results are only discussed briefly. Simulations of under-ventilated fires have also been conducted previously by Tuovinen [31] but with the RANS-code (see section 4.1) SOFIE (Simulation Of Fires In Enclosures) [32]. Beard has discussed the importance of using models in a correct way and also reported that there can be large variation in the results from simulation between different users [33].

2 Aim, objectives, and definitions

Based on the background information above, the goal of this report is to:

- Evaluate and present experimental results to investigate how different configurations in a retail premises affect the smoke spread and temperature distribution in the premises.
- Present experimental data for comparison of experimental smoke spread and temperature distribution to computer simulation results.
- Investigate how FDS simulates under-ventilated fires.

The overall aim is to increase our understanding of smoke spread and temperature distribution during fires in retail premises.

An important sub-aim has been to investigate how CFD codes, and particularly FDS, treats under-ventilated fires. This part of the work was performed as a Master of Science thesis at Department of Fire and Safety Engineering and Systems Safety at Lund University.

FDS is the only CFD program that is used and validated in this report and is chosen because there are reasons to believe that FDS is the most common CFD-program for smoke filling in Sweden today. Other codes were used and validated against the retail premises tests in the project by the Swedish Rescue Services Agency [2, 3]. Further, the authors hope that the report can be of use to CFD users that wish to validate other codes.

Since evaluation of the experimental results and presenting them is an important objective in itself, more experimental results are presented than have been used for comparison with the CFD simulations. The aim has also been to present the results in such a way that they can be useful to others who wish to compare their models or simulations with experimental data. Therefore a significant amount of information concerning well-ventilated fires is also presented in this report that can be used for other comparisons and validations.

“Under-ventilated fire” and “ventilation controlled fire” are used as synonyms in this report.

3 Under-ventilated fires

Before the validation it is necessary to clarify why it is relevant to discuss under-ventilated fires and when under-ventilated fires occur. The under-ventilated case was selected to be part of a Masters of Science degree [34]. Under-ventilated fires often arise in three types of scenarios:

1) In enclosures with no or small ventilation openings where the oxygen level can start to fall quickly depending on the size of the enclosure. A typical enclosure is a storage or supply room.

2) The second typical scenario is a room or enclosure with a low ceiling height compared to the heat release rate of the fire. If flames are in the smoke layer, the fire will become ventilation-controlled. This is the case for many buildings, e.g. unsprinklered office landscapes.

3) The third kind of under-ventilated fire is where there is a very large fire but the oxygen cannot reach the fuel source since there is a complex three dimensional geometry of the fire or a significant amount of unburned gases surrounding the fire. This means that an under-ventilated fire may occur even in big open volumes.

In under-ventilated fires the soot and CO production are much higher than in a well-ventilated fire [35-37]. This, combined with the information that most deaths in fires are related to the poisoning by carbon monoxide [38], indicates that under-ventilated fires need to be simulated as correctly as possible. It should here be noted that there are two different processes that are important to understand: a) the chemical reactions and reaction products near the fire and in the upper gas layer and b) the spread of these reaction products.

4 CFD and simulation of fires

The use of computer based fire simulations has gone hand in hand with the performance of computers and their development in time. Zone models (two-zone models) were the first computer simulation approach to be widely accepted and used, much because of their simplifications which results in relatively low computer power requirements. The two-zone model splits the enclosure into two zones, one hot upper layer and one cold lower layer. With today's computer power zone models performs a simulation in a matter of seconds. One example of zone model code is BRANZFIRE [39].

The more complex approach to simulate fires is using CFD (Computational Fluid Dynamics). Within the family of CFD codes there are a number of different approaches that can be used to simulate reality, which are described in more detail in section 4.1. CFD models demand much more computer power than two-zone models and, therefore, have had limited use in engineering smoke spread applications until recently. Previously, CFD modelling was mainly a tool in research projects. Traditionally the RANS-type of CFD code has been applied more because it is more computationally efficient than the LES-type of CFD-code, see section 4.1. Recently, however, the LES-type of CFD-code is becoming more dominant [40]. This is due to the fact that increasing computer power now allows transient fire behaviour to be modelling using such codes.

4.1 What is CFD?

CFD is short for Computational Fluid Dynamics and is a method to numerically solve the governing equations of fluid dynamics. The equations solved are the set of Navier stokes equations governing continuity and conservation of energy, mass, velocity and species. The reason why the equations are solved numerically is no analytical solution for the full Navier Stokes equations exists [41].

In CFD programs a calculation domain is specified and divided into cells called grid cells. It is in these cells that the conservation equations are solved. There are different kinds of approaches for solving the equations, the most common of which are DNS, LES and RANS as described below.

DNS

DNS stands for Direct Numerical Solution and is, as the name implies, a direct way to numerically solve the transport equations. This requires a resolution at Kolmogorovs micro scale. This is the smallest scale where turbulence is the governing parameter, i.e., approximately 10^{-6} in the length scale [42]. This makes it impracticable for smoke spread scenarios because of the computer power that it demands.

In FDS, see section below, it is possible to perform DNS calculations if the grid is set fine enough.

LES

LES (Large Eddie Simulation) assumes that all the turbulent energy is preserved in the largest scale, i.e. everything under the largest scale (grid cell) is not calculated. If the grid is set fine enough LES converts to a DNS. To deal with phenomena that take place under the largest scale, the code uses so called sub-grid models like combustion or radiation models. The code works on a transient time line and the time step is, therefore, a limitation since every calculation is based on the previous time step [42].

FDS (Fire Dynamics Simulation) is one CFD program that uses LES-code. FDS is the first widely spread CFD code on transient fire driven flow. The program is developed by

NIST, the National Institute of Standards and Technology (U.S. Department of Commerce). FDS is a dos-program and any visualisation must be done in another (post-processor) program, in most cases the program Smokeview. FDS has been working for over 35 years but it was made public in 2000 [43]. Upgrades have since been released and the version used in this report is the fifth major release. The program is free of charge and can easily be downloaded from the internet which is the major reason for its widespread application.

RANS
The approach of RANS (Reynolds Averaged Navier Stokes (equations)) is to decompose instantaneous values to a mean value with fluctuations. A RANS-code is most often used for steady state simulations because it executes Taylor expansion series with convergence for every time step [44]. This makes it independent of what has happened earlier (in time) in the simulation. If it is desirable to conduct a transient simulation with many time steps, the program is not time efficient.

SOFIE (Simulation Of Fires In Enclosures) is a computer program which is based on a RANS-code. Despite its name, SOFIE is written to model more fluid dynamics problems than just fire dynamics [32]. The program was developed by several institutes, e.g. Cranfield University, SP Technical Research Institute of Sweden, and the Lund University. SOFIE is a dos-based program and requires a pre-processor for the geometry of the enclosure, for example the program AC3D, and a post-processor for visualisation of the results is also necessary. SOFIE is free of charge and can easily be downloaded from the internet. It is significantly more difficult to use than FDS, however, and has remained largely a research tool.

Application
CFD is used in different areas but within the field of fire safety, smoke filling of enclosures is one of the most frequent applications, both for research and analytical fire safety design in buildings. Fire safety design consultants are frequent users of CFD-codes for smoke filling of enclosures. CFD is often used for the verification of analytical solutions for buildings fire safety design. A typical analytical design that includes CFD and FDS is an evacuation investigation. The height of the smoke layer, the temperature, the visibility and the toxicity are important parameters in such an investigation. These parameters can be addressed by using FDS which calculates them on a transient time line. The time to critical conditions is then compared to the available evacuation time to establish whether the required evacuation time is less than that available.

4.2 FDS and the Mixture Fraction combustion model

As mentioned previously, FDS uses sub-grid models to model phenomena which cannot be resolved in the largest eddy (grid cell). An example of this is the combustion model which by default assumes a single step reaction with predestined products that occur infinitely fast, i.e., the combustion model used by FDS is a “mixture fraction model” or “mixed is burnt model”. As its name implies it is mixing controlled which means that when fuel gases and oxygen mix they are immediately and completely burned. This is a good approximation for well-ventilated fires but a poor approximation of under-ventilated fires. For under-ventilated fires, the heat release rate will be too high and burning will take place where it should not. To account for this, FDS uses a simple empirical expression that describes whether or not the mix of fuel vapour and oxygen are allowed to burn, see Figure 4.1.

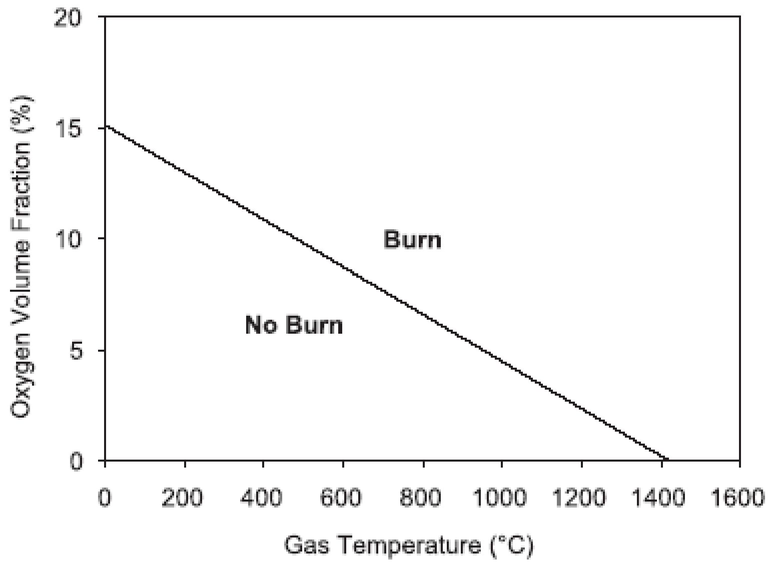


Figure 4.1 The correlation for when the fire is allowed to burn [29].

This simple expression creates, however, several errors. The most important error is its grid dependence. The temperature of the flame is very dependent on the grid resolution. A fire may burn in one resolution but not in another. Since the temperature in the flame increase with a finer mesh resolution, this means that the fire may go out in the simulation while it would burn in the reality. A second important error is due to FDS' assumption of adiabatic flame temperatures. In reality the temperature is not adiabatic but lower which can result in sustained burning of the fire in the simulation after extinction of the real fire [45]. Another feature that can be observed in some cases is that the unburned fuel (the fuel from the fire source is still added even if the fire is under-ventilated and complete combustion does not occur) is combusted in places where there should not be any combustion, e.g. when the unburned fuel reach areas with high oxygen concentration but the temperature is too low to lead to combustion in reality.

5 Validation

5.1 Validation and Verification

Since a validation of FDS for under-ventilated fires is part of this study it is appropriate to define what a validation is. Validation and verification are two words that are often used synonymously. In *"Credible CFD – Verification and Validation*" [46] they are defined as follows:

Validation – *"The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model".*

Verification – *"The process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model"*

Or in other words, a validation checks that the right equations are solved and verification checks that the equations are solved in the right way. It could of course be said that when doing an overall comparison between simulation results and experimental data, it can be difficult to separate validation from verification.

Why should a validation be done? How is a validation performed in a good manner? A validation creates confidence and credibility that the code contains a correct model, the process also makes it easier to quantify error and uncertainty.

The standard E 1355-05a*"Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models"* [47] contains an evaluating process of fire modelling. However, depending on the purpose of the validation it can be performed in different ways. One can examine the equations and the source code to see whether they are solved correctly, or one can compare the simulations to experimental data. The latter makes the process of finding actual error in the equations or in the programming more difficult. It gives, however, a direct estimation of how well the program actually simulates the scenario to which it is compared. Which method should be used must be determined based on the goal of the validation. If the goal is to further develop the code so that it may simulate a problem in a better way in the future, then a close examination of the equations might be the best approach. If the goal is to improve the current usage, then comparison with experimental data may be the best approach.

5.2 Error and Uncertainty

In the validation, the terms error and uncertainty are frequently used and the difference needs to be clarified. In *"Credible CFD – Verification and Validation"* [46] they are defined as follows:

Uncertainty – *"A potential deficiency in any phase or activity of the modelling process that is due to the lack of knowledge"*

Error – "*A recognisable deficiency in any phase or activity of the modelling process that is due to the lack of knowledge"*

Or in other words, uncertainty is a deficiency that may exist but that one is not sure of, while the deficiency "in" an error is known.

5.3 Experimental and computer modelling uncertainty

Not only computer modelling is associated with uncertainties and errors. The experimental results also have uncertainties and may contain errors. The measurement of reality can never be an exact representation of the real world, e.g., the set-up is usually a simplification of what is to be studied and does not fully represent reality, the measuring devices affect the surrounding, and errors and uncertainties are inherent to the measuring devices themselves. A thermocouple has, for example, some thermal inertia which is dependent on the thickness of the material, a light beam sent out from a laser is dependent on how clean the lamp is, an oxygen reader must be calibrated correctly, etc. Another problem when dealing with fires is that fires to some extent have inherent random behaviours, which means that the results from one experiment to another can differ for the same scenario. How large or how significant these differences are depend on the scenarios and set-ups. The way of studying these features is to perform repetition tests. During the test series, two pairs of repetition tests were performed.

The relevance of the error or uncertainty must, of course, be taken into account. In some cases a temperature difference of 5 ºC is significant while in other cases it is not. The acceptable error or uncertainty must be decided for each case. It is difficult to quantify the differences between measured reality and actual reality but by using different measuring devices, the error or uncertainty can be quantified to a certain degree. In the experiments presented within this report, e.g., the temperature is measured using thermocouples with different thickness which gives an indication of the influence of the radiation. For further information about experimental uncertainty in this context see for example *"Verification and Validation of Selected Fires Models for Nuclear Power Plant Applications Volume 2: Experimental Uncertainty"* [48].

A problem when comparing simulation results with experimental data is the "combined uncertainty". Since both the computer model and the experimental test are associated with errors and uncertainties it makes the comparison of single data points difficult. In the case of fires there are also often natural variations that can be very difficult to simulate or predict. One way to solve this problem, or at least decrease the uncertainty, is to use averaging when possible. Parameter studies and analyses of different factors and trends can be another way to understand and minimise the problem.

Since the validation in this report focuses on the overall treatment of a model and not the exact function of, for example, the source code for under-ventilated fires, more factors that can affect the results are brought into play. Something other than the combustion model may effect the results, e.g., the geometry or grid resolution. This can be examined by thorough sensitivity analysis but only to a certain extent. It is not possible to test all the functions included in the simulation, but a selection must be made depending on the aim of the validation. Some results from such a sensitivity variation are presented in this report.

6 Scale modelling

When using scale modelling it is important that the similarity between the full-scale situation and the scale model is well-defined. A complete similarity involves for example both gas flow conditions and the effect of material properties. The gas flow conditions can be described by a numerous of non-dimensional numbers, e.g. the Froude number, the Reynolds number, and the Richardson number. For perfect scaling, all of these numbers should be the same in the model-scale model as in the full-scale case. This is, however, in most cases not possible and it is often sufficient to focus on the Froude number:

$$Fr = \frac{u^2}{gL} \qquad (1)$$

where *u* is the velocity, *g* is the acceleration of gravity, and *L* is the length. This so called Froude scaling has been used in the present study, i.e., the Froude number alone has been used to scale the conditions from the large scale to the model scale and vice versa. Further information about scaling theories can be obtained from for example references [49-52]. Table 6.1 contains a list of scaling models used for a variety of parameters.

Table 6.1 A list of scaling correlations for the model tunnel.

Type of unit	Scaling model	Equation number
Heat Release Rate (HRR) (kW)	$\dot{Q}_F = \dot{Q}_M \left(\frac{L_F}{L_M}\right)^{5/2}$	(2)
Velocity (m/s)	$u_F = u_M \left(\frac{L_F}{L_M}\right)^{1/2}$	(3)
Time (s)	$t_F = t_M \left(\frac{L_F}{L_M}\right)^{1/2}$	(4)
Energy (kJ)	$Q_F = Q_M \left(\frac{L_F}{L_M}\right)^{3} \frac{\Delta h_{c,M}}{\Delta h_{c,F}}$	(5)
Mass (kg)	$m_F = m_M \left(\frac{L_F}{L_M}\right)^{3}$	(6)
Temperature (K)	$T_F = T_M$	(7)

a) Index M corresponds to the model scale and index F to the full scale (L_M=1 and L_F=2 in the present case).

SP has a long experience of using scale models for studying different phenomena [53-58]. It is a method that is highly suitable for parameter variation as tests can be conducted more economically in reduced scale. In the experiment series presented here a scale of 1:2 was used. The simulation was performed using the geometry and scale of these experiments (i.e., the results were not simulated scaled to real scale).

7 Experiments

7.1 Experimental set-up

The fire tests were performed inside a room built in the SP fire hall. The purpose was to simulate a retail premises including both areas with shelves and open areas without shelves. The lay-out of the room is shown in Figure 7.1. The dimensions of the room were 18 m × 7.5 m × 2.4 m and were chosen to represent 1:2 scale of retail premises with the dimensions 36 m × 15 m × 4.8 m. When referring to the different walls of the room the view point is from the short wall furthest away from the fire, i.e., the short wall near the fire is call the "back wall", the other short wall is called the "front wall", the upper long wall is call the "right wall" and the lower long wall is called the "left wall". The room hade two small openings, one in the back wall and one in the front wall. These openings were 0.5 m × 0.25 m and were positioned centrally with the bottom 5 cm above the floor. In the front wall, in the corner where the front wall and the right wall meet, was a door (0.705 m × 2.03 m) that was used during the ignition procedure. The door in the front wall was only opened during the ignition period, i.e. 30 s – 35 s in the beginning of each test. During the rest of each test this door was closed.
The walls where made of wooden frames covered by 10 mm Promatect® H. Most of the ceiling was also made of 10 mm Promatect® H. However, 3.4 m of the ceiling over the width of the room furthest away from the fire was made of 6 mm Masterboard. Furthermore, approximately 5 m of the ceiling closest to the wall near the fire were protected by 20 mm Roxull insulation. Physical data for these materials can be found in Table 7.1. The floor in the room was the floor in the fire hall.

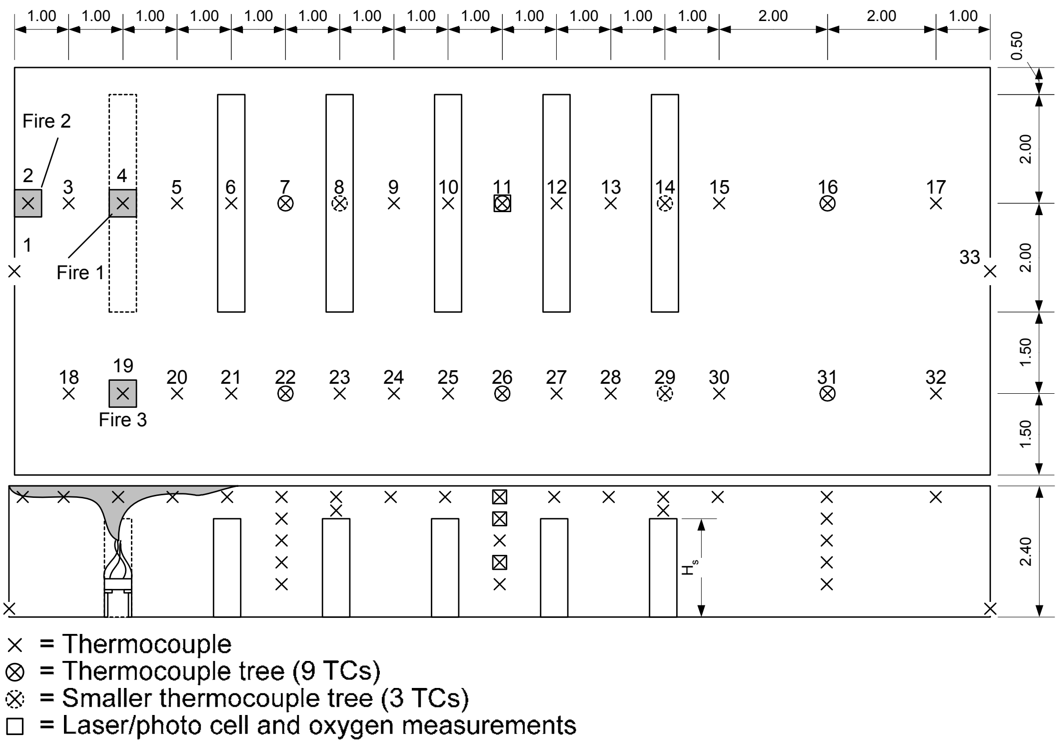


Figure 7.1 Experimental set-up and measurement positions. Note that × in the thermocouple tree only schematically represent the thermocouples in these trees. The exact heights of the TCs in the trees are described in Section 7.2.

The fire source consisted of heptane pools of different sizes. Three different pool sizes were used: 1) 305 mm × 305 mm × 100 mm, 2) 500 mm × 500 mm × 150 mm, and 3) 650 mm × 650 mm × 150 mm. The amount of fuel (a depth of approximately 60 mm) was chosen to give a burning time of approximately 15 minutes for the two smaller pools (pool 1 and pool 2). For pool 3 the same amount of fuel as for pool 2 (15 L) was used giving a fuel depth of approximately 36 mm. A water layer was added to give a free board of 10 mm in all three cases, i.e. 30 mm of water for pool 1 and 80 mm of water for pool 2 and 104 mm for pool 3. The pan with fuel was placed on a platform configuration positioned on load cells. The fuel surface was located 62 cm above the floor.

Table 7.1 Physical data for materials used in the experimental set-up.

Material	Density (kg/m^3)	Conducticity (W/m/K)	Heat capacity (kJ/kg/K)
Promatect H, 20 ºC	860	0.170	0.740
Promatect H, 200 ºC	860	0.214	0.922
Promatect H, 400 ºC	860	0.241	1.031
Masterboard	910	0.220	1.09
Roxull insulation	180	0.039	0.79

Prior to the test series, a number of pre-tests were performed with the heptane pools of different sizes burning freely outside the room. Figure 7.2 shows the heat release rates for the different heptane pools. The heat release rate is based on the mass loss rate and the heat of combustion for heptane (44.56 MJ/kg) and a combustion efficiency of 0.92. There is a difference both in maximum heat release rate and in the burning time. In Figure 7.3 the heat release rate and the time scale have been calculated to correspond to full scale. Note that the measurement of the HRR for the pools have been performed for freely burning condition (not inside a room) and that the conditions inside a room during a fire can alter the mass loss rate and the combustion efficiency.

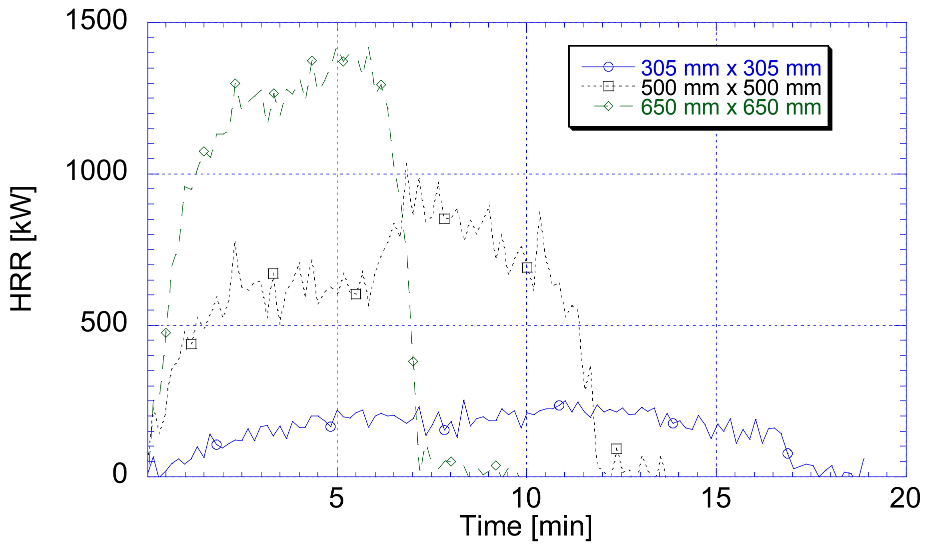


Figure 7.2 Heat release rates for the free burning heptane pool fires of different sizes.

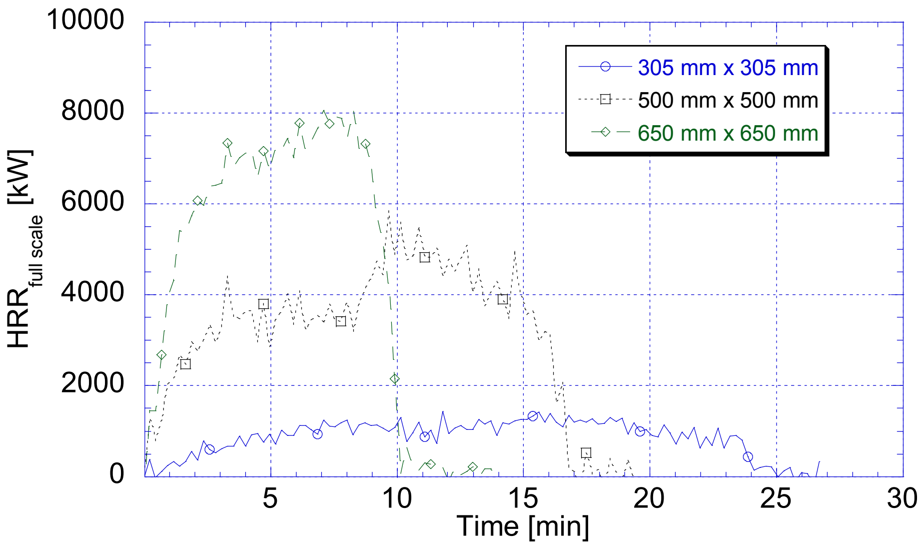


Figure 7.3 Heat release rates for the free burning heptane pool fires of different sizes. The heat release rate and the time has been calculated to correspond to full scale.

Simulated shelves were included in six of the tests. The shelves were made as blocks 4 m long and 20 cm wide. The height of the shelves, H_s, was 1.8 m. The material in the blocks was wooden joists covered with non-combustible boards (6 mm Masterboard). The reason for this design of the simulated shelves was to study the effect the shelves in the overall smoke spread and not to study fire or smoke spread within the shelves. Five simulated shelves were included in the tests with shelves (see Figure 7.1). The fire position “Fire 1” was at the centre of an imagined shelf if the same distances were to be used between all the shelves. There was, however, no shelf placed in this position. This is marked as a dashed line in Figure 7.1. Fire position “Fire 1” simulates a fire in a free standing shelf, while position “Fire 2” simulates a fire in a shelf fixed to the wall and position “Fire 3” simulates a fire in a free standing pallet load or display.

Most of the tests were performed with the fire in the position “Fire 1”. For comparison a few tests were performed with the two other fire positions (see Figure 7.1 and Table 7.2).

Three video cameras were used for recording observations in each test. Camera 1 and Camera 2 were aimed through windows in the left wall, while Camera 3 was aimed through a window in the front wall. Camera 1 recorded the fire (and smoke height marks on the short end of the first shelf object, counted from the fire, see Figure 7.4) through a window (55.5 cm × 39 cm) on the left side, 135 cm from the back wall with the bottom of the window 71.5 cm above the floor. Camera 2 recorded the height of the smoke layer by filming marks on the short end of shelf object no 3. The window (55 cm × 40.5 cm) for Camera 2 was positioned on the left side, 848 cm from the back wall with the bottom 71 cm above the floor. The window (54.5 cm × 40 cm) for Camera 3 was positioned with its left side 102.5 cm from the left wall. Camera 3 recorded two escape route signs, one on the back wall and one on shelf object no 2 (see Figure 7.4). In addition to the camera windows there was an observation window in the right wall, near the fire. The observation window (30.5 cm × 55 cm) was position with its right side 312 cm from the back wall and its bottom 133 cm above the floor. For description of the different walls see the text near Figure 7.1.

Figure 7.4 Height marks on shelf object no 1 and escape route sign on shelf object no 2.

7.2 Measurements

During the tests several different parameters were measured. The parameter that was measured in by far the most positions is the temperature. In Figure 7.1 the measurement positions are presented. The different parameters measured are briefly described below.

Smoke density

The optical density, i.e. the smoke density, was measured using a laser/photocell-system. The lasers were transverse lasers with an optical power of 5 mW and a wavelength of 650 nm. Both lasers and photocells were placed inside boxes with overpressure to avoid contamination by soot from the fires. Each box had a tube for the light in the measurement direction. The measurement distance (distance between the ends of the tubes) was 0.5 m. The optical density can be represented by the extinction coefficient, *k* (m^{-1}), which is defined as

$$k = \frac{1}{L}\ln\left[\frac{I_0}{I}\right] \qquad (8)$$

where *L* is the length of beam through smoky environment, I_0 is the light intensity in a smoke free environment, and *I* is the light intensity for a light beam having traversed a certain length (*L*) of smoky environment.

The smoke density was measured at three different heights (0.05 m, 0.20 m, and 0.80 m from the ceiling) at position 11 (see Figure 7.1).

Temperature

The temperature was measured using thermocouples (type K) placed out as shown in Figure 7.1. Two different diameters of thermocouples were used, 0.25 mm (mainly used) and 0.8 mm (for comparison).

Most of the thermocouples were positioned 5 cm below the ceiling. However, in the positions 7, 11, 16, 22, 26, and 31 thermocouple trees with nine thermocouples were installed and in the positions 8, 14 and 29 thermocouple trees with three thermocouples were installed. The thermocouples in the large thermocouple trees with nine thermocouples were placed at the following distances below the ceiling: 0.05 m, 0.10 m, 0.20 m, 0.40 m, 0.60 m, 0.80 m, 1.00 m, 1.40 m, and 1.90 m. The thermocouples in the small thermocouple trees with three thermocouples were placed at the following distances below the ceiling: 0.05 m, 0.20 m, and 0.40 m.

Velocity
The velocity through the two small openings of the room (Position 1 and 33, respectively) was measured with bidirectional probes [59] at two heights in each opening (6 cm and 19 cm from the bottom of the opening) and calculated using the differential pressure equation. Note that the bottom of the opening was 5 cm from the floor. A positive velocity corresponds to flow out of the room and a negative velocity corresponds to flow into the room.

Mass loss rate
The mass loss rate (MLR) was measured by placing the fuel container on a scale and measuring approximately every second. Note that the mass loss rate presented in the diagrams in the appendix has been smoothed. First the mass signal was smoothed as five second averages and then the calculated mass loss rate is given as a running 10 s average. This is done to simplify the presentation of the overall change in the mass loss rate. It also makes the signal easier to use if needed as input data for simulations. An illustration of the effect of the smoothing is given in Figure 8.1.

It is difficult to say anything about the heat release rates in the different cases since there is no exact knowledge of the combustion efficiency, which depends on the conditions inside the room. A comparison between the MLR measured inside the room and the MLR for the corresponding pool size measured freely burning outside the room is presented in Figure 8.6.

Oxygen
The oxygen level was measured at the height 0.80 m from the ceiling at position 11 by extracting the air to an oxygen analyzer (PMA 10). The oxygen measurements were available for Test 3 to Test 11.

The tests were monitored by the staff at SP. The tests were also recorded by different video cameras from different angles. Information from these observations can be found in Appendix 1. In Section 7.1 there is a description of the positions of the different video cameras used.

7.3 Experimental procedure

The tests started with two minutes of background measurement before ignition (this time is not included in the output of the results). This was done both to check all instruments and to obtain a measure of the background conditions. The ignition of the pool fires was done manually with matches which meant that the door in the front wall was open for 30 s – 35 s. The door was then closed for the rest of each test. When ignited, the pools were allowed to burn until all the fuel was consumed. Three different parameters were changed during the test series: the size of the fire, the position of the fire and the presence or absence of shelves. The test program is presented in Table 7.2. The HRR for the different pool sizes (freely burning conditions) is presented in Section 7.1.

Table 7.2 Test program.

	Fire size (mm × mm)	Fire position	Shelves	Amount of fuel (L)
Test 1	305 × 305	Fire 1	Yes	5.42
Test 2	500 × 500	Fire 1	Yes	15
Test 3	500 × 500	Fire 1*)	Yes	15
Test 4	650 × 650	Fire 1	Yes	15
Test 5	500 × 500	Fire 2	Yes	15
Test 6	500 × 500	Fire 3	Yes	15
Test 7	305 × 305	Fire 1	No	5.42
Test 8	500 × 500	Fire 1	No	15
Test 9	500 × 500	Fire 1*)	No	15
Test 10	650 × 650	Fire 1	No	15
Test 11	500 × 500	Fire 2	No	15

*) Repetition test

8 Experimental results

The results presented in Table 8.1 are the maximum/minimum values for the different parameters. This is to give an overview of the results. Detailed results can be found in Appendix 2 and Appendix 3. Note that some of the max/min values are reached near or just after the time when the fire was extinguished. For the velocities, the highest velocities outwards and inwards, respectively, through the openings are presented. It can be noted that for most of the tests the maximum outward velocity can be found in the upper part of the opening in the front wall in the first part of the test, while the maximum inward velocity in most cases can be found in the upper part of the opening in the back wall, near the time for the extinction of the fire.

Table 8.1 Summarized results for Test 1 – Test 11. The times are given in minutes.

	Temperature Pos 4, 5cm (ºC)		Temperature Pos 8, 5cm (ºC)		Temperature Pos 11, 5cm (ºC)		Temperature Pos 11, 80cm (ºC)	
	Max	Time	Max	Time	Max	Time	Max	Time
Test 1	416	4.31	124	13.2	106	13.1	54	20.3
Test 2	1038	5.76	299	8.80	252	9.30	133	9.50
Test 3	1037	4.03	301	7.83	254	12.7	149	13.1
Test 4	1068	2.80	414	4.24	332	4.17	201	4.87
Test 5	553	2.81	276	2.86	239	6.66	142	8.90
Test 6	331	6.79	217	13.1	201	13.1	145	13.5
Test 7	382	14.4	104	6.68	90.0	8.70	55.6	21.8
Test 8	1031	5.46	243	8.68	222	8.68	137	9.35
Test 9	1022	7.08	25	10.8	225	6.94	141	12.4
Test 10	1061	2.01	394	5.09	307	5.10	206	5.39
Test 11	453	7.01	272	7.76	240	8.21	155	8.77

	Mass loss rate[a)] (g/s)		Velocity (m/s)		Velocity (m/s)		Optical density, 80 cm (1/m)		Oxygen level (Vol %)	
	Max	Time	Max[b)]	Time	Min[b)]	Time	Max	Time	Min	Time
Test 1	4.8	8.5	0.69[c3)]	0.31	-1.60[c1)]	25.5	1.02	6.92	-	-
Test 2	16	2.6	1.21[c1)]	1.19	-2.60[c1)]	17.2	2.57	17.5	-	-
Test 3	18	6.5	1.62[c3)]	1.18	-2.66[c1)]	15.6	3.63	15.6	14.0	16.0
Test 4	35	3.0	3.01[c3)]	0.93	-3.19[c1)]	8.45	3.83	3.58	11.7	9.57
Test 5	43	9.7	2.40[c3)]	1.26	-2.36[c1)]	15.0	2.09	4.74	13.9	14.4
Test 6	17	3.9	1.81[c3)]	1.01	-2.56[c1)]	16.9	2.29	16.4	13.8	18.0
Test 7	4.0	5.2	0.64[c2)]	0.98	-1.30[c1)]	31.0	0.77	23.8	18.8	31.7
Test 8	14	5.0	1.81[c3)]	1.18	-2.30[c1)]	18.9	2.82	13.4	12.9	17.5
Test 9	15	3.7	1.67[c3)]	1.69	-2.33[c1)]	18.2	3.17	16.2	12.3	17.3
Test 10	33	3.5	3.58[c3)]	0.94	-3.42[c1)]	8.08	-	-	8.8	8.77
Test 11	19	2.1	1.89[c3)]	0.99	-2.45[c1)]	14.4	-	-	10.5	14.9

a) Given as the maximum 10 s average.
b) For the velocity "Max" means the maximum outflow velocity and "Min" means the maximum inflow velocity.
c1) Corresponds to Pos 1, 19 cm above the bottom of the opening (24 cm above the floor).
c2) Corresponds to Pos 1, 6 cm above the bottom of the opening (11 cm above the floor).
c3) Corresponds to Pos 33, 19 cm above the bottom of the opening (24 cm above the floor).
c4) Corresponds to Pos 33, 6 cm above the bottom of the opening (11 cm above the floor).

Mass loss rate

Three different fire sizes were used to simulate different fire scenarios in the tests, see Table 7.2. The larger the fire size the higher the expected mass loss rate (MLR). The placement of the fire also influences the size of the fire since the radiation from the walls and ceiling depends on the position of the pool.

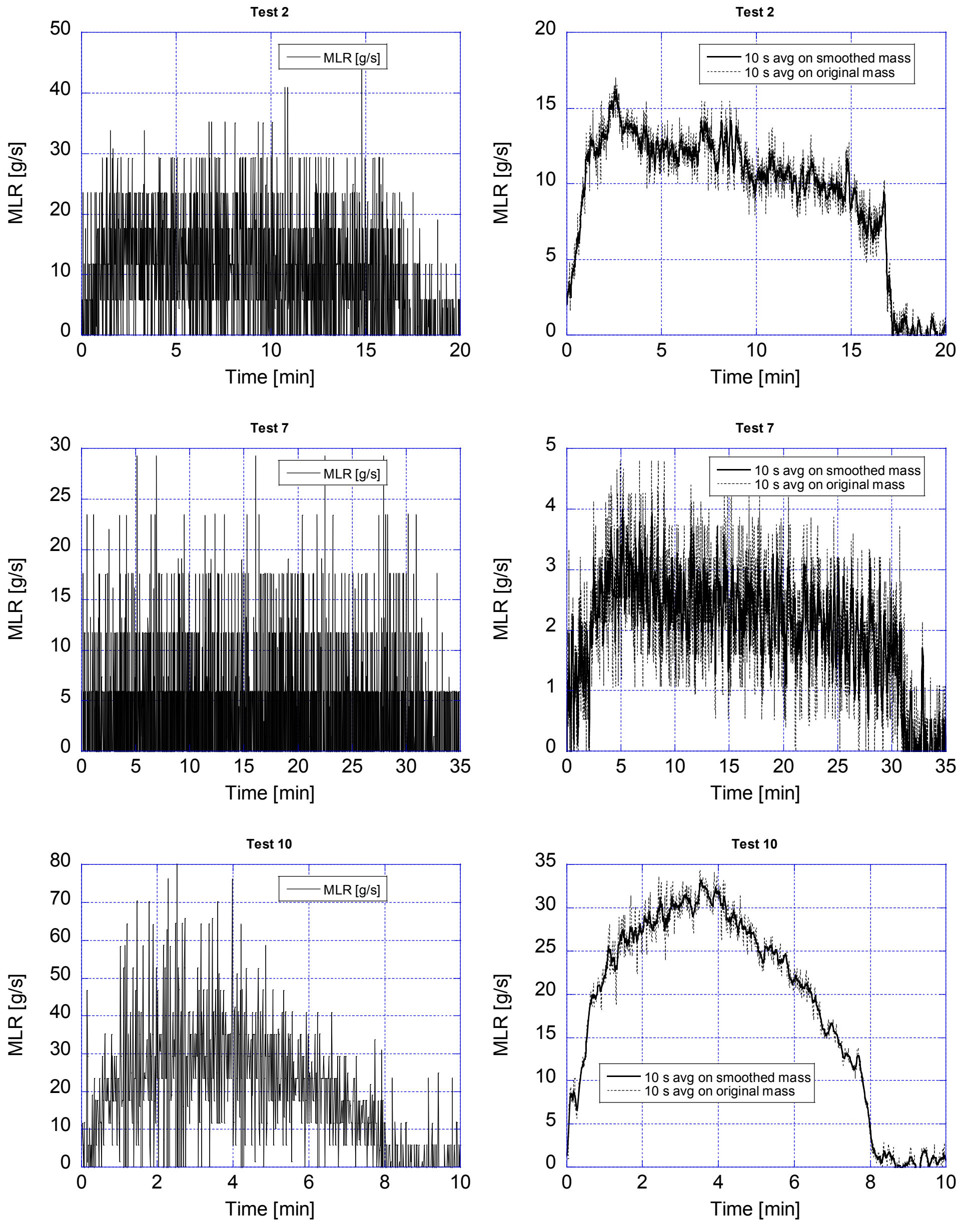


Figure 8.1 Comparison of different ways of calculation and presenting the MLR. For the three different tests (Test 2, Test 7, and Test 10, respectively), three different ways of presenting the MLR are illustrated, i.e., the MLR calculated from the original mass signal (left), MLR calculated from original mass signal and presented as 10 s average (dotted line), and MLR calculated from a smoothed mass signal and presented as 10 s average (solid line).

The MLR is calculated by differentiating the signal from the load cells under the fuel pan. The relatively small changes in mass between each time step, gives a highly fluctuating MLR. Therefore, some kind of averaging of the MLR is needed to obtain a useful measurement. The problem and an example of a solution are illustrated in Figure 8.1, where the MLR calculated from the original mass signal is presented for tests 2, 7 and 10, together with the MLR calculated from original mass signal and presented as 10 s average (dotted line) and the MLR calculated from a smoothed mass signal and presented as 10 s average (solid line).

The mass loss rates in the diagrams below are based on a smoothed mass signal and then averaged over 10 seconds. This is done to present the overall change in mass loss rates although fluctuations can still be observed. For Tests 1 and 7, which had the same fire size and position (but with and without shelves, respectively), the maximum MLR is approximately 3-5 g/s which, assuming complete combustion, corresponds to about 130 kW - 220 kW. The mass loss rate stays at its maximum for about 20 minutes after which it is rapidly reduced to give a burn time of 25 – 30 minutes, see Figure 8.2.

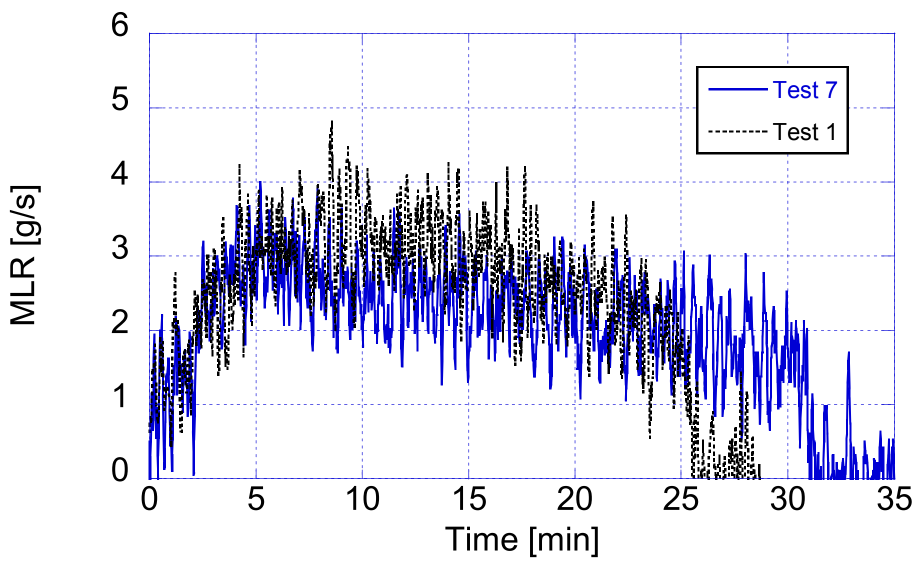


Figure 8.2 Mass loss rate for Test 1 and Test 7, based on 10 s averages of smoothed MLR signal.

For Test 3 and Test 9, which had the same fire size and position, the mass loss rate exhibits an almost steady state period (the maximum is higher) of approximately 13 g/s which, assuming complete combustion, corresponds to 580 kW. The MLR stays at its steady value for about 5 minutes after which it gradually decreases for a complete burn time of 17-19 minutes, see Figure 8.3.

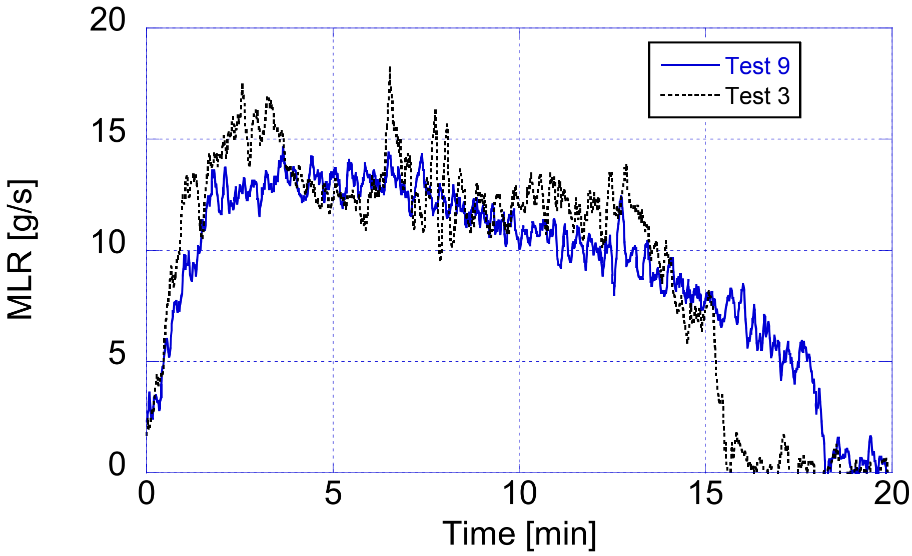


Figure 8.3 Mass loss rates for Test 3 and Test 9.

Test 4 and Test 10 had a maximum mass loss rate of 30-35 g/s which, assuming complete combustion, corresponds to 1340- 1560 kW. The MLR stays at its maximum for no more than two minutes after which it decreases in steps giving a burn time of 8-9 minutes, see Figure 8.4.

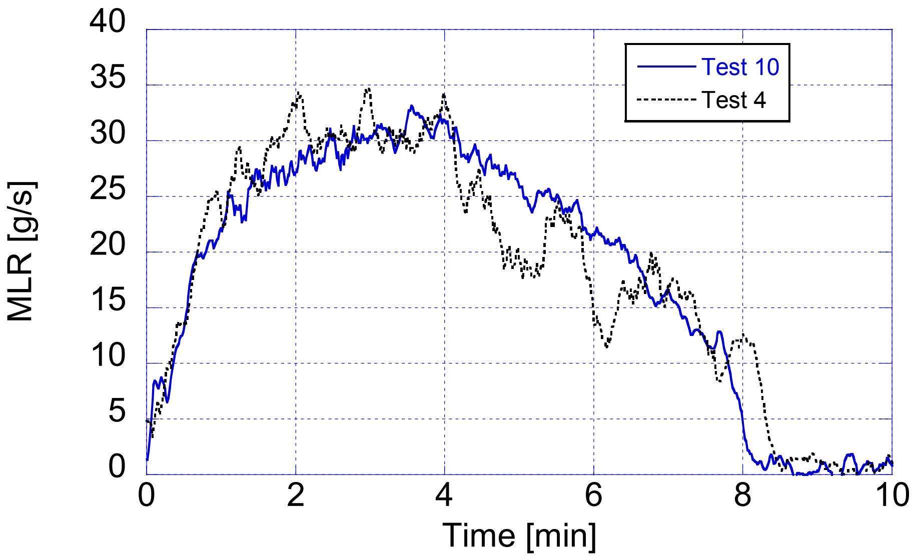


Figure 8.4 Mass loss rates for Test 4 and Test 10.

In Test 5 and Test 6 the fire had other placements than in the rest of the tests. In Test 5 the fire was placed flush to the wall which resulted in a slightly higher maximum MLR than the other fire with area of 500 mm × 500 mm, see Figure 8.3 and Figure 8.5. In Test 6 the fire was placed out on the floor, i.e., in a region without shelves during a test with shelves, and its MLR follows the other fires with the same pool size. Test 11 was a repetition test of Test 6 but without shelves which also gives a slightly higher mass loss rate. The MLR for tests 5, 6 and 11 is given in Figure 8.5.

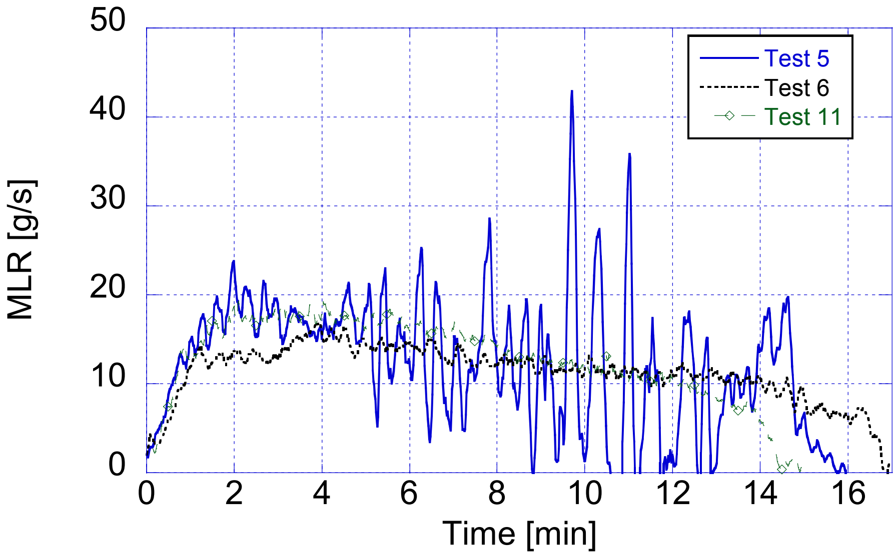
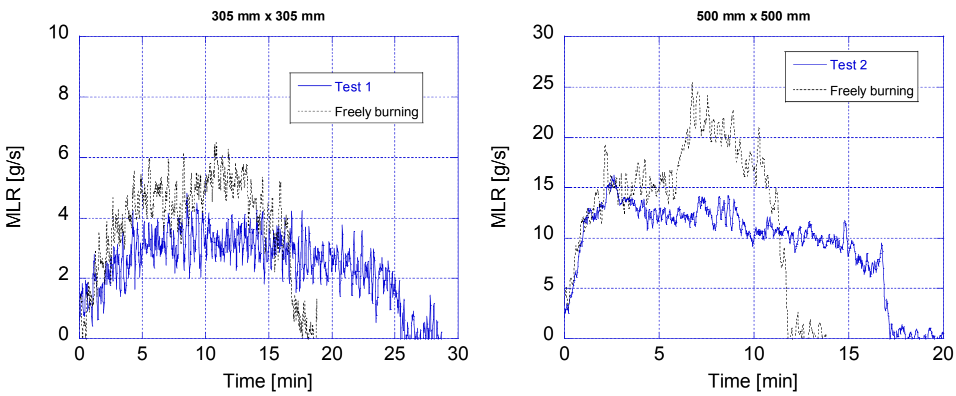


Figure 8.5 Mass loss rate for Test 5, Test 6 and Test 11.

The mass loss rates in Test 1 and 7 show no direct signs of being under-ventilated, see Figure 8.2. The curves for the mass loss rate in Test 4 and 10 shows more signs of being under-ventilated, see Figure 8.4. In the two large fires the MLR, after reaching its peak, slowly starts to decrease where a well-ventilated fire would have an approximately constant mass loss rate and a quick decrease when the fuel runs out.

It can be seen from Figure 8.3 and Figure 8.4 that there seem to be some effect of the shelves on the burning characteristics. The MLR for the cases with shelves varies more than the MLR for the cases without shelves.

The room has an effect of the burning. A comparison of the MLR registered during tests inside the room and freely burning tests, respectively, is presented in Figure 8.6. The conditions inside the room affects the combustion and the combustion efficiency generally giving a lower MLR, except for an initial period of time. Another effect that can also be seen is due to the radiation from the walls and ceiling towards the fuel surface. The larger the fire source, the larger this effect and for the largest fire there is actually a period of time when the MLR inside the room is larger then the corresponding MLR for the freely burning conditions.



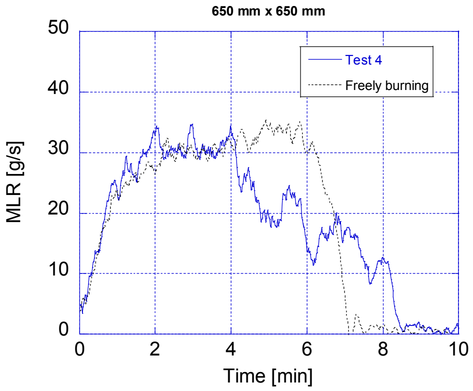


Figure 8.6 Comparison between MLR for tests inside the room and freely burning tests.

Temperature

The temperature is strongly correlated to the heat release rate (HRR). The HRR is in turn strongly correlated to the MLR, especially in a well ventilated fire. Within the same test, the temperature varies between the different positions and different heights. In Appendix 2, graphs for the temperature measurements are presented. In this sections, examples of temperature profiles in position 7 for different tests are given.

For Test 1 and Test 7 the average temperature in the hot upper region of the enclosure is in the interval 80 ºC -120 ºC, see Figure 8.7 .

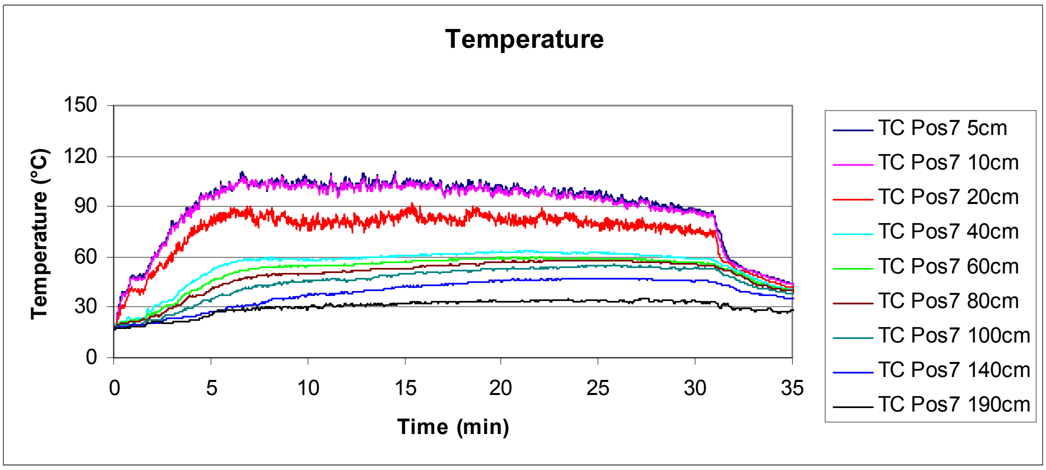


Figure 8.7 Test 7 with the fuel area 305 × 305 mm (Pos 7).

For Test 2, 3, 8 and 9 the average temperature in the hot upper region of the enclosure is in the interval 200 ºC - 250 ºC, see Figure 8.8 for Test 8.

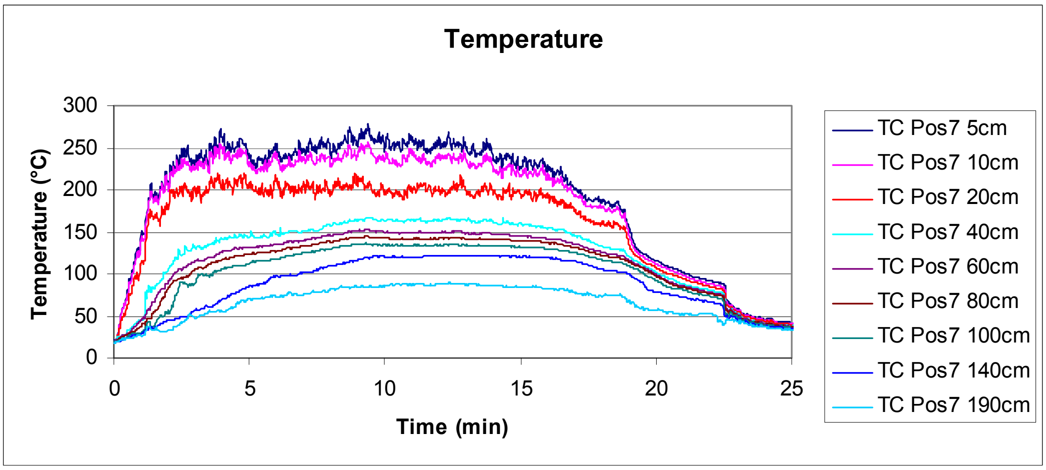


Figure 8.8 Test 8 with the fuel area 500 × 500 mm (Pos 7).

For Test 4 and Test 10 the temperature in the hot upper region of the enclosure is in the interval 300 ºC – 450 ºC, see Figure 8.9 and Figure 8.10.

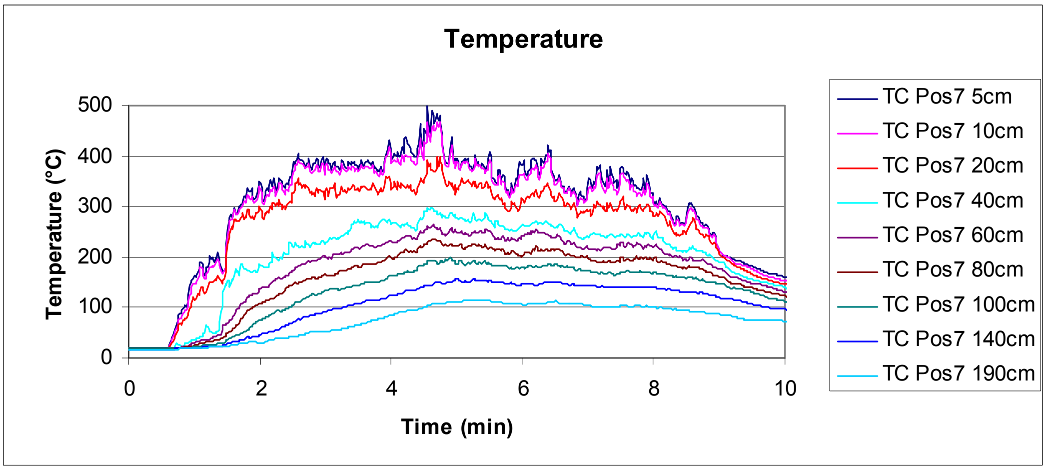


Figure 8.9 Test 4 with the fuel area 650 mm × 650 mm (Pos 7).

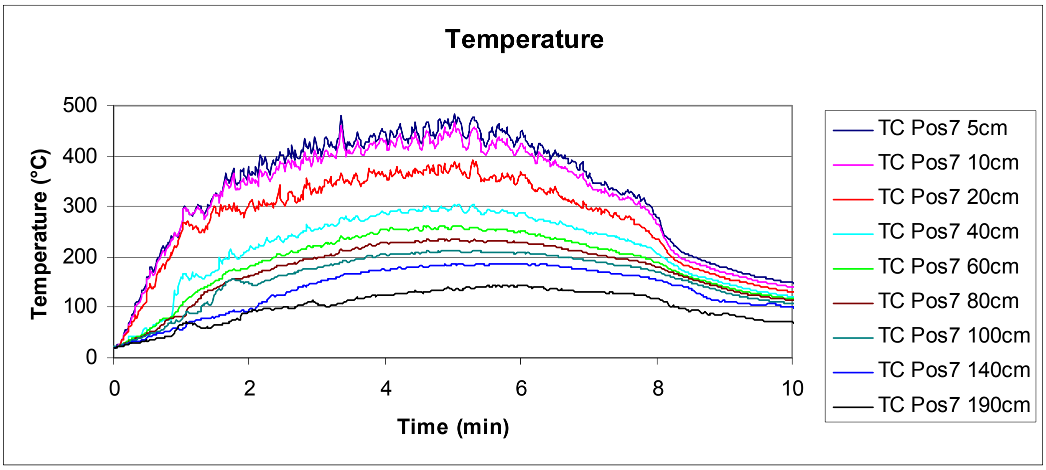


Figure 8.10 Test 10 with the fuel area 650 mm × 650 mm (Pos 7).

The average temperature in the upper region in Test 5, 6 and 11, which had the same fire size as Test 2, 3, 8 and 9, do also stays in an interval from 200 ºC – 250 ºC, see Figure 8.11 for Test 5.

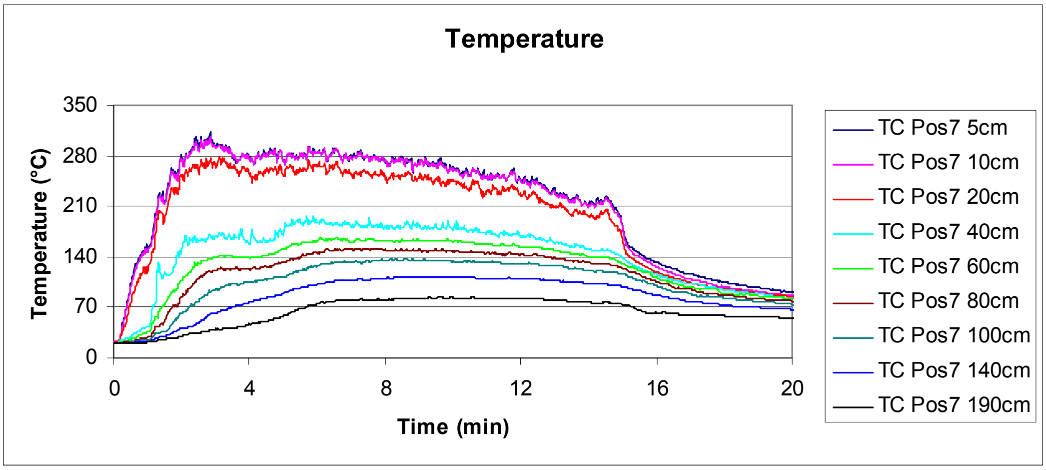


Figure 8.11 Test 5 with the fuel area 500 mm × 500 mm (Pos 7).

Velocity

With an increase in fire size, the velocities also increase and start to fluctuate more, see for example Figure 8.12 and Figure 8.13. A positive value of the velocity corresponds to a gas flow out through the opening while a negative value corresponds to an inflow of air.

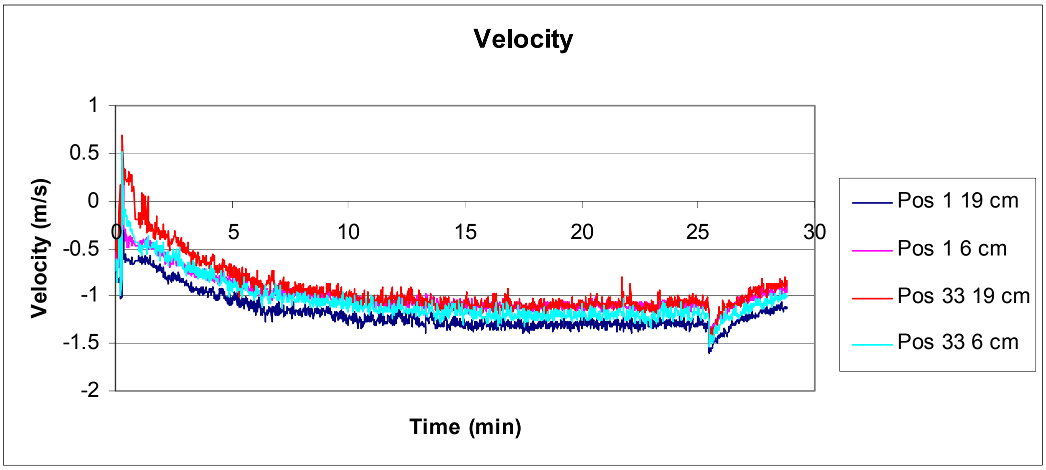


Figure 8.12 Velocity measurement, Test 1

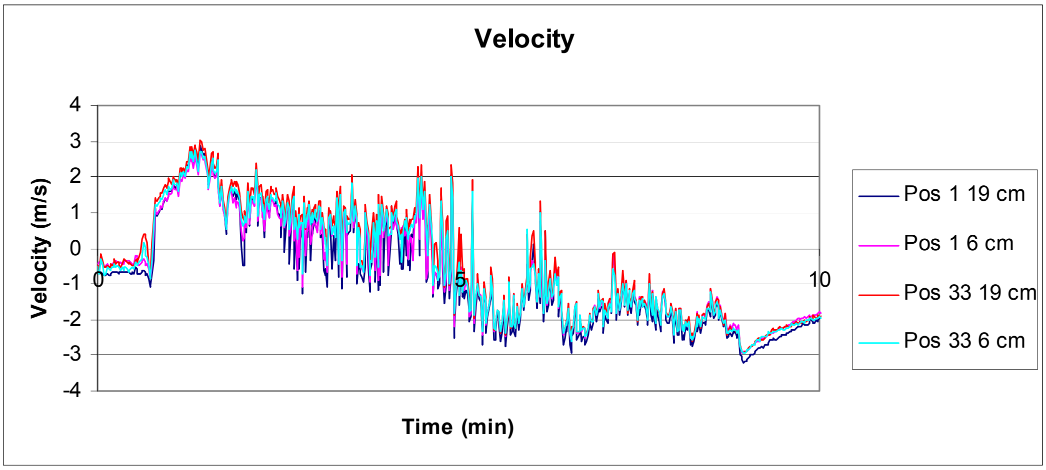


Figure 8.13 Velocity measurement, Test 4

Oxygen level

The oxygen level is measured 80 cm down from the ceiling in position 11, see Figure 7.1. There is no data for Test 1 but Test 7 show that the oxygen level for the smallest fire size only decreases to approximately 18-19 vol-%. For Test 2, 3, 5, 8 and 9, which have the medium fire size, the oxygen level decreases to approximately 15 vol-%. The oxygen level for Test 10, which had the large fire size, goes down to just below 10 vol-% (see Figure 8.14). While the oxygen level for Test 4 decreases to around 12 vol-%. This means that the tests with small and medium fires will probably not achieve under-ventilated conditions while the test with large fire size will.

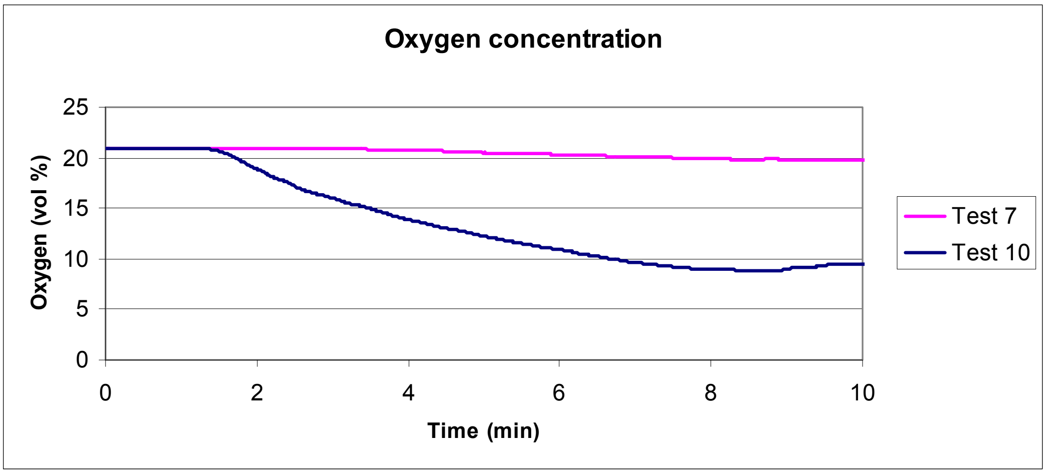


Figure 8.14 Oxygen level for Test 7 and Test 10.

Optical density

The optical density for Test 1 and 7, the small fire size, is around 1 m^{-1}. The optical density for Test 2, 3, 5, 6, 8 and 9, the medium fire size, is in the interval from around 2 m^{-1} – 3 m^{-1}. For Test 4 and 10 the optical density is in the interval from 3.5 m^{-1} – 5 m^{-1}. Test 11 stands out from the other "medium fires" with an optical density of about 4 m^{-1}. The results for the optical density show that the difference in smoke density for the well ventilated fire and the under-ventilated fire (Test 7 and 10) is approximately a factor 5, see Figure 8.15 and Figure 8.17.

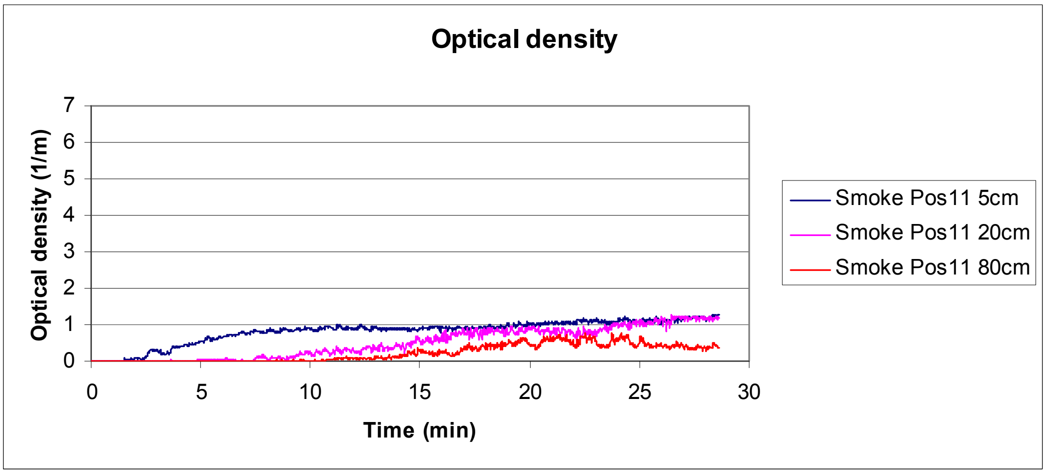


Figure 8.15 Optical density, Test 7

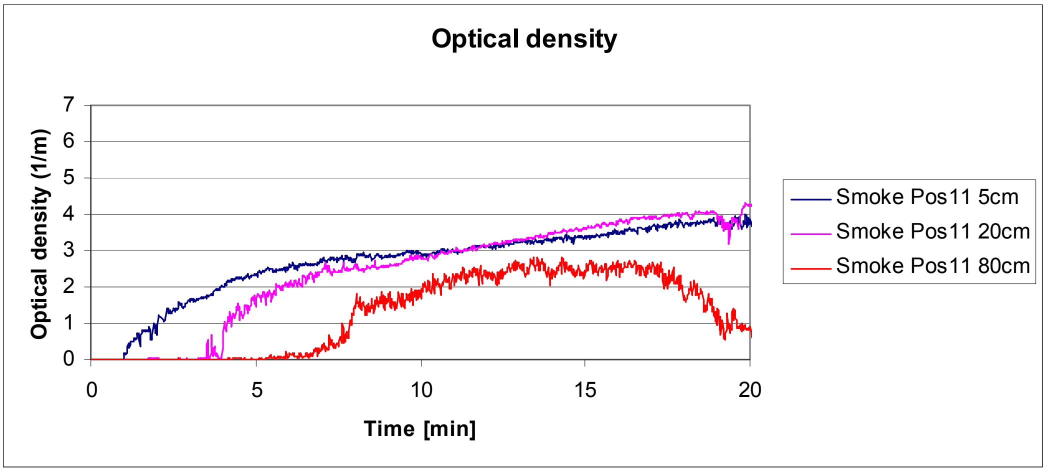


Figure 8.16 Optical density during Test 8.

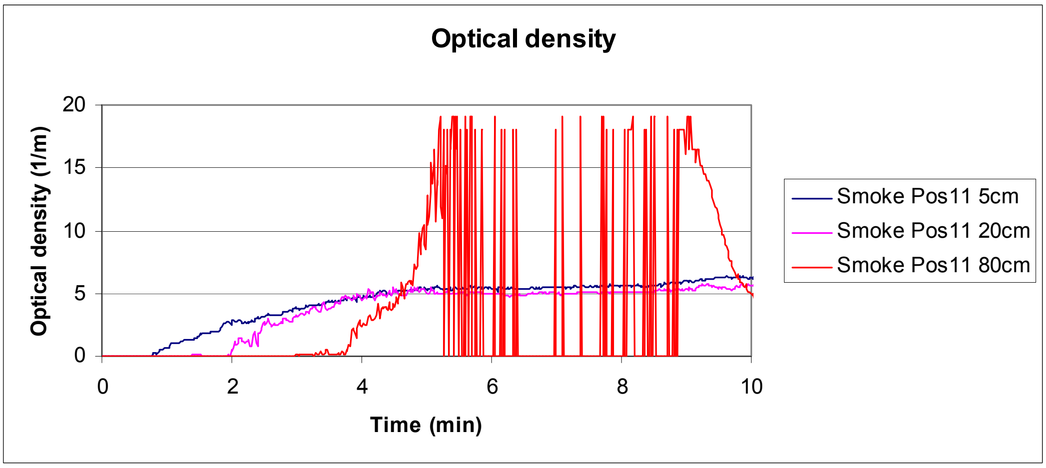


Figure 8.17 Optical density during Test 10.

Configuration comparison

The existence of the shelves may affect the smoke spread by obstructing the smoke spread and may also stop the mixing of the gases in the room. The difference is first investigated by visual monitoring (video recording by Camera 1) of the descent of the smoke layer, which is presented in Table 8.2. Note that it in some tests it was difficult to see any distinct smoke layer from the position analysed and presented here. In Appendix 1, test protocols are presented with some smoke observations by an observer outside another window, with another view. The position and descent of the smoke layer can also, to some extent, be defined by temperature measurement, presented below and in more detail in Appendix 2.

Table 8.2 Smoke fill results, time in minutes.

Height above the floor	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
1.8	15	2	2	1	2.5	3.3	21.5	2	2.5	1	2.5
1.5	19	2.5	2.5		3	3.5-4	26.5	2.5	3	1.5	3.5
1	19	6	5	2.5	4	5.5	30	5	5	2.5	4.5
0.5	24	6.5	6	3	4.5				7.5	3.5	5.5
Completely dark		7	7.5	3	5	7.5		7	8	3.5	6

Tests 1 and 7 had difficulty building up a distinct hot upper gas layer and the conditions were close to well mixed.

Although a direct visual measurement of the smoke spread can give a good estimation of the overall smoke spread it is easy to misinterpret the descent of the smoke layer. Therefore, the temperatures at different heights and different times are investigated by comparing the temperature profiles for different tests. In Figure 8.18 –Figure 8.19 comparisons of the temperature profiles in Pos 7 for Test 2 and Test 8 are presented for two different times.

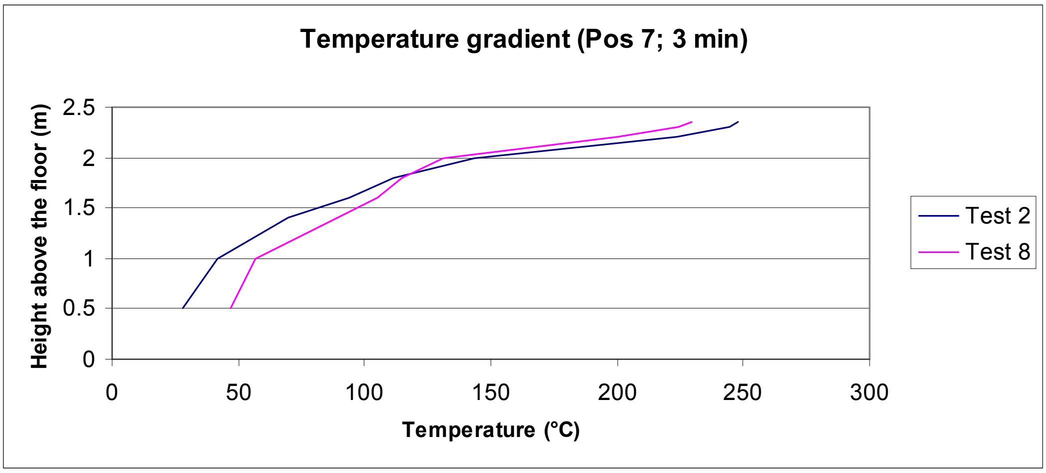


Figure 8.18 Comparison of temperature gradient for Test 2 and Test 8 (Pos 7; 3 min).

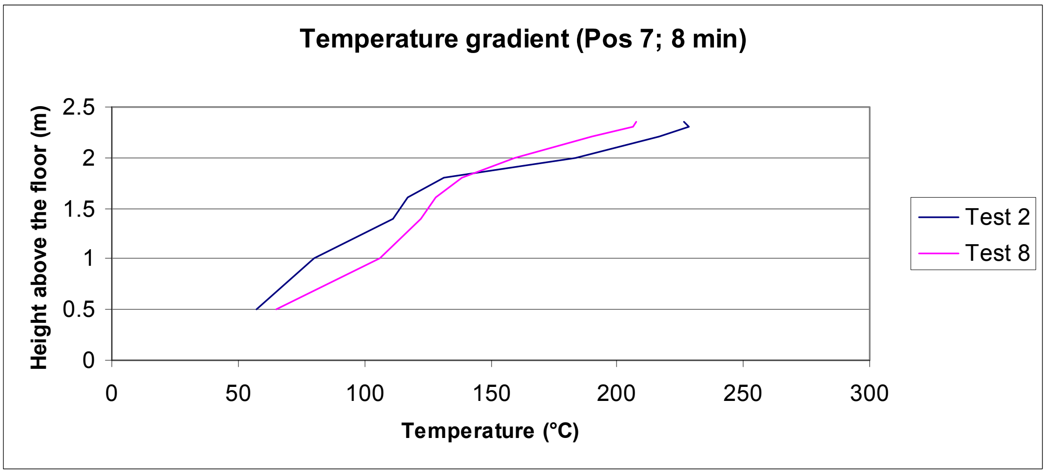


Figure 8.19 Comparison of temperature gradient for Test 2 and Test 8 (Pos 7; 8 min).

It is difficult to say exact how the shelves affect the smoke spread since the data is to a certain degree contradictory. The smoke-fill results from the video monitoring show no clear difference. However, the temperature profiles show that the temperature is higher in the top of the compartment (above the shelves; see Figure 8.20 and Figure 8.21 for Pos 8) and lower in the lower region (between the shelves) when the shelves are present compared to when they are not. This could be explained by the fact that the shelves reduce the mixing of hot and cold gases.

It was seen in Figure 8.3 and Figure 8.4 that the shelves had some effect on the burning rate (MLR). This might be a "confinement effect", where the shelf closest to the fire acts as an extra obstruction which can affect both the flow pattern near the fire and the radiation to the fire. When comparing with real situations in retail premises one should remember that fire spread between the shelves (due to the presence of combustible material on the shelves) would probably significantly alter the fire development.

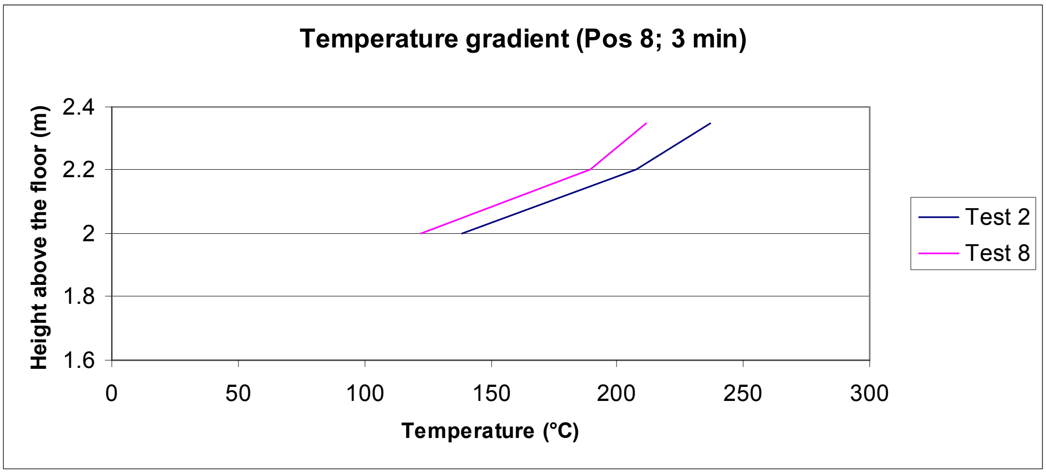


Figure 8.20 Comparison of temperature gradient for Test 2 and Test 8 (Pos 8; 3 min).

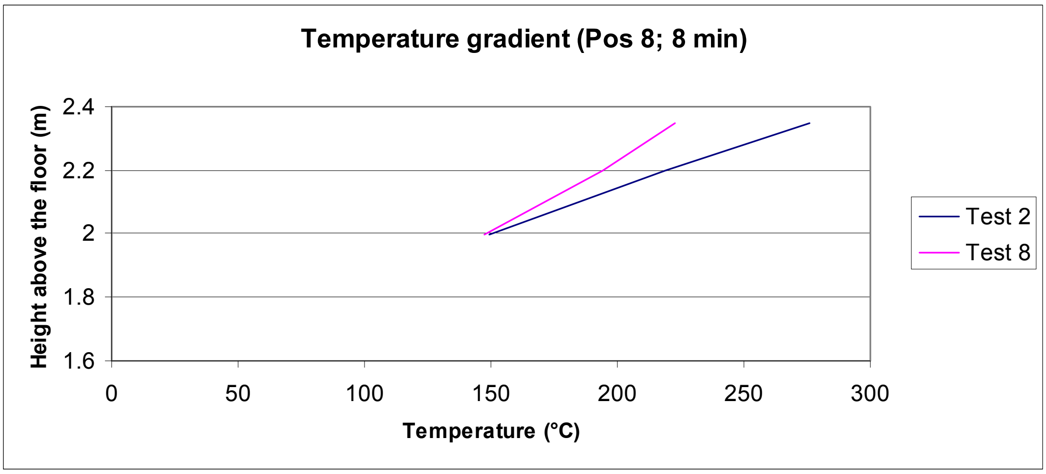


Figure 8.21 Comparison of temperature gradient for Test 2 and Test 8 (Pos 8; 8 min).

Fire position and fire size

The placement of the fire was varied, see Figure 7.1. Fire position 3 is quite similar to Fire position 1 without shelves. The difference between Fire 2 (Test 5), which was close to the wall, and Fire 1 (Test 2 and Test 3), which was a fire on the floor "in" a shelf, is more interesting since the MLR (see Figure 8.22) should be affected by this change in placement. This is due to the fact that the radiation from the hot wall can increase the MLR and thereby the temperatures. On the other hand the entrainment of air is prevented by the presence of the wall, often leading to longer flames.

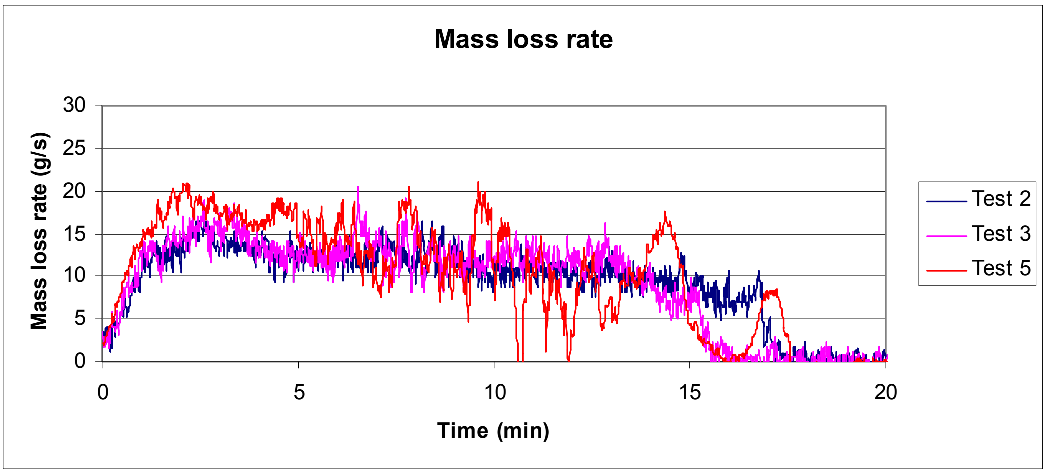


Figure 8.22 Mass loss rate comparison between tests 2, 3, and 5.

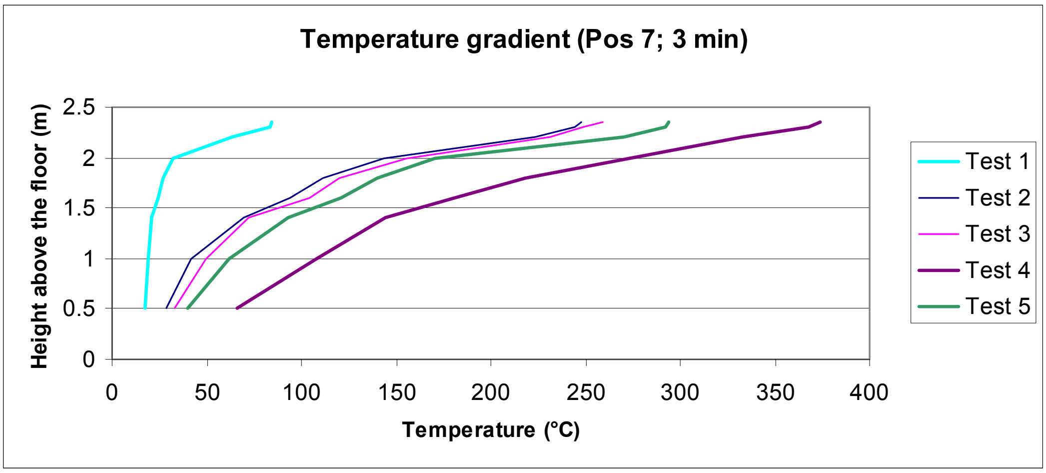


Figure 8.23 Temperature comparison (Pos 7; 3 min).

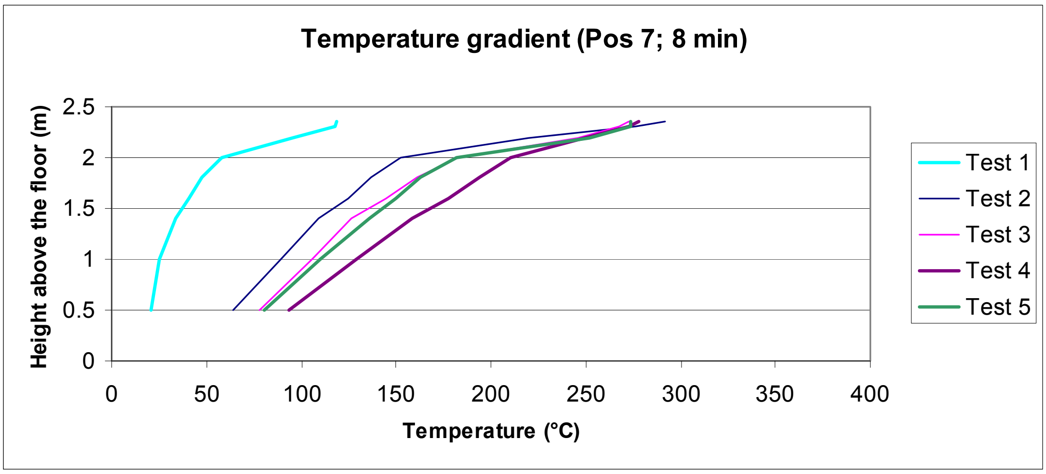


Figure 8.24 Temperature comparison (Pos 7; 8 min).

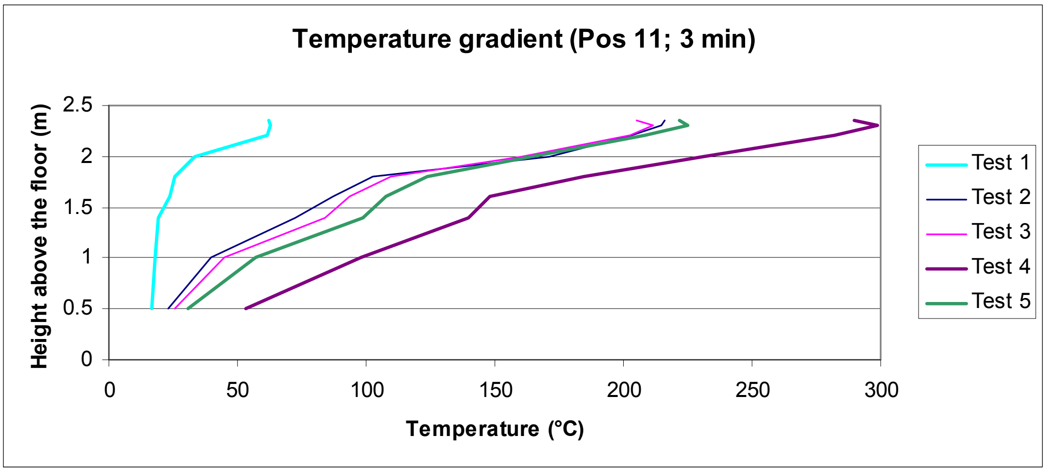


Figure 8.25 Temperature comparison (Pos 11; 3min).

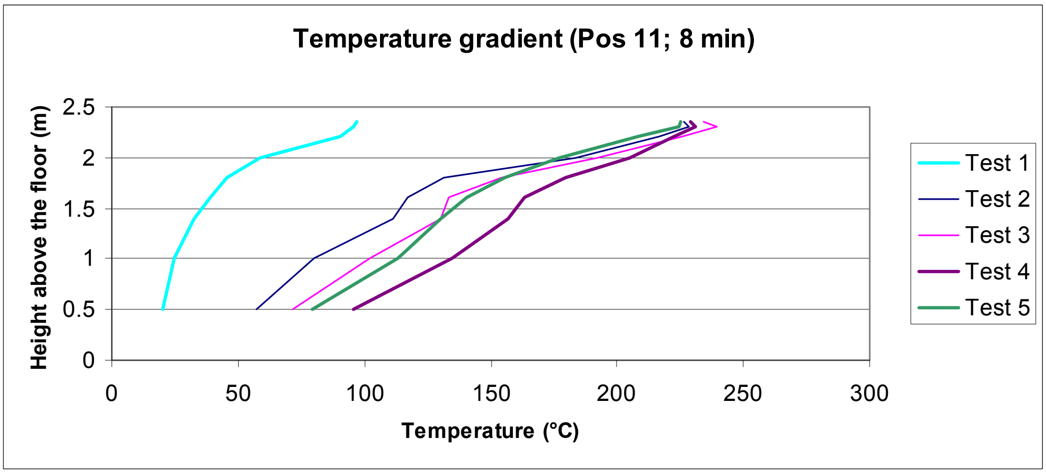


Figure 8.26 Temperature comparison (Pos 11; 8 min).

In Figure 8.23 – Figure 8.26 the temperature profiles in Position 7 and Position 11 are compared for different fire positions. Test 3 is a repetition of Test 2. In the beginning of the tests the temperature in Pos 7 and Pos 11 in Test 2 and Test 3 are rather similar and lower than the corresponding temperature profiles for Test 5 (where the fire was placed near the back wall). However, later in the test (after 8 min) the temperature for Test 3 are higher than Test 2 and closer to the one for Test 5 (see Figure 8.24 and Figure 8.26). This effect can also be seen in Figure 8.22 where the mass loss rates for Test 2 and Test 3 are very similar in the first part of the test, but start to differ somewhat after a while leading to a more intense and faster burning fire in Test 3. The MLR for Test 5 is higher than in Test 2 and Test 3 in the first part of the test, but starts to fluctuate after approximately six minutes. Figure 8.23 – Figure 8.26 also show that the group of temperature graphs for Test 2, Test 3 and Test 5 stay between the corresponding temperature for Test 1 (with the smallest fire source) and Test 4 (with the largest fire source), even if the temperature closest to the ceiling for the medium fire get closer to the one for the largest fire later into the test (see Figure 8.24 and Figure 8.26).

8.1 Sensitivity and errors in the experiments

As discussed in section 5.3 it is important to realize that the results presented are not reality but only a measure of reality. Differences exist because the measurement equipment has inherent error and uncertainties associated with their use. To validate FDS for under-ventilated fires this uncertainty must be quantified or at least discussed. For the experimental results this can be done by comparing different measurements.

The temperature error can be discussed based on observations from different experiments or measurements from different thermocouples in the same experiment. During the test series thermocouples with different diameters were used, some with a diameter of 0.25 mm and some with a diameter of 0.8 mm. The thickness can create different readings since the “thinner” responds more quickly than the “thicker” thermocouples due to differences in their thermal inertia. The thin thermocouple is also affected by the convection to a greater degree. The different readings show that the difference is small and is only really visible during the build up and decline phases of the fire. This is probably a result of the thermal inertia, when temperature stabilizes in the room then there is almost no difference. The largest differences in “real values” are for the measuring points closest to the ceiling. Since the differences are relatively small, the measurements of gas concentrations have not been corrected for radiation effects.

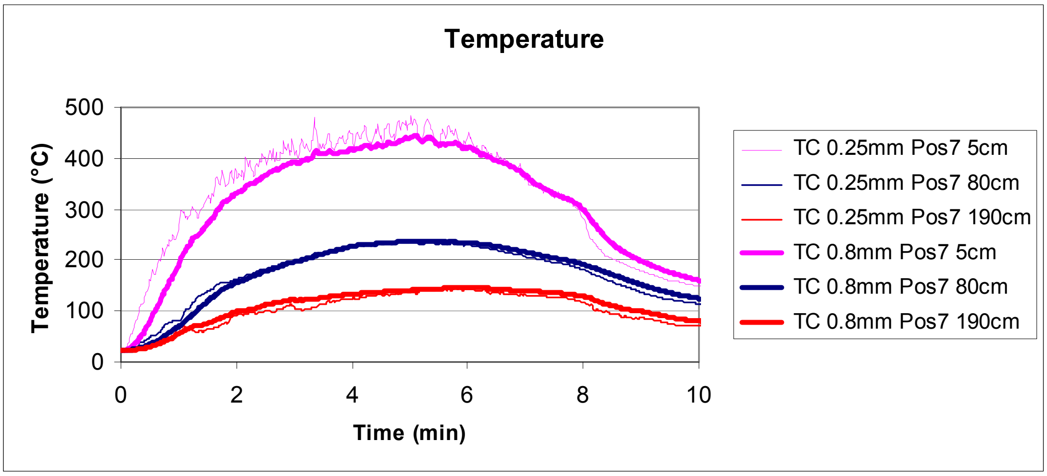


Figure 8.27 Comparison between 0.25 mm and 0.8 mm thermocouple (Test 10).

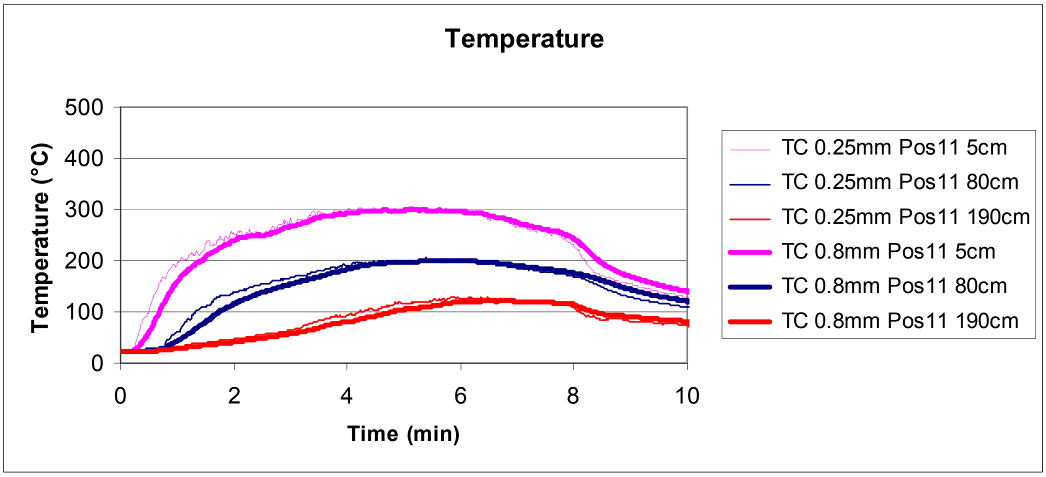


Figure 8.28 Comparison between 0.25 mm and 0.8 mm thermocouple (Test 10)

The weighing scale is another source of uncertainty that can have a large impact on the results. By comparing the MLR between two tests with the same configuration the repeatability and test set-up of the weighing scale can be investigated. There are, of course, many other factors that can affect the results, e.g., the initial temperatures of the walls and the temperature of the fuel container. Despite this, the repeatability is good between Test 8 and Test 9, see Figure 8.29.

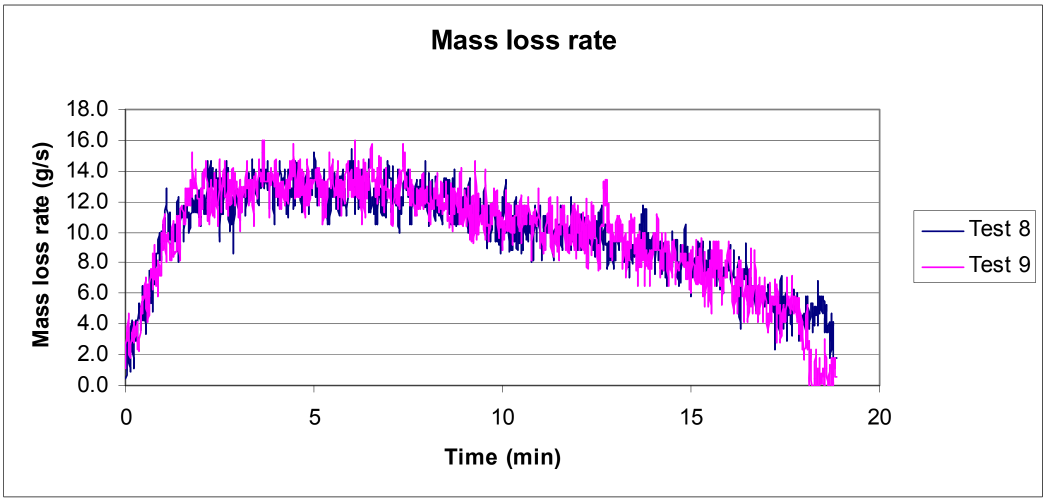


Figure 8.29 Comparison between mass loss rates in Test 8 and Test 9.

The visibility is measured via a laser/photocell system, which measures the extinction over a certain length. In the tests, the laser and the photocell, respectively, were placed in positively pressurized boxes, which decreases the risk that the laser and the photocell become sooty. In Figure 8.30 the smoke densities of two tests can be seen. The difference is the biggest closest to the ceiling but for the other measuring points the differences are less than 10 %. Note that this shows the repeatability more than the uncertainty of the measurements. It is, however, an interesting comparison to make.

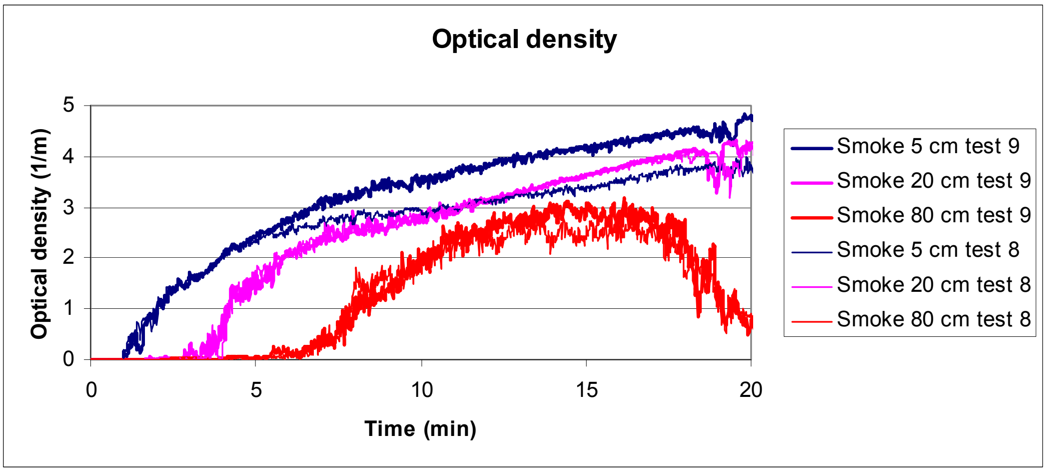


Figure 8.30 Comparison of the smoke density in Test 8 and 9.

The velocity measurements are conducted using bidirectional probes and the placement of the probes is very important. Whether they are placed “in the opening” or just inside or outside has a significant impact on the readings. In the experiments presented in this report they were place in line with the outer wall. The vertical placement is even more important as there can be very high velocities in the top of the opening and quite low velocities in the middle (or close to a stationary zone between incoming fresh air and outgoing fire gases). The velocity in an opening is in general difficult to measure [60] reliably. The velocity results are therefore difficult to use quantitatively and can only provide a qualitative understanding of the direction of flow and the changes of flow during a test.

How long time it takes before the door it shut after manual ignition of the pool fires is important for the pressure build up in the room. For the final 7 tests (Test 5-11) there is data which shows that the door was shut after 30 – 40 seconds, which is a relatively small timeframe and therefore with a relatively small pressure build up.

Another factor that affects the results is the leakage area if a leakage occurs and the size and the position of the leak. If there is a large amount of leakage then pressure build-up is not likely in the enclosure. The extent and position of leakage is difficult to describe and quantify, but has been estimated, visually, to be small.

9 Simulations

The aim of the simulations was to study how well FDS can simulate under-ventilated fires. Therefore, one test with well ventilated conditions and one test with under-ventilated were selected. The cases represented by Test 7 and Test 10 are used in the simulations because Test 7 is well ventilated (smallest fire source) while Test 10 is under-ventilated (largest fire source). The reason why Test 7 and 10 are used instead of Test 1 and 4 is because there were no shelves in Test 7 and 10 which limits obstruction effects and limit the number of parameters affecting the results. Again, the simulations were performed to evaluate the potential of and problem connected with the simulation of under-ventilated fires, not to validate the simulation of a certain configuration.

The simulations were done in FDS Parallel version 5.1.6 (windows 64 bit) and were performed on a computer cluster at the University Collage of Borås. The cluster consists of 8 dual core processors and approximately 64 Giga byte of RAM-memory.

9.1 The process

Initially the properties of the materials in the scenario were investigated. The properties of the heptane were chosen after discussion with Göran Holmstedt [45]. The soot yield and carbon monoxide yield were chosen for well ventilated fires. The reason for this is that the fire will reach ventilation controlled stages (for case 1), where the yields is not expected to be accurate for under-ventilated fires. The properties of the construction materials were taken from data sheets or information from the manufacturers for the products used in the experiments. The geometrical set-up was defined such that the enclosure was surrounded by air.

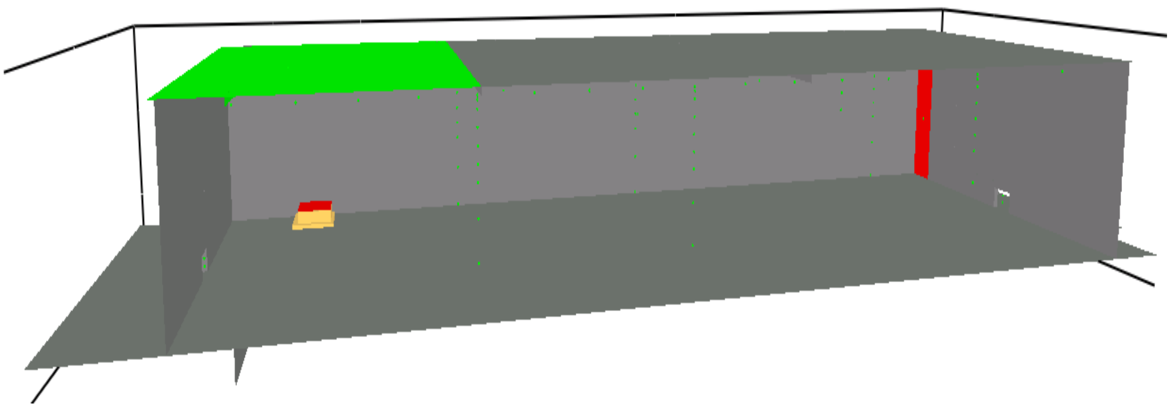


Figure 9.1 Geometrical set-up, the green is ceiling section with insulation, the red in the short wall is the door.

Since the calculations were conducted in a parallel system of 8 cores, the computational domain was divided into 8 meshes and each mesh was then calculated on a separate core. The set-up was defined based on the experimental set-up and can be viewed in Figure 9.1. A finer mesh was used around the fire (5 cm cubes near the fire compared to 10 cm cubes in the rest of the domain) and the total amount of grid cells, in the reference scenario, was about 600 000. The number of grid cells per mesh are described in Appendix 13.

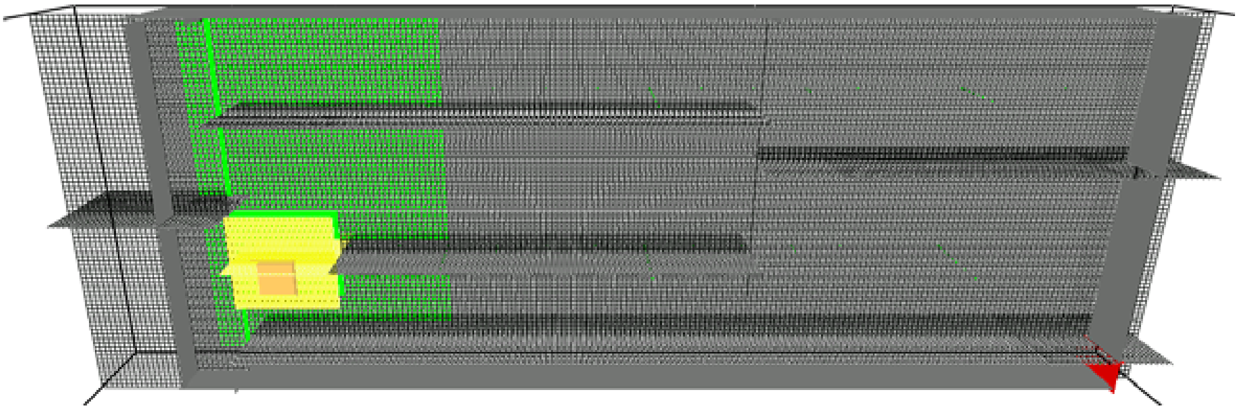


Figure 9.2 The mesh set-up seen from below, each vertical mesh line constitute a mesh, the yellow is the fire mesh.

Initially a great deal of time was spent optimising FDS. According to the FDS user guide [43] and work by Dittmer and Jämtäng [61] there is no significant time gain by using unsynchronized meshes in a parallel simulation. The reason for this is that when the mesh with the smallest time step is taking up most of the computer time, the other meshes with a longer time step just sit and wait to be updated. But if the meshes with the smaller time steps contain a lesser number of grids than the coarser, then the fine and the coarser mesh could be designed to have same computer work load.

The fire growth were controlled via the MLR which was based on the experimental results, see FDS input file in Appendix 14.

Assumptions and Simplifications

Geometrical simplifications were made for the small openings where the 5 cm plinth at the floor was ignored because of the mesh resolution. In the experiments, the ceiling furthest away from the fire (3.4 m from the door wall) was made of 6 mm Masterboard instead of 10 mm Promatect. In the simulations, this was ignored and Promatect was used for the whole ceiling. Furthermore, the legs of the fuel platform were ignored.

One very important simplification is that no leakage areas were included. This is the case since leakage is almost always in form of small cracks which are smaller than the finest grid size. In FDS there is a function to simulate leakage area but this can only be applied for enclosures with no openings and therefore cannot be used in this case. To simply open a slit that would match the leakage area is not a good approach since that would have an affect on the flow fields. It is difficult do exactly determine the leakage area in the test but it was estimated to be low.

Models used

By default FDS has several models included to model, e.g., for sub-grid phenomena, see FDS User Guide [43] and Technical guide [29] for a complete list. A model which has been included by active choice is the “grey gas radiation model” with 104 solid angles and 15 polar angles. Heat transfer through walls was also chosen since the thermal interactions of the hot gases with the walls was deemed to be important.

9.2 Results and comparison with SP tests

In the simulations the fires are defined as ventilation openings that release heptane. The MLR is specified in the FDS input script, see Appendix 14. The HRR is then determined by the conditions in the enclosure. Iin the diagrams below the HRR in the simulations is referred to as the *predefined* HRR. Two different experimental cases were selected for the simulation. These cases correspond to Test 7 and Test 10. In the simulations these cases are referred to as Case 7 and Case 10, respectively.

Case 7

In case 7 the HRR does not diverge from the pre-defined value which means that a "complete" combustion is taking place, see Figure 9.3.

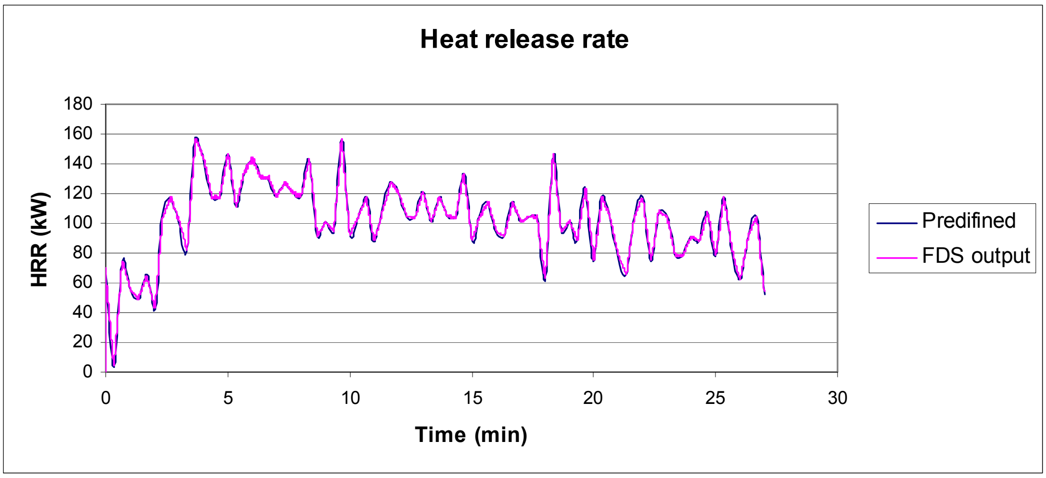


Figure 9.3 Comparison between the predefined heat release rate and the FDS output (Case 7).

The oxygen level does, however, differ from the experimental results, see Figure 9.4, where the oxygen level is lower in the FDS simulation. This does not affect the HRR as the oxygen level stays above ventilation controlled levels but can be important in other aspects. The average difference in oxygen level in pos 11 is approximately 5 %.

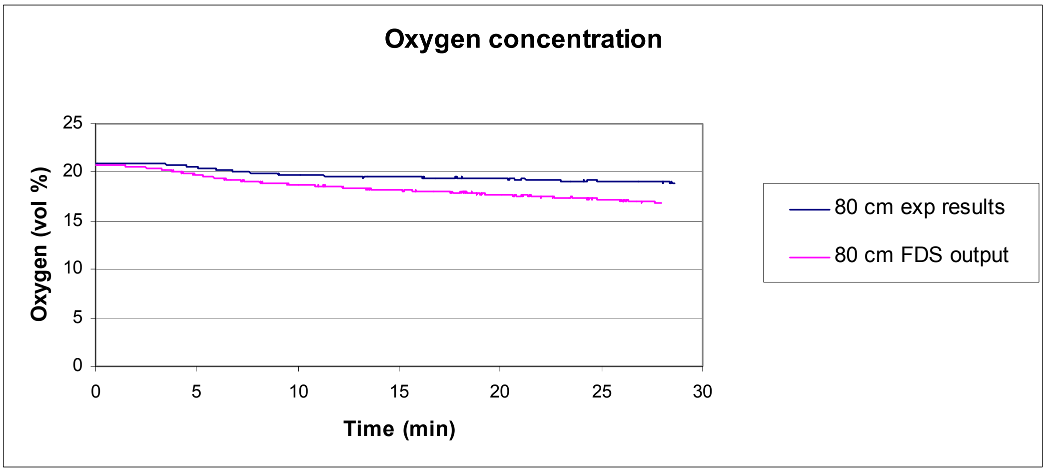


Figure 9.4 Comparison of the oxygen levels Case 7 (Pos 11).

The average difference in temperature between simulation and experiment is 5-15 %, see Figure 9.5.

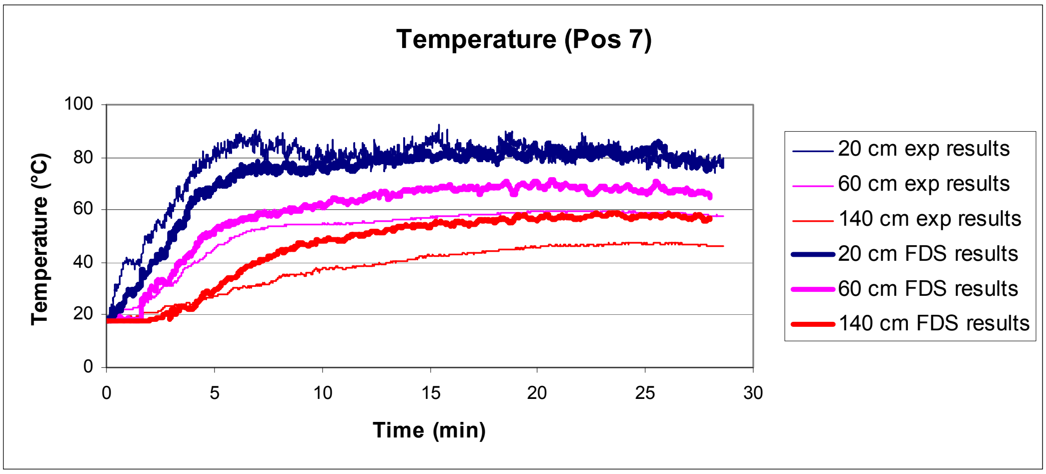


Figure 9.5 Comparison of the temperatures (Case 7, Pos 7).

Case 10

After the first four minutes, the HRR and the temperatures in the room drop quickly by 50-60 % whereas the experimental results show no such drop. The FDS output HRRPUA (Heat Release Rate Per Unit Area) shows that the fire is struggling to survive after about four minutes and that it goes out at the fuel source after about six minutes. After six minutes burning takes place in the two openings at the bottom of the short walls. This is, however, not the case in the experimental results where the fire is ventilation controlled but still burning at the fuel source.

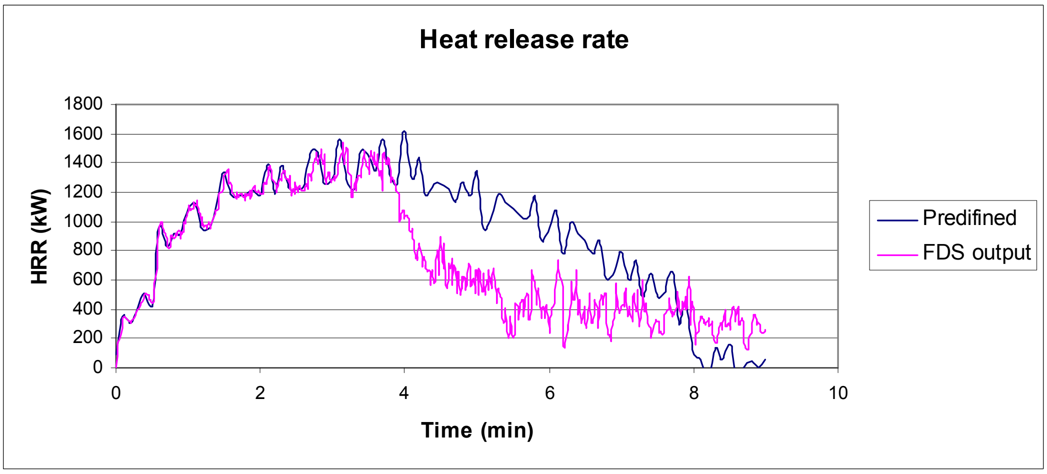


Figure 9.6 Comparison of the heat release rates (Case 10).

The oxygen level diverges almost immediately and after approximately four minutes it reaches the “no burn zone”, compare Figure 4.1 and Figure 9.7. The oxygen level described in Figure 9.7 is given for position 11 but the oxygen level is according to the calculations approximately the same in the near field of the fire.

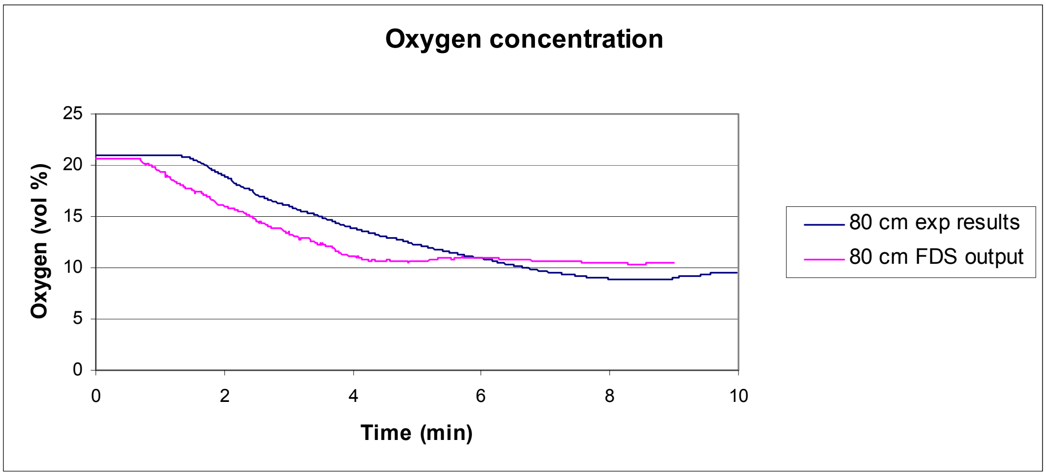


Figure 9.7 Comparison of the oxygen levels (Case 10).

During the first four minutes, where the results indicate no ventilation limiting effects, the temperature in the upper region of the enclosure is approximately 250 ºC –300 ºC. The lower part of the enclosure has a temperature of approximately 100 ºC – 150 ºC. The oxygen level differs by around 20 % (average) and the temperature differs by around 10-20 %, see Figure 9.8

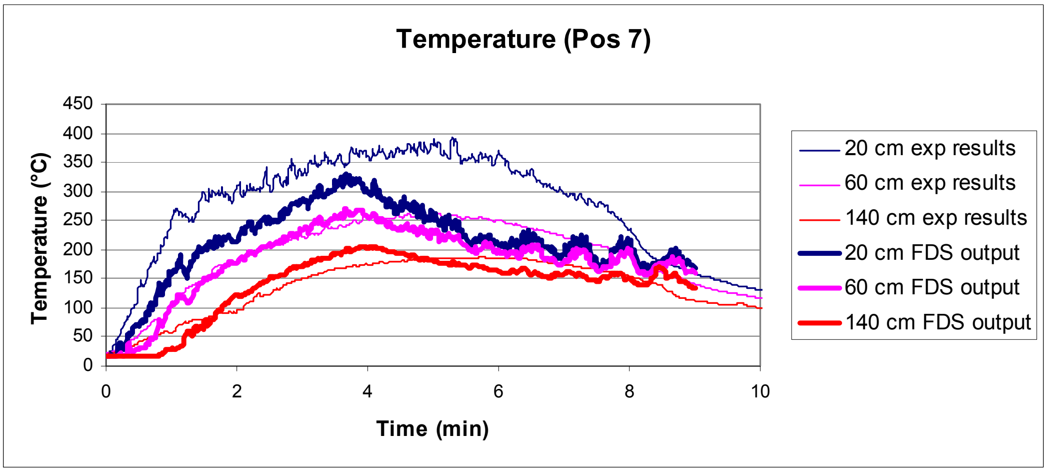


Figure 9.8 Comparison of the temperatures Case 10 (Pos 7).

9.3 Sensitivity and error factors for the simulations

In section 8.1 the uncertainty and the errors in the experimental results were estimated by comparing different measuring devices and different tests. Sensitivity analysis was performed to estimate the uncertainty and errors involved in the simulations. There are many factors that can affect the results but they can be divided into two groups. The first is related to computer or computational error in which errors due to the code is also included. The second is related to scenario specific assumptions. Through out the sensitivity analysis it is only case 10 that will be simulated since case 7 was not under-ventilated. In Table 9.1 the variation of different parameters in the sensitivity analysis is presented.

Table 9.1 Differences in the sensitivity analysis.

	Reference (Base)	Serial	Synchronized	8n
Calculation	Parallel	Serial	Parallel	Parallel
Mesh connection	Unsynchronized	Unsynchronized	Synchronized	Unsynchronized
Number of cells	600 000	600 000	600 000	4 800 000
Width of fire mesh (m)	2 x 2	2 x 2	2 x 2	2 x 2
Nr of fire meshes	2	2	2	2
Mass loss rate factor	1	1	1	1
	Reference (Base)	**Small fire**	**1 fire mesh**	**0.7 MLR**
Calculation	Parallel	Parallel	Parallel	Parallel
Mesh connection	Unsynchronized	Unsynchronized	Unsynchronized	Unsynchronized
Number of cells	600 000	600 000	600 000	600 000
Width of fire mesh (m)	2 x 2	1 x 1	2 x 2	2 x 2
Nr of fire meshes	2	2	1	2
Mass loss rate factor	1	1	1	0.7

Computational error and sensitivity

The reference scenario was investigated in a parallel (8 cores) calculation (in the appendices referred to as the "base scenario"). A serial calculation was also performed, however, to check for any differences. The results are presented in Appendix 7 which shows that the average differences in oxygen level and the temperature are around 2-5 % relative difference. The HRR do however differ about 50 % at some specific moments, see Figure A7.1, the reason for this is most likely the small difference in oxygen level. The absolute (not relative) difference in oxygen level can be found within the interval of 11 – 12 vol-%, which is an interval sensitive to change. It is most likely that the fuel burn at 12 vol-% but not at 11 vol-%.

The reference scenario used unsynchronized meshes and the FDS user guide states that there is a lesser connection between the meshes than when using synchronized meshes [43]. To test if there is any difference, a simulation was also conducted with synchronized meshes. The results can be viewed in Appendix 10 and show that there is very little difference (average less than 1 %) in the temperatures and the oxygen level. In the HRR there is a difference of about 30 % for a short period of time after about five minutes.

The scenario was also simulated with different grid sizes where the reference scenario had approximately 600 000 grid cells with 5 cm × 5 cm × 5 cm in the near field of the fire and 10 cm × 10 cm × 10 cm in the far field. In the grid sensitivity analysis, the grid size was halved which increases the total number of grid cells with a factor eight (8n) resulting in around 4 800 000 grid cells. In the sensitivity analysis the grid cells were 2.5 cm × 2.5 cm × 2.5 cm in the near field and 5 cm × 5 cm × 5 cm in the far field of the fire. The results are shown in Appendix 11 which shows that the average relative difference in oxygen level and the temperature is between 5-10 %. The heat release rate differs about 40 % for a short moment of time after about 5 minutes. This can also be explained by a difference in oxygen level in sensitive interval (vol-%). In this case the oxygen difference is bigger than in the earlier sensitivity analysis.

The difference between the n and the 8n scenario can be explained by the fact that the temperatures are calculated as an average of the entire grid cell. A large grid cell may therefore have different concentration in different parts of the cell that is not resolved. When the grid resolution is set finer then different concentrations, which existed in the large cell, can be resolved in the small (fine) grid cell. If for example one large grid cell contains two equally large concentrations volumes, where the oxygen level in one volume is 5 vol-% and 15 vol-% in the other, then the average oxygen level is 10 %. When the grid resolution is set finer and the two different concentrations volume end up in one grid cell each, then there is one grid cell with 5 vol-% and one with 15 vol-% which means that one of them may burn while in the large cell (10 vol-%) this combustion may not take place. These small ”pockets” of higher oxygen levels is not identifiable in a slice file. By using the HRRPUA (Heat Release Rate Per Unit Area) for all meshes this phenomenon can be observed, see Figure A11.1. The simulation is not grid independent but the results are still useful and the difference is not significant implying that conclusions can be drawn from the results.

Near the fire there are more complex phenomena e.g. more turbulence. This is the reason why a fine grid resolution is wanted in the near field of the fire. The size of the finer mesh in the near field of the fire is important since complex turbulence phenomenon is best resolved in the finer mesh. Therefore a simulation is performed where the region in the near field of the fire with finer mesh is smaller than in the reference scenario. The results are presented in Appendix 9 and show an average difference of around 1 % for the temperatures and the oxygen level. Even the HRR shows a good resemblance and only diverges once by about 30 % for a short while.

To be able to run the calculations as efficiently as possible the volume including the fire and the volume above the fire was divided into two different meshes. This is necessary since it is more efficient to have one mesh on each computer core. The FDS user guide states that it is not wise to put mesh boundaries in sensitive areas because the turbulence may not be accurately described in the transition between the meshes. Therefore, one simulation was done with just one mesh in the near field of the fire (instead of two). The results are presented in Appendix 8. The results show an average difference of about 5-10 % for the oxygen level and the temperature. The heat release rate diverge by about 25 % for a short while.

Scenario specific assumptions

Important scenario specific assumptions, when it comes to how under-ventilated fires, are the soot yield and the carbon monoxide yield. They are important since they are two of the design parameters that can be used to assess critical conditions (visibility and toxicity). Soot and carbon monoxide yield are strongly affected by the combustion efficiency, i.e., the oxygen level. The soot yield may increase by a factor 5 and the carbon monoxide yield by a factor 100 when the fire becomes under-ventilated [35]. The soot and carbon monoxide yield are directly specified by the user and the production rate (in percent) stays the same independent of the combustion efficiency. Ideally one would be able to change the production rates over time in FDS. The new two-step reaction function in FDS 5 can predict the carbon monoxide but the validity of this function cannot be determined for the present case due to lack of experimental data.

The simplification of no leakage from the room can lead to a higher pressure since there is always leakage through small cracks in reality. The higher pressure will not have a significant effect but depending on the position of the openings they can have a significant effect on local oxygen concentrations.

Another parameter that effects the validation of FDS for under-ventilated fires is the predefined MLR or MLRPUA (Mass Loss Rate Per Unit Area). FDS assumes perfect combustion of the fuel vapour. Lowering the MLRPUA is approximately the same as controlling the effectiveness of the combustion. Therefore, a simulation was performed where the MLRPUA was multiplied by a factor 0.7 which is a more realistic combustion efficiency. The results, see Appendix 12, indicate that the temperature in some measurement points is lower than in the experiments. The average difference is around 5-

10 % for both the temperatures and the oxygen level (see Figure 9.9). Once the fire has gone out the average difference is about 20-30 %. The fact that the oxygen level starts to decrease earlier than the experimental results is still present but when the oxygen level approaches the no burn zone limit, the difference is smaller than when perfect combustion is assumed.

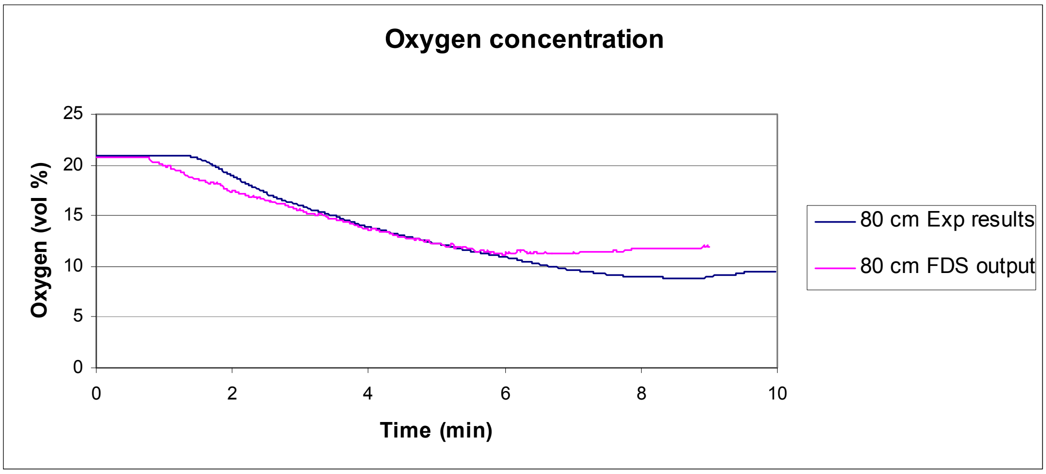


Figure 9.9 Comparison of the oxygen level for case 10 (0.7xMLR).

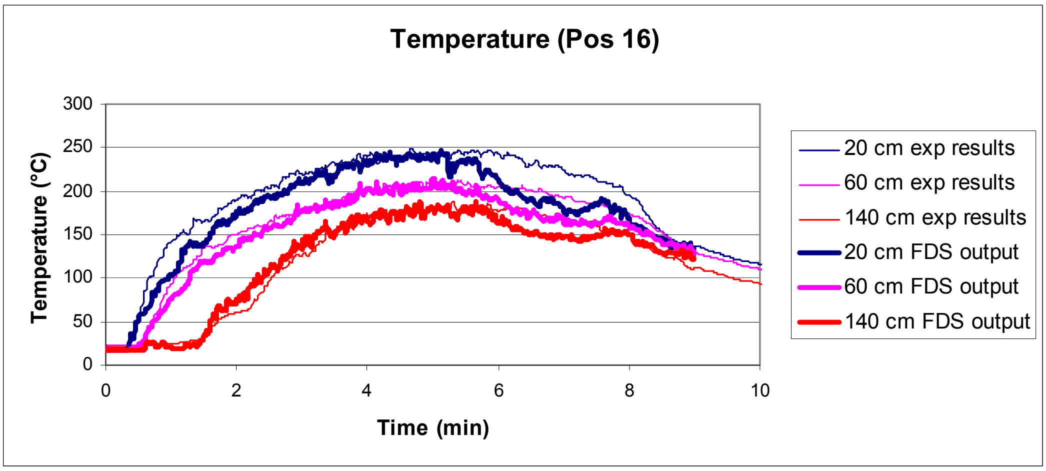


Figure 9.10 Comparison of the temperatures in Pos 16 for case 10 (0.7xMLR).

10 Discussion

Experimental results:
The size of the fires are important for the MLR and the HRR. One big difference between the tests is that for the small fires (with a fire area of 350 mm × 350 mm) there are no signs of ventilation control. The MLR stays approximately constant, see Figure 8.2. For the two largest fires (Test 4 and Test 10), phenomena indicating ventilation controlled fires like the pulsation of smoke outside the openings can be seen. The MLR for these tests also indicates a ventilation controlled fire since the MLR first goes up fast and then decreases slowly over time before it goes out, see Figure 8.4. If the fires had been well ventilated they should have continue to increase or at least stayed constant and then quickly decreased when the fire begins to ran out of fuel. This makes sense since the fires could be expected to be fuel controlled in the beginning and as the oxygen is consumed the burning efficiency will decrease and they will become ventilation controlled. The oxygen level in Test 10 reach as low as 9 vol-%, 80 cm below the ceiling (see Figure 8.14), which indicates that the fire is ventilation controlled. The comparison to freely burning tests also shows that the enclosing surface has an effect on the fire giving a higher MLR inside the enclosure for the largest fire compared to the corresponding free burning case.

The shelves affect the smoke movement to some extent. The tests with shelves have a higher temperature in the top of the enclosure, i.e. above the shelves, than corresponding tests without shelves. Similarly, temperature at the same height between the shelves is lower than in the test without shelves. The difference varies and it is difficult to quantify the difference. The difference is logical since when there are no shelves, it is easier for the smoke to mix in the entire enclosure. There might also be a radiation effect, at least close to the fire. The results show that the presence of the shelves also had an effect on the MLR of the fire source. As mentioned previously, shelves with combustible goods would alter the fire spread and fire development.

There are differences between the smoke movement for Test 5 (fire position 2) and that in the tests with fire position 1 and the same fuel amount as Test 5, i.e., Tests 2, 3, 8, 9. There is, however, no distinct pattern and it is difficult to draw any general conclusions from the differences other than that they are small.

The difference in the smoke density, a factor 5, matches similar information from the literature [35].

Simulations:
Case 7 shows no signs of being ventilation controlled and the output matches the experimental results quite well. The average difference between the temperatures in the experimental and the FDS results are about 10 – 20 %. If, however, the combustion efficiency had been lowered, as in case 10, then the temperature would probably have been an even better match.

It is important to note that the pre-defined HRR was not the actual HRR in the experiments, but is based on an assumption of complete combustion. Rather, the oxygen level and the temperatures provide the best basis for comparison between the experiments and the simulations.

The results for case 10 show that the average difference in oxygen level and temperature is about 5 % with a combustion efficiency of 0.7. When the fire reaches the no burn zone, the relative difference in the oxygen level is about the same (5-10 %), while the differences in temperatures (in position 7) increase to about 30 %. The reason for this is that the HRR is very sensitive to changes in the oxygen level near the no burn zone and that the mixture fraction combustion model assumes perfect combustion.

The sensitivity analysis shows that a difference of about 10 % in the temperatures is common due to different configurations. In the experimental results uncertainty was also estimated to be about 10 %.

The visibility and the carbon monoxide concentration is, as described above, dependent on the soot and carbon monoxide yield specified by the user. They do not change (with the combustion efficiency) over time in the simulation with the standard combustion model. For the carbon monoxide there is a new function in FDS 5 that allows the use of a two step reaction which can track the carbon monoxide change over time. Unfortunately the experimental data lacks readings for the carbon monoxide concentration which means that no comparison can be made between simulated carbon monoxide concentrations and experimental values. Readings do exist for the visibility, i.e., the soot-yield output. The soot yield can, however, not be changed (in percentage) over time but is constant. If yields for carbon monoxide and soot for well-ventilated conditions are used then this will lead to non-conservative results since the yields are much higher from an under-ventilated fire.

The key question is, therefore, how under-ventilated fires should be modelled? The most crucial parameter is the combustion efficiency, so that the oxygen level starts to decrease at the same time and with the same speed in the simulations as in reality. This can be difficult to achieve since it is not only a matter of the properties for the fuel but the geometry of the enclosure. Even if the combustion efficiency is set to its optimum it still does not solve the problem of obtaining realistic results for the soot yield. Therefore, the use of the visibility and the toxicity, in an under-ventilated fire, should be treated very carefully. This is a problem since they are the critical parameters that are most likely to reach critical levels first in an under-ventilated fire and therefore need to be used in design calculations.

It is very interesting that once the fire goes out it starts to burn in both the small openings. It could be expected in the opening closest to the fire but the temperature in the opening in the front wall should be too low for such behaviour. Further, there were no signs of such burning behaviour in the opening in the front wall during the experiments. This erroneous burning in a region where no burning took place is a problem for CFD simulations that is difficult to identify unless experimental information is also available.

It is interesting that in almost all the sensitivity analysis simulations there is an increase in the HRR for a short while after approximately 5 minutes which was not present in the reference scenario. In some simulations, this also contradicts the oxygen level which is lower than in the reference scenario. This short increase in HRR can be explained by the sensitivity of the combustion models to the oxygen level. To some extent this contradiction might be explained by the fact that the oxygen measurement were performed in position 11, see Figure 7.1, while the HRR is measured at the fuel and there are differences in the oxygen concentrations between those two positions.

There is a function in FDS for dealing with leakage but it demands that the room is completely sealed wit no openings. Therefore the validity of this function could not be tested against the SP tests since there were openings in the walls.

11 Conclusions

In total eleven fire tests were performed inside a scale model (1:2) of retail premises. The aim of the project was mainly to produce well instrumented tests and experimental data that can be used for comparisons to simulations or other calculations of smoke spread and temperature distribution. The results are, therefore, presented both graphically and in tables. As an example, CFD simulations have been performed of a few selected cases. The results from these simulations have than been compared to the experimental results.

Depending on the sizes of the fires they are more or less ventilation controlled. The tests with small fires (Test 1 and Test 7) show no direct signs of being under-ventilated and Test 1 and Test 7 can be said to be well ventilated. The larger fires show more signs of being ventilation controlled, where pilot flames and smoke pulsation occurred at the openings. Test 4 and Test 10 (with the largest fire source) can, therefore, be said to be ventilation controlled.

For the fires with the largest fuel area, that creates under-ventilated fires, the difference (compared to well ventilated tests) in the optical density is a factor 5.

The data is partially contradictory but the smoke movement is affected by the presence of the shelves. The shelves makes it more difficult for the smoke to mix in the enclosure and therefore the temperatures are higher above the shelves than in the corresponding test without shelves and lower between the shelves.

The comparison between the experimental data and the simulation indicates that FDS can easily underestimate the oxygen level and thereby the HRR, leading to an underestimation of the temperatures. The validation has shown that the simple empirical expression for when the fire is allowed to burn is very sensitive to the oxygen level and if used without proper precautions it may produce large (partly unphysical) differences. This was for example seen in the under-ventilated case. It is also clear that the temperatures for well ventilated cases may be overestimated and that the use of visibility and toxicity (soot and carbon monoxide yields) are related to even larger uncertainties. It should, however, be noted that there are cases where the temperature from the simulations and the temperature measurements correspond relatively well with each other. This depends on the simulation case, the position in the set-up and the time period compared. It should also be noted that the quality of the results from computer simulations often depend also on the user and the way the reality is simulated and how the models are used. That is probably the situation also in this case. Therefore, the aim has been to in detail describe how the experiments were performed and how the parameter variation in FDS was done.

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Appendix 1 Test protocols

The observations of the smoke given in this Appendix were mainly performed via the observation window in the right wall (see description in Section 8.1). “Extinguished” means that the fire went out; no manual extinguishment was performed.

Test 1

Table A1.1 Experimental set up and initial conditions for Test 1.

Test info	Test 1		Surroundings	
Fuel	Heptane		Temperature (°C)	18.8
Volume fuel (L)	5.4		Humidity (%)	14
Fire size, side (mm)	305		Pressure (Pa)	100800
Fire size, area (m^2)	0.093025		Fuel temp (°C)	9.6
Fire position	1			
Fuel height (cm)	62			
Shelves?	Yes			
Ventilation (m^3/h)	20000			

Test protocol

-2 min 0 s	Measurement start
0 min 0 s	Ignition
3 min 20 s	The smoke reaches approximately 1.5 m above the floor
26 min 10 s	Extinguished

Test 2

Table A1.2 Experimental set up and initial conditions for Test 2.

Test info	Test 2		Surroundings	
Fuel	Heptane		Temperature (°C)	19.6
Volume fuel (L)	15		Humidity (%)	14
Fire size, side (mm)	500		Pressure (Pa)	100700
Fire size, area (m^2)	0.25		Fuel temp (°C)	10.8
Fire position	1			
Fuel height (cm)	62			
Shelves?	Yes			
Ventilation (m^3/h)	20000 and 40000			

Test protocol

-2 min 0 s	Measurement start
0 min 0 s	Ignition
2 min 0 s	The smoke reaches approximately 1.5 m above the floor
6 min 0 s	The smoke reaches approximately 1 m above the floor
7 min 0 s	Smoke all the way down to the floor.
17 min 8 s	Extinguished

Test 3

Repetition test of Test 2.

Table A1.3 Experimental set up and initial conditions for Test 3.

Test info	Test 3		Surroundings	
Fuel	Heptane		Temperature (°C)	18.8
Volume fuel (L)	15		Humidity (%)	14
Fire size, side (mm)	500		Pressure (Pa)	100700
Fire size, area (m^2)	0.25		Fuel temp (°C)	20
Fire position	1			
Fuel height (cm)	62			
Shelves?	Yes			
Ventialtion (m^3/h)	40000			

-2 min 0 s	Measurement start
0 min 0 s	Ignition
3 min 20 s	The smoke in level with the lower edge of the observation window, 1.3 m above the floor
15 min 35 s	Extinguished

Test 4

Table A1.4 Experimental set up and initial conditions for Test 4.

Test info	Test 4		Surroundings	
Fuel	Heptane		Temperature (°C)	20
Volume fuel (L)	15		Humidity (%)	20
Fire size, side (mm)	650		Pressure (Pa)	98600
Fire size, area (m^2)	0.4225		Fuel temp (°C)	17.6
Fire position	1			
Fuel height (cm)	62			
Shelves?	Yes			
Ventilation (m^3/h)	40000			

-2 min 30 s	Measurement start
0 min 0 s	Ignition
2 min 0 s	The smoke reaches approximately 1 – 1.2 m above the floor
3 min 30 s	Pulsations in the floor opening near the fire can be observed
7 min 30 s	It is burning “outside” the fuel pan
8 min 29 s	Extinguished

Test 5

Table A1.5 Experimental set up and initial conditions for Test 5.

Test info	Test 5		Surroundings	
Fuel	Heptane		Temperature (°C)	18.5
Volume fuel (L)	15		Humidity (%)	22
Fire size, side (mm)	500		Pressure (Pa)	98600
Fire size, area (m^2)	0.25		Fuel temp (°C)	14.7
Fire position	2			
Fuel height (cm)	62			
Shelves?	Yes			
Ventilation (m^3/h)	40000			

Test protocol

-2 min 0 s Measurement start
0 min 0 s Ignition
0 min 34 s Smoke reaches the door.
1 min 7 s The smoke layer is 1 dm above the shelves
1 min 25 s The smoke layer reaches the top of shelves
2 min 7 s Smoke 15 cm above window of camera 1, i.e. approximately 1.25 m above the floor.
2 min 50 s The smoke is some centimetres above window of camera 1
4 min 0 s Smoke has descended down to observation window and is covering half of the window of camera 1 (i.e. approximately 0.9 m above the floor). Some thin smoke can be seen somewhat lower than that. The back wall is very hot and is making a creaking sound.
8 min 35 s Completely dark in the room from the observation window. The lights at the other wall cannot be seen through the smoke.
8 min 55 s It looks like the fire is having some problem staying alive.
12 min 15 s There is smoke coming out of one of the corners in the back wall
14 min 53 s Extinguished.

Test 6

Table A1.6 Experimental set up and initial conditions for Test 6.

Test info	Test 6		Surroundings	
Fuel	Heptane		Temperature (°C)	19.9
Volume fuel (L)	15		Humidity (%)	22
Fire size, side (mm)	500		Pressure (Pa)	98600
Fire size, area (m^2)	0.25		Fuel temp (°C)	14.6
Fire position	2			
Fuel height (cm)	62			
Shelves?	Yes			
Ventilation [m3/h]	40000			

Test protocol

-2 min 0 s Measurement start
0 min 0 s Ignition
0 min 36 s Smoke reaches the door
1 min 25 s Smoke just below the shelves,
1 min 45 s The smoke is 25 cm left to the top of window of camera 1, i.e. approximately 1.35 m above the floor.

2 min 5 s	The smoke seems to be lower on the other side than on the wall with the observation window.
2 min 24 s	The fire has spread out from the fuel container to the bench, towards the back wall.
3 min 57 s	The beams of the platform below the fuel pan seem to be on fire
4 min 40 s	Thin smoke fills the entire room but the thick layer stays at half of the height of window of camera 1, i.e. approximately 0.9 m above the floor.
5 min 10 s	The smoke layer has now descended to half of the observation window, i.e. approximately 1.6 m above the floor.
7 min 15 s	The beams of the platform are no longer on fire.
8 min 15 s	There is some pulsation of smoke from the opening in the back wall; the smoke goes out and is then drawn back again, not much is staying on the outside.
8 min 50 s	If one looks in through the small opening in the back wall one do not see much.
9 min 10 s	The fire can hardly be seen from the observation window.
10 min 50 s	The fire can hardly be seen; some flames near the fuel are visible, but just for half a meter before they disappear up in the black smoke.
12 min 25 s	There is still some pulsation in the opening in the front wall.
13 min 35 s	There is some smoke pulsations from the opening in the back wall, but not as much as in the opening in the front wall
14 min 17 s	Now one cannot see the fire anymore, just some orange colour in the smoke.
15 min 20 s	Through the opening in the back wall one can see that the fire is still burning heavily
16 min 50 s	Extinguished.

Test 7

Table A1.7 Experimental set up and initial conditions for Test 7.

Test info	Test 7		Surroundings	
Fuel	Heptane		Temperature (°C)	19.6
Volume fuel (L)	5.4		Humidity (%)	23
Fire size, side (mm)	305		Pressure (Pa)	98600
Fire size, area (m^2)	0.093025		Fuel temp (°C)	13.3
Fire position	1			
Fuel height (cm)	62			
Shelves?	No			
Ventilation (m3/h)	40000			

Test protocol

-2 min 0 s	Measurement start
0 min 0 s	Ignition
2 min 35 s	The smoke has now descended down to 70 cm from the ceiling; further away from the fire it has descended more.
3 min 40 s	The smoke continues to descend to 1 meter from the ceiling between the shelves.
4 min 16 s	The thicker smoke is approximately 1 meter from the ceiling.
6 min 20 s	The smoke has now descended to half of the observation window, i.e. approximately 1.6 m above the floor.
31 min 1 s	Extinguished

Test 8

Table A1.8 Experimental set up and initial conditions for Test 8.

Test info	Test 8		Surroundings	
Fuel	Heptane		Temperature (°C)	18
Volume fuel (L)	15		Humidity (%)	22
Fire size, side (mm)	500		Pressure (Pa)	98600
Fire size, area (m^2)	0.25		Fuel temp (°C)	14
Fire position	1			
Fuel height (cm)	62			
Shelves?	No			
Ventilation (m^3/h)	40000			

Test protocol

-2 min 0 s Measurement start
0 min 0 s Ignition
0 min 33 s Smoke reaches the door.
1 min 38 s The smoke has descended and covers about 1/3 of the observation window, i.e. approximately 1.7 m above the floor.
2 min 33 s The smoke has descended and covers about half of the observation window, i.e. approximately 1.6 m above the floor.
3 min 0 s The smoke is in level with the observation window (i.e. approximately 1.33 m above the floor.; it is getting difficult to see anything .
18 min 50 s The fire goes out.

Test 9

Repetition test of Test 8.

Table A1.9 Experimental set up and initial conditions for Test 9.

Test info	Test 9		Surroundings	
Fuel	Heptane		Temperature (°C)	19.3
Volume fuel (L)	15		Humidity (%)	22
Fire size, side (mm)	500		Pressure (Pa)	974
Fire size, area (m^2)	0.25		Fuel temp (°C)	13.3
Fire position	1			
Fuel height (cm)	62			
Shelves?	No			
Ventilation (m^3/h)	40000			

Test protocol

-2 min 0 s Measurement start
0 min 0 s Ignition
0 min 34 s Smoke reaches the door.
1 min 10 s The smoke has descended to approximately 1.8 m above the floor.
2 min 48 s Thin smoke is covering the entire observation window. The level of the thick smoke is just above the upper edge of the observation window.
15 min 32 s Pulsations with smoke can be observed in the opening in the front wall. Most of the smoke is sucked in again. The frequency of the pulsations is approximately 1 s.
18:09 Extinguished.

Test 10

Table A1.10 Experimental set up and initial conditions for Test 10.

Test info	Test 10		Surroundings	
Fuel	Heptane		Temperature (°C)	17.8
Volume fuel (L)	15		Humidity (%)	22
Fire size, side (mm)	650		Pressure (Pa)	973
Fire size, area (m^2)	0.4225		Fuel temp (°C)	16.5
Fire position	1			
Fuel height (cm)	62			
Shelves?	No			
Ventilation (m^3/h)	40000			

Test protocol

0 min 27 s The smoke reaches the door
1 min 05 s The smoke is descending fast, the thick smoke is already at approximately 1 m meter from the floor
1 min 25 s About half of the observation window is covered with thick smoke; it looks to be somewhat lower at the shelves, maybe a little more than 1 m above the floor.
1 min 58 s The smoke continues to descend and is now at the bottom of the observation window.
2 min 12 s It darkens fast in the room, and the floor lamp furthest away from the observation window is not visible, no wall lamps are now visible
2 min 30 s It is getting darker and darker
4 min 10 s Signs of smoke pulsation can be seen at the opening in the back wall, but only a small amount of smoke is exiting the opening.
4 min 55 s At the other opening (in the front wall) much more smoke is coming out. Regular pulsation. Some of the smoke is sucked in but quite an amount of smoke is exiting the opening.
6 min 15 s The pulsations seem to be about once every second
6 min 45 s The fire is very difficult to see from the observation window; one can just see some orange colours through the smoke.
8 min 6 s Extinguished

Test 11

Table A1.11 Experimental set up and initial conditions for Test 11.

Test info	Test 11		Surroundings	
Fuel	Heptane		Temperature (°C)	19.5
Volume fuel (L)	15		Humidity (%)	22
Fire size, side (mm)	500		Pressure (Pa)	971
Fire size, area (m^2)	0.25		Fuel temp (°C)	15.3
Fire position	1			
Fuel height (cm)	62			
Shelves?	No			
Ventilation (m^3/h)	40000			

Test protocol

0 min 34 s Smoke reaches the door
1 min 18 s The smoke is approximately 70 cm from the ceiling

1 min 32 s	The smoke has descended down to about 1.3 -1.4 m from the floor at the second marker ruler.
2 min 6 s	The smoke is still descending and it is getting difficult to se the wall lamp furthest to the left.
2 min 20 s	The smoke has descended to about half of the observation window.
2 min 32 s	The lamp furthest to the left is no longer visible.
3 min 12 s	The smoke is now a few centimetres above the bottom of the observation window.
3 min 24 s	If one leans down one can see the central lamp on the other wall but one cannot see it through the smoke.
3 min 41 s	The same goes for the floor lamp furthest away, if one look at the bottom of the observation window one can see it but if one looks just 10 cm higher up it is almost gone.
3 min 57 s	The lamp in the middle on the wall is no longer visible and the one furthest to the right is getting difficult to see.
5 min 57 s	At the opening in the back wall there is an alternating flow; one could say pulsating but with no smoke.
6 min 22 s	Now no lamps are visible through the observation window and it is difficult to see the flames
6 min 44 s	In the opening in the front wall there is smoke pulsating; some smoke is sucked back in again and some smoke is going out.
8 min 42 s	At the opening in the back wall, one could see pulsations of smoke but much less then in the front wall.
10 min 32 s	The only way to see the fire now is through the opening in the back wall. Nothing can be seen through the observation window.
13 min 47 s	It is still pulsating in the opening in the front wall and the pulsation is faster then 1 per second.
14 min 25 s	The fire seems to be extinguished.

Appendix 2 Time-resolved graphs

Test 1

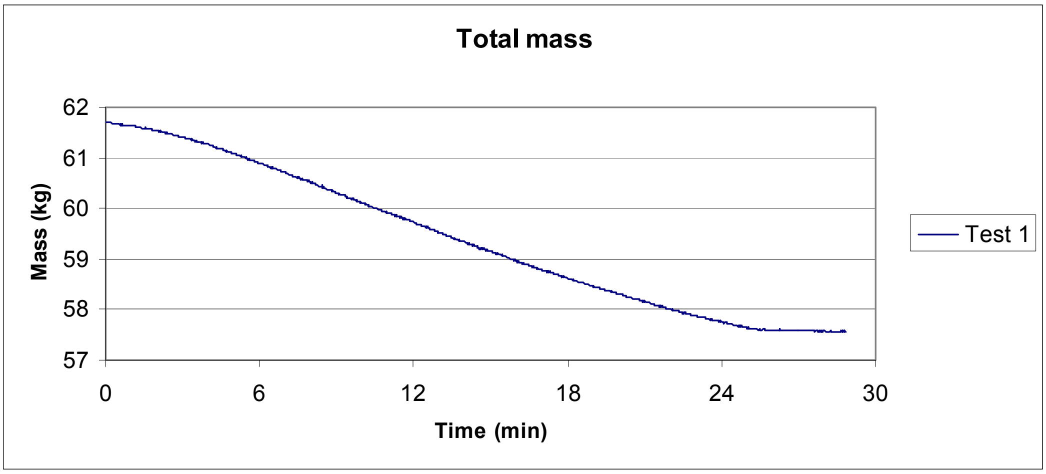

Figure A2.1 Total mass for Test 1.

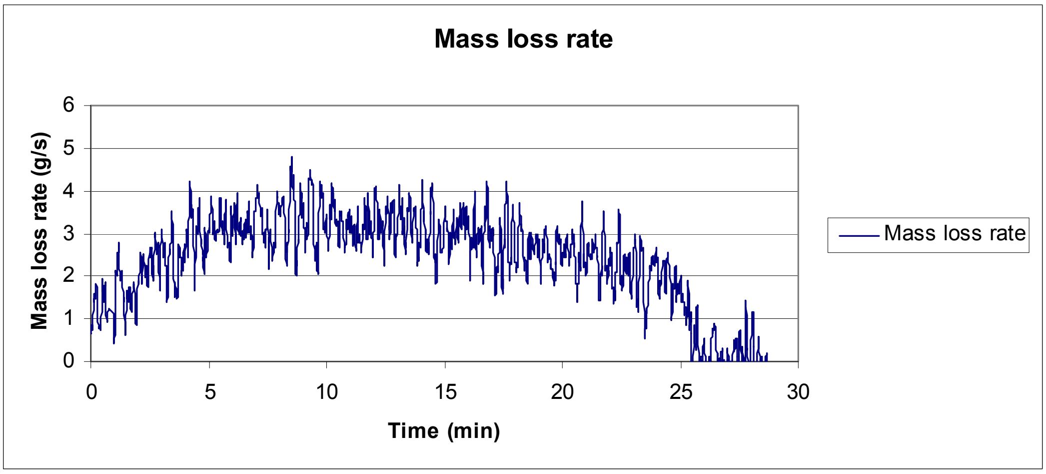

Figure A2.2 Mass loss rate for Test 1.

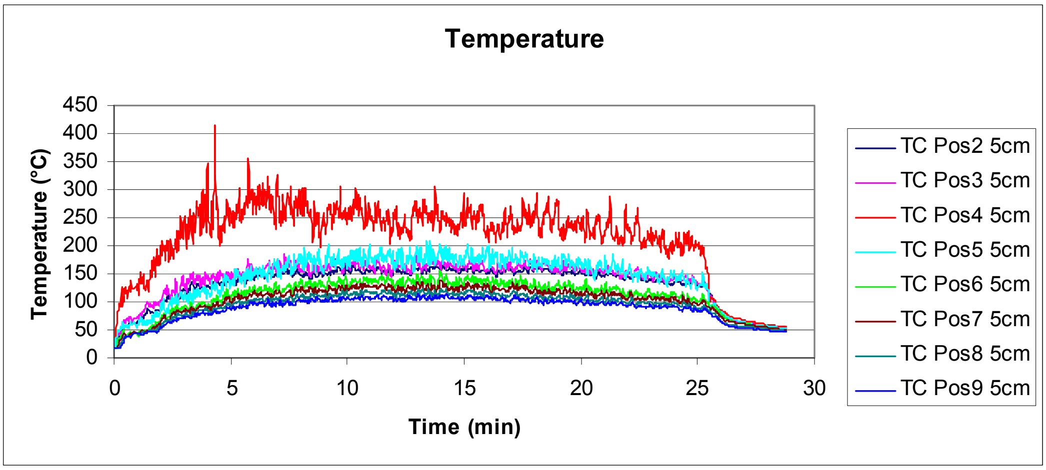

Figure A2.3 Temperature profiles for Test 1.

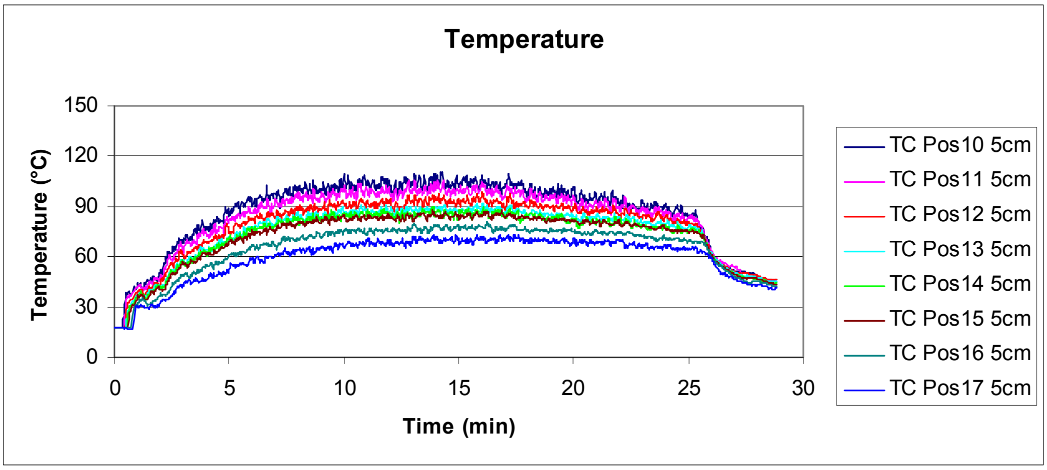

Figure A2.4 Temperature profiles for Test 1.

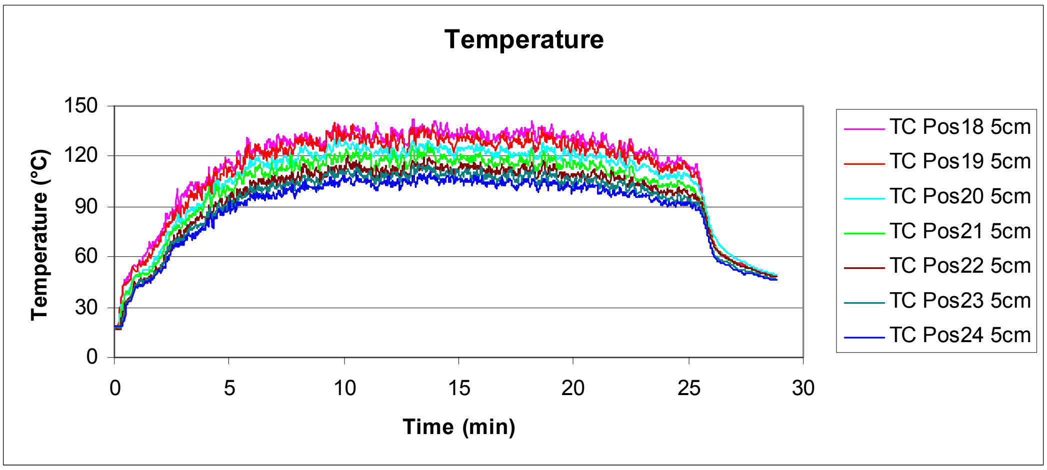

Figure A2.5 Temperature profiles for Test 1.

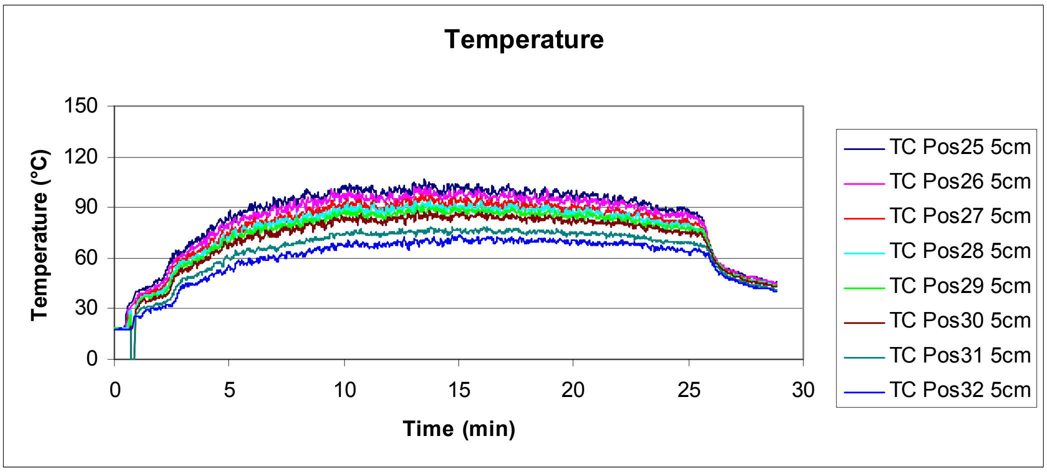

Figure A2.6 Temperature profiles for Test 1.

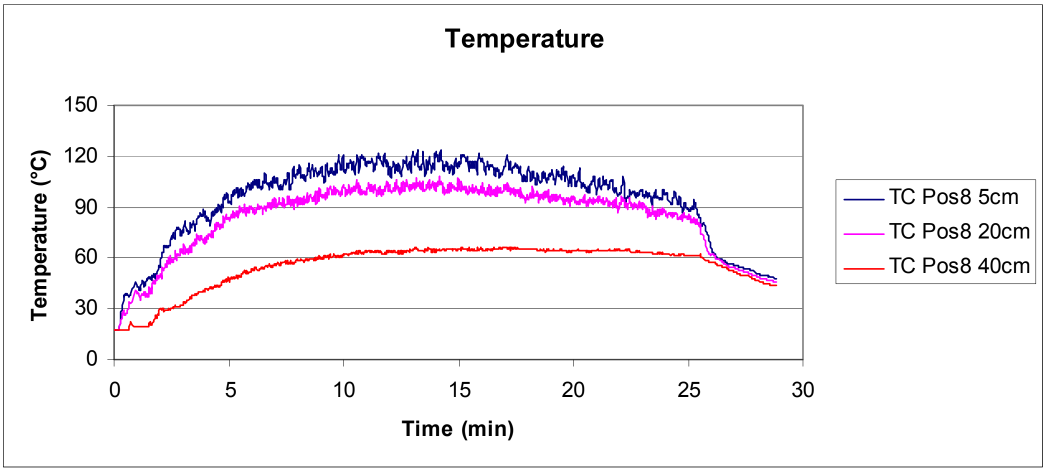

Figure A2.7 Temperature profiles Pos 8 for Test 1.

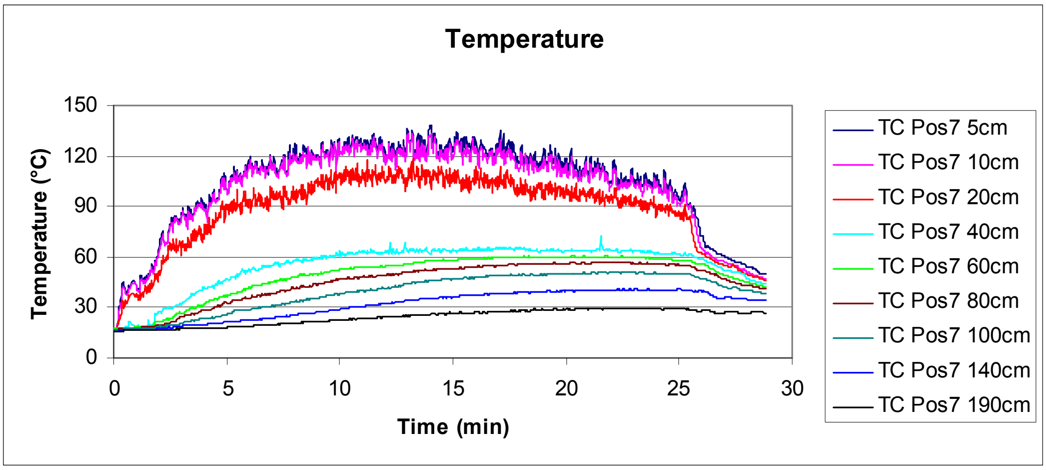

Figure A2.8 Temperature profiles Pos 7 for Test 1.

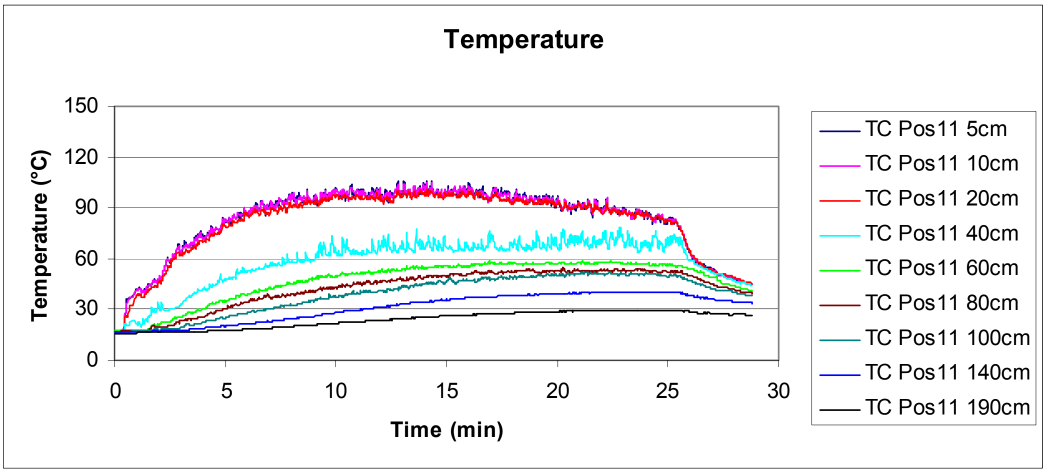

Figure A2.9 Temperature profiles Pos 11 for Test 1.

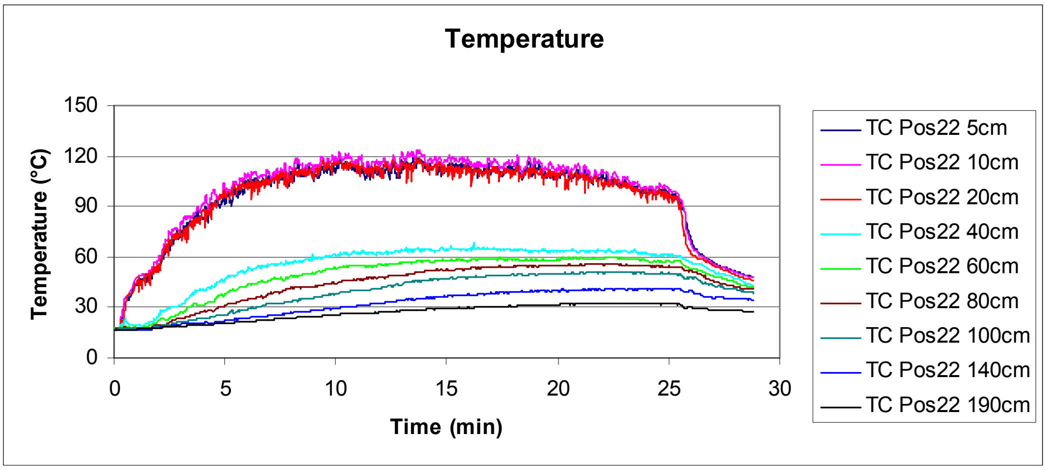

Figure A2.10 Temperature profiles Pos 22 for Test 1.

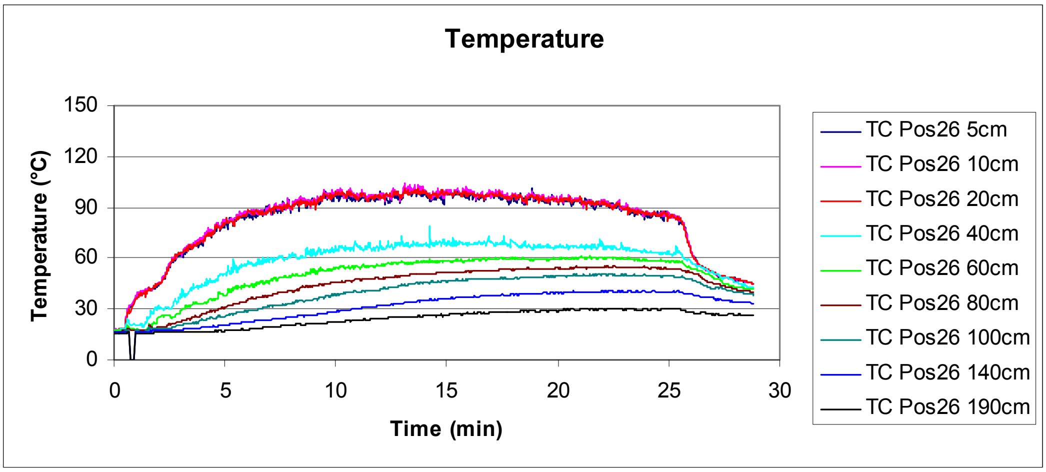

Figure A2.11 Temperature profiles Pos 26 for Test 1.

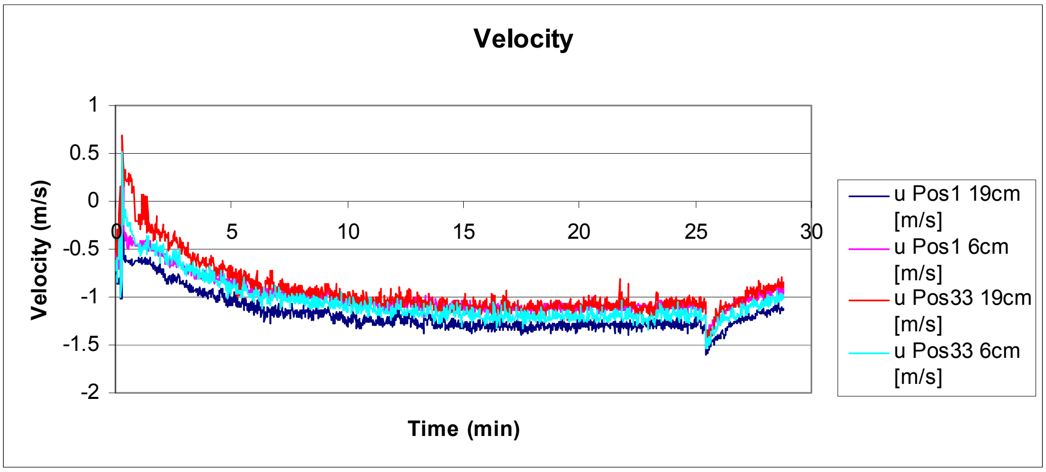

Figure A2.12 Velocity profiles for Test 1.

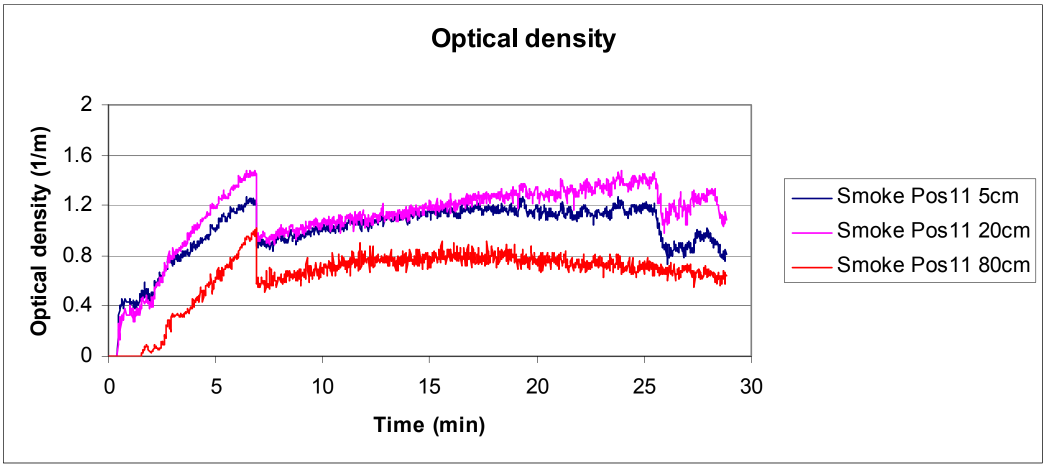

Figure A2.13 Optical density for Test 1.

Test 2

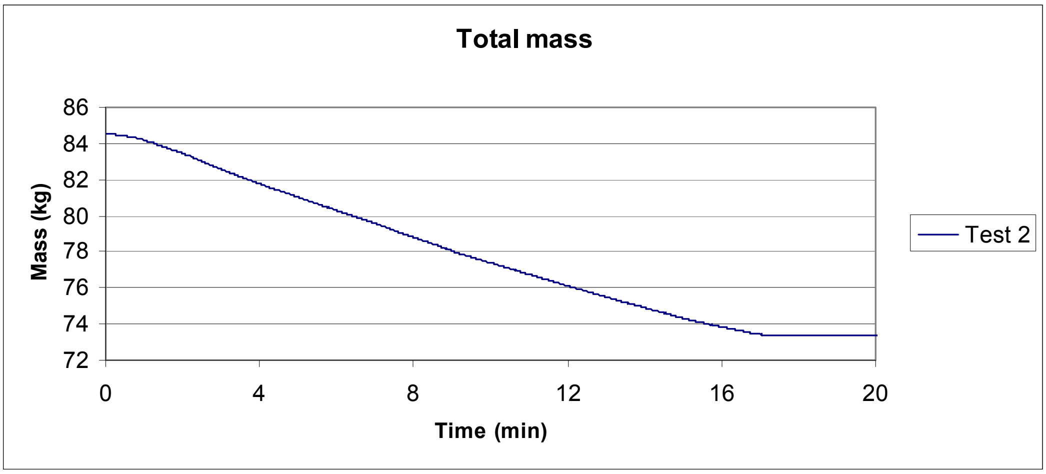

Figure A2.14 Total mass for Test 2.

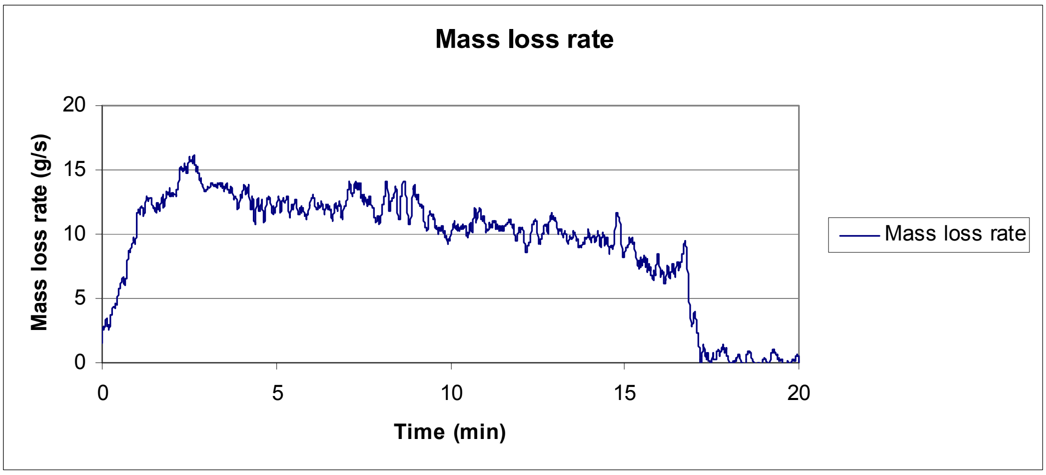

Figure A2.15 Mass loss rate for Test 2.

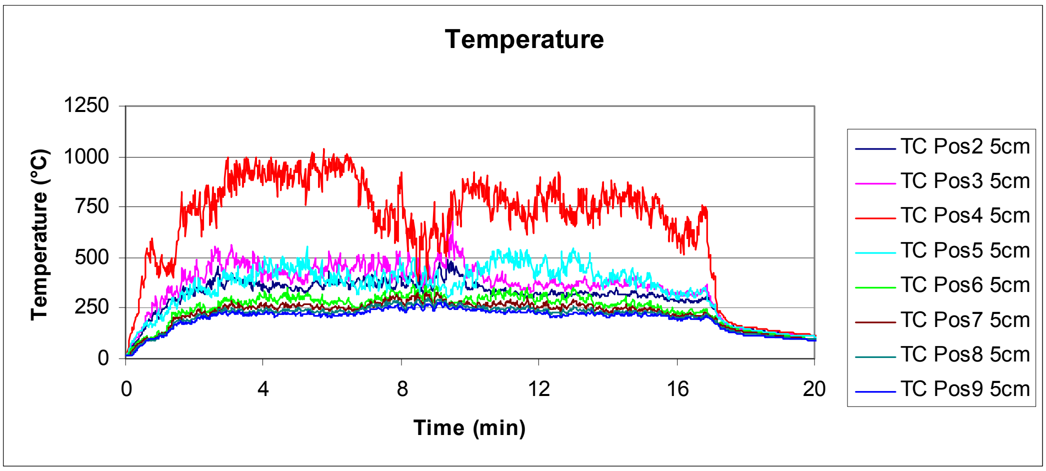

Figure A2.16 Temperature profiles for Test 2.

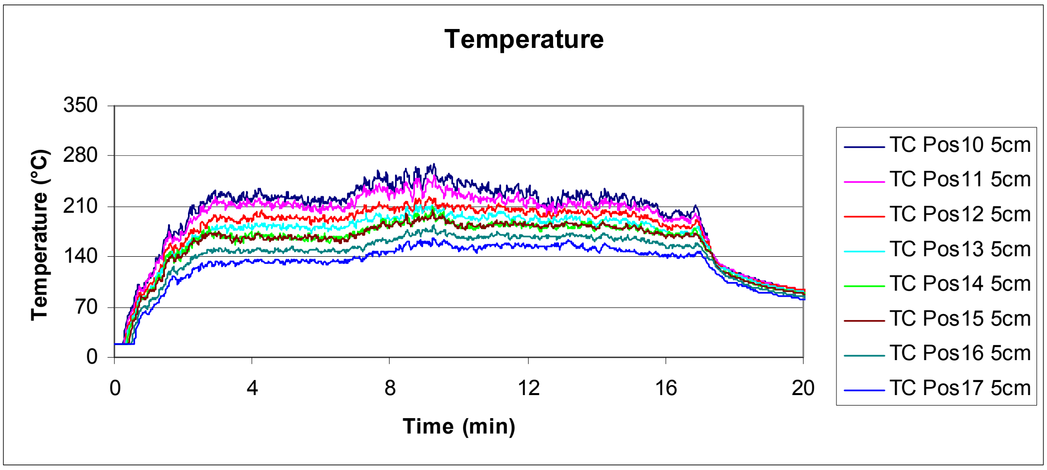

Figure A2.17 Temperature profiles for Test 2.

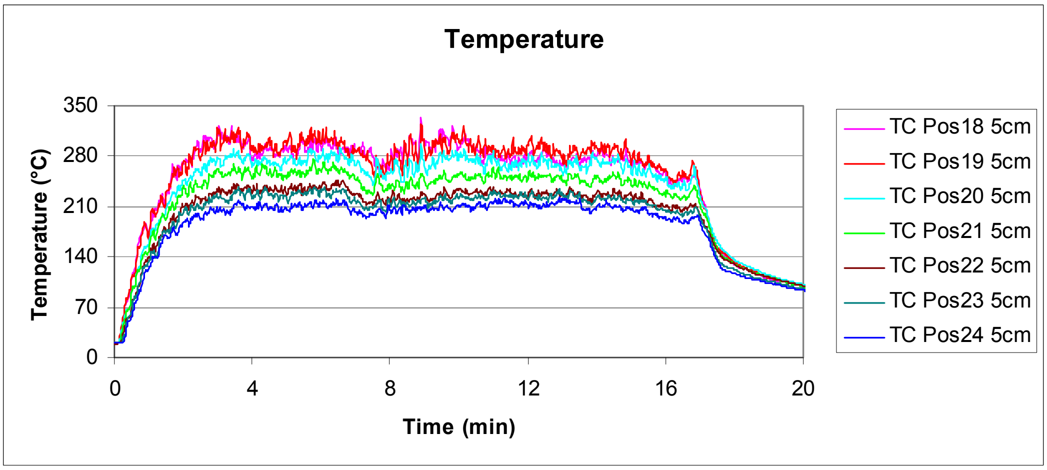

Figure A2.18 Temperature profiles for Test 2.

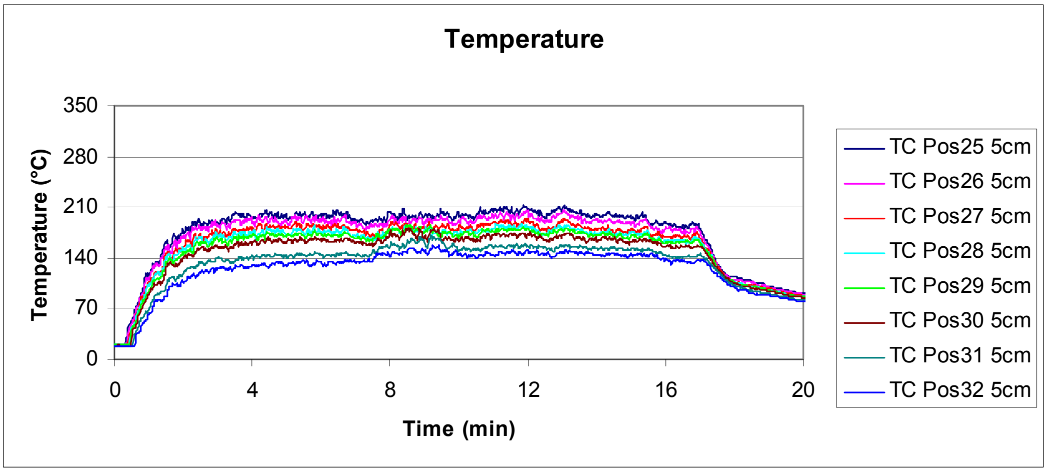

Figure A2.19 Temperature profiles for Test 2.

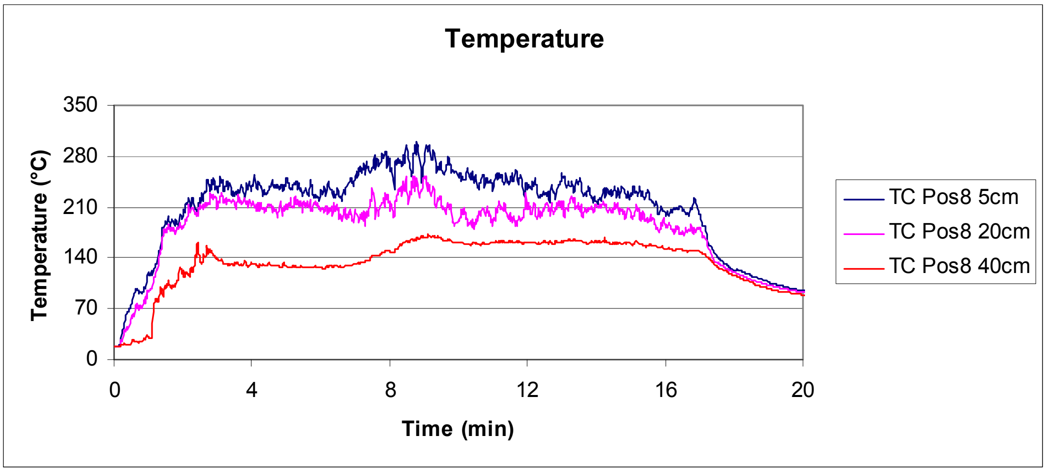

Figure A2.20 Temperature profiles Pos 8 for Test 2.

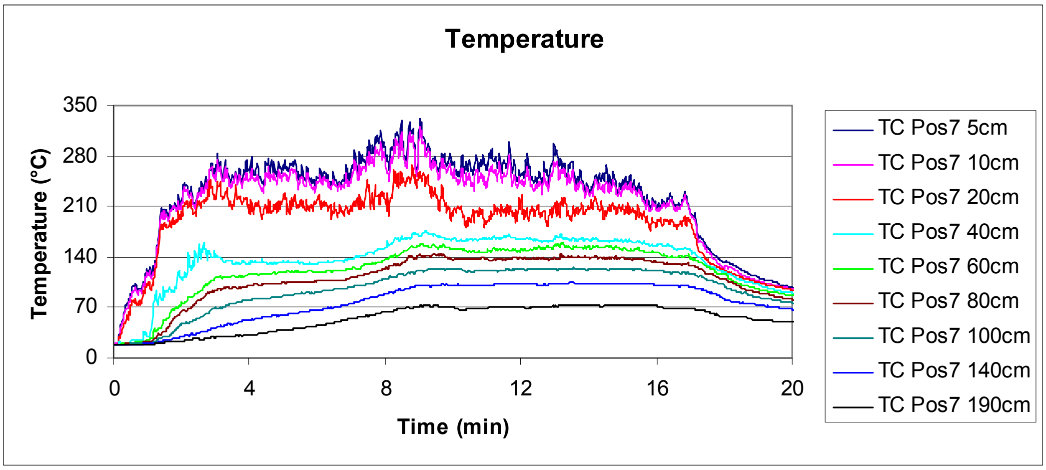

Figure A2.21 Temperature profiles Pos 7 for Test 2.

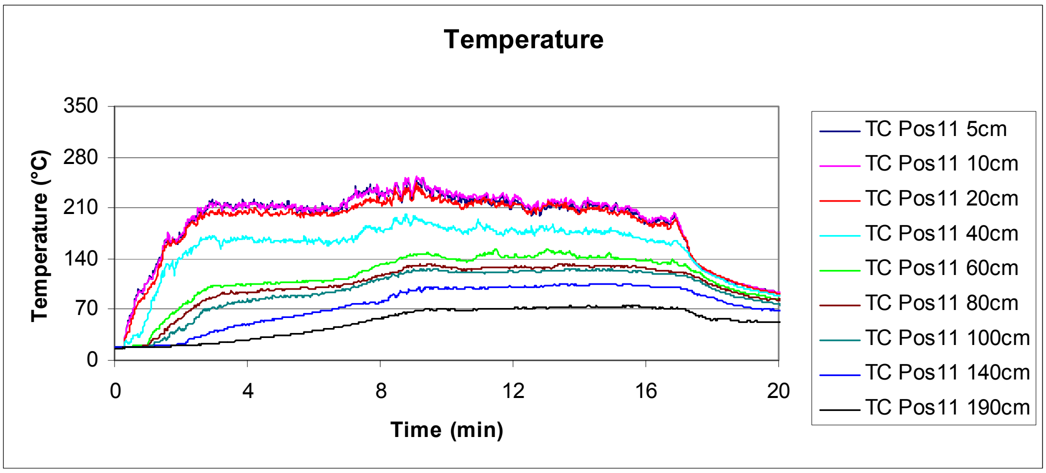

Figure A2.22 Temperature profiles Pos 11 for Test 2.

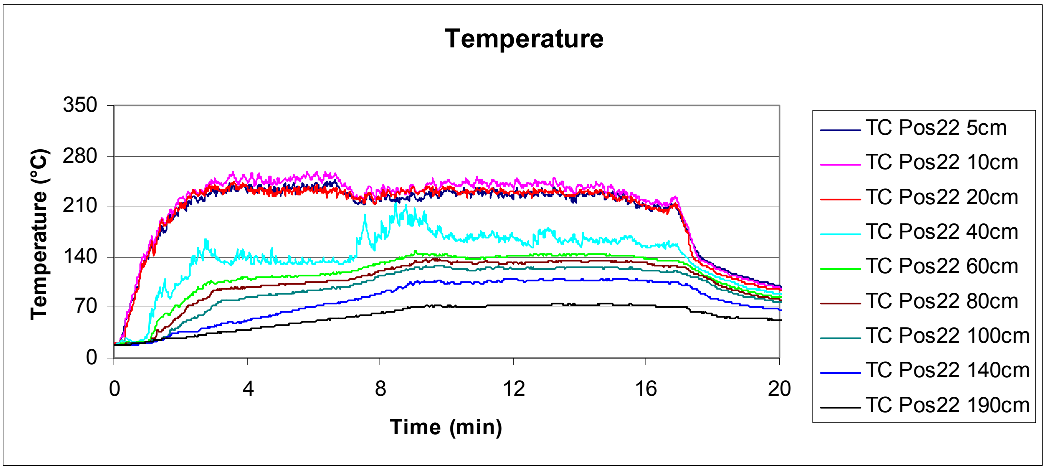

Figure A2.23 Temperature profiles Pos 22 for Test 2.

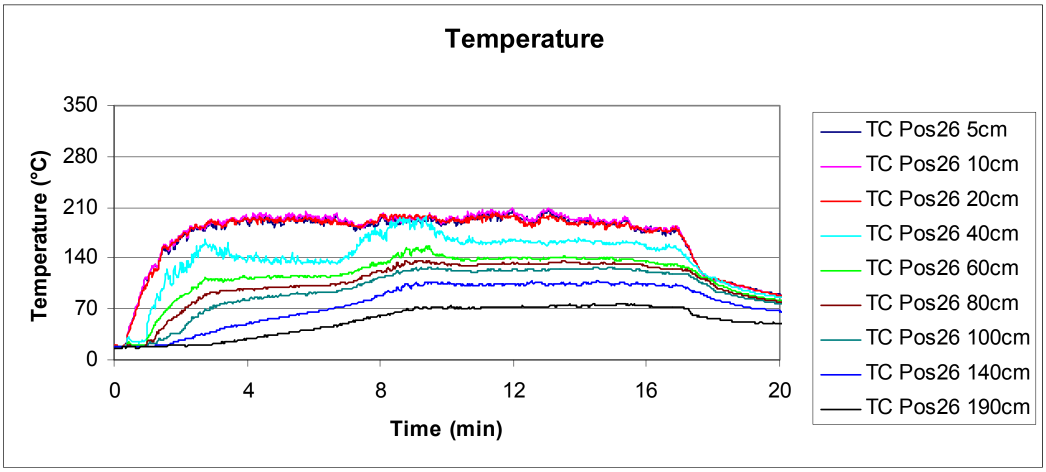

Figure A2.24 Temperature profiles Pos 26 for Test 2.

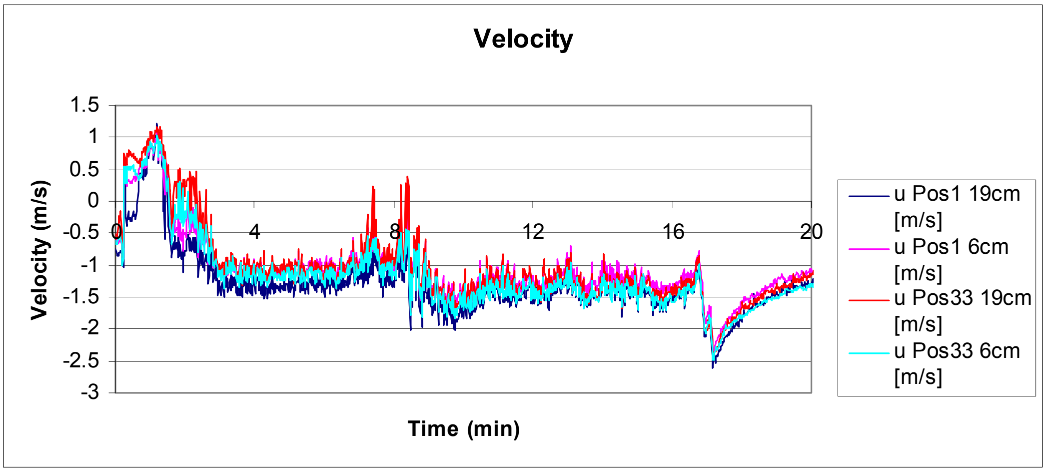

Figure A2.25 Velocity profiles for Test 2.

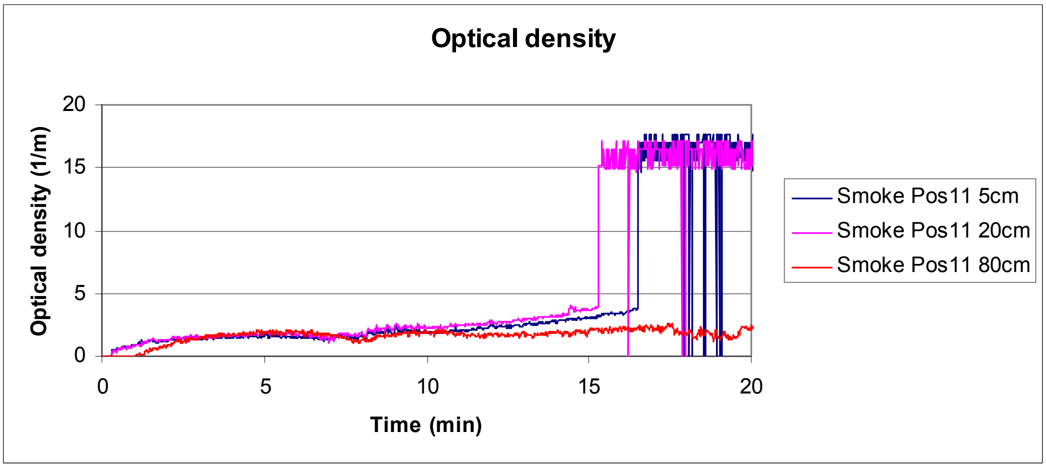

Figure A2.26 Optical density for Test 2.

Test 3

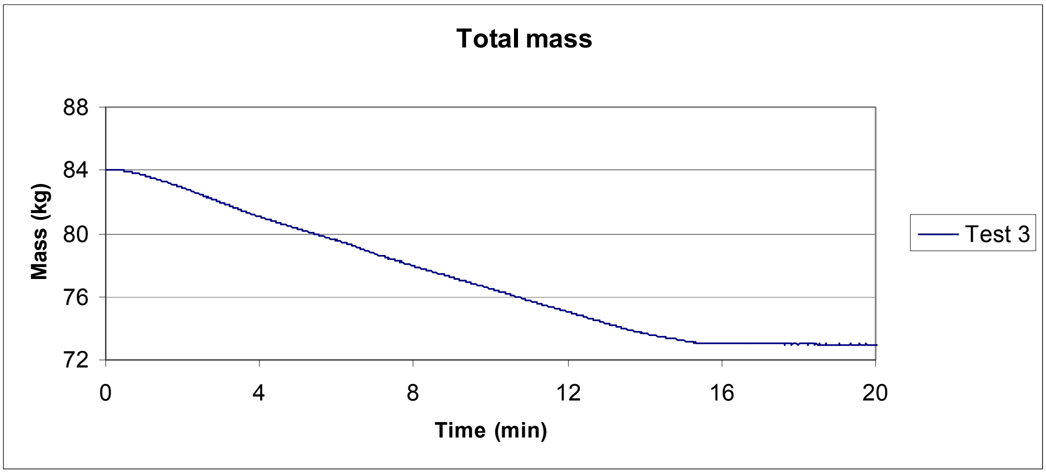

Figure A2.27 Total mass for Test 3.

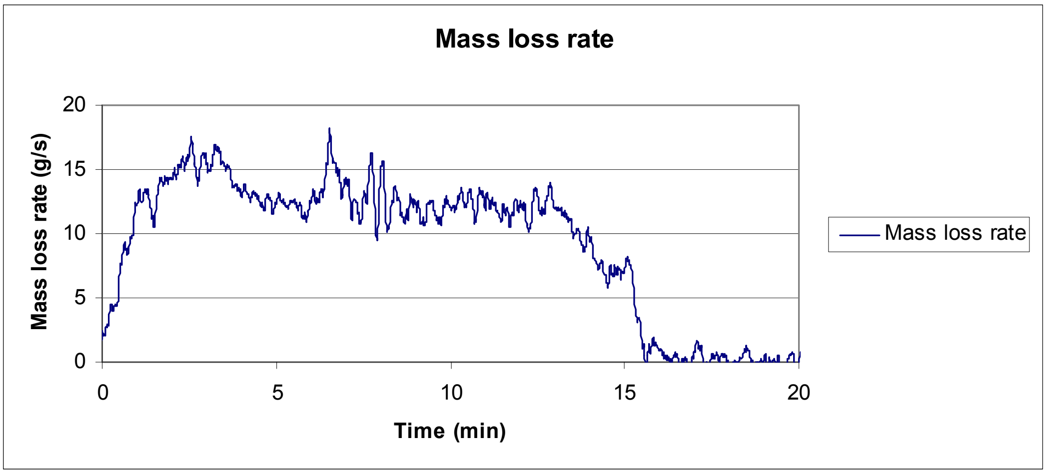

Figure A2.28 Mass loss rate for Test 3.

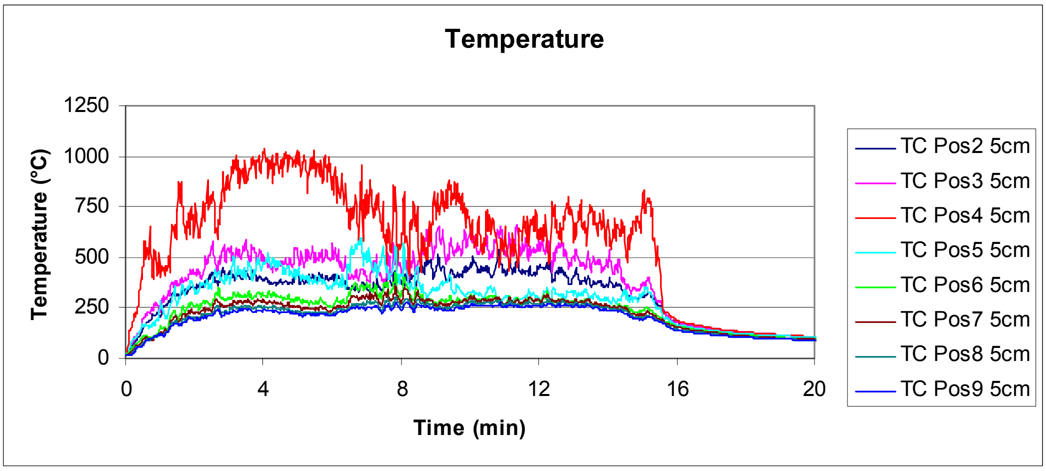

Figure A2.29 Temperature profiles for Test 3.

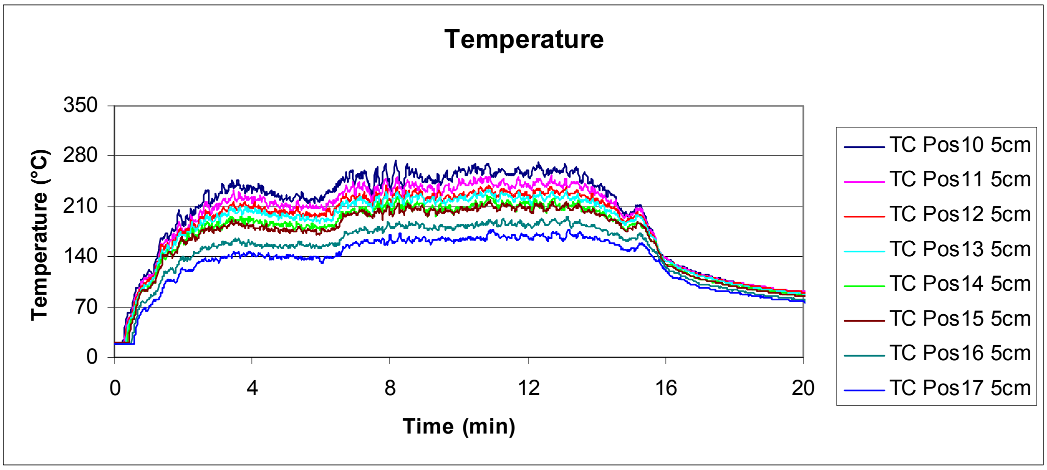

Figure A2.30 Temperature profiles for Test 3.

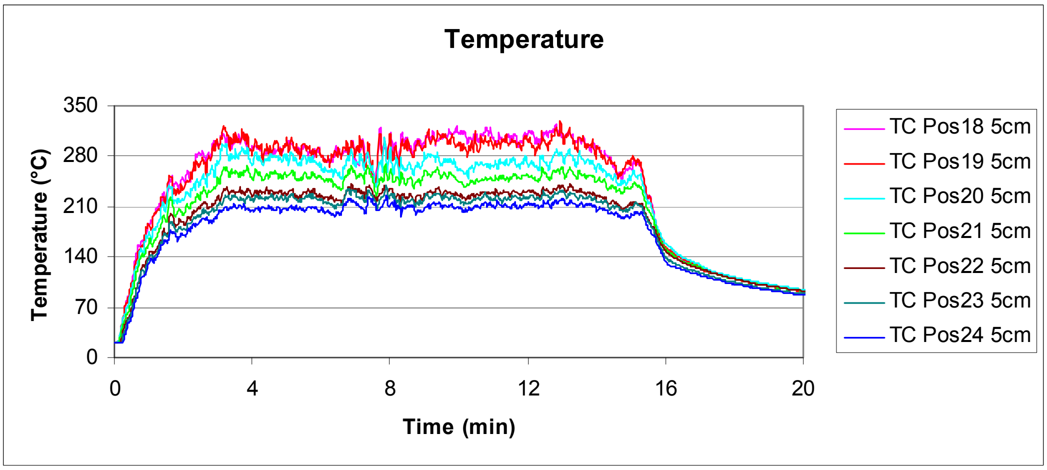

Figure A2.31 Temperature profiles for Test 3.

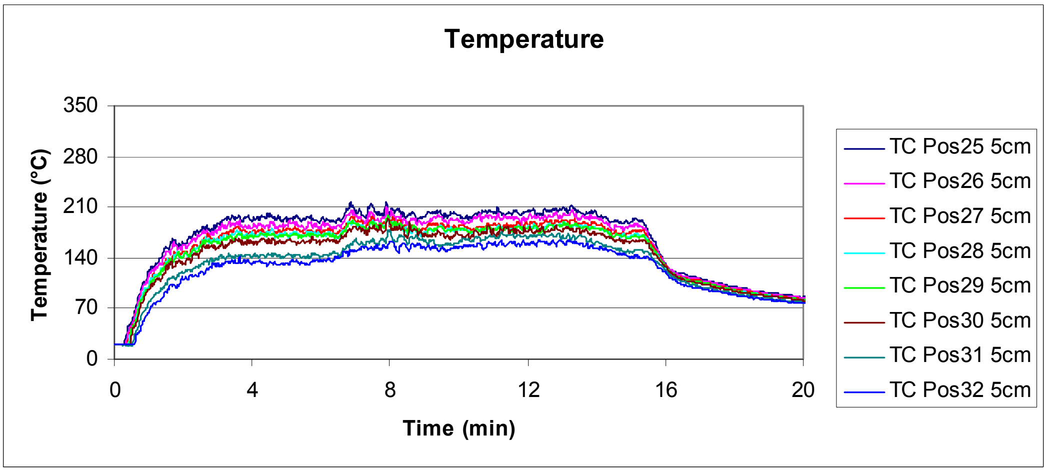

Figure A2.32 Temperature profiles for Test 3.

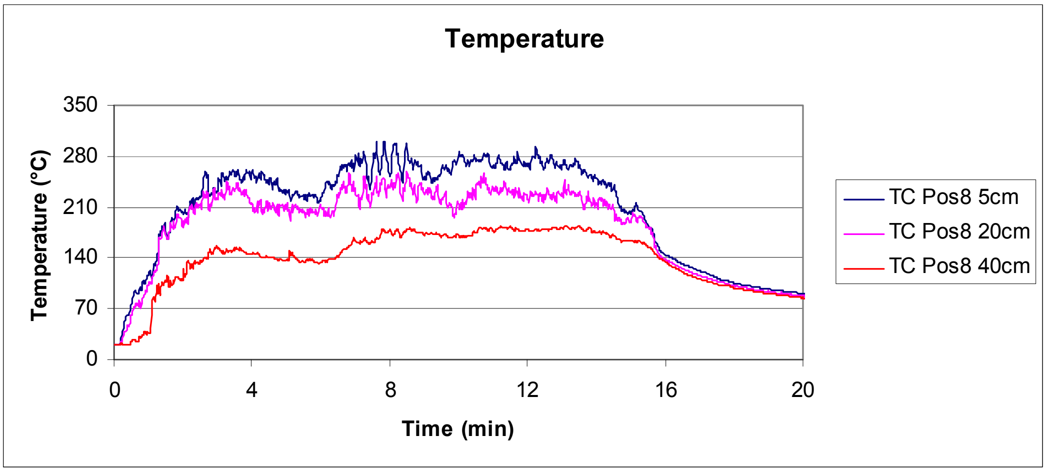

Figure A2.33 Temperature profiles Pos 8 for Test 3.

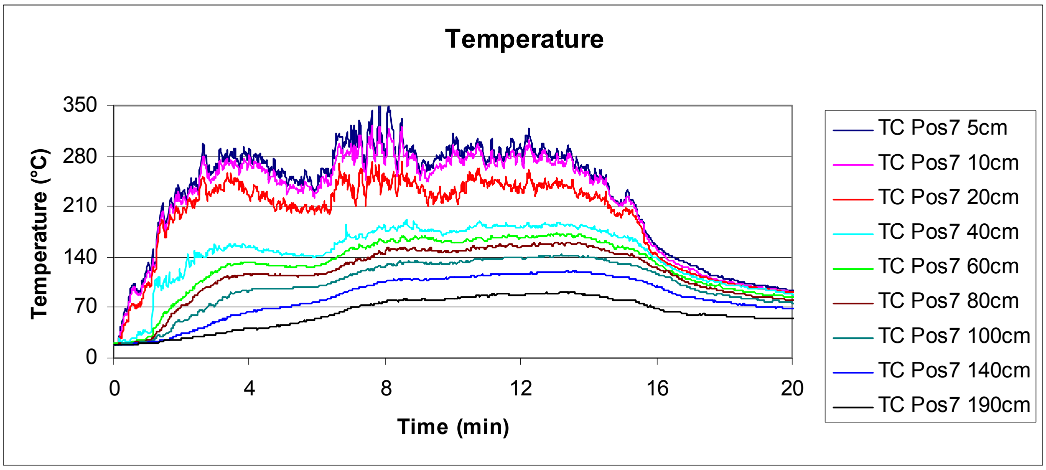

Figure A2.34 Temperature profiles Pos 7 for Test 3.

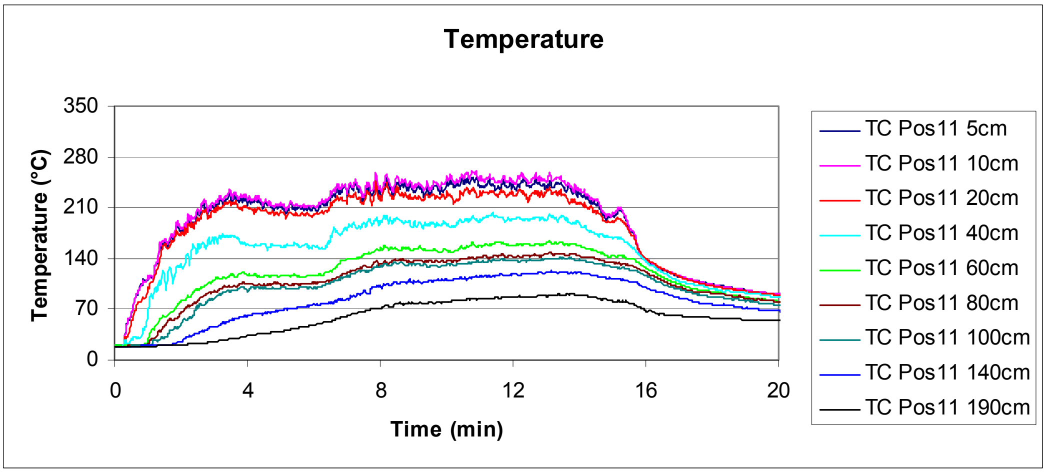

Figure A2.35 Temperature profiles Pos 11 for Test 3.

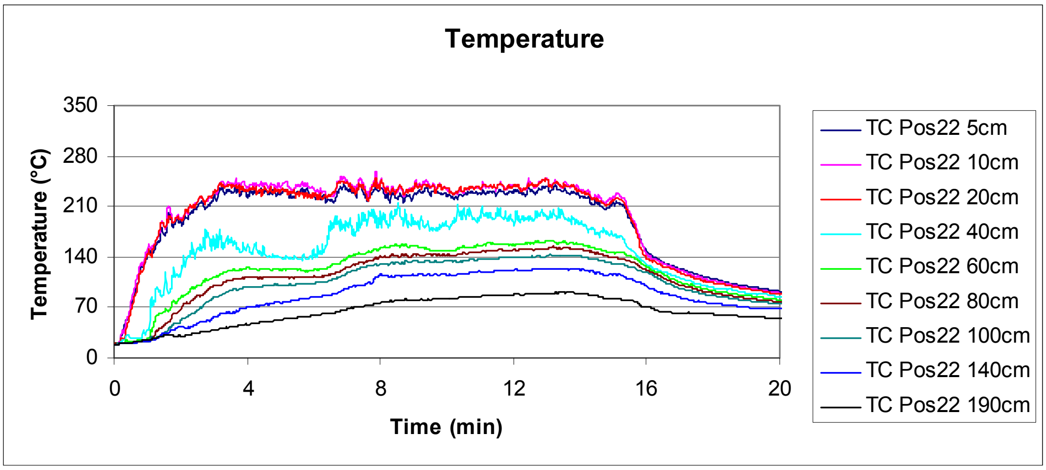

Figure A2.36 Temperature profiles Pos 22 for Test 3.

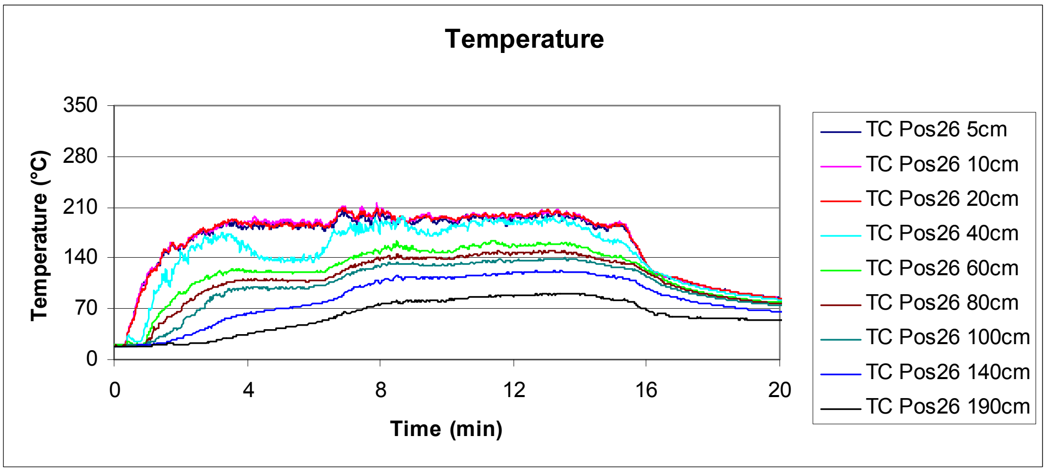

Figure A2.37 Temperature profiles Pos 26 for Test 3.

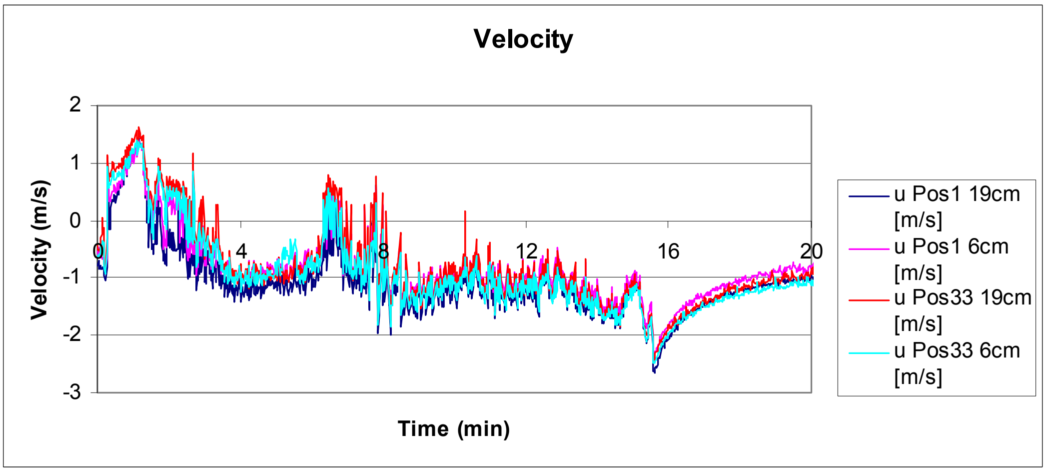

Figure A2.38 Velocity profiles for Test 3.

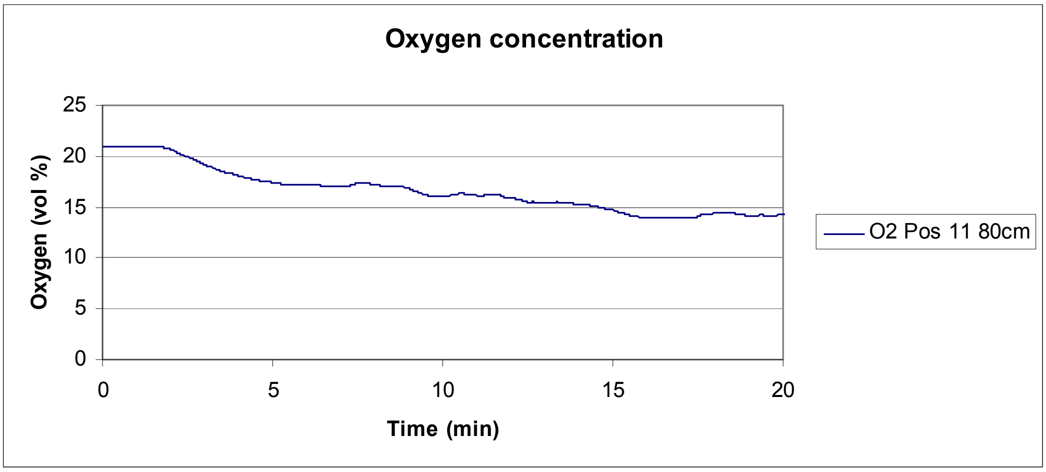

Figure A2.39 Oxygen concentration for Test 3.

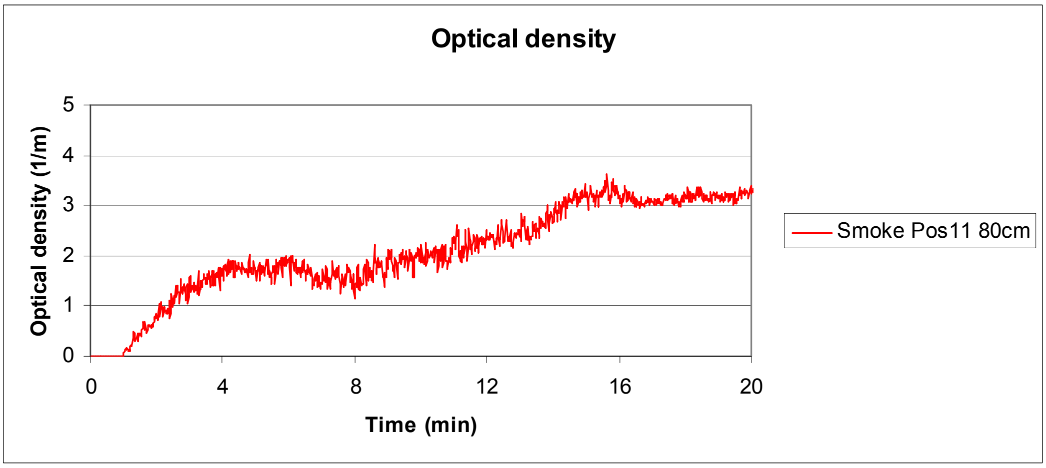

Figure A2.40 Optical density for Test 3.

Test 4

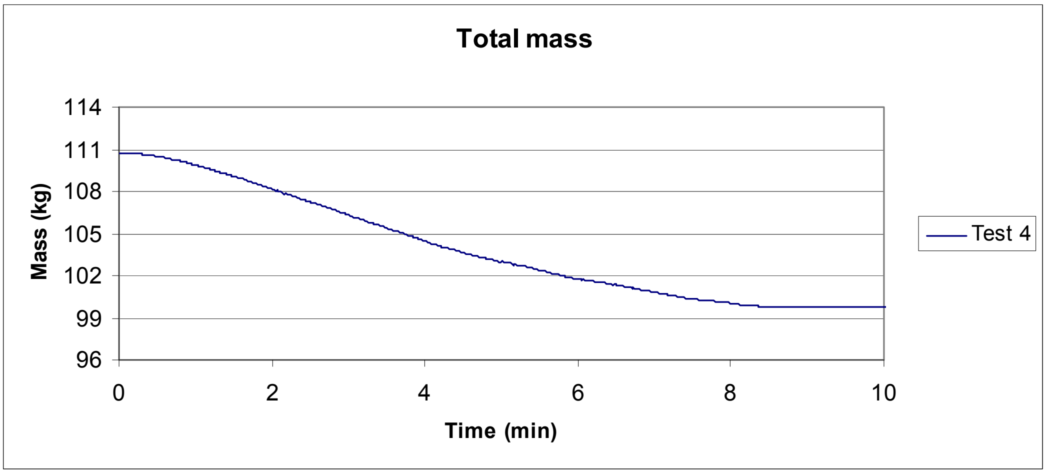

Figure A2.41 Total mass for Test 4.

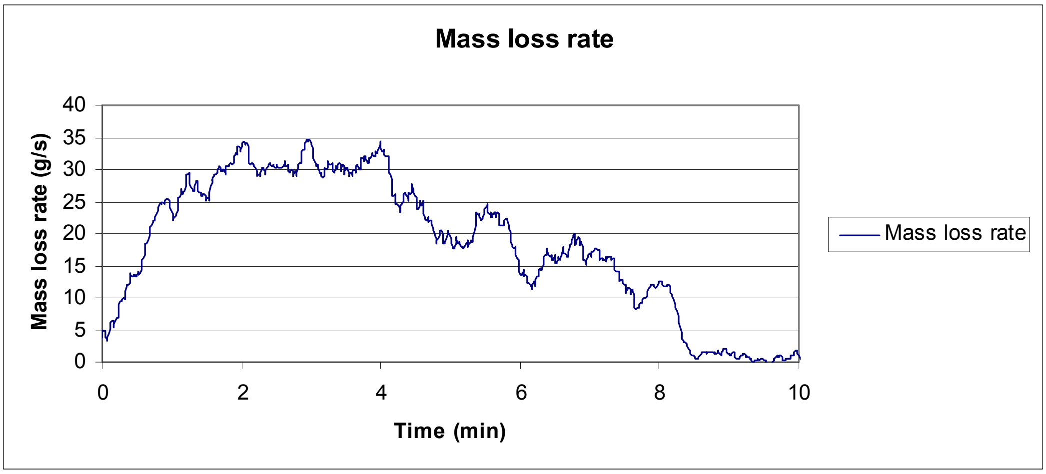

Figure A2.42 Mass loss rate for Test 4.

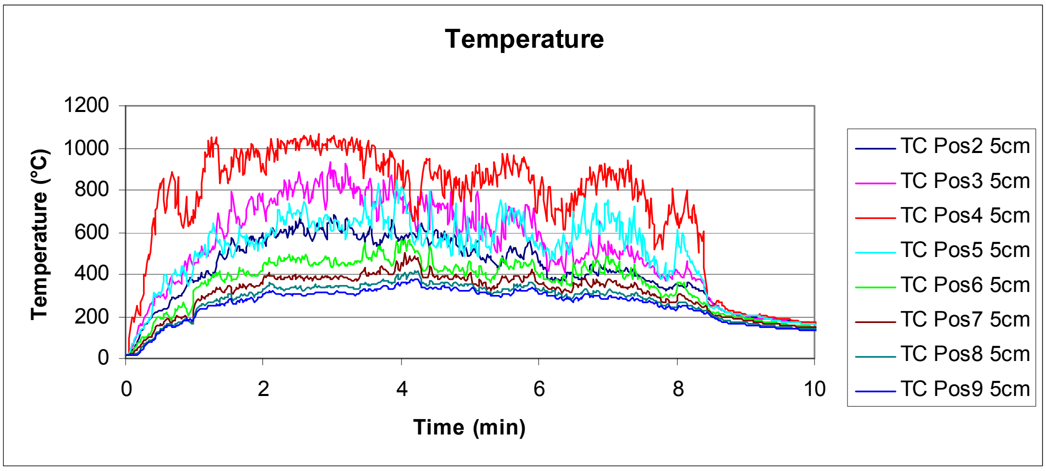

Figure A2.43 Temperature profiles for Test 4.

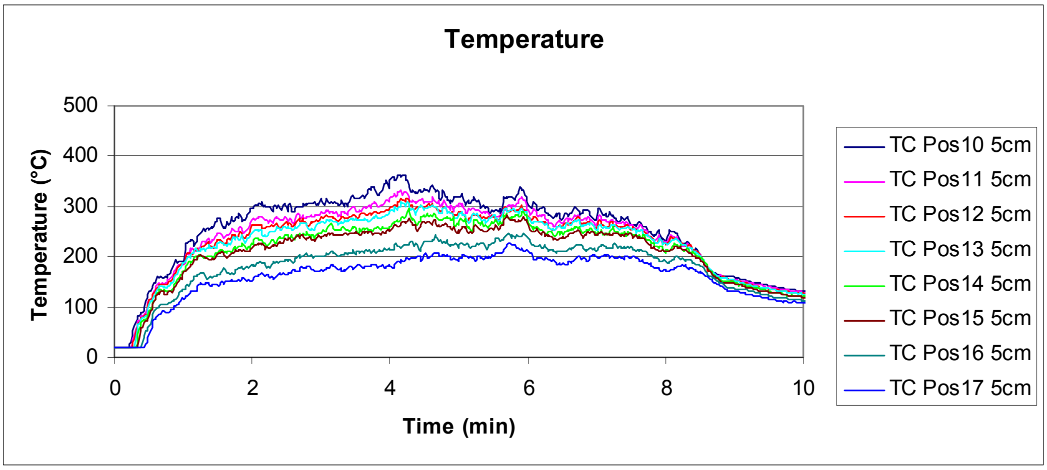

Figure A2.44 Temperature profiles for Test 4.

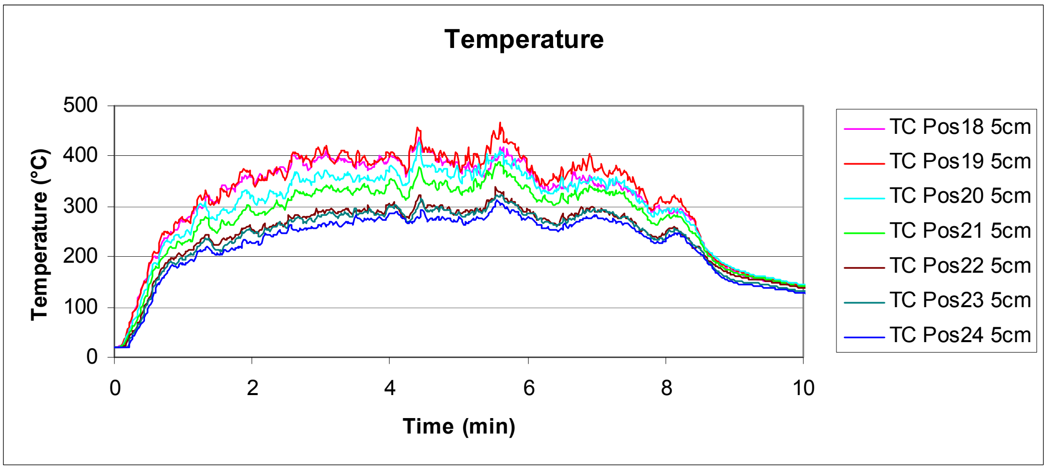

Figure A2.45 Temperature profiles for Test 4.

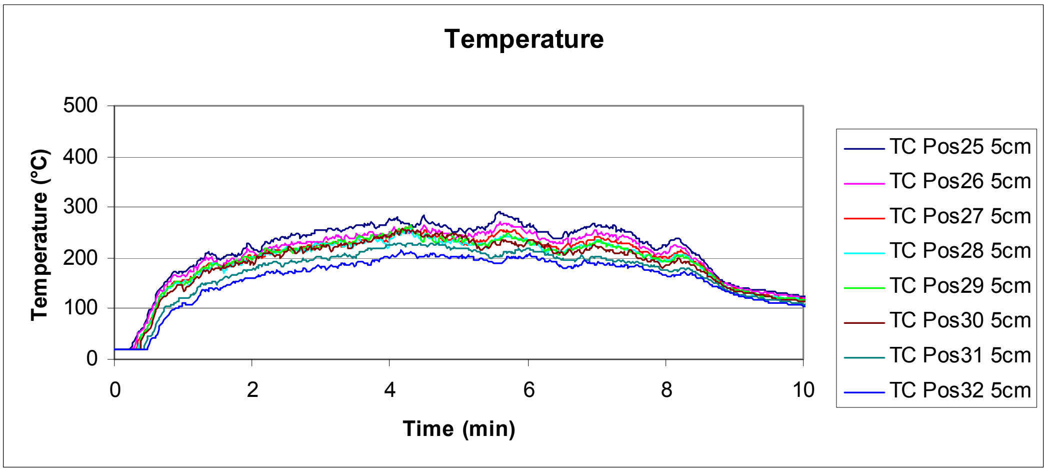

Figure A2.46 Temperature profiles for Test 4.

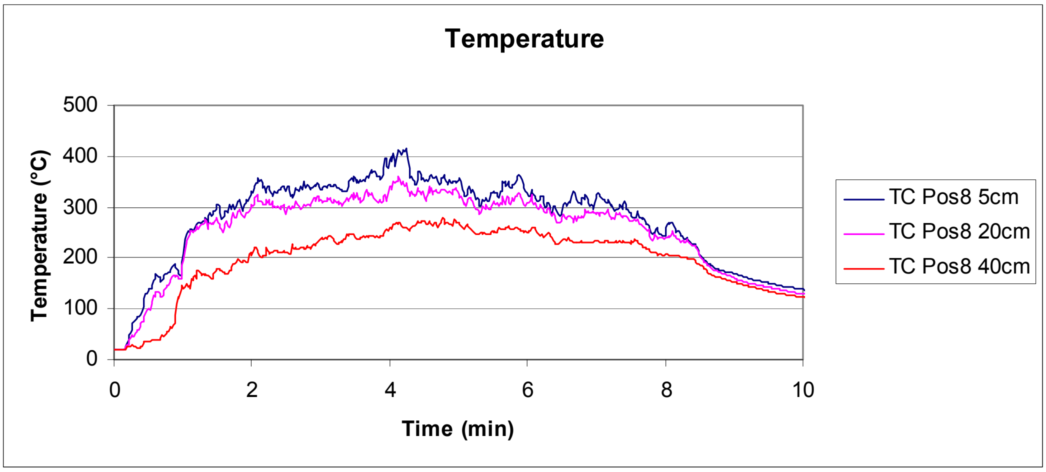

Figure A2.47 Temperature profiles Pos 8 for Test 4.

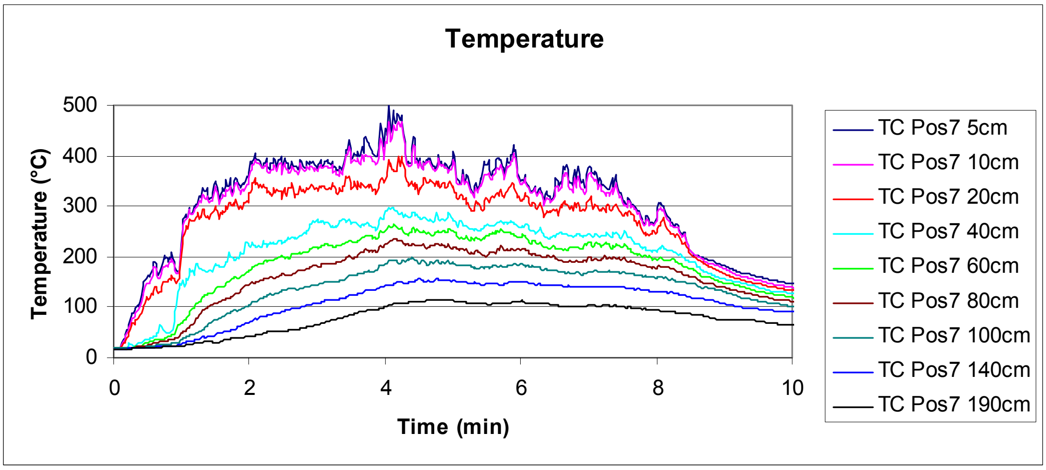

Figure A2.48 Temperature profiles Pos 7 for Test 4.

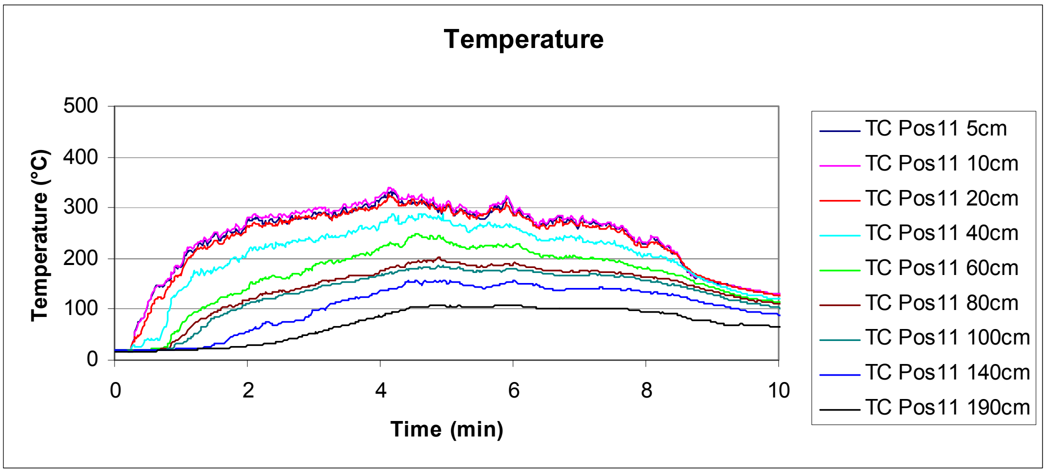

Figure A2.49 Temperature profiles Pos 11 for Test 4.

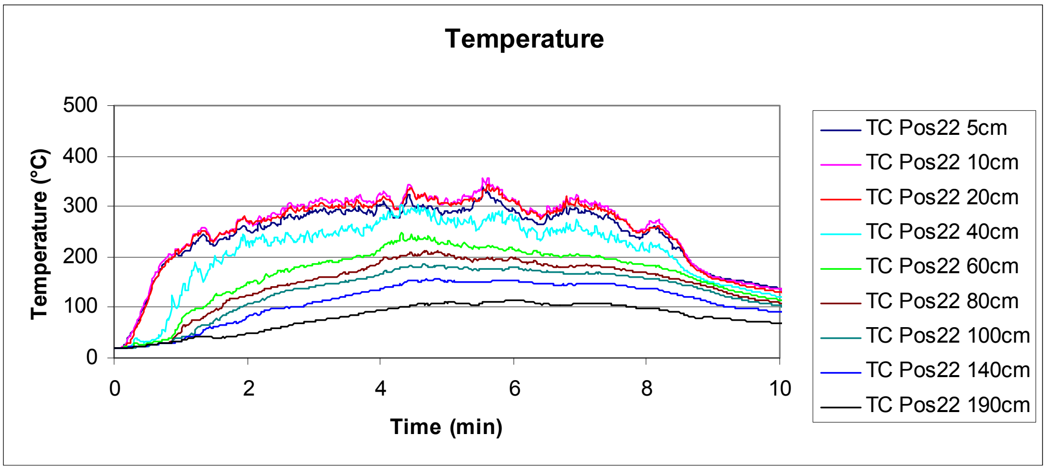

Figure A2.50 Temperature profiles Pos 22 for Test 4.

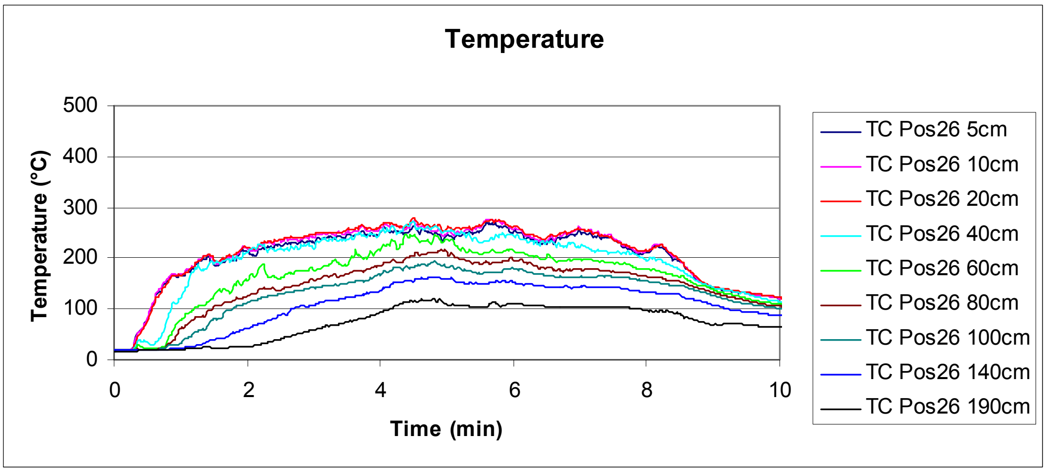

Figure A2.51 Temperature profiles Pos 26 for Test 4.

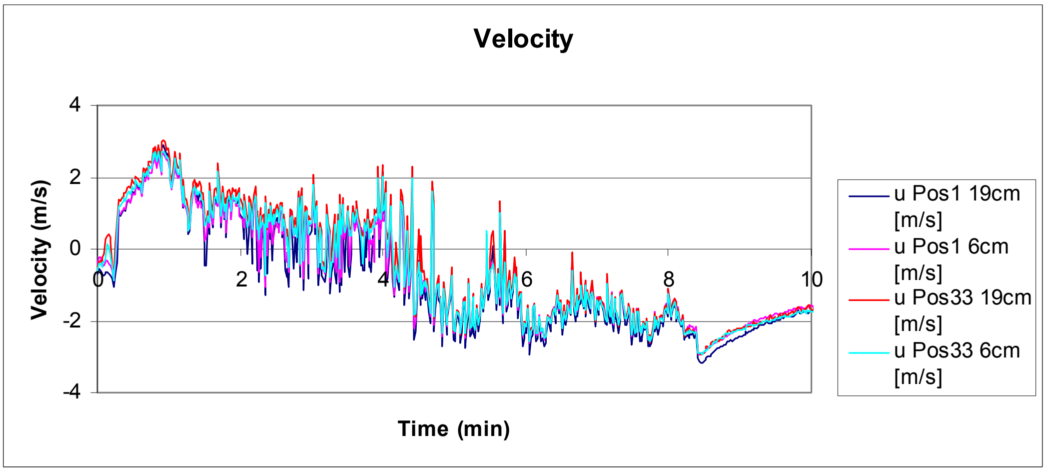

Figure A2.52 Velocity profiles for Test 4.

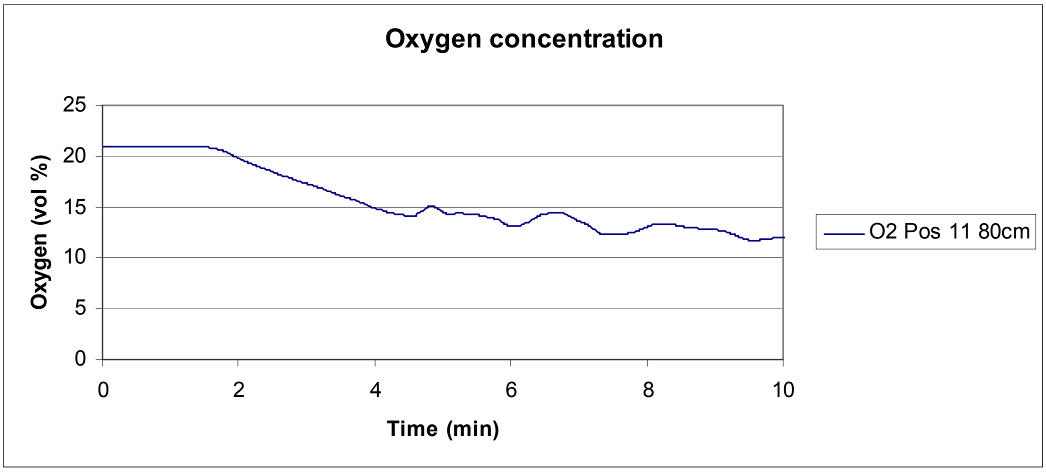

Figure A2.53 Oxygen concentration for Test 4.

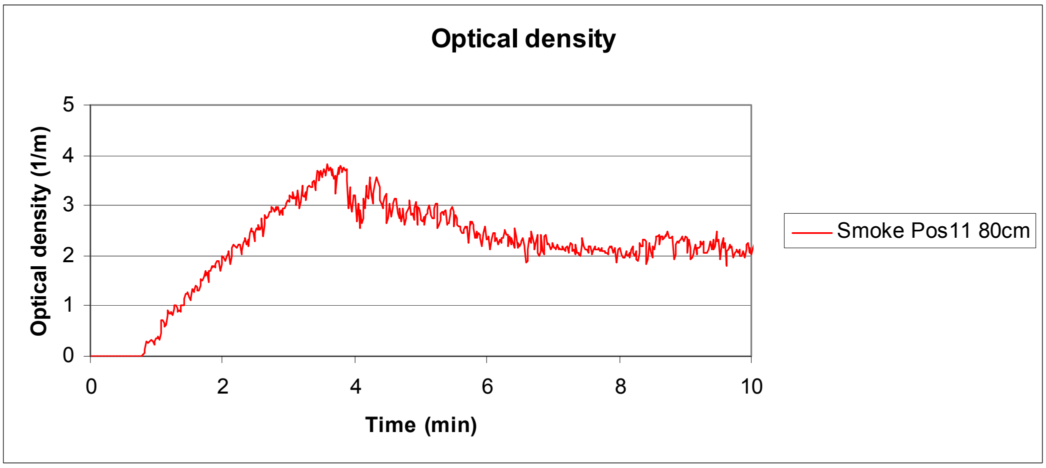

Figure A2.54 Optical density for Test 4.

Test 5

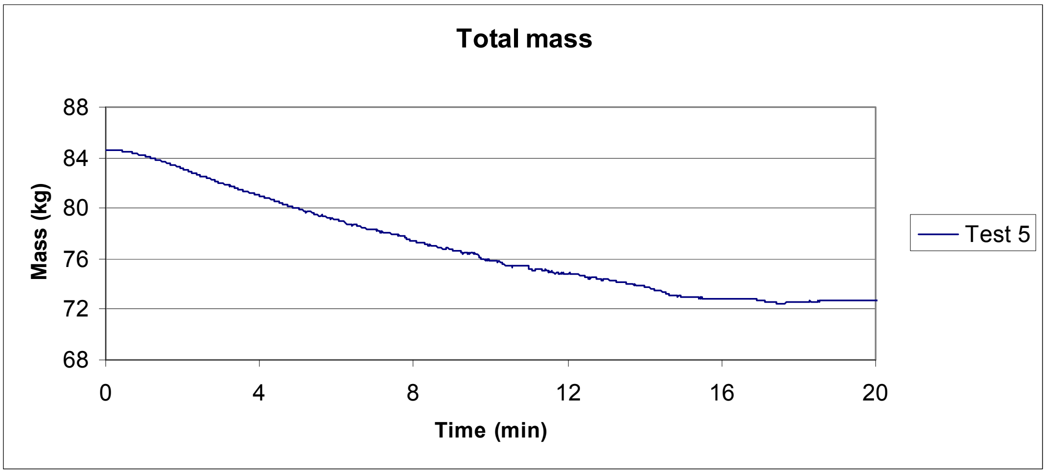

Figure A2.55 Total mass for Test 5.

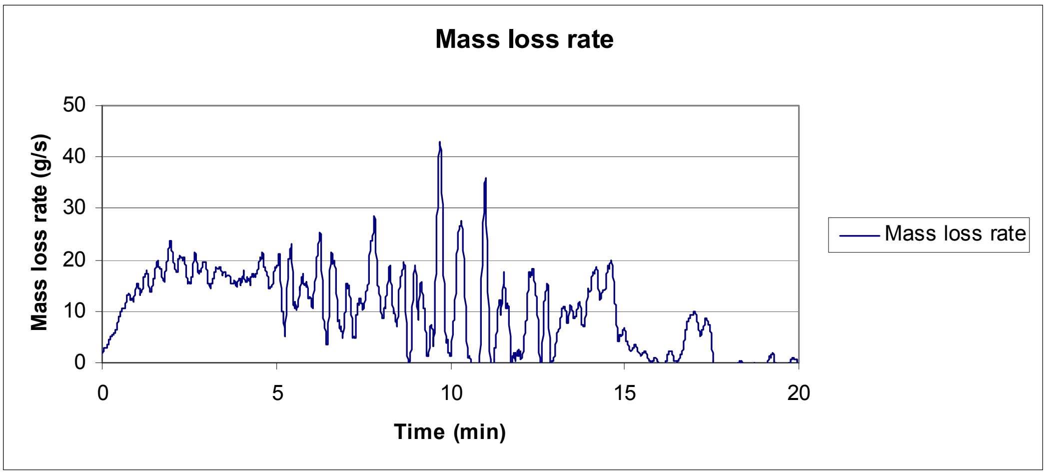

Figure A2.56 Mass loss rate for Test 5.

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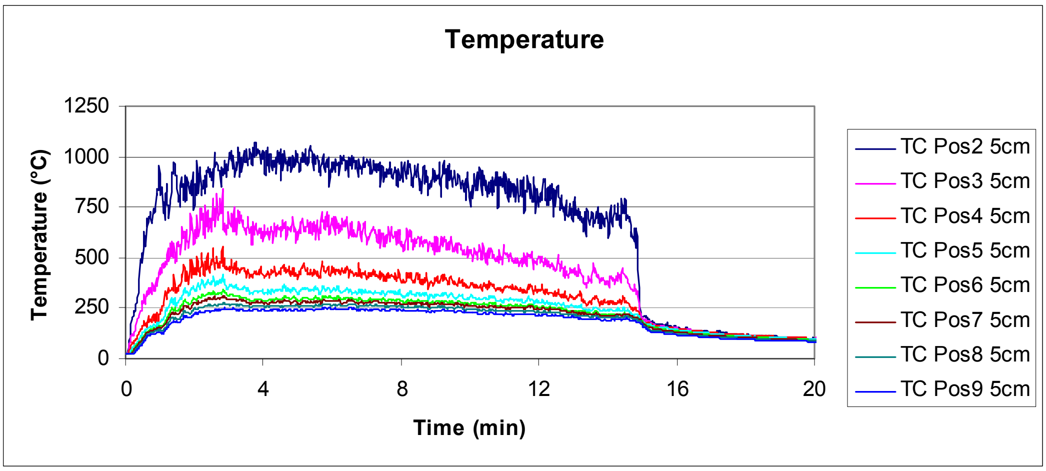

Figure A2.57 Temperature profiles for Test 5.

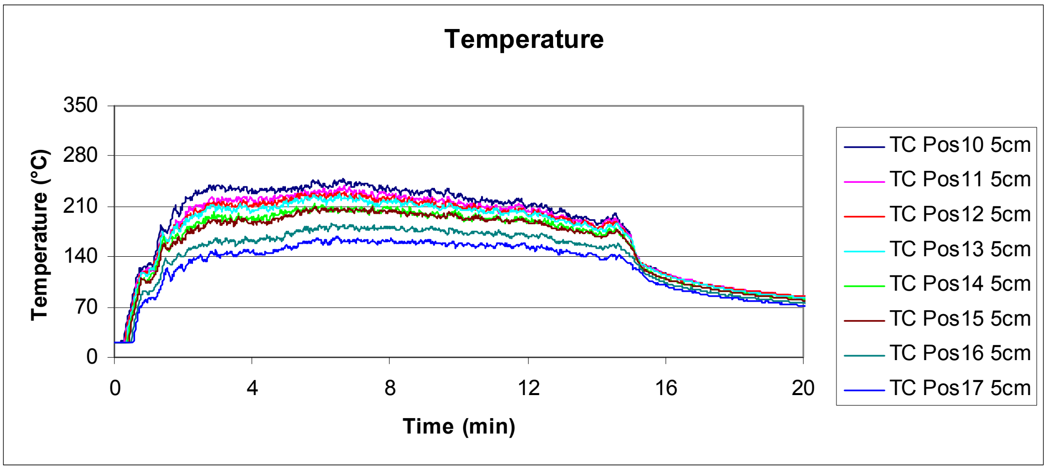

Figure A2.58 Temperature profiles for Test 5.

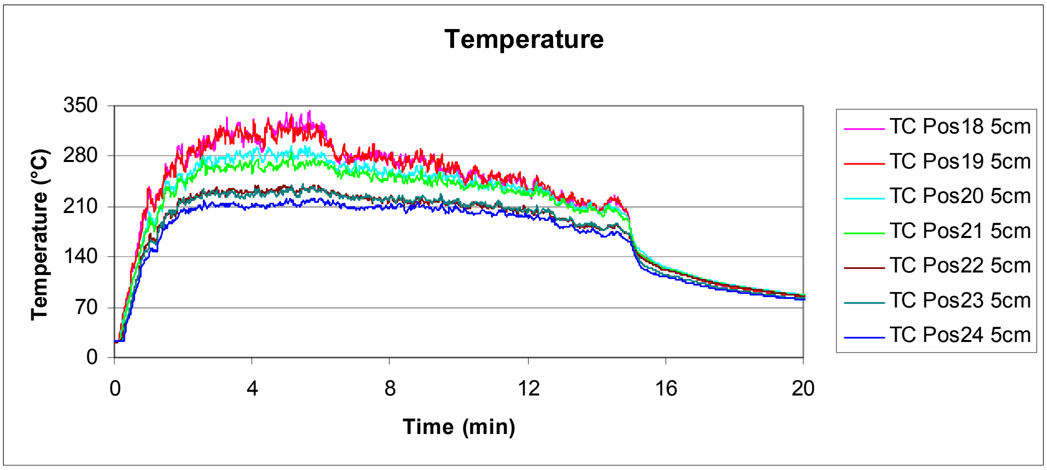

Figure A2.59 Temperature profiles for Test 5.

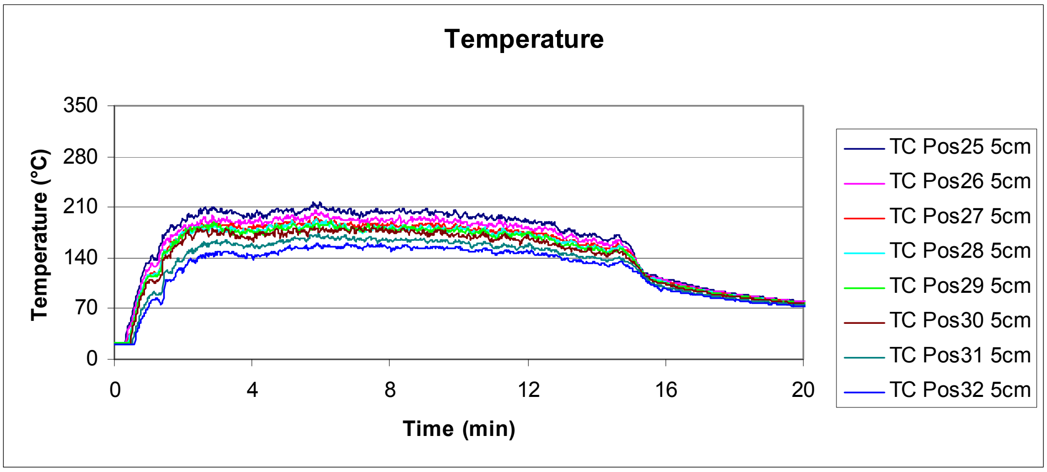

Figure A2.60 Temperature profiles for Test 5.

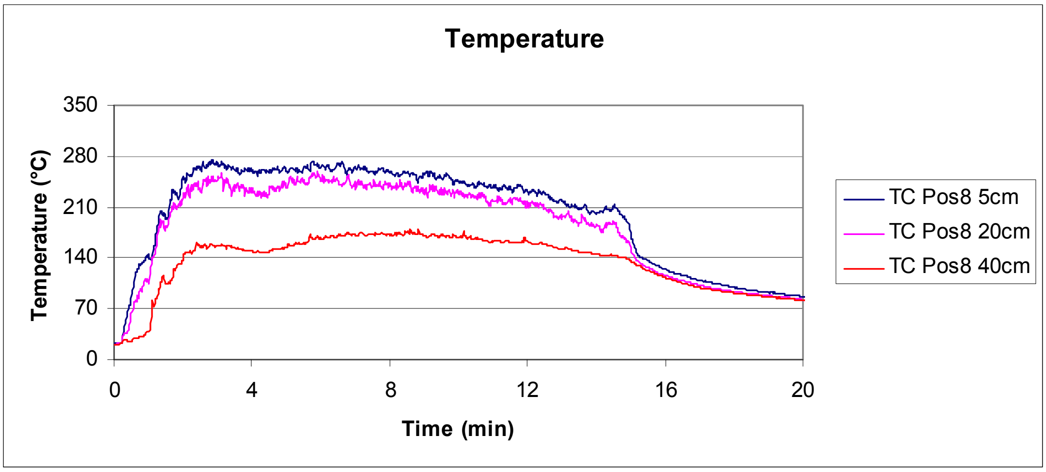

Figure A2.61 Temperature profiles Pos 8 for Test 5.

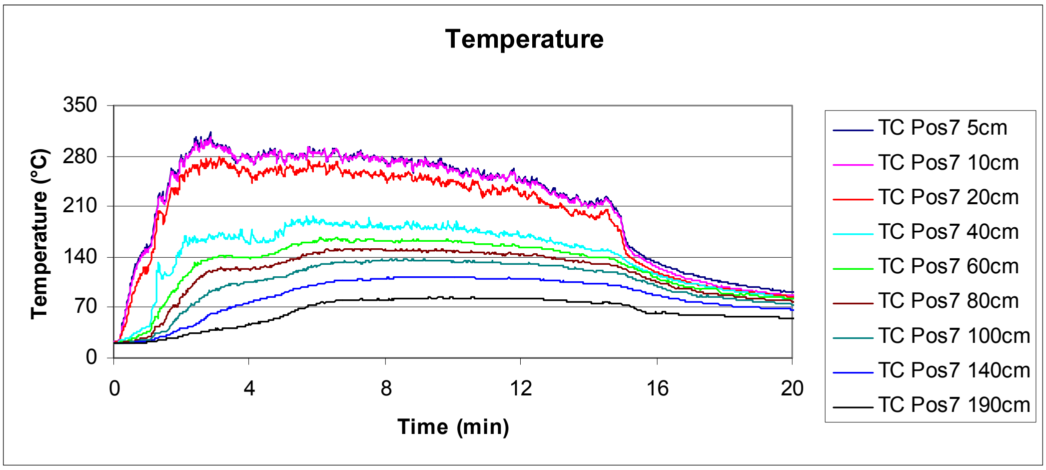

Figure A2.62 Temperature profiles Pos 7 for Test 5.

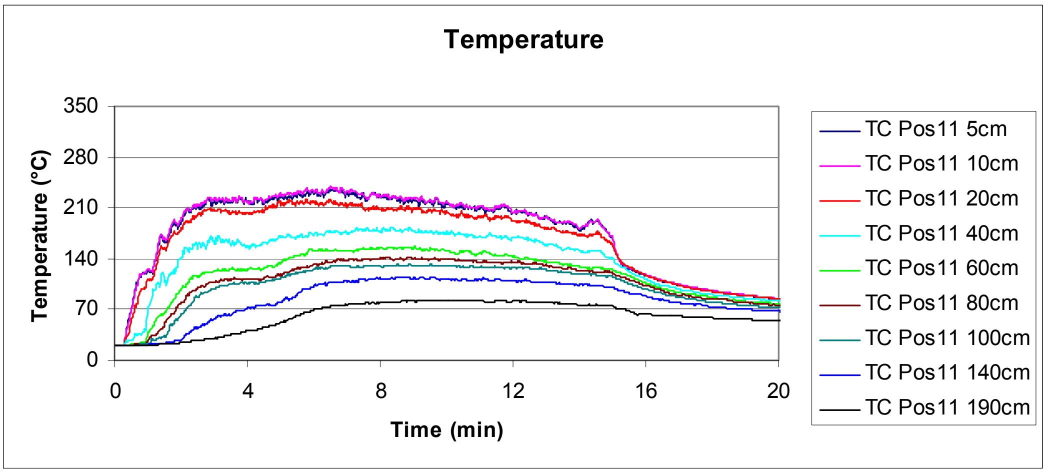

Figure A2.63 Temperature profiles Pos 11 for Test 5.

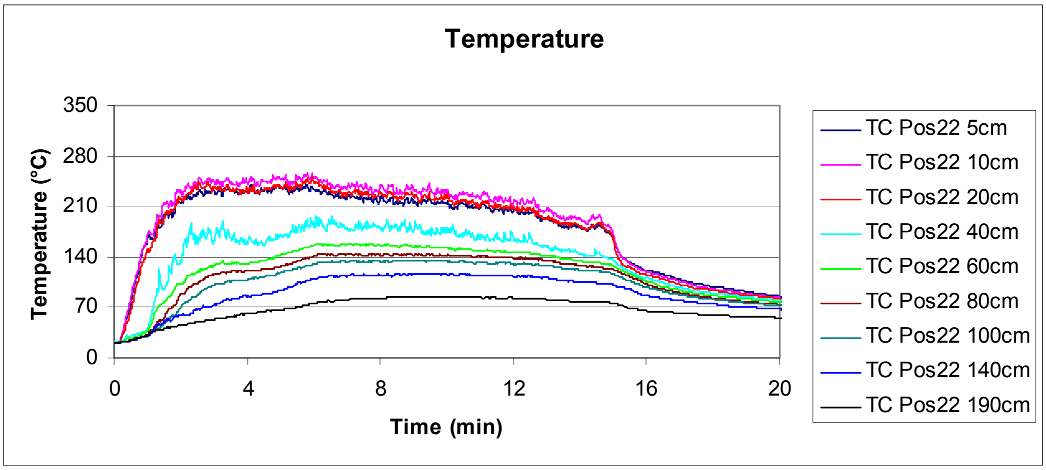

Figure A2.64 Temperature profiles Pos 22 for Test 5.

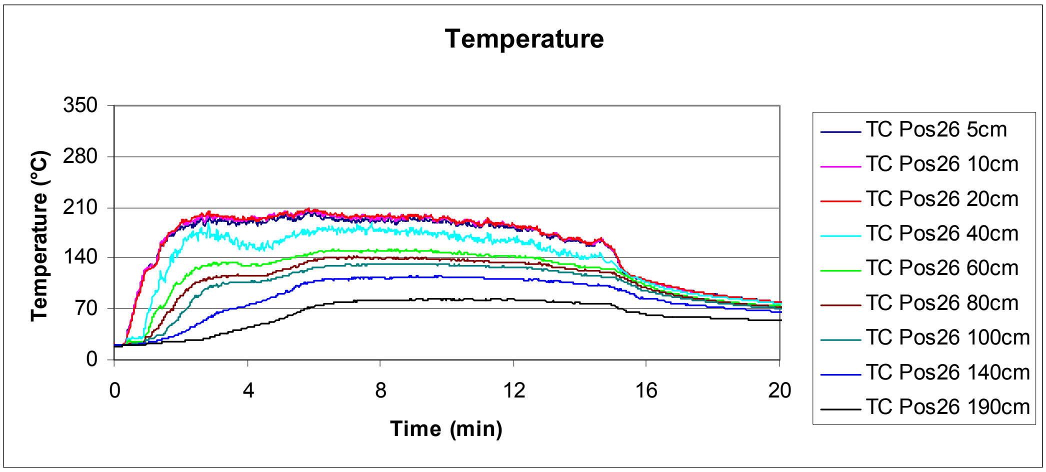

Figure A2.65 Temperature profiles Pos 26 for Test 5.

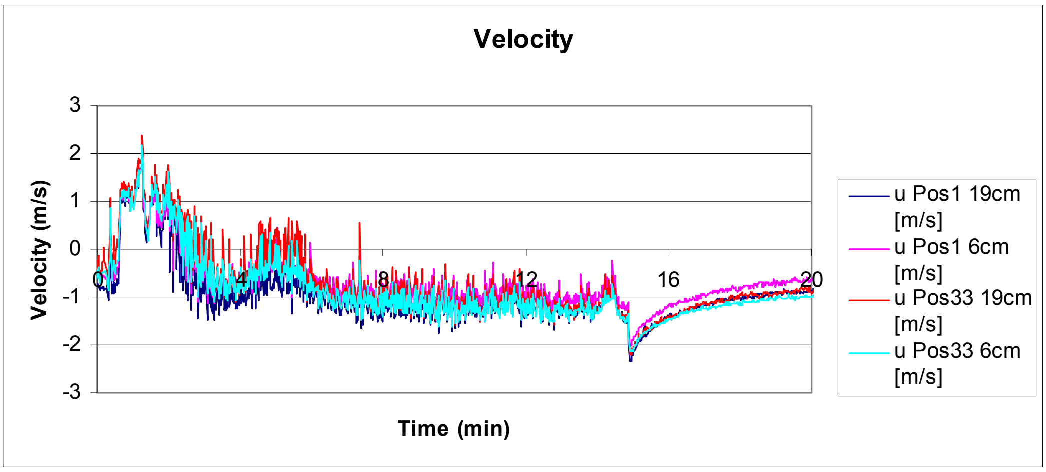

Figure A2.66 Velocity profiles for Test 5.

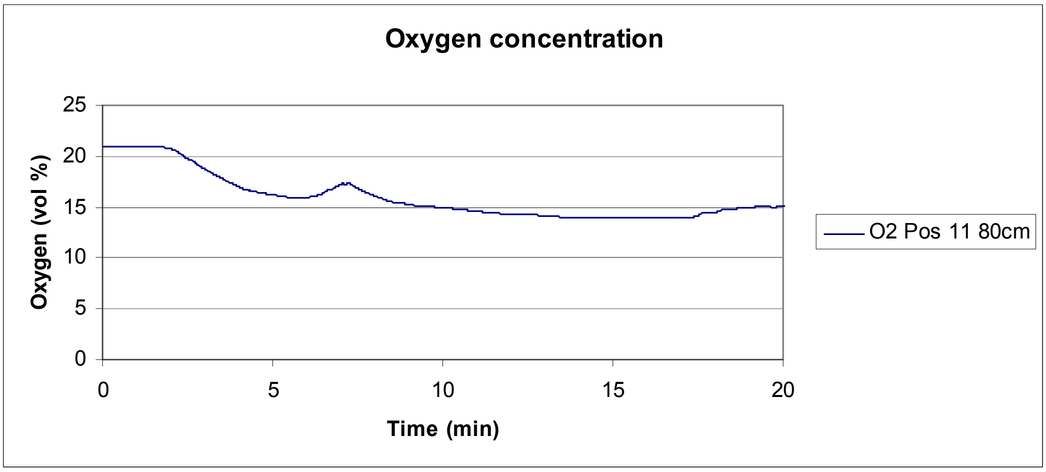

Figure A2.67 Oxygen concentration for Test 5.

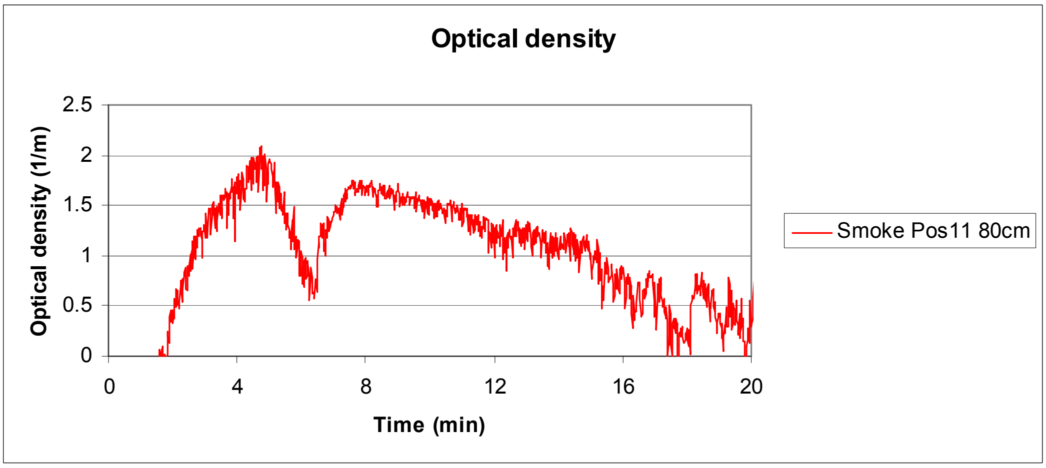

Figure A2.68 Optical density for Test 5.

Test 6

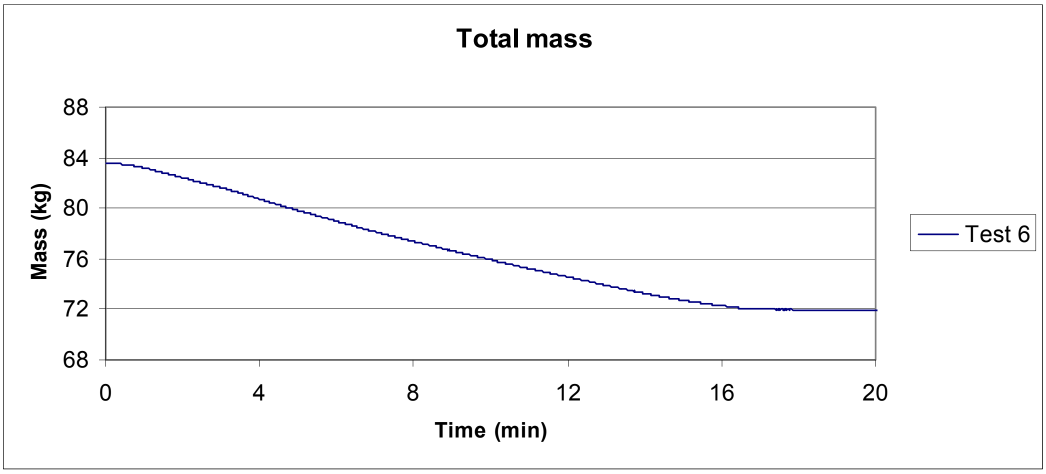

Figure A2.69 Total mass for Test 6.

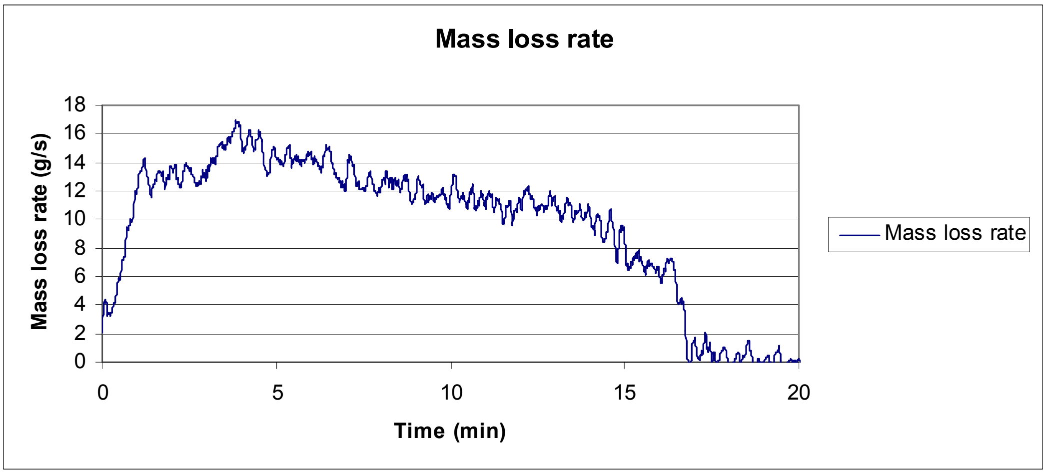

Figure A2.70 Mass loss rate for Test 6.

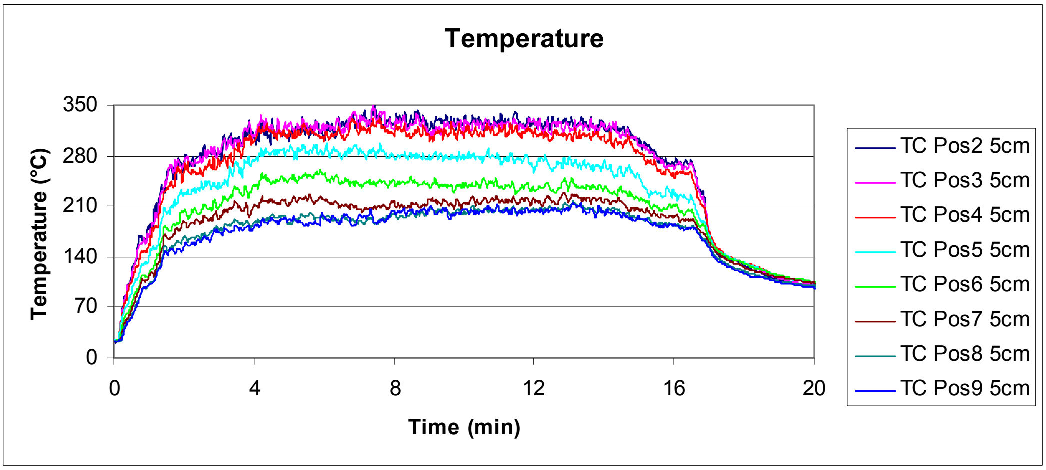

Figure A2.71 Temperature profiles for Test 6.

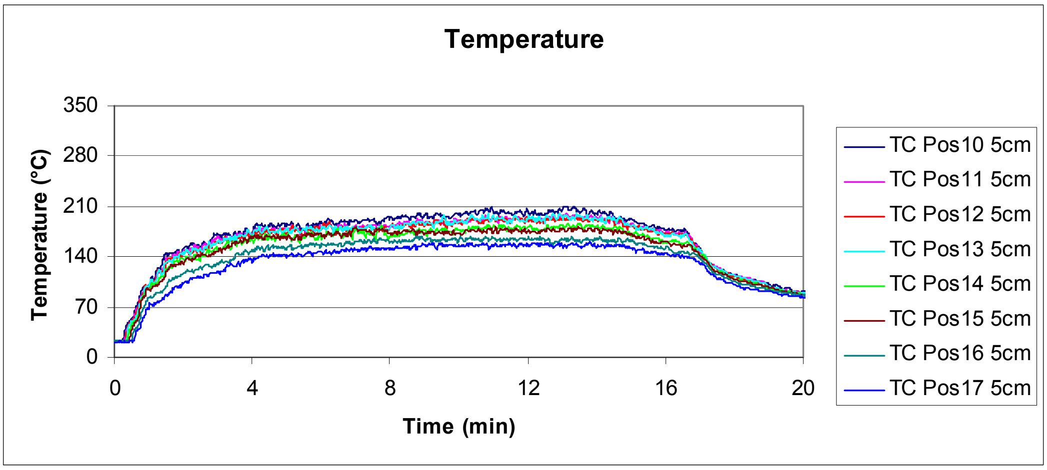

Figure A2.72 Temperature profiles for Test 6.

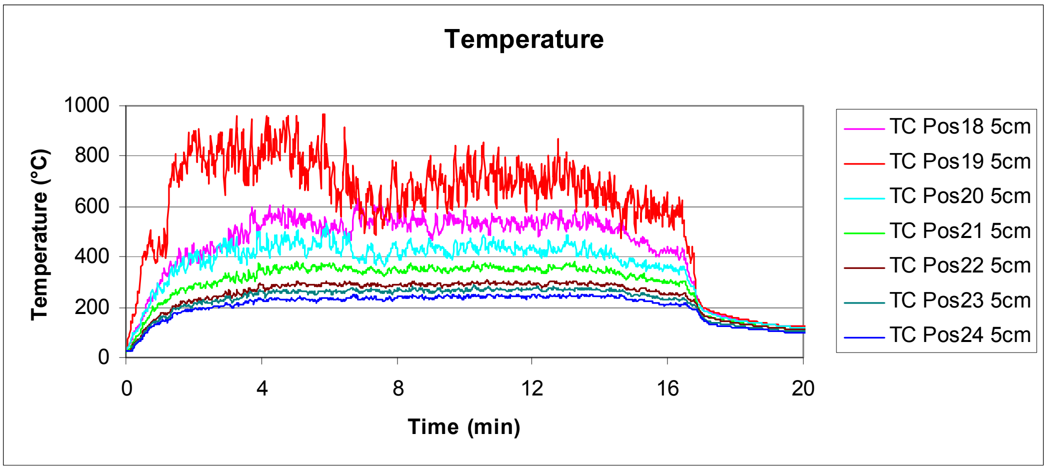

Figure A2.73 Temperature profiles for Test 6.

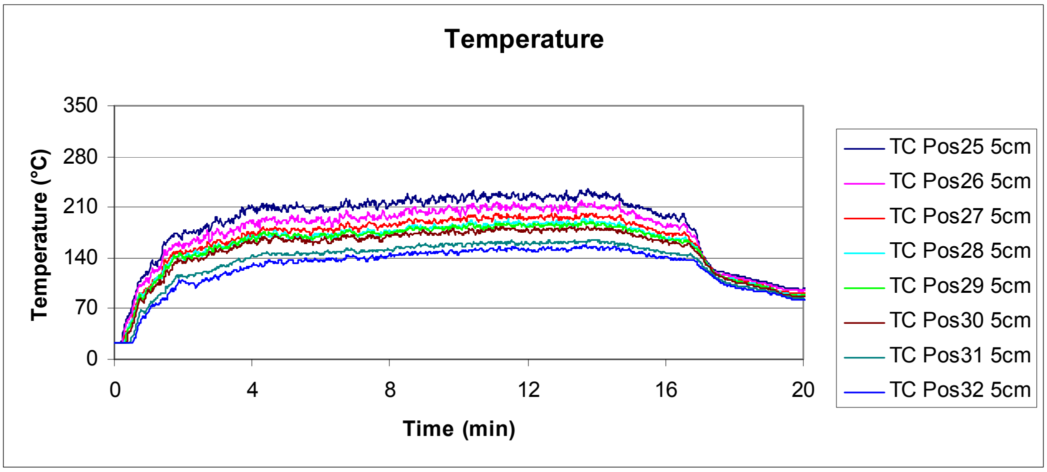

Figure A2.74 Temperature profiles for Test 6.

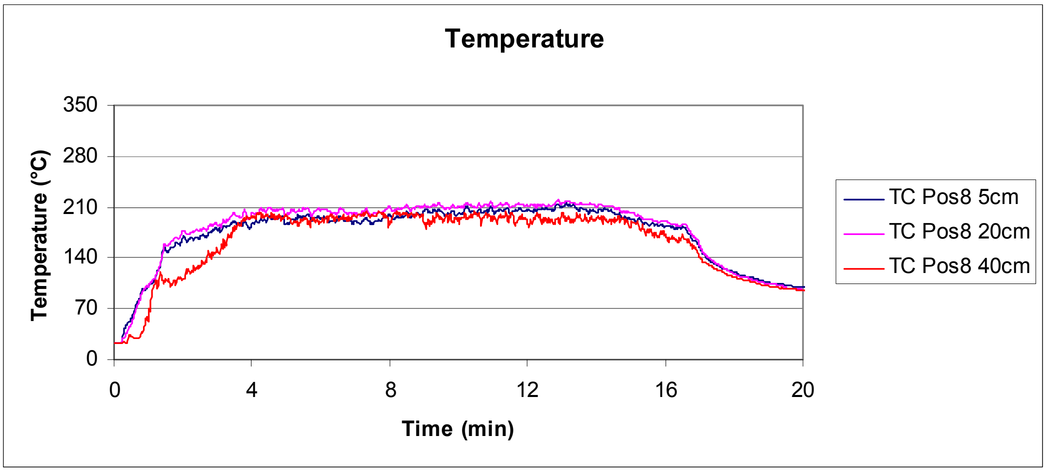

Figure A2.75 Temperature profiles Pos 8 for Test 6.

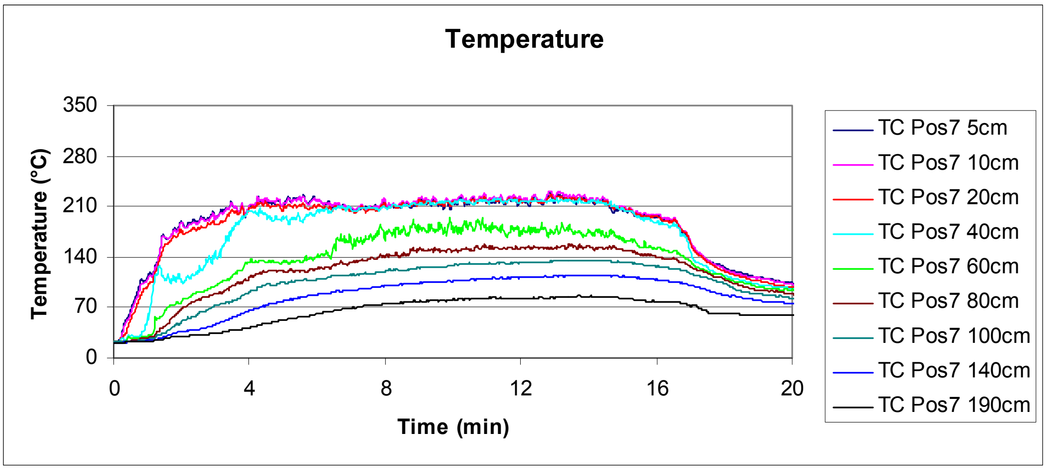

Figure A2.76 Temperature profiles Pos 7 for Test 6.

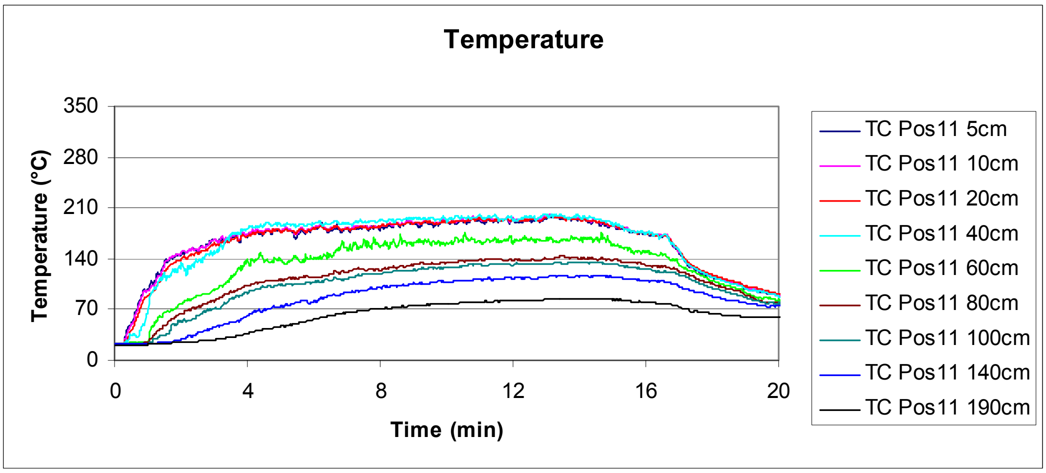

Figure A2.77 Temperature profiles Pos 11 for Test 6.

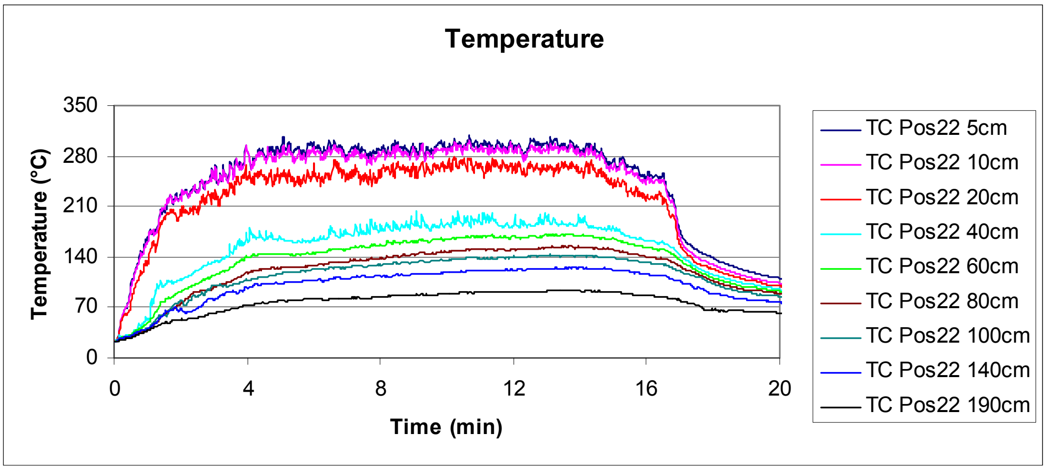

Figure A2.78 Temperature profiles Pos 22 for Test 6.

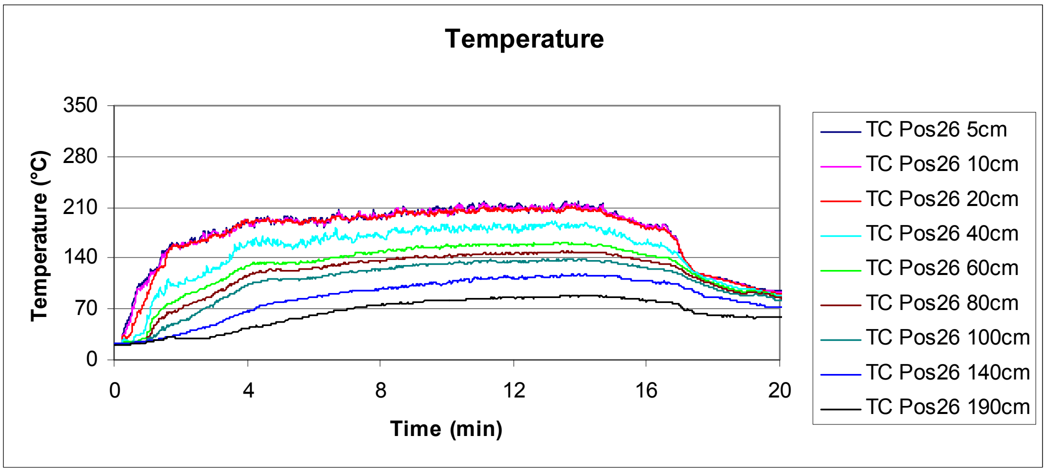

Figure A2.79 Temperature profiles Pos 26 for Test 6.

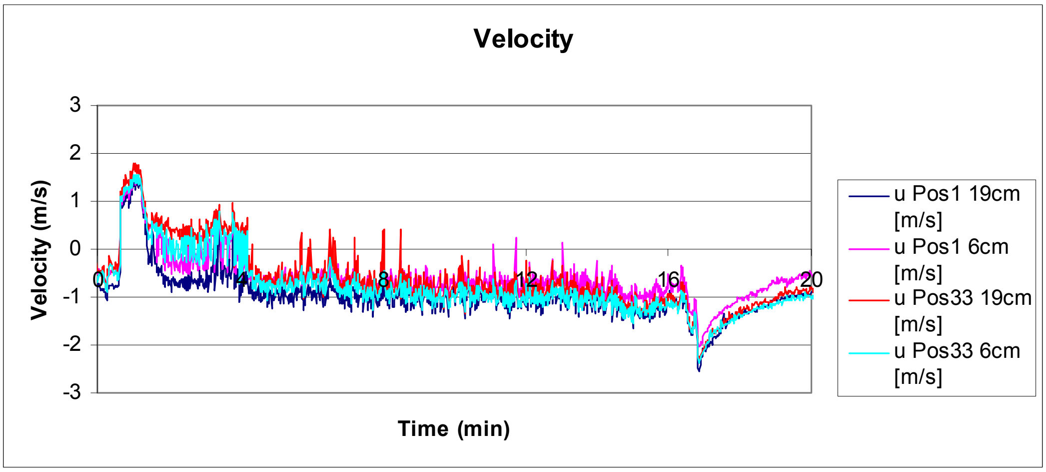

Figure A2.80 Velocity profiles for Test 6.

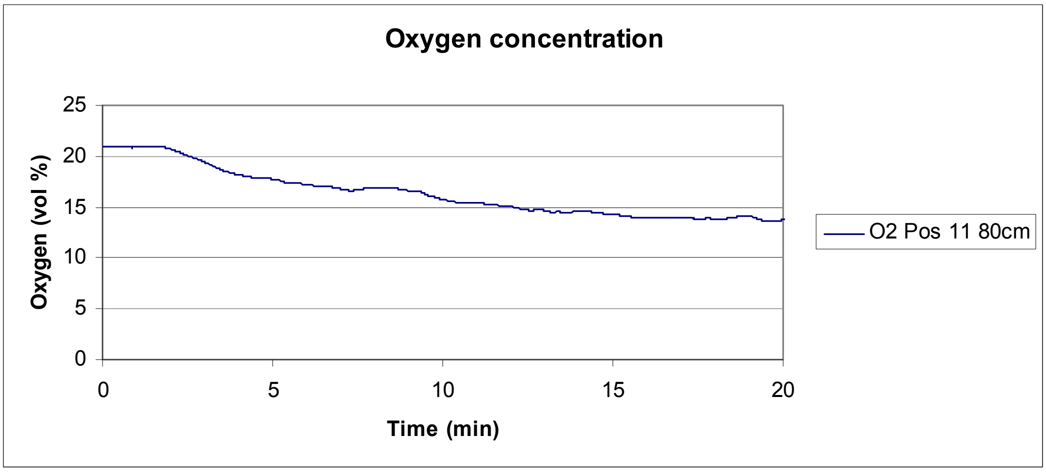

Figure A2.81 Oxygen concentration for Test 6.

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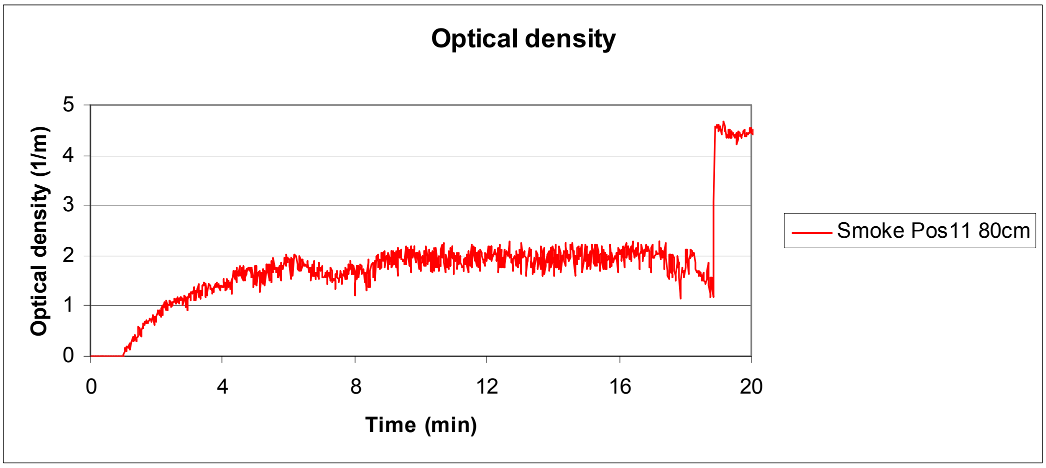

Figure A2.82 Optical density for Test 6.

Test 7

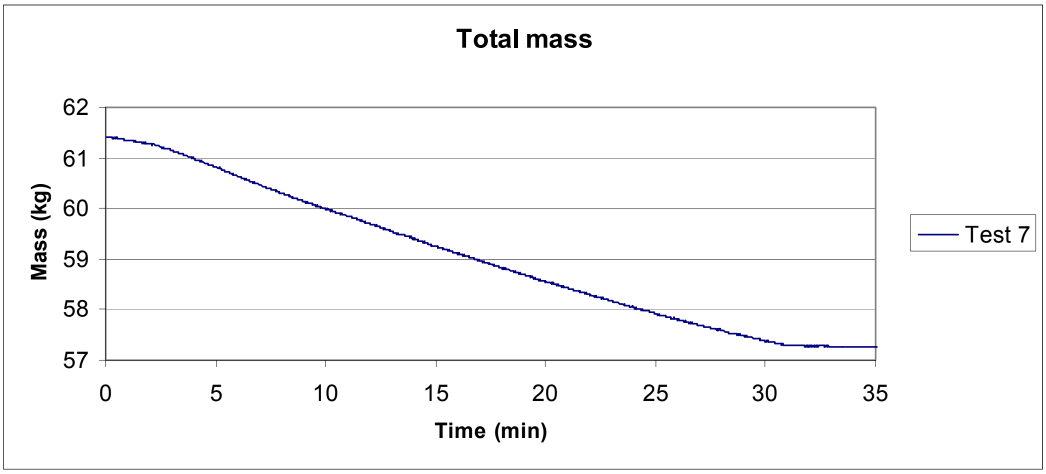

Figure A2.83 Total mass for Test 7.

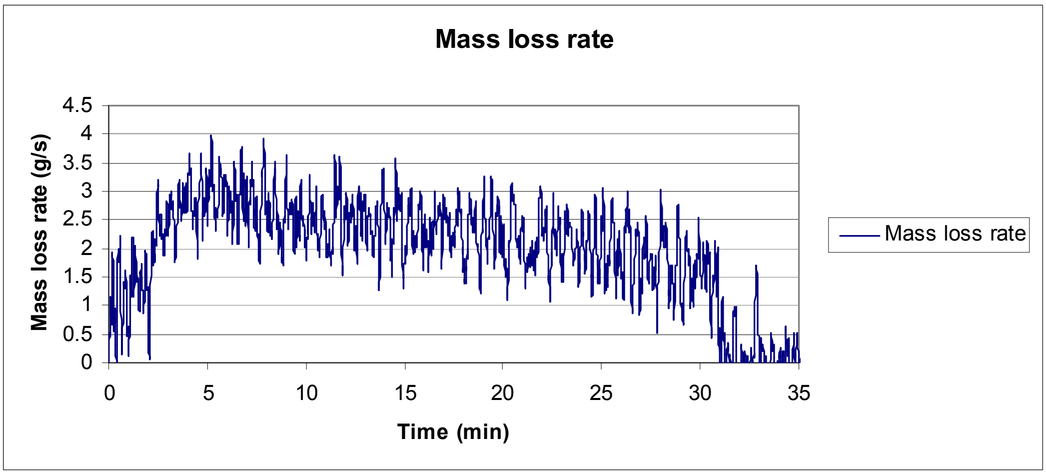

Figure A2.84 Mass loss rate for Test 7.

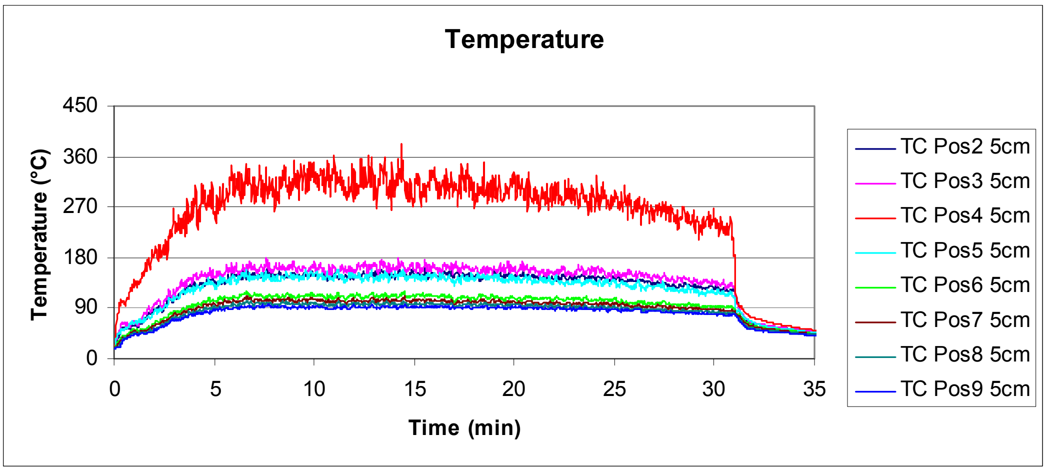

Figure A2.85 Temperature profiles for Test 7.

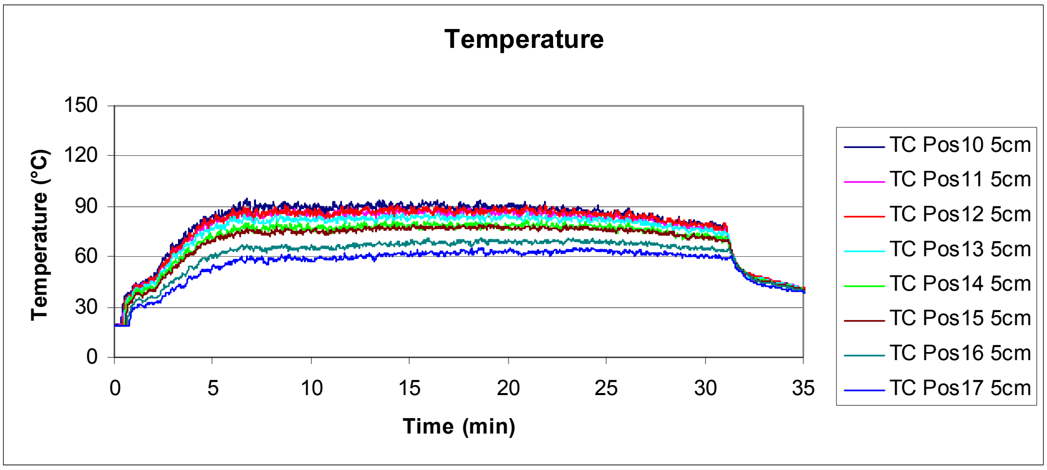

Figure A2.86 Temperature profiles for Test 7.

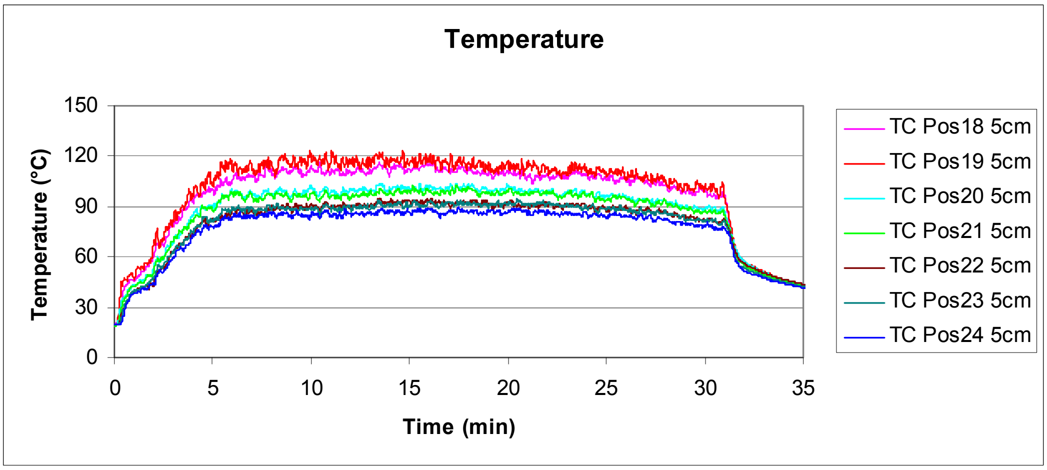

Figure A2.87 Temperature profiles for Test 7.

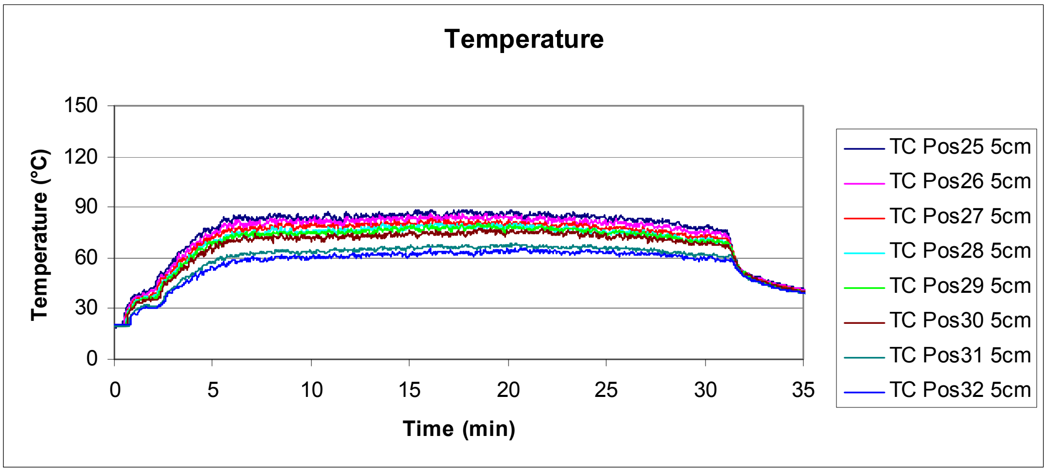

Figure A2.88 Temperature profiles for Test 7.

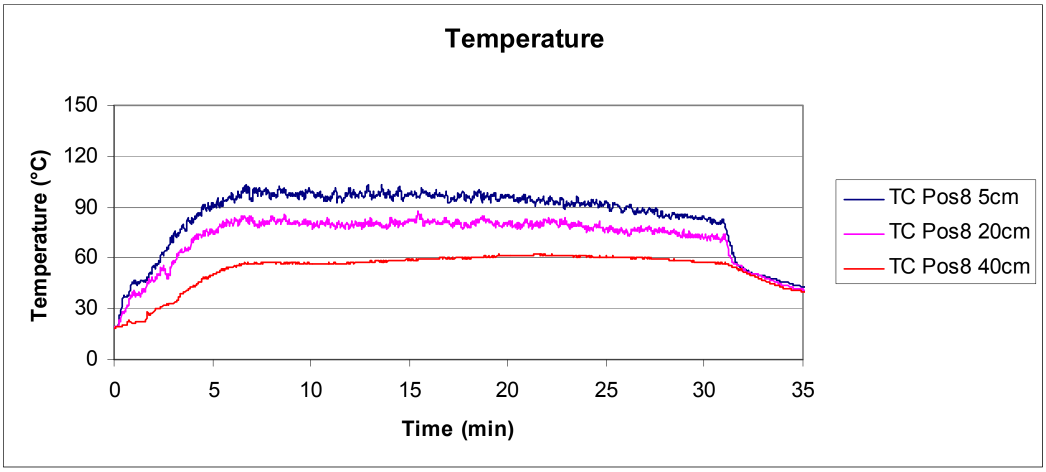

Figure A2.89 Temperature profiles Pos 8 for Test 7.

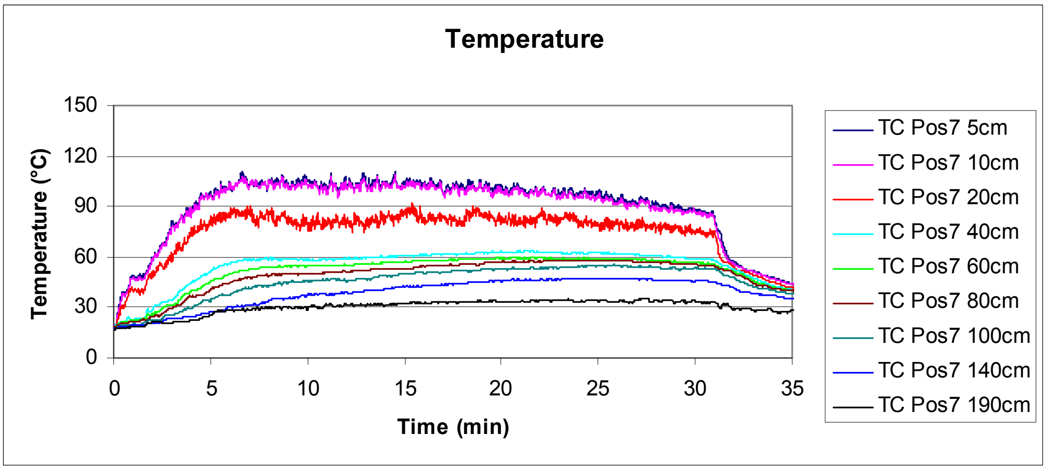

Figure A2.90 Temperature profiles Pos 7 for Test 7.

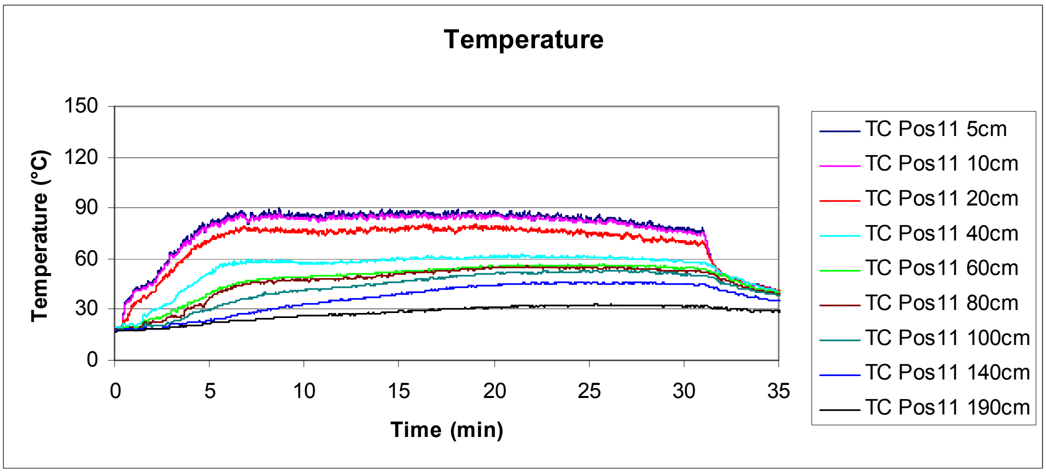

Figure A2.91 Temperature profiles Pos 11 for Test 7.

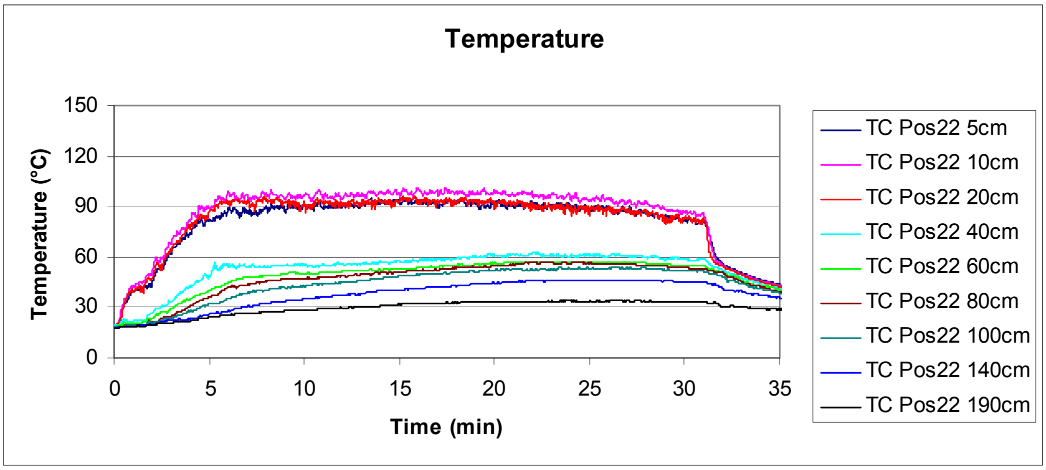

Figure A2.92 Temperature profiles Pos 22 for Test 7.

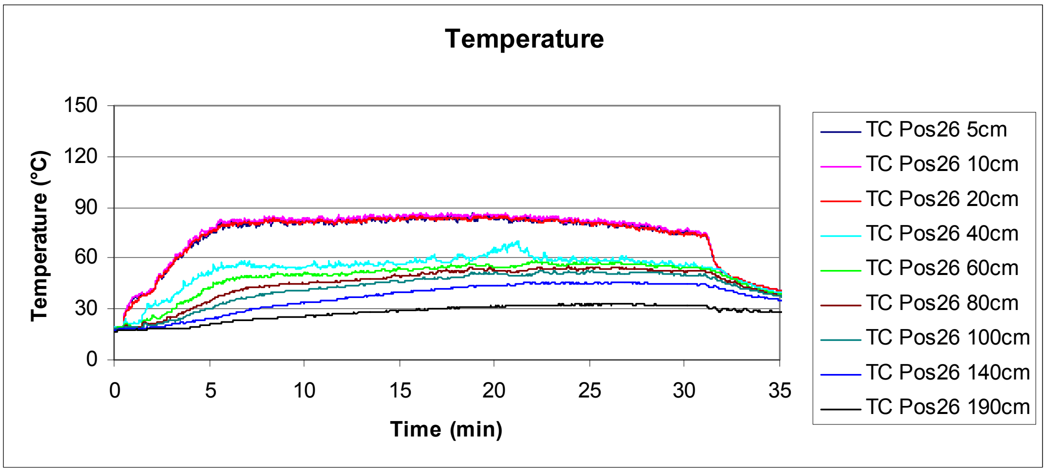

Figure A2.93 Temperature profiles Pos 26 for Test 7.

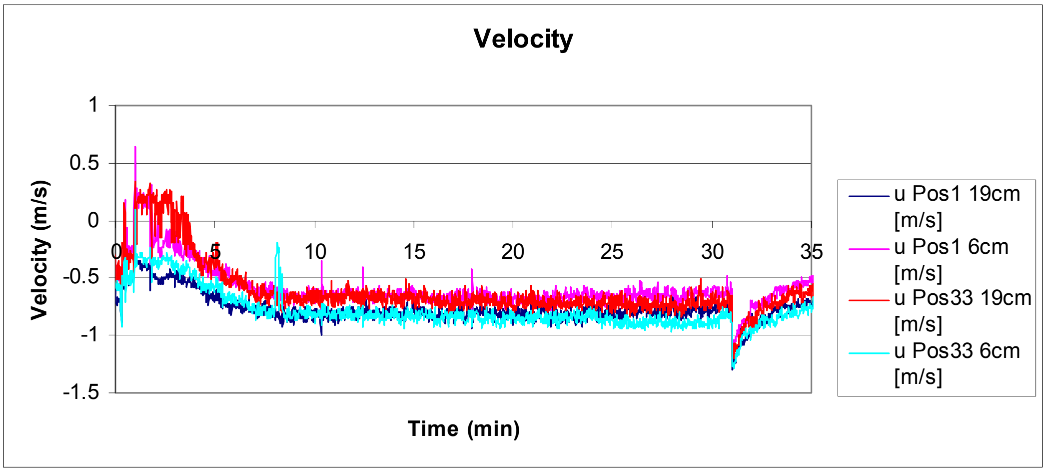

Figure A2.94 Velocity profiles for Test 7.

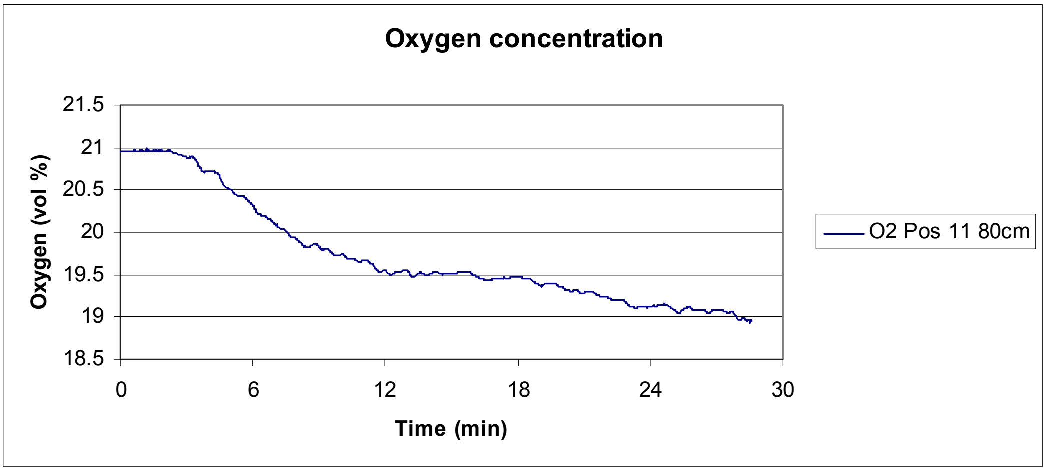

Figure A2.95 Oxygen concentration for Test 7.

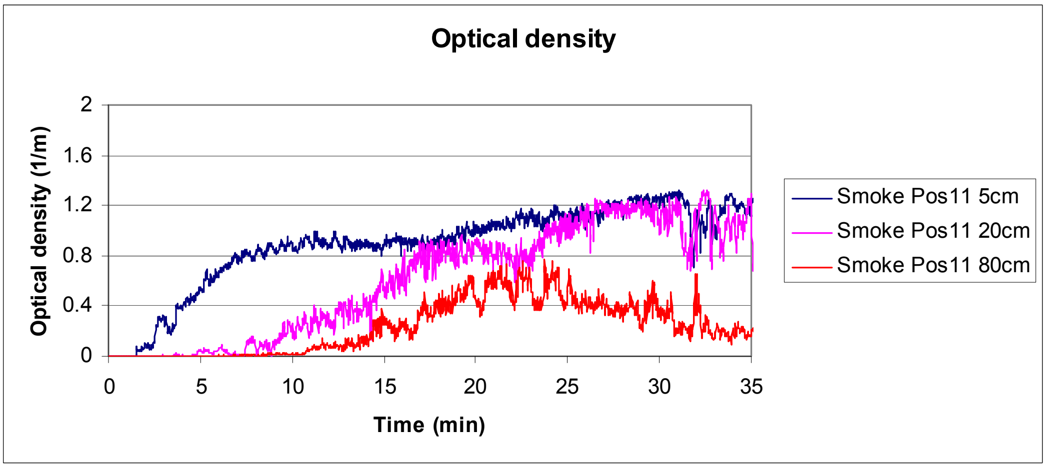

Figure A2.96 Optical density for Test 7.

Test 8

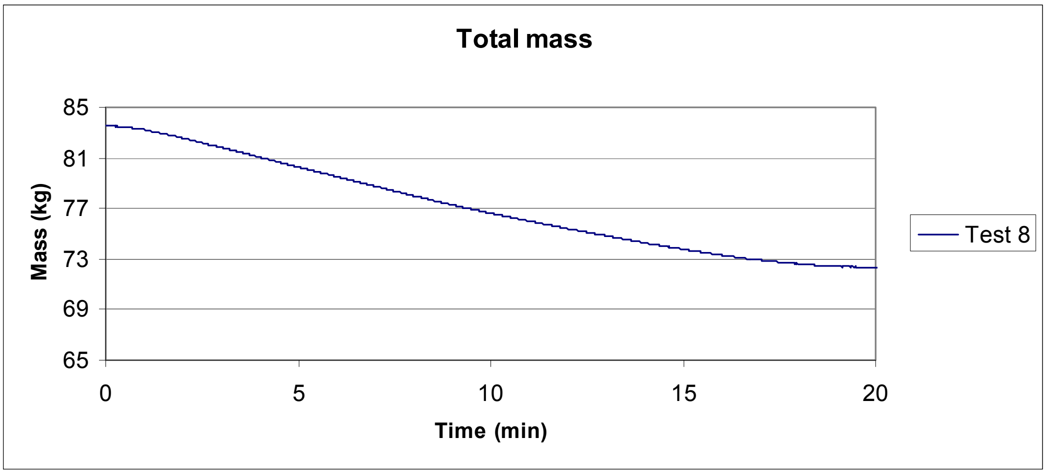

Figure A2.97   Total mass for Test 8.

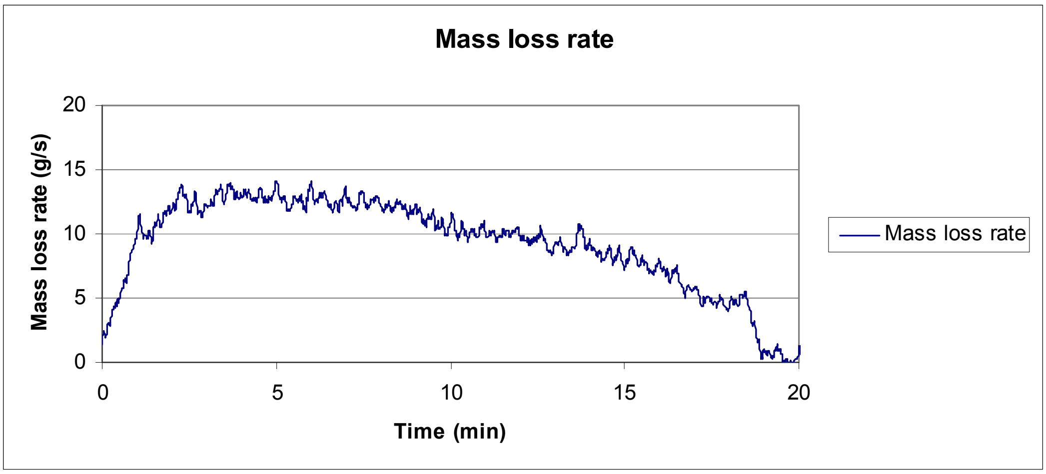

Figure A2.98   Mass loss rate for Test 8.

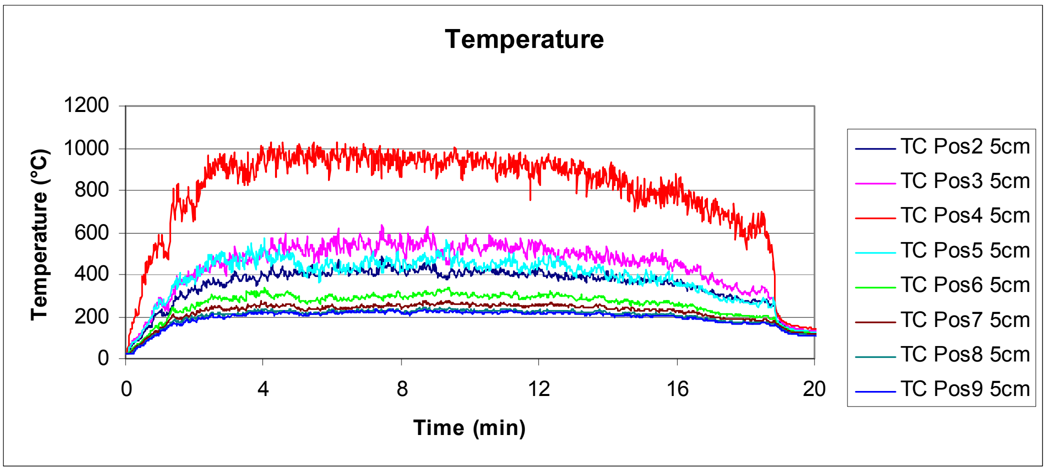

Figure A2.99   Temperature profiles for Test 8.

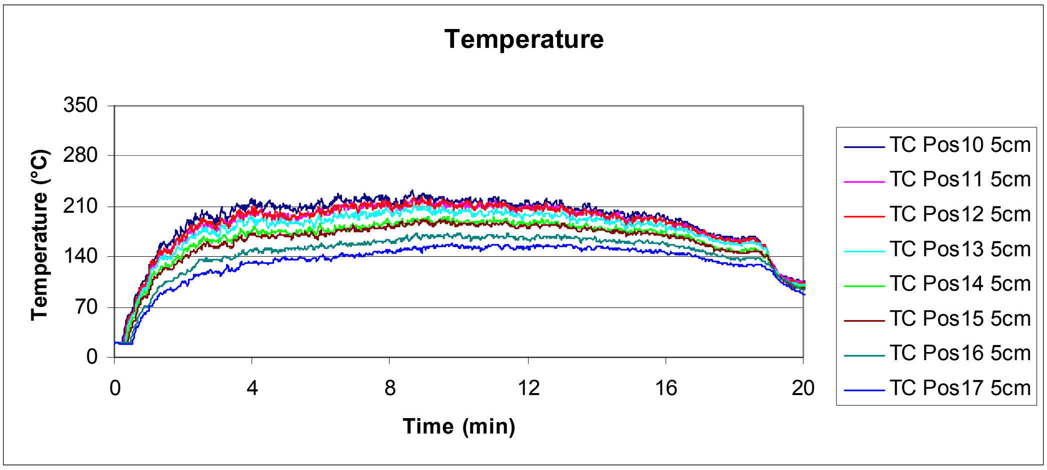

Figure A2.100 Temperature profiles for Test 8.

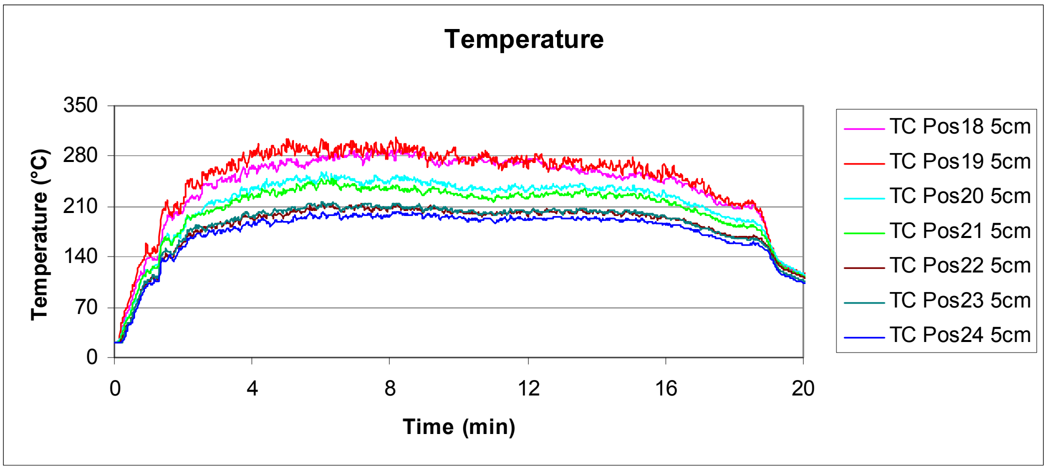

Figure A2.101 Temperature profiles for Test 8.

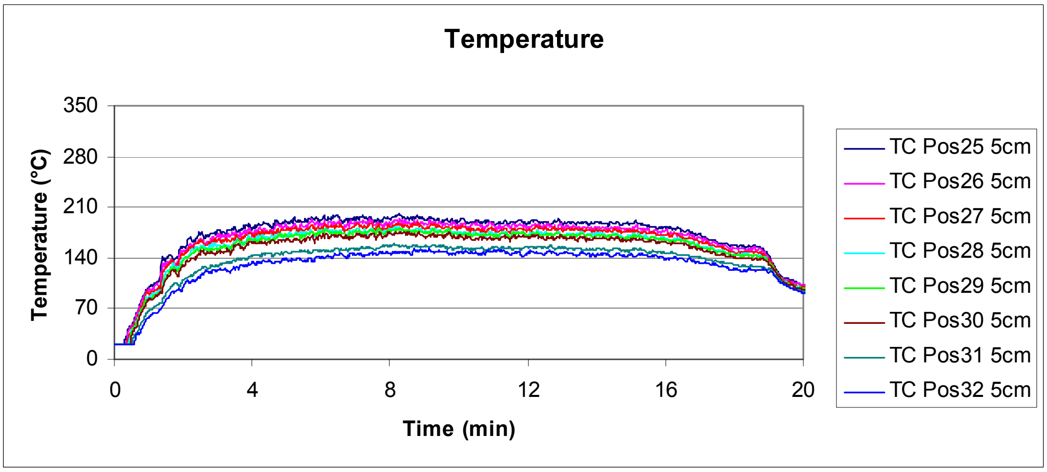

Figure A2.102 Temperature profiles for Test 8.

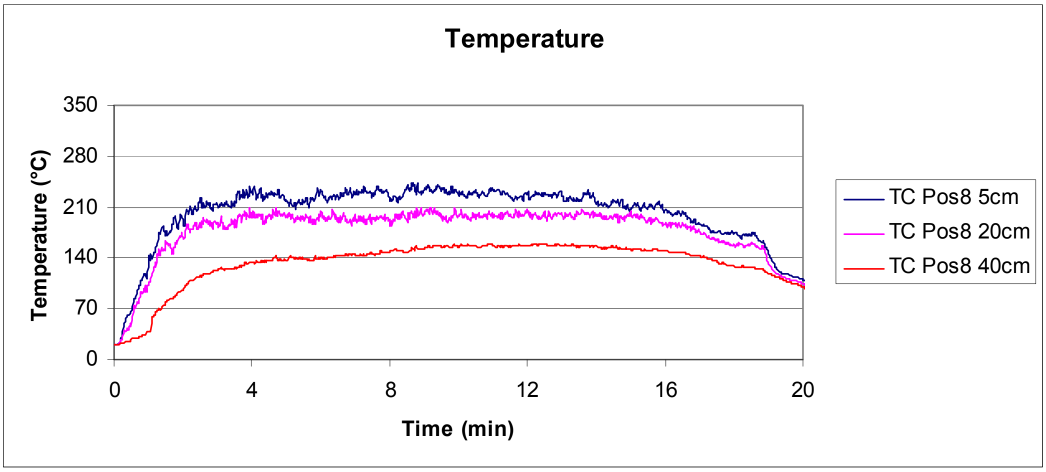

Figure A2.103 Temperature profiles Pos 8 for Test 8.

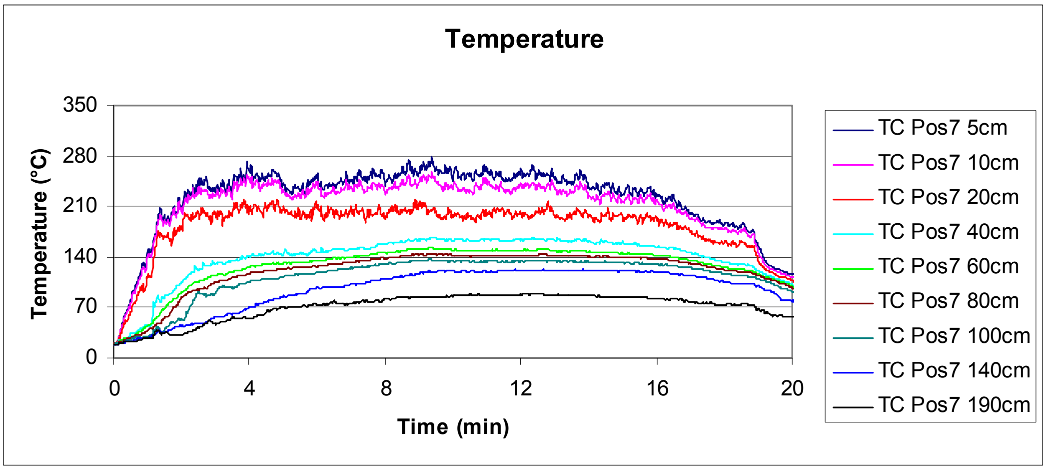

Figure A2.104 Temperature profiles Pos 7 for Test 8.

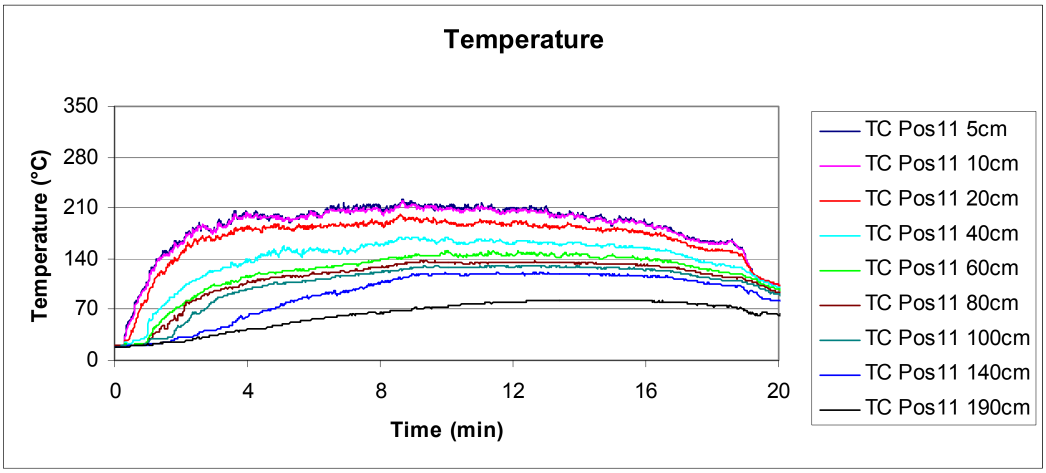

Figure A2.105 Temperature profiles Pos 11 for Test 8.

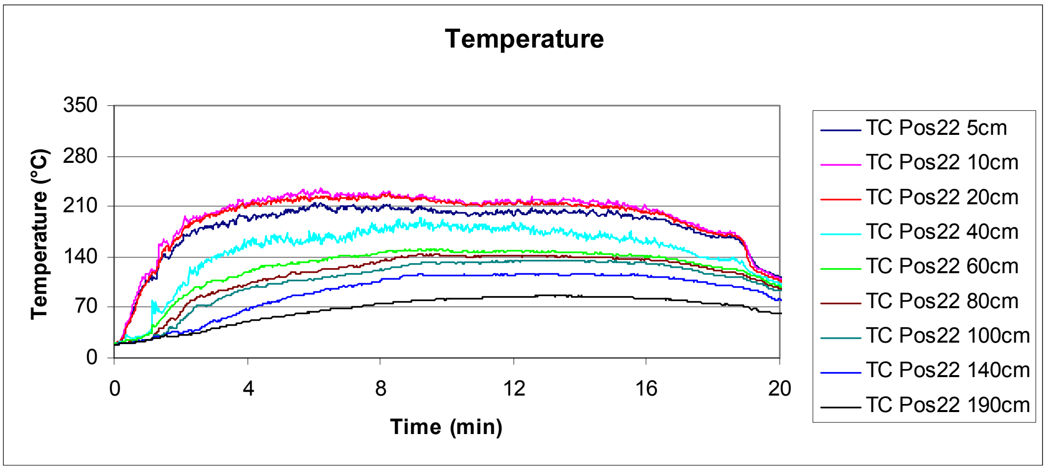

Figure A2.106 Temperature profiles Pos 22 for Test 8.

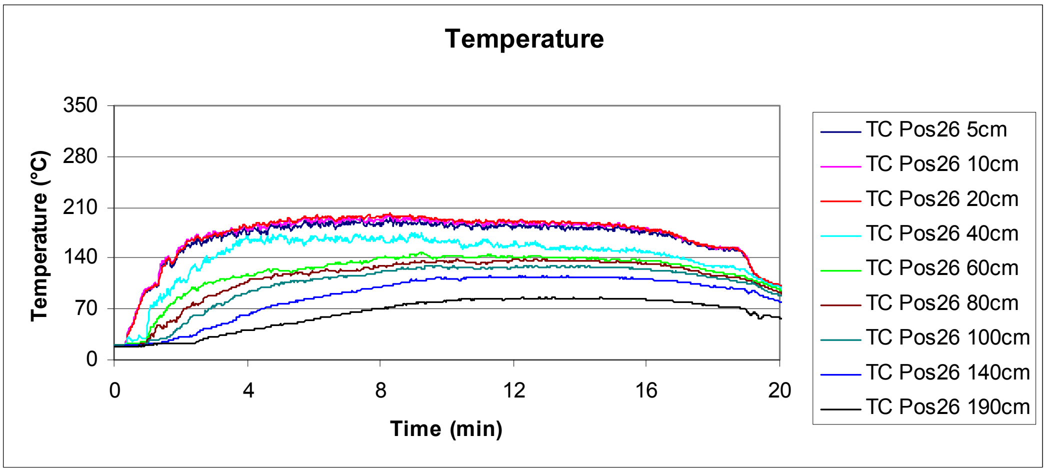

Figure A2.107 Temperature profiles Pos 26 for Test 8.

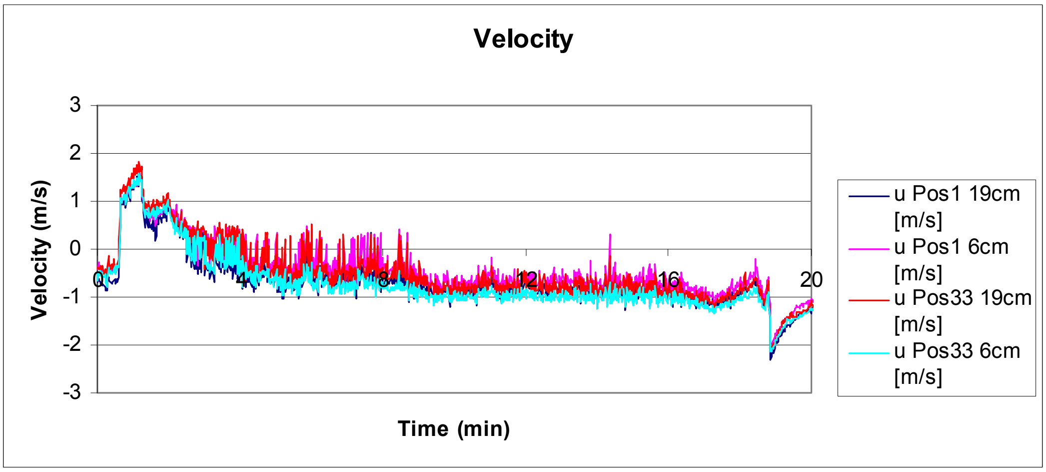

Figure A2.108 Velocity profiles for Test 8.

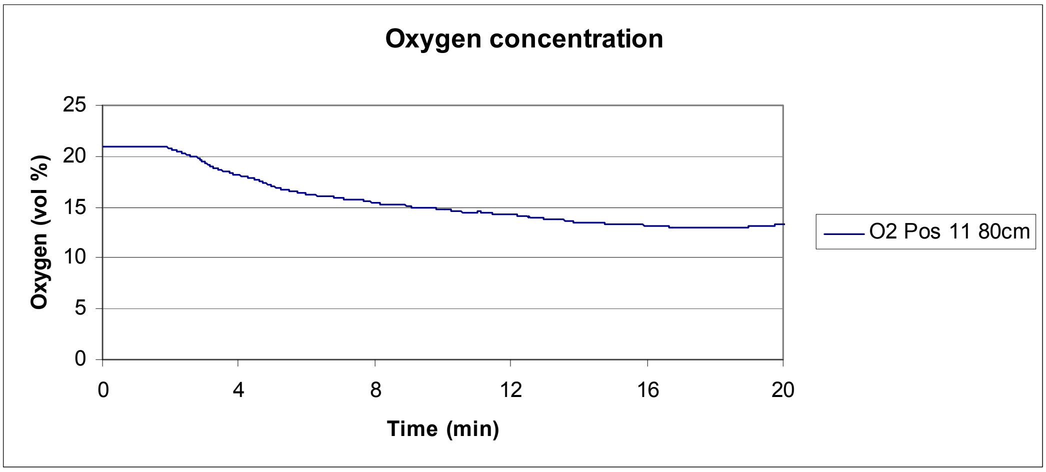

Figure A2.109 Oxygen concentration for Test 8.

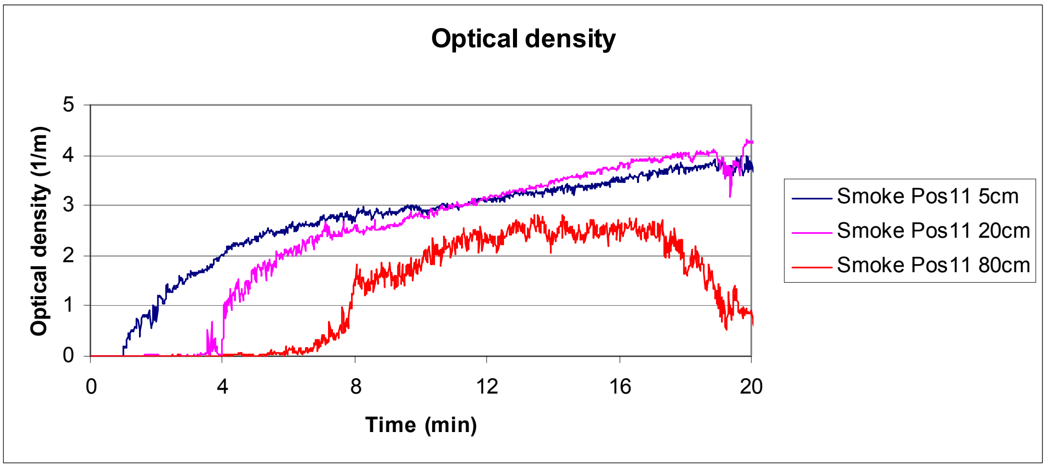

Figure A2.110 Optical density for Test 8.

Test 9

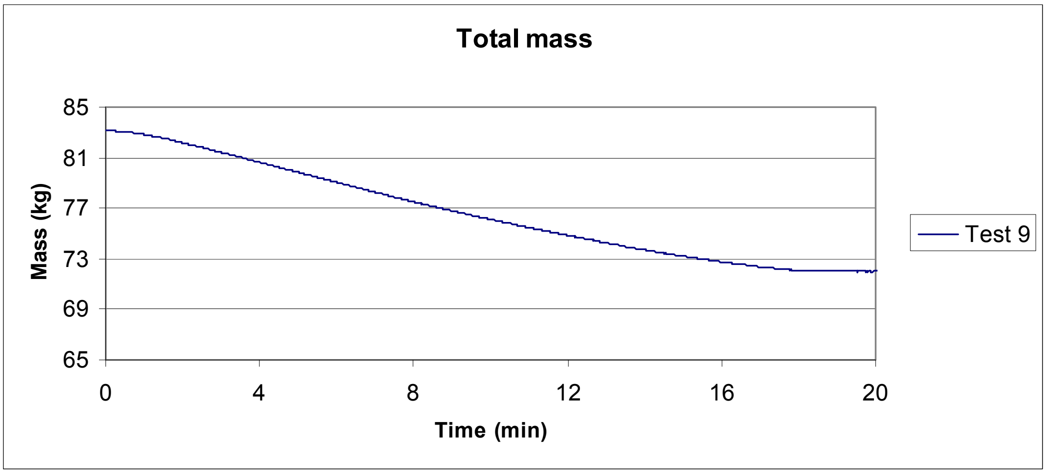

Figure A2.111 Total mass for Test 9.

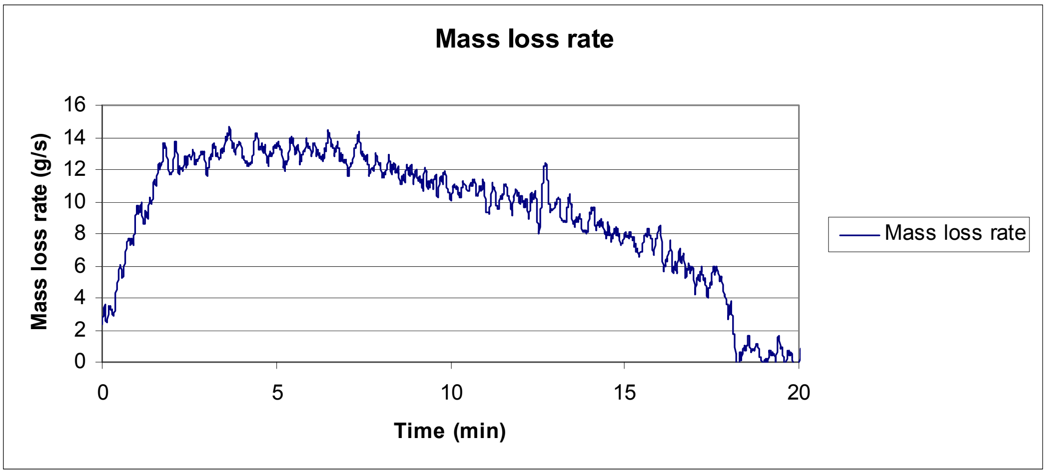

Figure A2.112 Mass loss rate for Test 9.

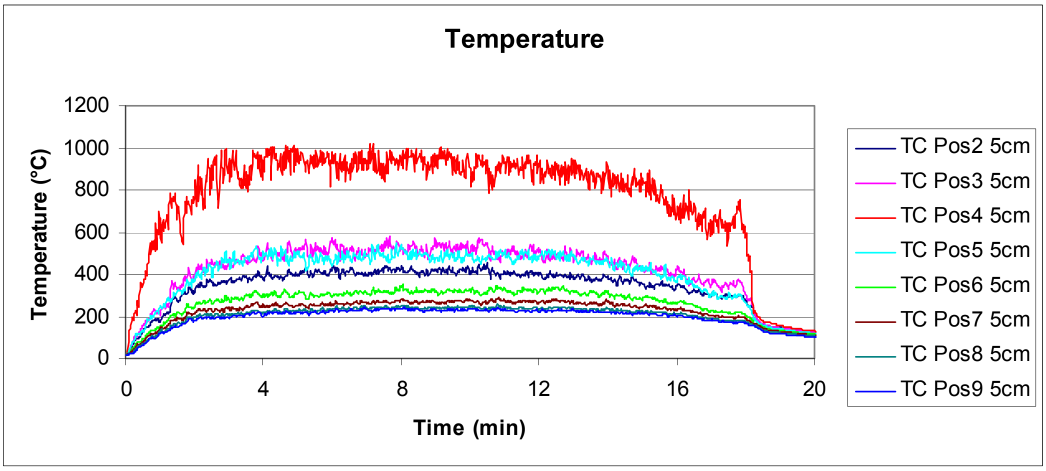

Figure A2.113 Temperature profiles for Test 9.

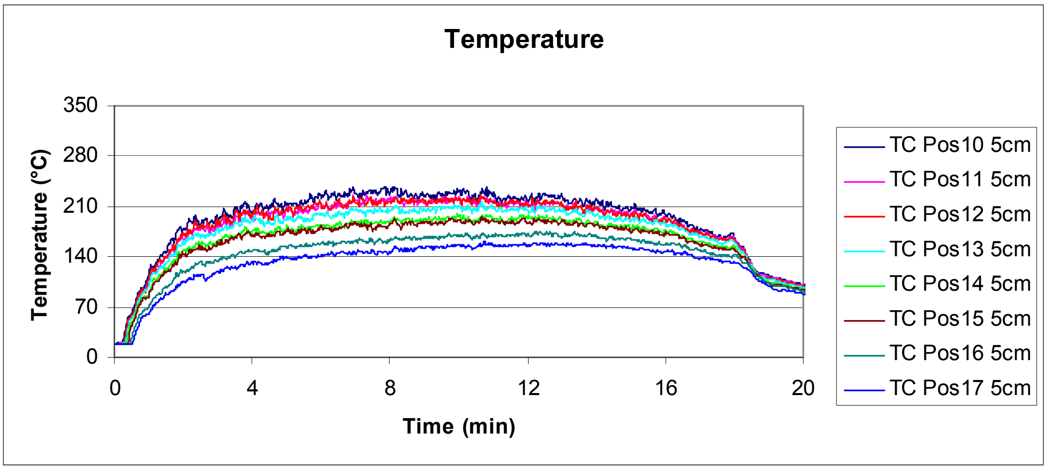

Figure A2.114 Temperature profiles for Test 9.

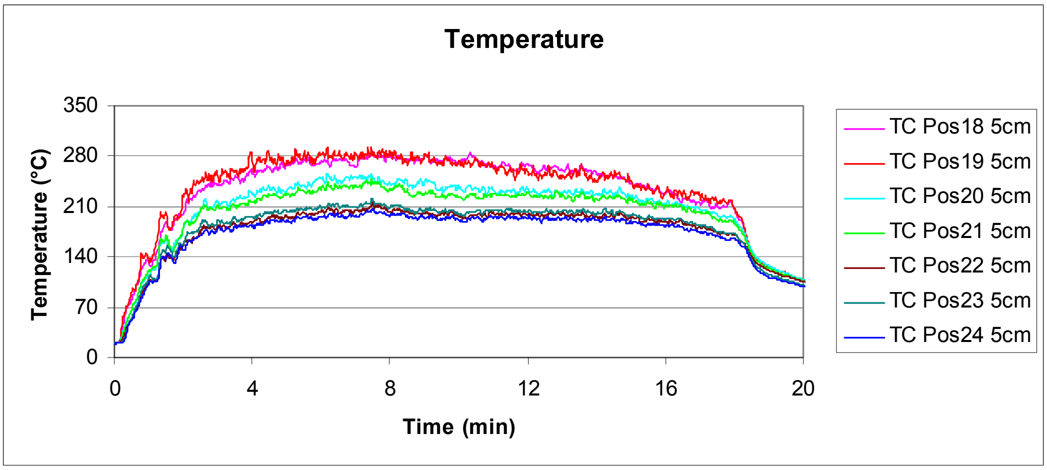

Figure A2.115 Temperature profiles for Test 9.

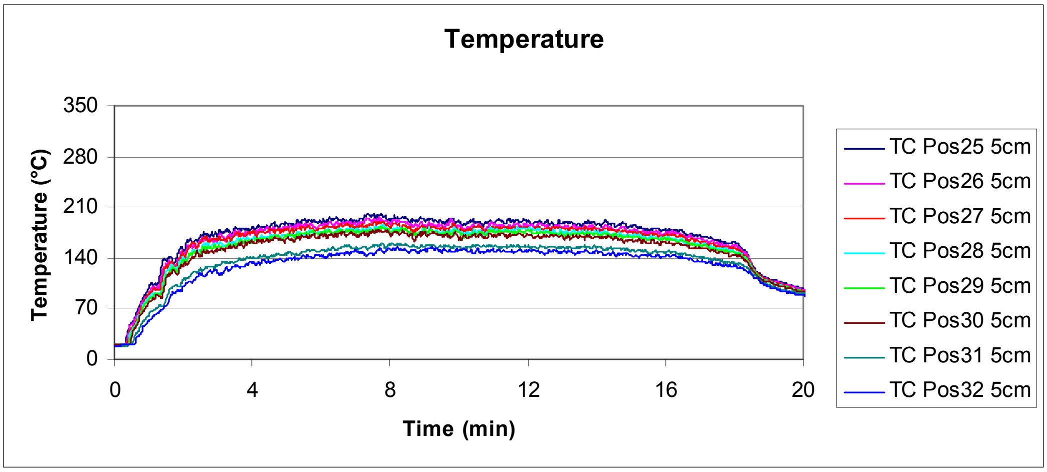

Figure A2.116 Temperature profiles for Test 9.

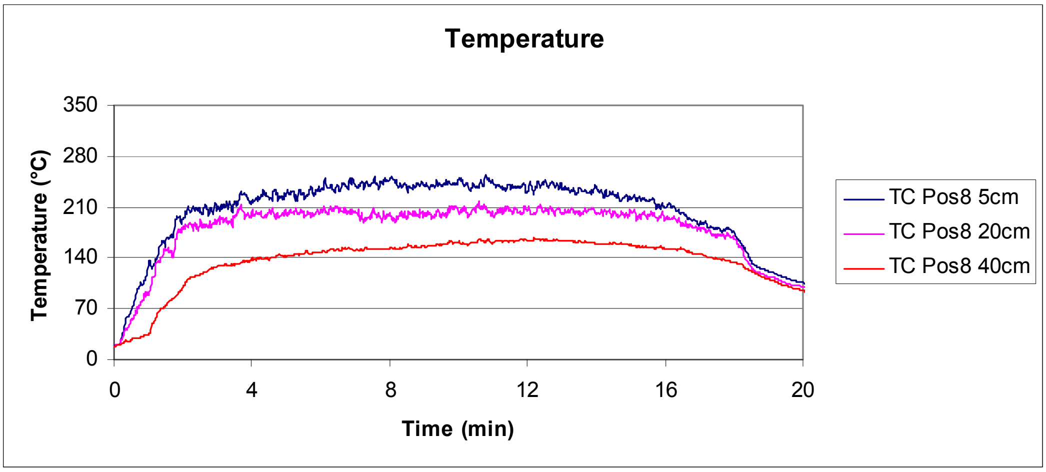

Figure A2.117   Temperature profiles Pos 8 for Test 9.

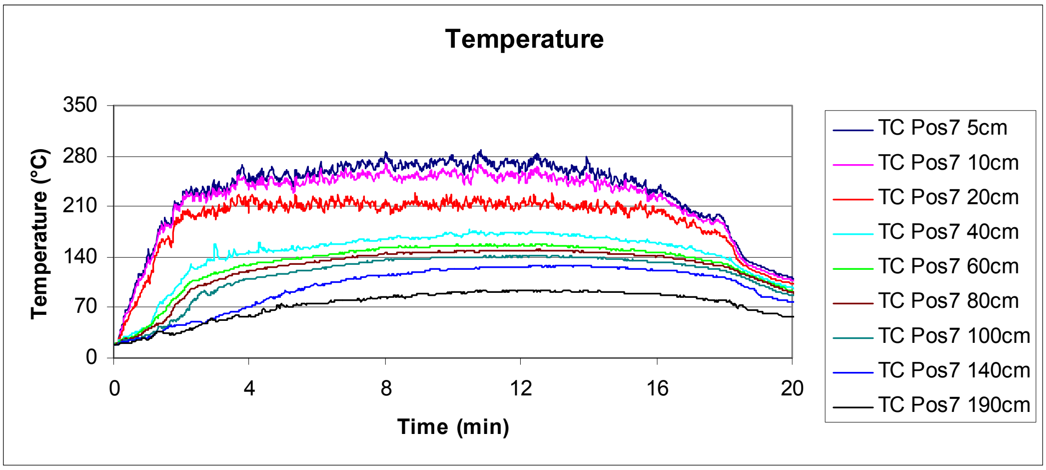

Figure A2.118   Temperature profiles Pos 7 for Test 9.

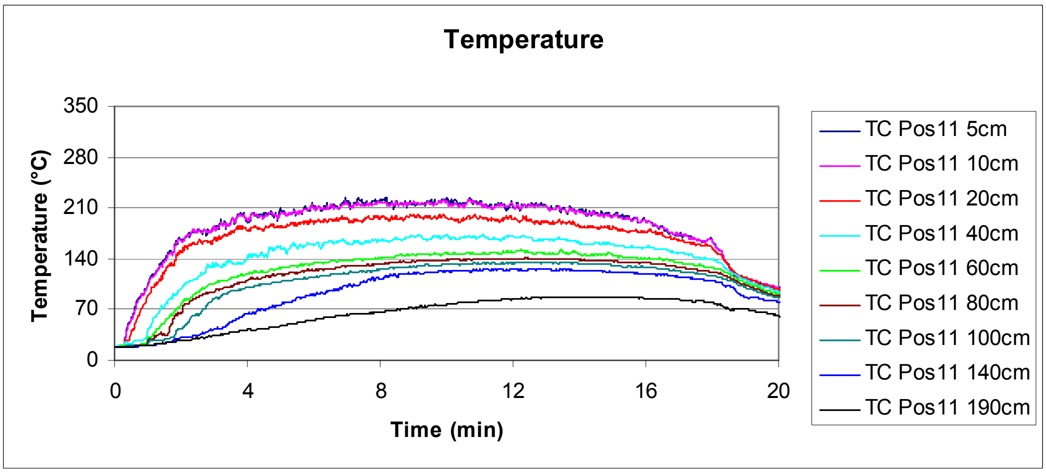

Figure A2.119   Temperature profiles Pos 11 for Test 9.

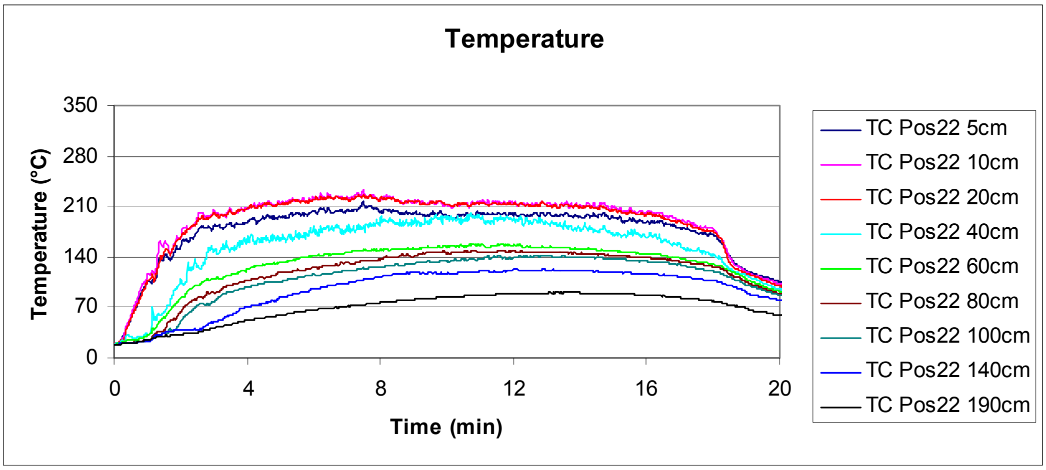

Figure A2.120 Temperature profiles Pos 22 for Test 9.

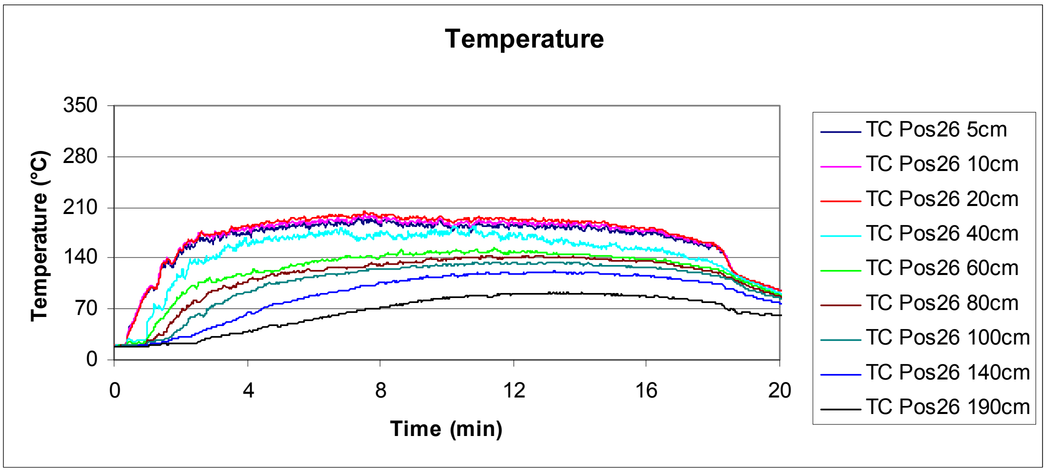

Figure A2.121 Temperature profiles Pos 26 for Test 9.

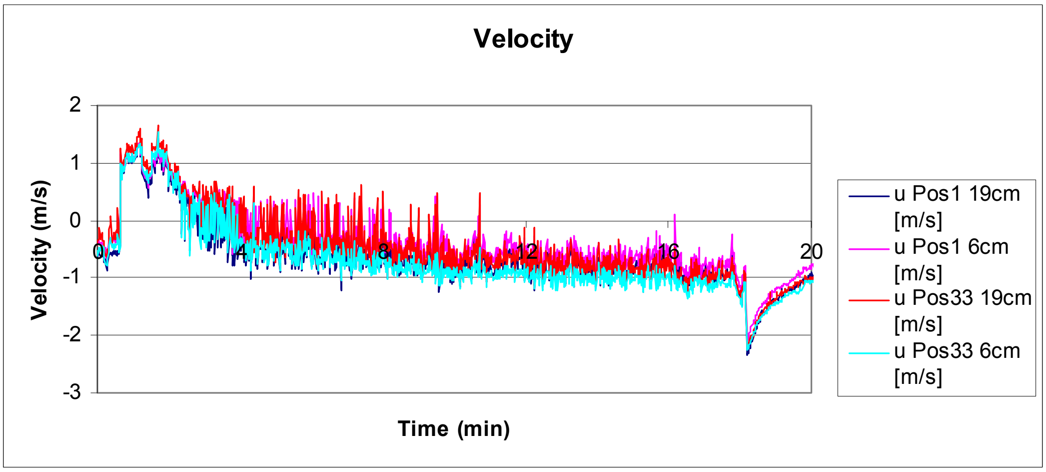

Figure A2.122 Velocity profiles for Test 9.

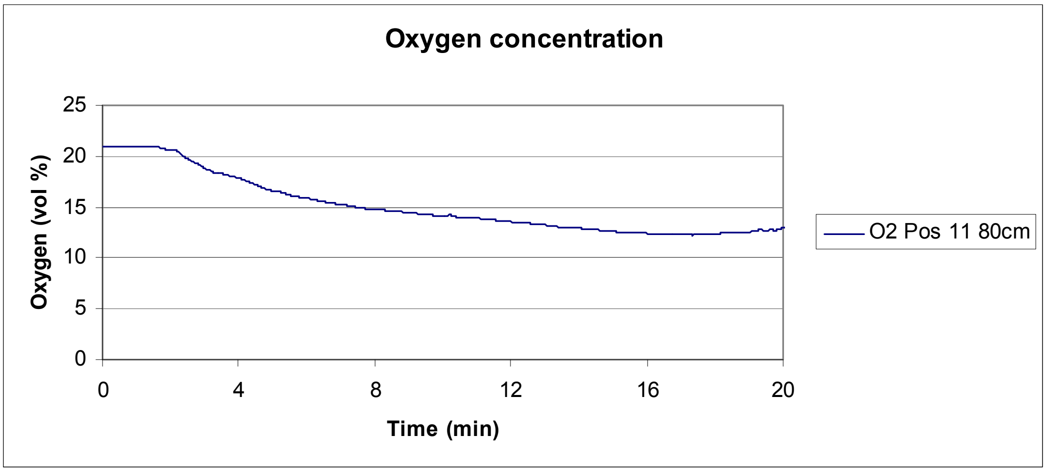

Figure A2.123 Oxygen concentration for Test 9.

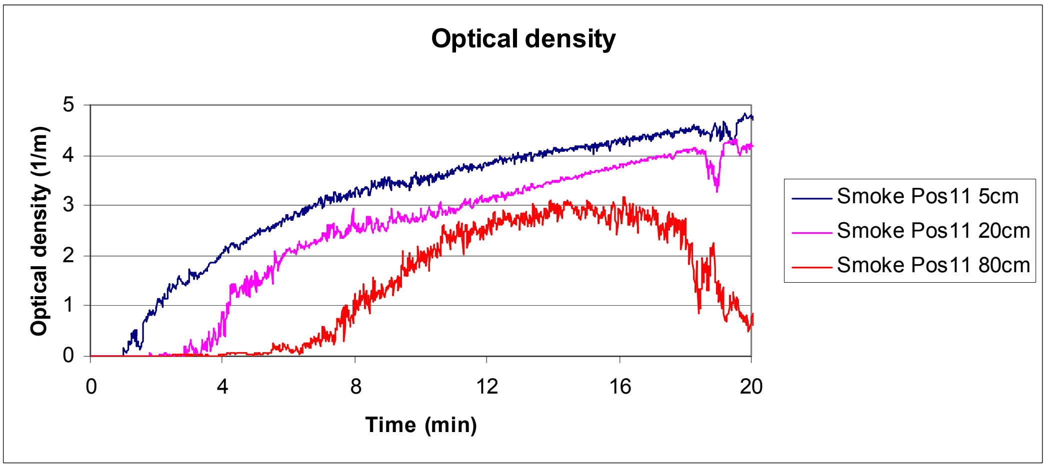

Figure A2.124 Optical density for Test 9.

Test 10

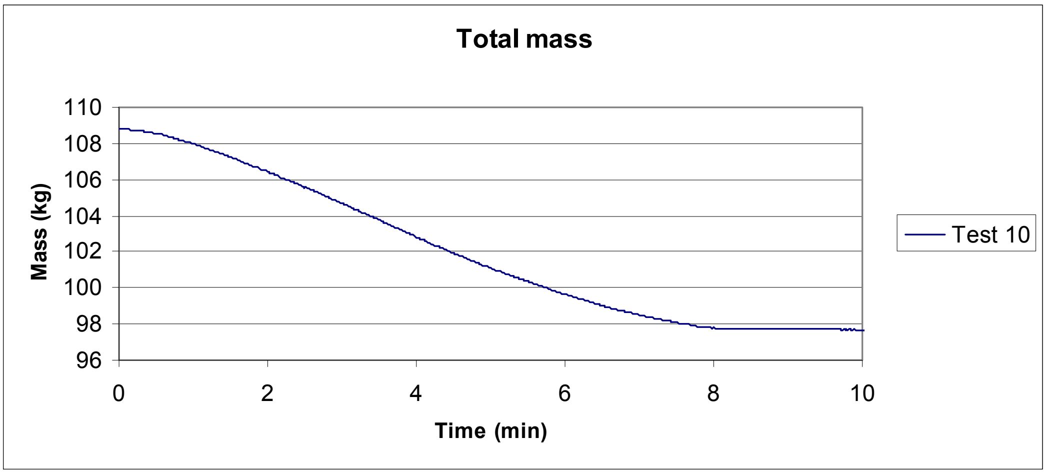

Figure A2.125 Total mass for Test 10.

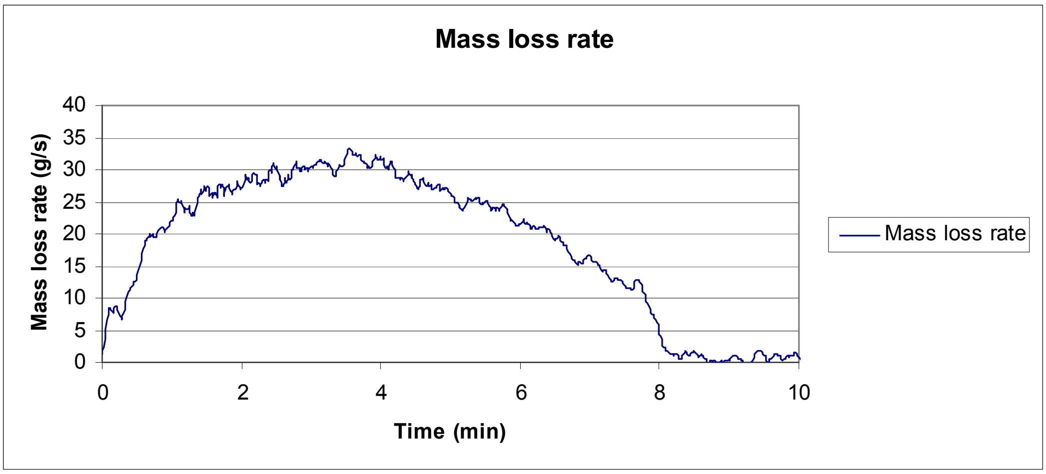

Figure A2.126 Mass loss rate for Test 10.

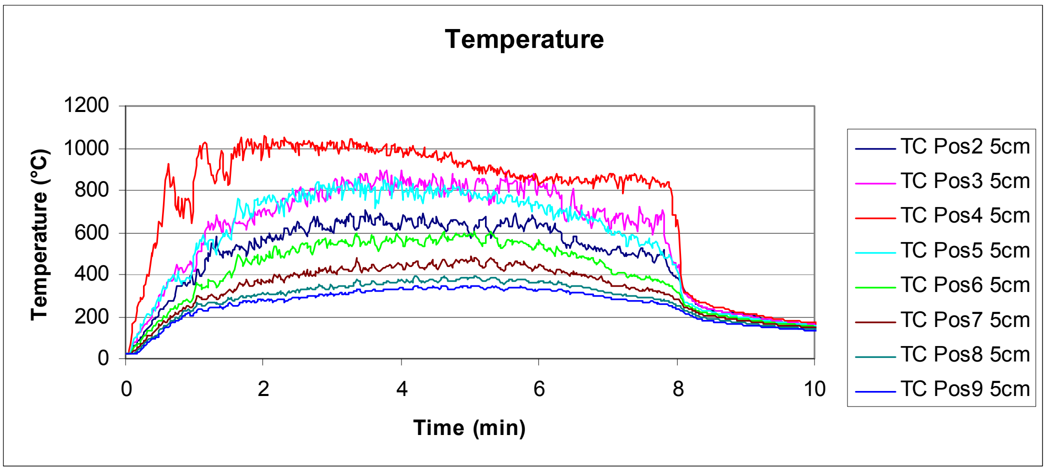

Figure A2.127 Temperature profiles for Test 10.

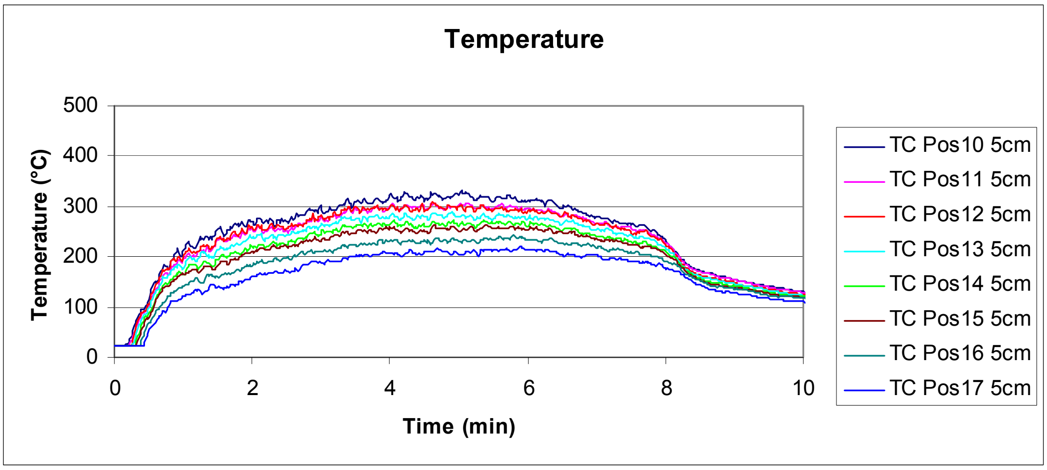

Figure A2.128 Temperature profiles for Test 10.

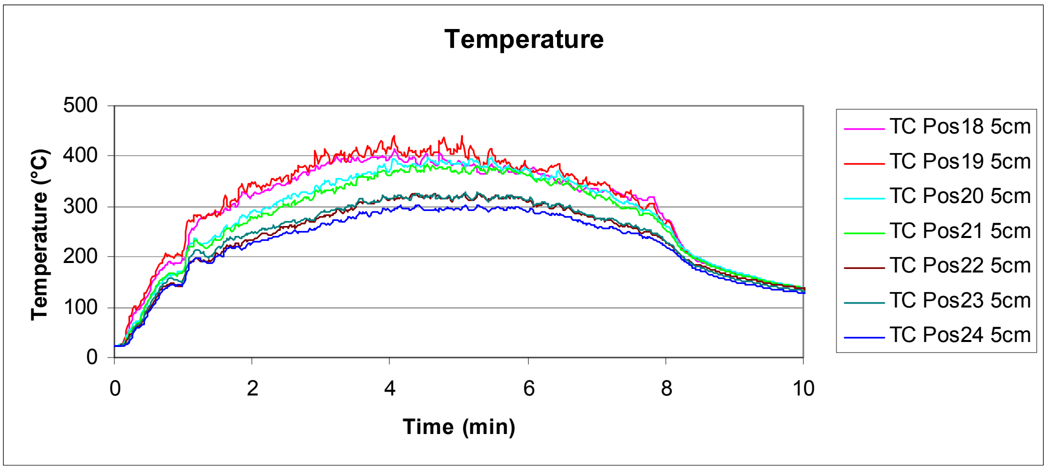

Figure A2.129 Temperature profiles for Test 10.

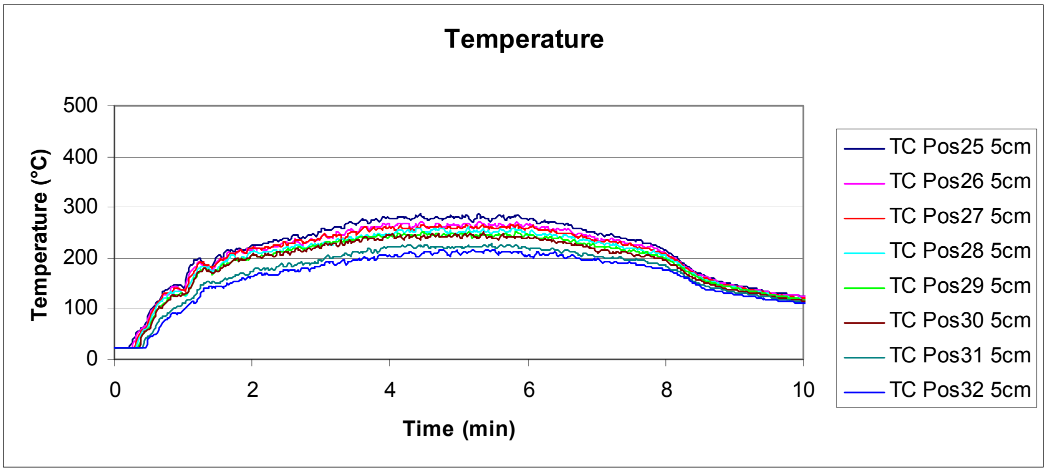

Figure A2.130 Temperature profiles for Test 10.

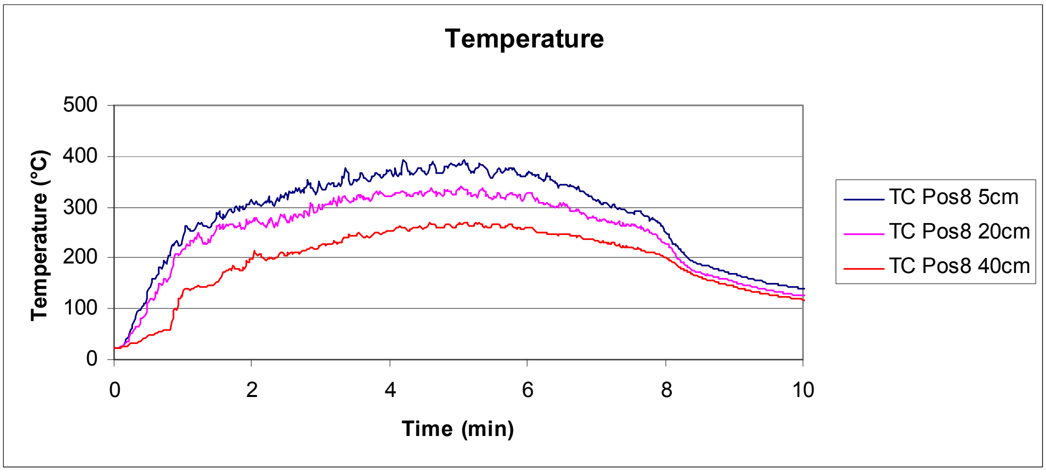

Figure A2.131 Temperature profiles Pos 8 for Test 10.

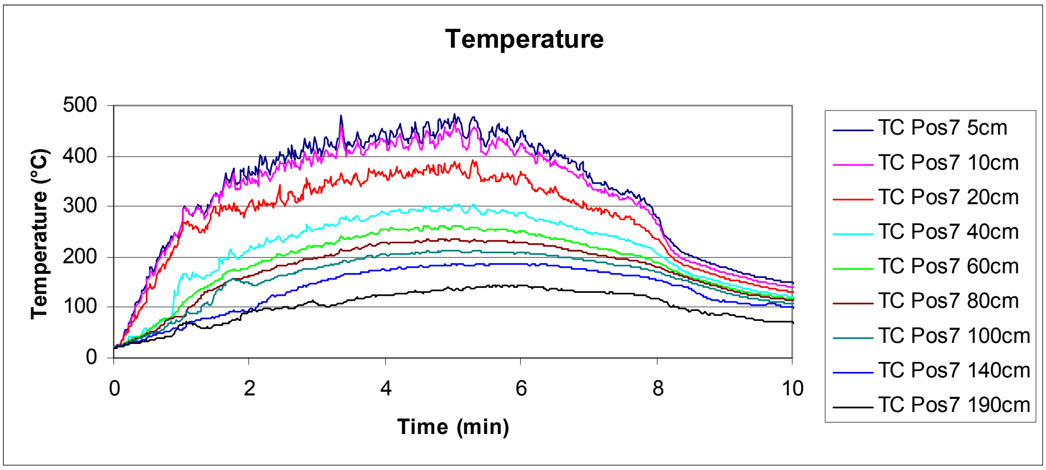

Figure A2.132 Temperature profiles Pos 7 for Test 10.

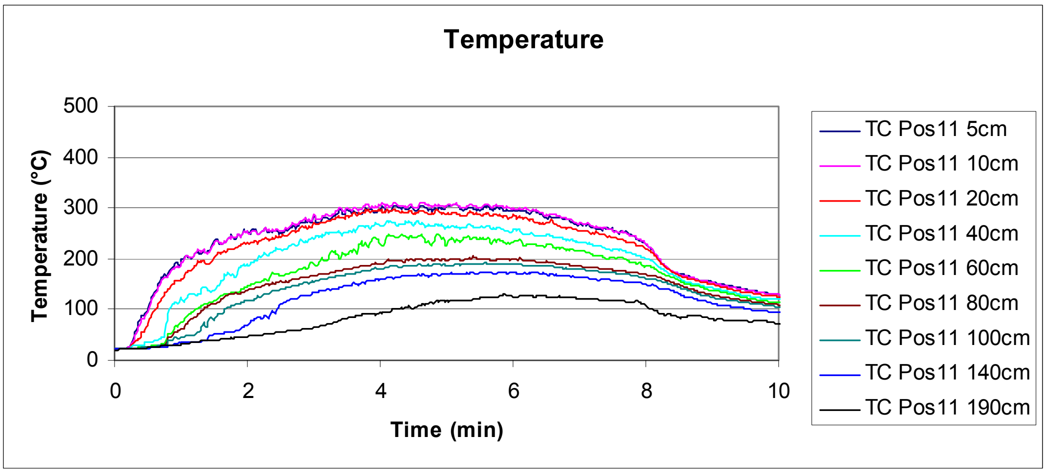

Figure A2.133 Temperature profiles Pos11 for Test 10.

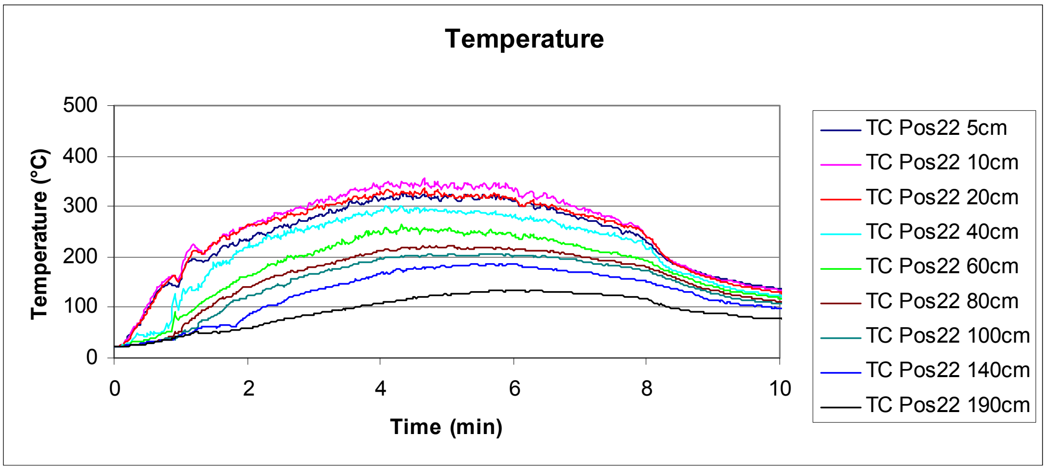

Figure A2.134 Temperature profiles Pos 22 for Test 10.

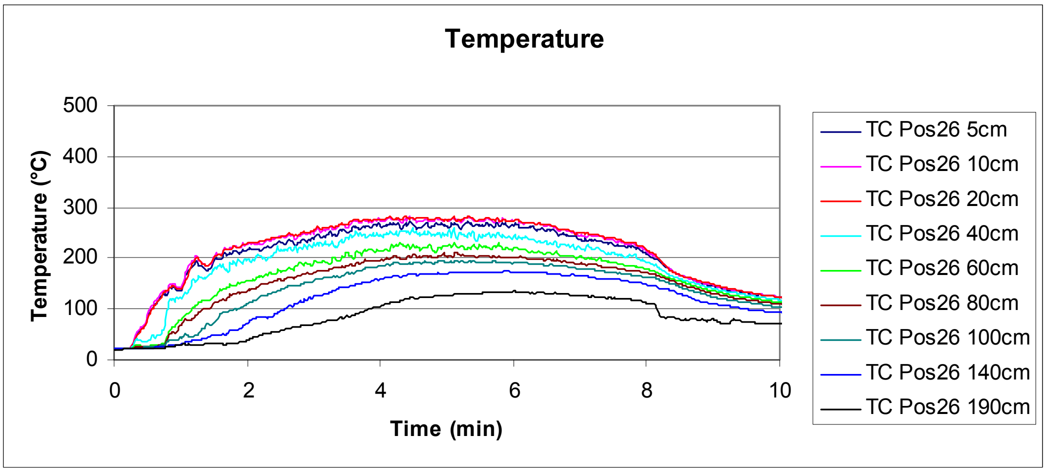

Figure A2.135 Temperature profiles Pos 26 for Test 10.

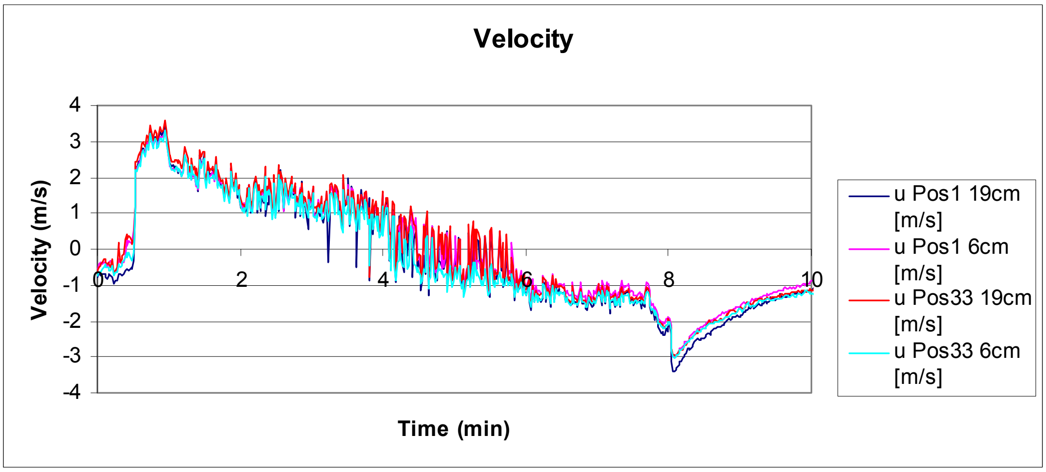

Figure A2.136 Velocity profiles for Test 10.

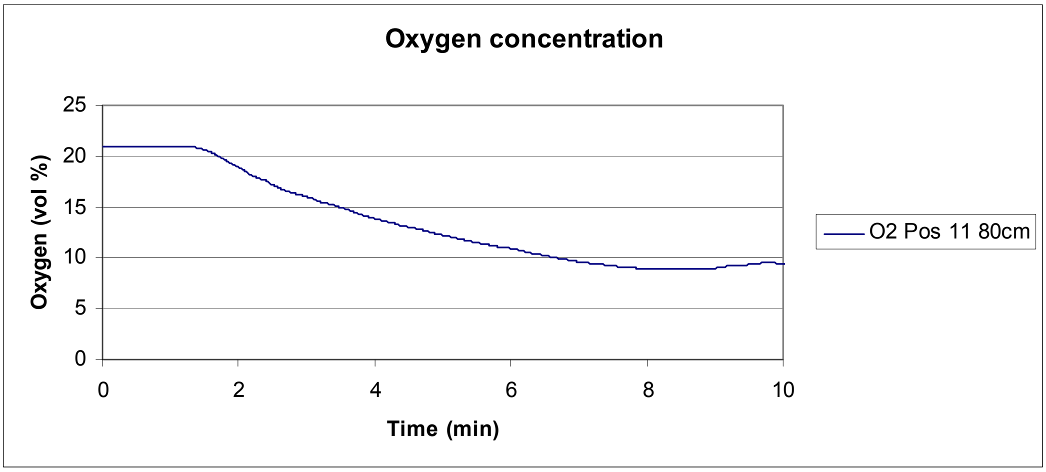

Figure A2.137 Oxygen concentration for Test 10.

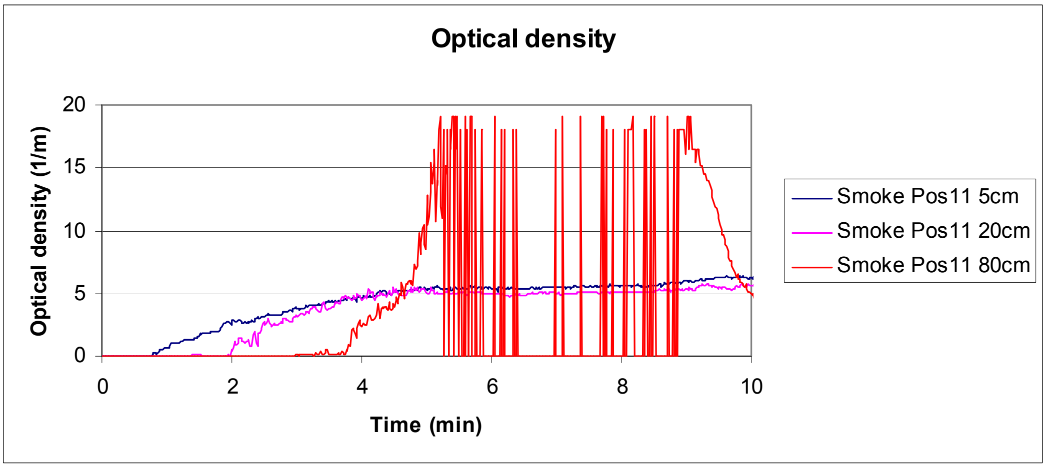

Figure A2.138 Optical density for Test 10.

Test 11

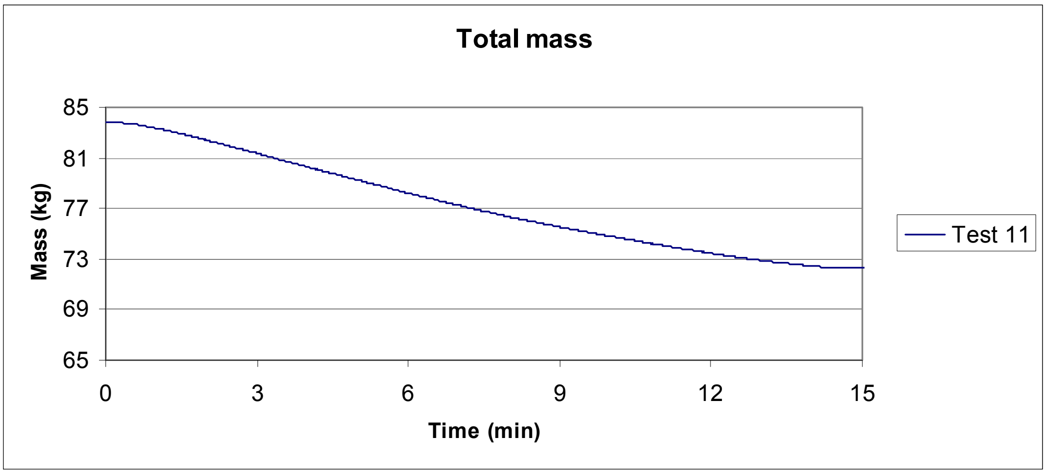

Figure A2.139 Total mass for Test 11.

Figure A2.140 Mass loss rate for Test 11.

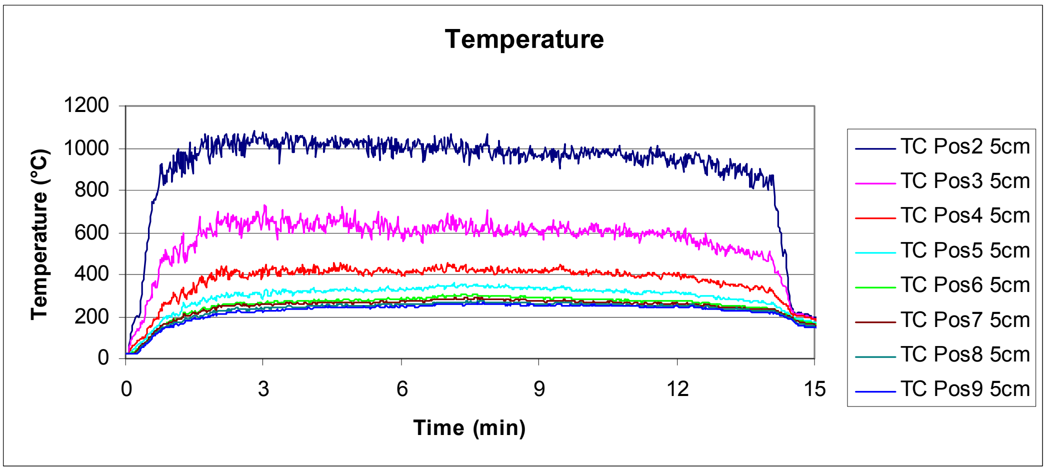

Figure A2.141 Temperature profiles for Test 11.

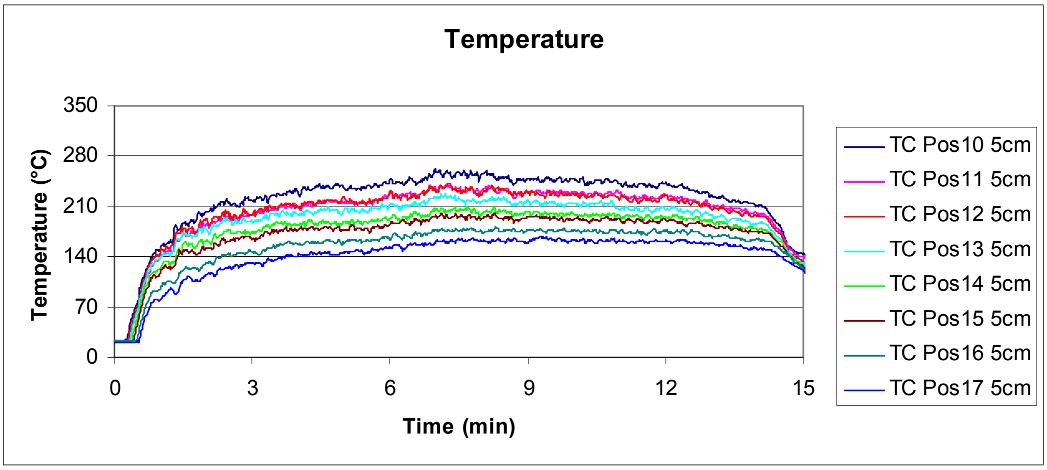

Figure A2.142 Temperature profiles for Test 11.

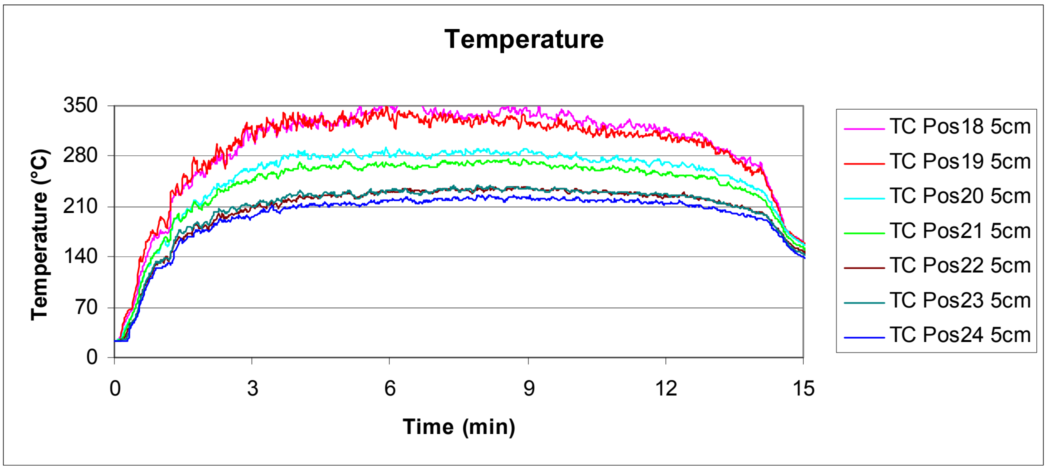

Figure A2.143 Temperature profiles for Test 11.

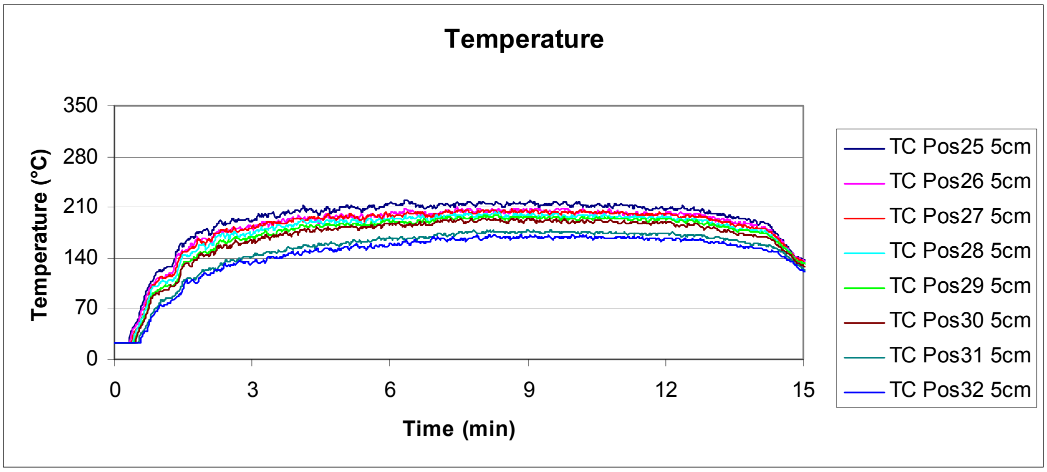

Figure A2.144 Temperature profiles for Test 11.

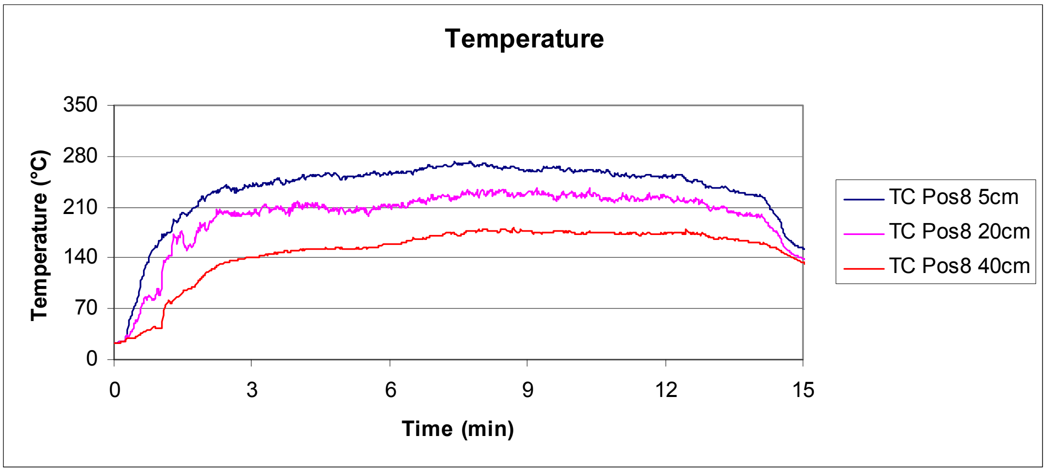

Figure A2.145 Temperature profiles Pos 8 for Test 11.

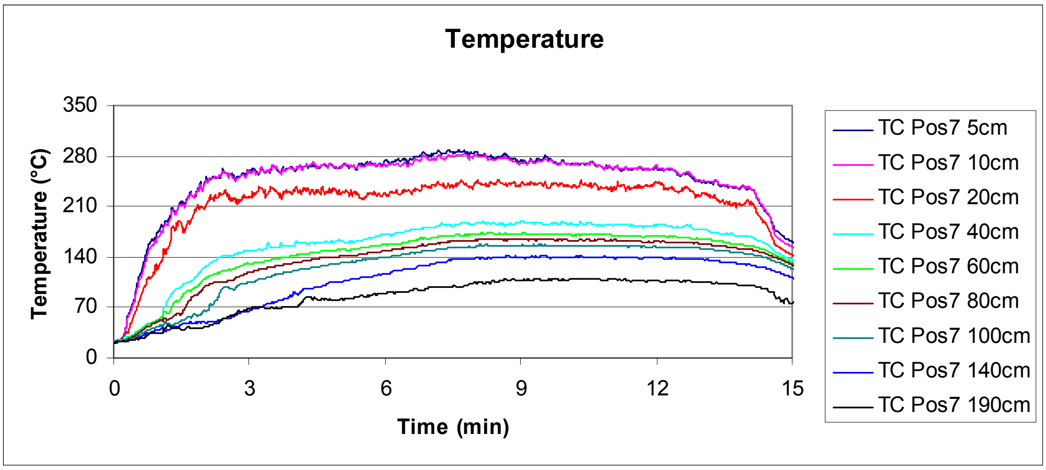

Figure A2.146 Temperature profiles Pos7 for Test 11.

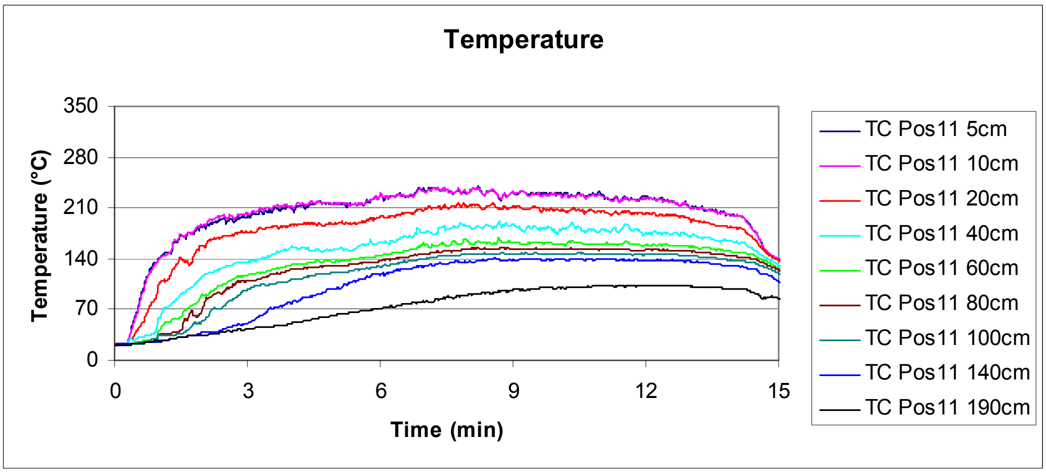

Figure A2.147 Temperature profiles Pos 11 for Test 11.

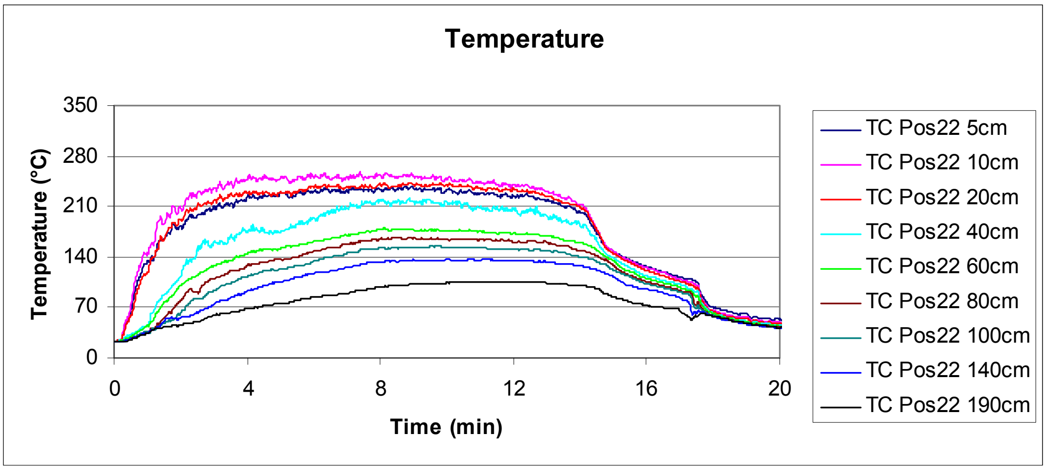

Figure A2.148 Temperature profiles Pos 22 for Test 11.

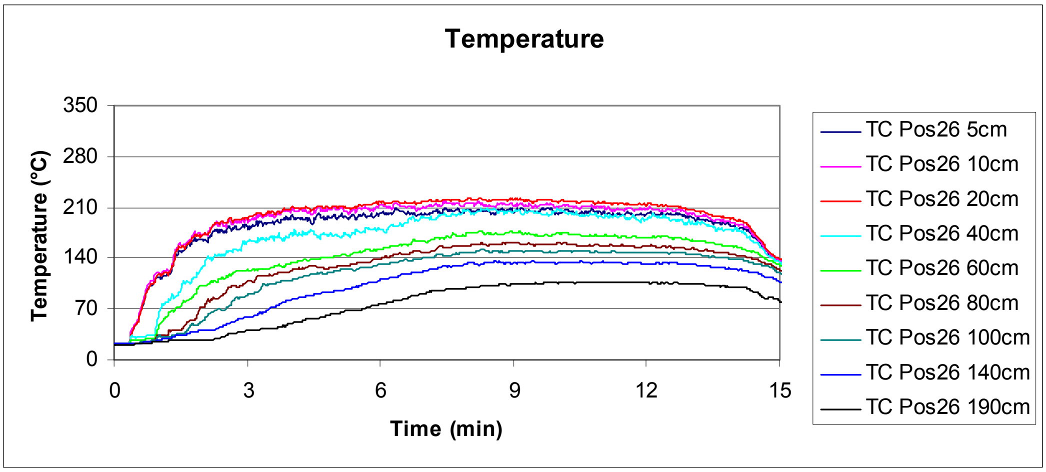

Figure A2.149 Temperature profiles Pos 26 for Test 11.

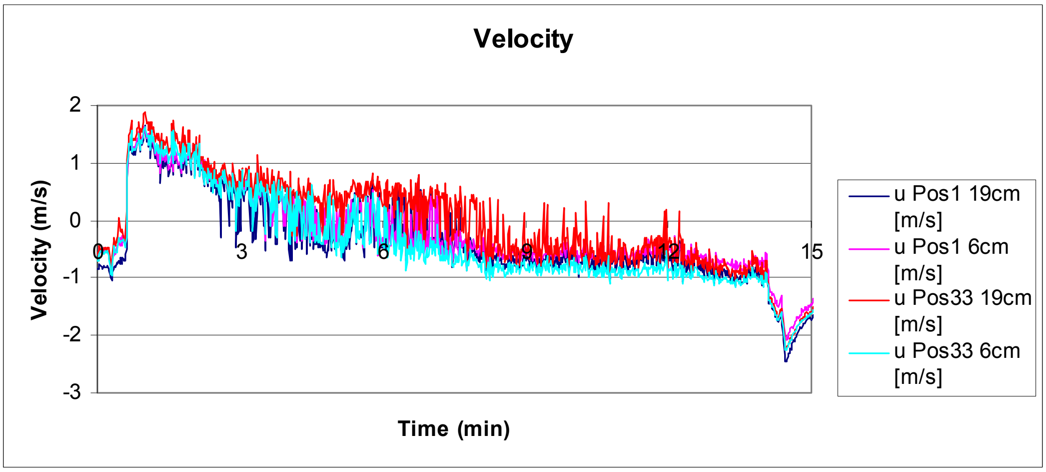

Figure A2.150 Velocity profiles for Test 11.

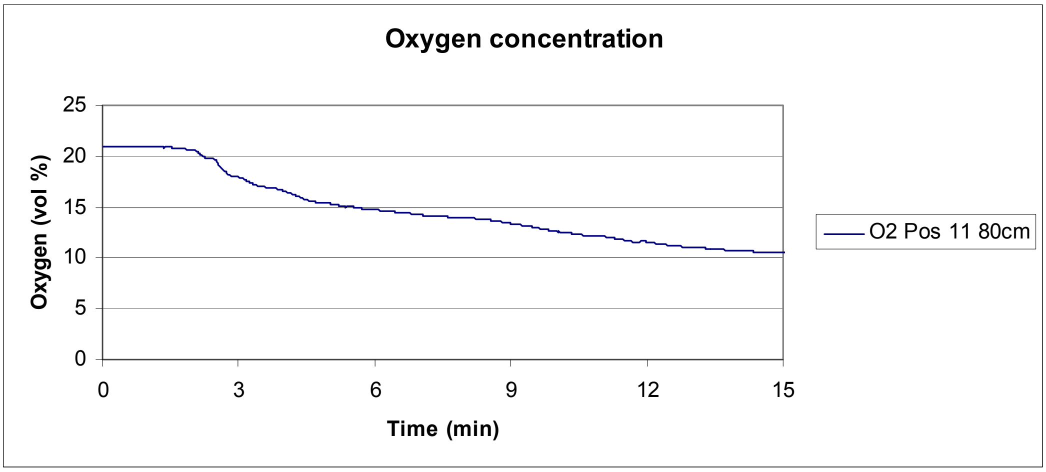

Figure A2.151 Oxygen concentration for Test 11.

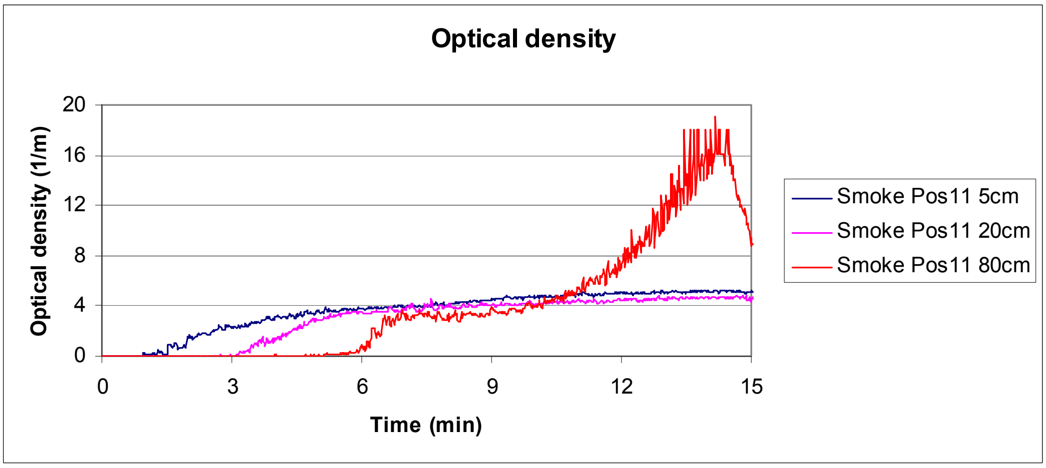

Figure A2.152 Optical density for Test 11.

Appendix 3 Values for measured parameters at selected times

A table of all the measurements at a few different selected times. Note that the values are given as single values and not as averages.

In the measurement tables the data is presented as follows:

The total mass include the platform arrangement, pool, and fuel.

The mass loss rate presented in the diagrams in the appendix has been “smoothed”. First the mass signal was smoothed as five second averages and then the calculated mass loss rate is give as a running 10 s average.

TC Pos4 5cm: stands for thermocouple position 4, and 5 cm from the ceiling. The data given is the temperature (°C).

TC08mm Pos11 5cm: stands for thermocouple (wire diameter = 0.8 mm) position 11 and 5 cm from the ceiling. The data given is the temperature (°C).

u Pos1 6cm: stands for the velocity (m/s) in position 1, 6 cm from the bottom of the opening (i.e. 6 cm + 5 cm = 11 cm from the floor). A positive value indicates a velocity out from the room.

TC Fuel: thermocouple at the fuel surface The data given is the temperature (°C).

O2 Pos 11 80cm: The oxygen level in position 11, 80 cm from the ceiling, given in vol-%.

Smoke Pos11 5cm: The Optical density in position 11, 5 cm from the floor, calculated using D_L=-1/L ln(I/I_0) , given in 1/m.

Test 1

Table A3.1 Experimental results at selected times for Test 1.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	12.3	12.1	17.5	17.6	17.6	17.6	17.6	17.4	17.5
5.0	13.3	12.3	135.4	147.2	255.6	134.3	133.0	103.4	98.6
10.0	12.7	12.2	155.6	161.1	253.7	178.8	171.5	132.6	121.6
15.0	12.8	12.2	159.6	168.0	256.5	181.5	175.0	136.0	125.0
20.0	13.0	12.2	153.4	157.2	233.3	164.5	166.4	122.4	119.0
25.0	13.6	12.2	128.2	133.8	201.8	125.8	131.9	100.9	94.6

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	17.5	17.4	17.3	17.2	16.9	16.5	16.1	16.0	17.2
5.0	98.4	88.2	46.8	36.7	32.6	25.8	21.3	18.1	96.7
10.0	121.7	107.9	63.3	53.1	47.2	38.0	28.9	22.4	119.3
15.0	120.9	110.3	64.6	58.2	53.2	47.0	36.2	26.8	120.7
20.0	115.8	99.7	63.5	60.0	56.2	50.3	39.9	29.1	113.4
25.0	92.1	86.9	61.5	58.1	55.4	50.0	40.7	29.2	95.6

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	16.8	15.8	17.6	17.6	17.4	17.5	17.8	17.6	17.4
5.0	29.9	18.3	92.4	84.1	47.9	87.0	84.4	82.1	83.5
10.0	44.7	22.8	113.9	100.9	62.0	107.6	107.8	102.3	101.2
15.0	52.5	26.9	116.5	106.6	65.5	103.8	102.5	98.5	99.2
20.0	55.8	29.3	108.4	95.1	63.8	101.7	102.0	96.8	95.9
25.0	55.3	29.9	88.5	83.0	61.3	84.0	83.6	83.5	83.0

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	17.3	17.7	17.4	17.0	16.7	16.4	16.1	17.5	17.4
5.0	79.6	47.2	34.8	30.6	25.1	20.1	17.6	77.8	75.5
10.0	96.8	63.5	49.8	43.0	37.6	28.3	21.9	96.5	94.2
15.0	98.1	66.8	55.8	50.4	46.2	35.8	26.2	96.9	95.8
20.0	92.3	66.0	56.6	52.7	50.4	39.3	28.9	93.0	91.3
25.0	82.0	68.7	56.1	52.0	49.5	39.9	29.5	81.9	82.5

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	17.2	16.2	17.8	17.5	17.6	17.7	17.6	17.6	17.6
5.0	27.5	17.5	74.5	71.8	71.5	68.2	50.5	68.7	60.9
10.0	41.6	21.4	91.6	86.3	85.3	85.4	64.2	84.6	75.5
15.0	48.9	25.6	92.6	87.7	84.1	84.1	72.7	82.9	75.8
20.0	52.0	28.4	89.4	84.3	82.8	80.7	67.2	81.0	74.9
25.0	52.1	29.5	81.1	77.9	75.3	75.1	63.1	74.6	69.2

Time (min)	TC Pos16 10cm	TC Pos16	TC Pos16	TC Pos16	TC Pos16	TC Pos16	TC Pos16 140cm	TC Pos16	TC Pos17

		20cm	40cm	60cm	80cm	100cm		190cm	5cm
0.0	17.6	17.6	17.4	17.6	17.3	17.0	16.3	15.5	17.4
5.0	61.9	61.5	50.2	43.4	31.5	24.8	20.3	17.5	52.8
10.0	76.6	76.0	66.5	59.4	45.2	36.7	27.3	19.7	65.5
15.0	76.4	76.7	69.0	61.8	50.6	44.9	35.2	25.2	69.0
20.0	75.4	76.3	70.7	61.3	52.5	47.2	38.1	27.0	71.3
25.0	70.2	70.1	65.1	59.9	53.3	48.7	39.3	27.5	64.5

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	18.6	18.4	18.4	18.1	18.0	17.4	17.9	17.9	17.7
5.0	116.3	110.2	106.4	103.5	99.7	91.1	95.8	96.3	46.9
10.0	138.5	134.0	127.1	125.9	119.5	110.1	118.8	115.1	60.9
15.0	130.3	128.8	123.7	122.1	116.5	112.9	117.1	111.8	64.3
20.0	132.7	128.2	124.1	121.2	117.7	109.1	112.5	108.7	63.7
25.0	114.7	113.7	108.0	108.4	102.4	97.0	100.7	95.7	61.4

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	17.4	17.1	17.1	16.4	16.4	17.8	17.6	16.6	17.7
5.0	38.1	31.5	25.5	22.1	20.4	89.9	29.7	20.6	93.9
10.0	53.4	44.5	38.3	29.7	25.7	109.8	43.9	26.0	109.6
15.0	58.2	52.5	47.3	36.4	29.4	110.1	51.1	29.7	109.0
20.0	58.8	55.1	50.3	40.1	31.7	106.8	54.0	32.3	102.3
25.0	58.0	54.4	50.5	41.1	32.5	96.8	53.8	33.1	93.2

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	18.5	17.8	17.9	17.7	17.9	17.7	17.4	16.9	16.8
5.0	92.9	87.0	80.1	82.9	80.6	50.7	38.2	31.1	25.6
10.0	105.8	101.2	96.4	99.1	97.7	65.8	54.3	45.7	38.4
15.0	106.9	101.6	98.3	99.6	98.8	67.9	58.3	51.3	45.8
20.0	99.5	96.8	93.6	94.6	93.3	67.0	59.7	54.3	49.7
25.0	91.5	88.4	85.6	86.1	85.1	63.9	58.4	53.7	49.4

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	16.3	15.8	17.5	16.9	16.3	18.3	18.8	18.2	18.0
5.0	20.4	17.2	73.1	28.0	17.6	73.1	71.9	69.2	68.9
10.0	28.4	22.5	91.4	42.8	22.8	92.1	89.3	86.5	84.9
15.0	35.9	26.6	92.8	49.0	26.9	93.3	90.1	88.6	86.1
20.0	39.5	28.7	90.1	51.4	29.5	90.8	86.3	85.4	82.6
25.0	40.2	29.9	81.7	51.8	30.4	81.2	80.6	78.1	76.9

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	17.7	17.7	17.9	18.1	17.9	17.3	17.2	17.2	17.1
5.0	51.1	68.4	60.0	61.3	61.0	47.9	44.4	31.6	25.9

10.0	66.1	83.2	73.9	75.9	75.2	64.4	57.7	46.6	36.6
15.0	68.2	84.7	76.5	78.8	79.2	66.8	63.6	52.3	44.7
20.0	67.7	83.9	74.3	76.4	76.6	66.3	61.2	54.9	47.3
25.0	63.6	74.8	69.4	71.2	70.7	62.2	59.6	54.2	47.8

Time (min)	TC Pos31 140cm	TC Pos31 190cm	TC Pos32 5cm	TC Pos33 19cm	TC Pos33 6cm	u Pos1 6cm (m/s)	u Pos1 19cm (m/s)	u Pos33 19cm (m/s)	u Pos33 6cm (m/s)
0.0	16.5	16.1	17.9	13.1	12.9	-0.5	-0.8	-0.5	-0.6
5.0	20.1	17.4	54.9	12.4	12.0	-0.8	-1.0	-0.7	-0.9
10.0	27.4	20.3	67.0	12.4	11.9	-1.1	-1.2	-1.0	-1.1
15.0	35.3	23.9	73.2	12.8	12.4	-1.1	-1.3	-1.0	-1.2
20.0	38.4	27.0	70.9	12.7	12.5	-1.1	-1.3	-1.1	-1.3
25.0	39.3	28.7	63.5	12.7	12.4	-1.1	-1.2	-1.1	-1.2

Time (min)	Mass (kg)	TC Fuel	O2 Pos 11 80cm (vol-%)	Smoke Pos11 5cm	Smoke Pos11 20cm	Smoke Pos11 80cm			
0.0	61.7	9.8	0.0	0.0	0.0	0.0			
5.0	61.1	25.3	0.0	1.0	1.2	0.6			
10.0	60.1	55.7	0.0	1.0	1.1	0.7			
15.0	59.1	107.3	0.0	1.1	1.2	0.8			
20.0	58.3	158.4	0.0	1.2	1.3	0.7			
25.0	57.6	170.9	0.0	1.2	1.4	0.8			

Test 2

Table A3.2 Experimental results at selected times for Test 2.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	12.0	11.8	19.3	19.3	19.6	19.7	19.7	19.3	19.3
5.0	21.6	18.8	335.8	391.9	970.8	471.7	452.2	316.8	265.3
10.0	17.9	15.7	345.1	414.7	825.6	423.8	405.1	305.9	267.3
15.0	18.3	16.1	313.6	378.7	820.7	351.0	377.3	263.4	239.8
20.0	15.2	13.5	111.7	109.8	115.2	110.1	116.9	99.0	97.5

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	19.2	19.1	19.0	18.8	18.5	17.9	17.4	17.3	19.1
5.0	253.2	221.5	134.1	119.5	104.7	86.2	59.7	39.5	254.6
10.0	250.1	198.1	165.1	151.0	135.4	123.2	101.5	71.0	266.6
15.0	232.6	205.4	161.1	150.9	139.4	123.5	103.5	73.3	236.6
20.0	95.6	94.4	90.2	86.7	81.0	76.5	67.4	50.8	103.3

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	18.5	17.2	19.2	19.1	19.0	19.0	19.2	19.0	18.9
5.0	103.0	38.8	250.0	212.9	128.6	220.6	221.3	214.2	211.5
10.0	138.3	70.9	249.5	192.5	160.5	240.4	245.8	235.2	234.5
15.0	140.3	74.5	225.3	195.7	158.6	216.2	217.6	206.5	211.6
20.0	88.6	54.1	94.6	92.8	89.1	91.9	93.0	93.6	93.5

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	18.9	19.1	18.8	18.6	18.2	17.7	17.0	19.0	19.0
5.0	204.7	163.5	106.9	98.7	88.4	57.5	33.7	208.2	199.5
10.0	218.7	178.4	139.8	127.9	123.8	99.9	70.4	228.3	219.5
15.0	202.4	177.9	142.1	129.9	124.5	104.5	73.4	209.0	205.0
20.0	92.1	89.4	83.9	83.8	77.1	67.9	51.8	98.7	95.9

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	18.8	17.2	19.0	18.8	19.0	18.9	18.8	19.0	18.9
5.0	92.7	31.6	195.4	178.4	167.7	168.4	125.6	165.5	149.6
10.0	126.9	66.6	211.6	198.5	183.5	185.2	143.0	180.7	165.0
15.0	129.4	72.3	196.0	187.5	181.9	181.7	156.3	179.5	164.0
20.0	86.0	52.9	93.5	90.9	88.6	86.5	82.9	88.3	84.4

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	18.8	18.7	18.6	18.5	18.3	18.1	17.3	16.1	18.2
5.0	150.7	151.3	131.0	118.1	98.3	88.1	54.3	31.5	136.1
10.0	167.0	166.4	146.1	139.1	132.2	121.9	103.5	66.0	151.1

15.0	163.7	159.0	149.0	141.0	134.4	123.9	104.6	71.7	148.2
20.0	83.9	84.6	81.1	79.7	78.5	77.0	66.1	48.0	80.8

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	20.4	19.9	20.0	19.9	19.8	19.1	19.6	19.5	19.4
5.0	293.0	296.6	270.5	269.9	250.4	227.7	243.2	231.6	135.0
10.0	289.4	299.5	282.4	275.5	254.8	233.5	244.7	235.1	169.4
15.0	263.6	269.5	255.6	262.4	240.3	228.5	233.9	221.3	162.1
20.0	98.8	99.3	102.3	105.6	97.9	99.5	97.0	94.9	88.7

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	18.9	18.6	18.3	17.8	17.5	19.6	19.1	17.8	19.8
5.0	113.2	102.1	88.8	62.2	45.5	227.6	100.1	45.2	224.0
10.0	143.0	134.7	126.8	103.7	71.7	226.4	133.4	73.1	222.3
15.0	142.1	133.7	125.7	108.9	74.2	226.1	133.8	76.2	218.9
20.0	84.2	81.0	77.8	67.3	53.2	105.7	85.2	56.1	95.4

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	19.8	19.5	19.1	19.1	19.5	19.3	19.0	18.6	18.2
5.0	205.7	199.4	191.9	197.5	195.2	135.3	113.7	99.1	89.8
10.0	209.7	197.3	190.1	193.6	191.4	170.0	141.2	130.4	123.5
15.0	207.4	193.5	189.6	193.9	187.7	159.2	138.4	133.1	126.3
20.0	94.0	91.0	90.1	88.6	89.0	85.9	81.6	79.8	76.9

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	17.7	16.6	18.9	18.3	17.2	19.3	19.8	19.5	19.1
5.0	58.5	35.6	181.6	97.0	35.2	183.7	172.0	169.6	166.7
10.0	105.5	71.5	182.0	130.2	70.3	180.6	172.7	169.5	170.2
15.0	103.3	75.4	182.0	130.7	74.8	180.9	175.8	170.7	170.0
20.0	67.0	50.4	92.5	82.5	52.0	87.2	86.2	85.8	86.0

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	18.9	19.3	18.9	19.1	18.9	18.6	18.5	18.4	18.3
5.0	131.4	163.3	142.3	146.5	146.7	131.8	119.7	103.7	85.9
10.0	162.4	164.2	150.0	155.7	157.7	155.2	144.4	132.7	122.5
15.0	152.4	161.8	153.4	157.7	157.1	152.6	139.3	131.9	124.5
20.0	83.7	85.2	81.8	82.6	83.0	83.0	79.6	78.0	75.1

Time (min)	TC Pos31 140cm	TC Pos31 190cm	TC Pos32 5cm	TC Pos33 19cm	TC Pos33 6cm	Mass (kg)	TC Fuel	O2 Pos 11 80cm (vol-%)	Smoke Pos11 5cm
0.0	17.8	16.8	19.1	12.1	12.0	84.5	10.9	-	0,0
5.0	54.3	32.8	129.0	12.9	12.6	81.0	26.8	-	1,6
10.0	105.9	64.6	145.6	15.0	14.5	77.4	68.7	-	1,8

15.0	105.9	72.2	144.3	14.8	14.2	74.3	178.4	-	3,1
20.0	65.9	49.7	80.2	13.8	13.3	73.4	69.6	-	15,8
Time (min)	**Smoke Pos11 20cm**	**Smoke Pos11 80cm**	**u Pos1 19cm (m/s)**	**u Pos1 6cm (m/s)**	**u Pos33 19cm (m/s)**	**u Pos33 6cm (m/s)**			
0.0	0,0	0.0	-0.8	-0.6	-0.5	-0.6			
5.0	1,8	1.9	-1.4	-1.0	-1.0	-1.2			
10.0	2,2	1.9	-1.7	-1.4	-1.5	-1.6			
15.0	3,7	2.2	-1.7	-1.5	-1.6	-1.7			
20.0	17,1	2.1	-1.3	-1.1	-1.1	-1.3			

Test 3

Table A3.3 Experimental results at selected times for Test 3.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	13.1	12.8	20.2	20.2	20.6	20.5	20.5	20.3	20.2
5.0	26.6	22.8	416.3	513.3	995.2	433.3	420.2	293.9	255.9
10.0	22.2	19.0	473.1	637.6	586.4	329.6	324.0	315.7	310.2
15.0	19.7	16.9	307.3	366.7	741.7	311.9	297.6	234.7	215.6
20.0	17.7	14.7	106.8	106.3	107.4	104.7	108.1	94.6	93.9

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	19.9	19.8	19.6	19.6	19.2	18.9	18.4	18.5	19.8
5.0	243.5	215.5	143.3	128.7	114.8	96.8	70.9	45.9	249.5
10.0	294.9	230.8	176.7	160.4	148.2	131.6	112.2	82.6	281.0
15.0	214.2	203.1	168.1	154.2	143.2	130.5	111.2	79.4	218.2
20.0	92.0	90.8	88.2	84.2	80.3	76.6	68.6	54.7	97.5

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	19.2	18.4	19.9	19.8	19.5	19.7	19.9	19.6	19.5
5.0	114.6	45.0	233.3	206.2	135.5	220.5	225.3	214.5	216.5
10.0	147.6	81.0	284.7	213.7	171.5	263.5	264.8	245.8	251.6
15.0	147.5	83.4	200.8	190.8	163.8	189.7	201.1	199.5	201.5
20.0	85.6	57.0	91.1	88.0	85.1	89.9	89.5	91.1	90.9

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	19.4	19.7	19.5	19.4	18.9	18.6	18.4	19.5	19.5
5.0	205.0	158.3	116.6	104.3	99.3	68.4	39.5	210.5	201.8
10.0	228.3	187.4	151.6	136.1	131.4	111.3	80.6	235.8	223.5
15.0	190.1	167.9	143.2	134.2	127.3	112.3	81.2	201.4	194.0
20.0	89.6	87.1	80.9	80.3	75.1	67.7	54.4	95.1	91.8

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	19.6	18.4	19.5	19.6	19.6	19.6	19.5	19.8	19.5
5.0	99.8	36.7	199.8	197.2	182.5	179.5	130.6	178.9	156.3
10.0	133.0	76.5	225.2	220.9	205.5	207.5	163.3	200.4	182.6
15.0	136.3	83.0	194.8	191.0	183.8	175.8	148.5	179.6	166.0
20.0	82.4	55.3	90.5	88.2	85.6	81.7	78.8	85.1	79.8

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	19.4	19.4	19.2	19.2	19.0	18.8	18.4	17.2	19.1
5.0	159.5	158.6	132.7	124.4	110.3	99.5	65.4	36.0	141.7
10.0	187.3	181.5	152.9	146.7	142.7	132.4	111.6	75.1	163.1
15.0	168.5	162.3	144.2	138.8	133.9	128.1	112.2	78.4	152.0

20.0	80.0	80.4	77.7	75.6	75.2	74.0	67.2	50.5	77.2
Time (min)	**TC Pos18 5cm**	**TC Pos19 5cm**	**TC Pos20 5cm**	**TC08mm Pos20 5cm**	**TC Pos21 5cm**	**TC Pos22 5cm**	**TC Pos22 10cm**	**TC Pos22 20cm**	**TC Pos22 40cm**
0.0	21.0	20.6	20.8	20.6	20.5	19.7	20.3	20.4	20.1
5.0	298.9	306.4	278.9	277.3	250.7	226.0	236.6	230.6	139.0
10.0	311.0	298.7	261.3	269.6	244.8	225.3	233.1	235.6	182.4
15.0	262.8	275.7	250.3	249.0	236.9	212.8	223.9	218.7	169.7
20.0	92.4	91.5	94.4	97.5	92.1	92.2	90.0	89.2	85.1
Time (min)	**TC Pos22 60cm**	**TC Pos22 80cm**	**TC Pos22 100cm**	**TC Pos22 140cm**	**TC Pos22 190cm**	**TC08mm Pos22 5cm**	**TC08mm Pos22 80cm**	**TC08mm Pos22 190cm**	**TC Pos23 5cm**
0.0	19.6	19.4	19.3	18.9	18.9	20.3	20.2	19.2	20.3
5.0	122.6	111.2	100.7	76.3	53.0	226.1	110.2	52.3	218.1
10.0	149.5	143.0	134.3	115.0	82.7	225.7	141.6	83.8	218.5
15.0	145.7	139.1	131.0	115.8	82.3	213.9	141.4	85.7	210.3
20.0	80.7	78.0	74.9	68.4	55.4	96.5	81.0	57.8	88.7
Time (min)	**TC Pos24 5cm**	**TC Pos25 5cm**	**TC Pos26 5cm**	**TC Pos26 10cm**	**TC Pos26 20cm**	**TC Pos26 40cm**	**TC Pos26 60cm**	**TC Pos26 80cm**	**TC Pos26 100cm**
0.0	20.6	19.8	19.8	19.7	20.1	19.9	19.6	19.3	19.3
5.0	205.4	195.5	185.7	192.7	187.6	136.6	120.8	109.1	98.1
10.0	208.7	198.5	190.9	196.0	195.6	175.8	148.6	138.0	129.4
15.0	199.4	190.9	183.5	187.3	186.0	165.8	143.0	135.3	127.9
20.0	87.7	85.9	85.0	84.6	84.7	82.5	78.7	76.8	74.5
Time (min)	**TC Pos26 140cm**	**TC Pos26 190cm**	**TC08mm Pos26 5cm**	**TC08mm Pos26 80cm**	**TC08mm Pos26 190cm**	**TC Pos27 5cm**	**TC Pos28 5cm**	**TC Pos29 5cm**	**TC Pos29 20cm**
0.0	18.8	18.1	19.8	19.0	18.6	20.1	20.5	20.3	20.0
5.0	69.5	43.0	179.3	107.1	41.5	178.5	172.1	173.0	169.4
10.0	112.5	81.6	187.2	136.6	79.5	181.8	180.1	181.0	181.7
15.0	114.8	82.7	179.1	135.6	84.8	176.0	170.8	168.4	170.2
20.0	66.2	53.9	86.7	78.4	54.8	83.4	82.1	82.1	82.2
Time (min)	**TC Pos29 40cm**	**TC Pos30 5cm**	**TC Pos31 5cm**	**TC Pos31 10cm**	**TC Pos31 20cm**	**TC Pos31 40cm**	**TC Pos31 60cm**	**TC Pos31 80cm**	**TC Pos31 100cm**
0.0	19.8	19.7	19.6	19.8	19.6	19.3	19.2	19.3	19.3
5.0	141.2	163.2	144.3	150.4	150.7	138.6	125.4	112.2	97.8
10.0	173.6	171.7	160.1	167.4	167.4	164.8	146.3	139.9	130.3
15.0	158.0	163.2	148.3	152.5	153.8	151.0	141.2	135.0	125.9
20.0	81.0	80.5	78.3	79.0	79.8	79.3	76.3	75.3	73.3
Time (min)	**TC Pos31 140cm**	**TC Pos31 190cm**	**TC Pos32 5cm**	**TC Pos33 19cm**	**TC Pos33 6cm**	**Mass (kg)**	**TC Fuel**	**O2 Pos 11 80cm (vol-%)**	**Smoke Pos11 5cm**
0.0	19.0	18.0	19.7	14.1	13.9	84.1	20.0	20.9	-
5.0	66.5	39.1	132.2	14.8	15.9	80.3	45.1	17.4	-
10.0	114.5	75.9	155.0	16.9	15.1	76.5	138.9	16.1	-
15.0	113.7	79.0	140.7	15.5	15.1	73.2	172.5	14.7	-
20.0	66.8	52.0	77.2	15.2	14.7	73.0	67.1	14.2	-

Time (min)	Smoke Pos11 20cm	Smoke Pos11 80cm	u Pos1 19cm (m/s)	u Pos1 6cm (m/s)	u Pos33 19cm (m/s)	u Pos33 6cm (m/s)			
0.0	-	0.0	-0.8	-0.6	-0.4	-0.6			
5.0	-	1.5	-1.1	-0.9	-1.0	-0.8			
10.0	-	1.9	-1.1	-0.9	-0.8	-1.1			
15.0	-	3.3	-1.3	-1.2	-1.2	-1.3			
20.0	-	3.3	-1.0	-0.9	-0.8	-1.0			

Test 4

Table A3.4 Experimental results at selected times for Test 4.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	14.6	14.3	19.2	19.1	19.3	19.1	19.1	19.1	19.0
5.0	25.8	20.3	494.3	632.0	771.8	563.2	566.0	455.8	407.0
10.0	19.7	17.1	166.4	162.3	169.7	160.9	174.8	151.1	146.7
15.0	18.9	17.0	101.2	99.2	100.8	99.1	102.6	89.4	91.4

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	19.0	18.9	18.8	18.9	18.6	18.2	17.7	17.5	18.8
5.0	391.1	339.5	272.3	250.5	217.9	187.2	152.6	113.1	379.0
10.0	139.0	132.6	127.1	119.4	112.1	101.1	90.8	64.2	156.3
15.0	89.9	88.3	83.2	81.3	77.5	72.4	67.8	54.3	94.9

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	18.4	17.3	19.1	19.0	19.0	19.2	19.5	19.1	19.1
5.0	220.2	109.6	354.3	324.2	269.5	327.1	319.9	304.6	311.8
10.0	124.8	73.7	138.1	129.3	122.6	132.4	131.5	129.4	130.0
15.0	81.2	56.4	90.3	86.3	85.0	88.0	87.6	88.2	87.8

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	18.9	19.3	19.0	18.4	18.1	18.0	17.7	19.2	19.1
5.0	304.3	272.9	231.7	192.6	182.2	151.1	105.5	300.0	303.2
10.0	127.2	120.1	114.3	110.4	103.0	89.6	66.2	139.3	136.2
15.0	86.5	83.5	77.5	76.3	71.0	66.0	52.8	91.9	88.0

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	18.8	17.7	19.6	19.3	19.3	19.2	19.2	19.3	19.2
5.0	193.1	98.6	286.8	286.8	271.2	265.8	244.4	245.6	222.4
10.0	121.4	69.3	127.3	126.4	121.1	120.3	111.0	120.0	112.4
15.0	78.6	53.7	86.5	82.7	82.0	78.3	75.6	81.2	76.2

Time (min	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	19.2	19.1	18.8	18.8	18.7	18.3	17.7	17.2	19.0
5.0	226.8	223.8	208.8	197.4	184.2	177.5	159.9	123.0	195.8
10.0	112.4	113.5	109.5	105.7	103.6	101.0	87.0	62.2	106.9
15.0	76.0	76.0	72.4	71.4	71.1	69.5	62.7	48.8	73.4

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm

0.0	20.2	19.8	19.4	19.2	19.4	19.1	19.6	19.6	19.4
5.0	378.3	384.7	358.9	369.7	334.2	290.1	313.0	306.8	271.4
10.0	139.8	141.6	143.4	152.6	140.9	138.4	136.0	129.9	121.1
15.0	86.5	87.6	90.4	92.9	87.6	88.4	86.0	84.4	81.3

Time ign (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	19.0	18.8	18.7	18.1	18.2	19.6	19.6	18.4	19.6
5.0	225.9	202.8	178.2	151.9	109.4	297.0	201.1	109.6	288.9
10.0	115.1	109.5	103.5	92.7	69.7	149.3	119.6	75.2	131.9
15.0	78.0	74.2	70.9	65.2	54.6	90.7	76.8	56.7	84.9

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	20.0	19.6	19.4	19.3	19.6	19.4	19.1	18.8	18.8
5.0	278.3	257.3	245.9	249.9	258.6	254.7	236.0	209.9	182.4
10.0	126.7	124.1	120.6	121.4	122.5	114.7	109.3	105.6	101.4
15.0	83.3	82.4	80.5	80.1	81.2	80.1	74.8	73.1	70.7

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	18.1	17.8	19.4	18.5	18.2	20.2	20.4	20.1	19.8
5.0	159.1	107.7	241.5	203.1	109.2	231.7	230.7	240.1	243.8
10.0	87.9	64.9	129.2	114.2	70.1	119.1	117.3	117.2	116.6
15.0	62.6	52.4	82.5	74.3	53.3	79.7	79.1	79.6	79.2

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	19.5	19.5	19.3	19.5	19.4	19.1	19.0	19.0	19.1
5.0	234.3	246.7	217.9	227.6	225.3	214.6	199.7	193.6	182.5
10.0	112.4	115.2	109.5	110.3	111.3	110.3	107.4	103.6	98.4
15.0	76.3	78.2	76.0	76.3	76.4	73.9	73.5	71.8	69.8

Time (min)	TC Pos31 140cm	TC Pos31 190cm	TC Pos32 5cm	TC Pos33 19cm	TC Pos33 6cm	Mass (kg)	TC Fuel	O2 Pos 11 80cm (vol-%)	Smoke Pos11 5cm
0.0	18.3	18.1	19.4	15.6	15.8	110.8	17.4	20.9	-
5.0	154.2	127.1	201.8	19.9	16.7	103.0	114.1	14.5	-
10.0	87.2	59.6	105.8	17.2	16.5	99.7	96.3	12.0	-
15.0	62.7	50.1	74.6	17.3	16.8	99.6	62.2	13.7	-

Time (min)	Smoke Pos11 20cm	Smoke Pos11 80cm	u Pos1 19cm (m/s)	U Pos1 6cm (m/s)	u Pos33 19cm (m/s)	u Pos33 6cm (m/s)			
0.0	-	0.00	-0.70	-0.43	-0.49	-0.59			
5.0	-	2.71	-2.57	-2.31	-2.27	-2.29			
10.0	-	2.02	-1.76	-1.56	-1.72	-1.75			
15.0	-	1.73	-0.99	-0.86	-0.85	-1.06			

Test 5

Table A3.5 Experimental results at selected times for Test 5.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	14.7	14.4	21.7	21.9	22.2	22.2	22.3	21.9	21.8
5.0	44.2	42.2	983.4	589.5	395.8	320.6	326.5	285.4	274.3
10.0	30.1	22.6	748.9	523.9	363.6	310.8	295.0	269.9	264.4
15.0	20.1	17.8	205.5	202.9	189.3	185.7	209.1	185.4	182.3
20.0	19.6	18.0	99.7	101.4	100.6	96.8	98.9	92.7	90.7
25.0	19.0	17.4	81.7	78.3	78.4	75.0	76.2	72.7	71.8

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	21.7	21.6	21.4	21.4	20.9	20.4	19.9	20.1	21.6
5.0	273.0	253.8	170.2	151.5	132.7	112.1	89.6	58.5	270.4
10.0	263.1	247.9	177.8	160.8	147.7	133.7	112.4	83.5	256.9
15.0	179.2	162.8	138.9	130.4	124.1	116.2	98.6	73.9	197.7
20.0	86.4	85.0	82.1	82.9	78.6	74.2	67.4	55.6	93.8
25.0	70.7	69.7	68.3	65.7	64.3	62.4	56.9	49.5	73.2

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	21.0	19.9	21.6	21.5	21.5	21.5	21.6	21.4	21.3
5.0	125.9	54.1	259.4	236.8	154.6	236.9	230.7	224.9	228.2
10.0	148.3	83.4	244.7	226.6	167.7	229.3	226.4	219.0	220.6
15.0	128.7	76.7	174.0	153.6	136.1	167.7	167.2	168.3	169.0
20.0	82.0	57.1	86.3	82.6	82.0	84.1	83.1	84.5	85.4
25.0	66.9	50.6	69.8	68.6	68.5	68.0	67.6	71.8	71.2

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	21.2	21.5	21.0	20.9	20.4	20.2	19.6	21.4	21.3
5.0	217.0	169.6	134.1	117.9	113.1	79.4	52.1	223.0	218.5
10.0	206.1	176.1	152.0	139.2	130.3	111.3	81.5	217.3	208.4
15.0	158.8	141.1	125.6	120.8	115.3	100.3	74.7	179.2	167.8
20.0	84.9	81.4	77.8	75.9	72.4	67.7	54.8	88.8	86.7
25.0	71.0	68.7	65.1	64.3	61.0	56.8	48.7	75.7	71.4

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	21.2	19.7	21.3	21.2	21.2	21.2	21.1	21.4	20.9
5.0	111.5	45.7	221.4	218.3	201.8	199.8	149.3	195.8	174.2
10.0	137.7	79.9	210.3	207.8	199.5	194.4	155.7	194.5	174.3
15.0	122.0	75.2	165.2	165.6	155.5	152.8	132.1	152.8	140.6
20.0	79.4	55.4	84.0	82.4	80.3	78.6	75.6	79.2	75.7
25.0	66.4	49.0	68.9	67.2	65.5	65.4	62.3	65.0	62.8

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	20.9	20.9	20.7	20.8	20.5	20.4	19.9	18.3	20.7
5.0	178.9	175.0	150.2	139.6	132.0	118.7	91.2	48.3	157.0
10.0	177.3	173.7	154.3	149.6	141.7	132.8	114.7	79.8	159.8
15.0	141.5	140.5	132.3	127.1	121.6	113.5	99.7	72.9	130.1
20.0	75.4	75.8	73.1	71.8	71.8	70.8	66.0	51.7	71.4
25.0	62.5	62.6	61.7	59.3	59.3	59.2	56.3	46.2	59.9
Time (min)	**TC Pos18 5cm**	**TC Pos19 5cm**	**TC Pos20 5cm**	**TC08mm Pos20 5cm**	**TC Pos21 5cm**	**TC Pos22 5cm**	**TC Pos22 10cm**	**TC Pos22 20cm**	**TC Pos22 40cm**
0.0	22.3	22.0	21.9	21.8	22.0	21.5	22.2	22.2	21.8
5.0	340.1	317.3	284.6	290.4	271.5	236.5	246.8	236.0	171.9
10.0	263.3	266.6	253.7	258.1	242.8	211.6	230.5	223.4	176.1
15.0	175.0	173.6	175.7	197.1	173.7	164.4	170.8	164.5	135.3
20.0	85.8	84.9	87.4	89.9	86.3	85.7	83.4	82.5	80.6
25.0	67.4	66.6	70.4	71.6	69.0	68.7	67.1	66.4	65.7
Time (min)	**TC Pos22 60cm**	**TC Pos22 80cm**	**TC Pos22 100cm**	**TC Pos22 140cm**	**TC Pos22 190cm**	**TC08mm Pos22 5cm**	**TC08mm Pos22 80cm**	**TC08mm Pos22 190cm**	**TC Pos23 5cm**
0.0	21.4	21.2	20.9	20.5	20.3	22.2	22.0	20.6	22.1
5.0	142.8	126.9	117.9	93.3	67.1	238.5	123.1	66.2	230.0
10.0	153.4	142.7	134.0	115.5	84.5	220.8	142.2	86.6	218.1
15.0	127.4	122.8	116.8	101.2	75.5	177.0	124.8	78.7	165.5
20.0	77.4	74.2	72.5	67.6	55.6	88.9	77.0	57.6	81.7
25.0	63.6	61.7	60.2	57.4	49.2	69.9	63.0	50.5	66.4
Time (min)	**TC Pos24 5cm**	**TC Pos25 5cm**	**TC Pos26 5cm**	**TC Pos26 10cm**	**TC Pos26 20cm**	**TC Pos26 40cm**	**TC Pos26 60cm**	**TC Pos26 80cm**	**TC Pos26 100cm**
0.0	22.1	21.7	21.2	21.1	21.6	21.5	21.3	20.8	20.8
5.0	219.1	208.0	197.0	201.6	201.5	165.1	135.7	122.9	113.7
10.0	207.7	198.4	191.2	195.0	196.0	176.0	147.8	139.3	131.3
15.0	157.4	155.1	150.8	150.9	152.5	133.6	124.6	119.7	114.2
20.0	80.8	80.2	79.9	79.2	79.4	77.6	73.9	72.4	70.9
25.0	65.1	65.2	64.6	64.1	64.7	64.7	62.6	60.3	58.8
Time (min)	**TC Pos26 140cm**	**TC Pos26 190cm**	**TC08mm Pos26 5cm**	**TC08mm Pos26 80cm**	**TC08mm Pos26 190cm**	**TC Pos27 5cm**	**TC Pos28 5cm**	**TC Pos29 5cm**	**TC Pos29 20cm**
0.0	20.2	19.0	21.2	20.5	19.7	21.5	21.9	22.1	21.5
5.0	90.3	55.9	189.5	118.0	51.1	188.8	182.5	180.4	182.2
10.0	113.9	83.2	188.1	137.7	81.9	182.6	181.9	178.3	178.0
15.0	99.6	74.9	154.3	119.9	76.3	146.2	144.2	141.6	141.0
20.0	66.4	53.8	81.3	73.9	55.0	78.3	78.2	77.4	77.4
25.0	56.4	47.8	65.1	60.6	48.4	63.4	64.2	64.0	64.1
Time (min)	**TC Pos29 40cm**	**TC Pos30 5cm**	**TC Pos31 5cm**	**TC Pos31 10cm**	**TC Pos31 20cm**	**TC Pos31 40cm**	**TC Pos31 60cm**	**TC Pos31 80cm**	**TC Pos31 100cm**
0.0	21.2	21.6	20.9	21.0	21.2	21.0	20.7	20.8	20.7

5.0	161.5	170.1	164.0	170.4	166.9	155.6	143.9	130.6	114.0
10.0	165.8	171.9	162.7	167.8	166.9	157.0	147.9	141.7	133.4
15.0	138.3	137.6	131.6	134.2	134.4	129.5	125.2	118.9	112.2
20.0	76.4	76.5	74.5	74.9	75.3	74.4	72.0	71.5	69.8
25.0	63.4	63.0	61.5	62.3	62.6	61.0	59.8	59.2	58.6

Time (min)	TC Pos31 140cm	TC Pos31 190cm	TC Pos32 5cm	TC Pos33 19cm	TC Pos33 6cm	Mass (kg)	TC Fuel	O2 Pos 11 80cm (vol-%)	Smoke Pos11 5cm
0.0	20.3	19.5	21.1	15.4	15.3	84.7	14.7	20.9	-
5.0	90.0	51.9	152.4	24.7	18.4	80.0	57.3	16.2	-
10.0	117.3	81.0	155.1	19.3	17.3	75.9	156.3	14.9	-
15.0	98.8	71.7	125.8	17.4	17.1	73.0	185.7	14.0	-
20.0	65.9	51.6	73.0	17.4	17.2	72.7	69.7	15.1	-
25.0	56.0	46.3	60.6	17.6	17.0	72.7	58.4	16.1	-

Time (min)	Smoke Pos11 20cm	Smoke Pos11 80cm	u Pos1 19cm (m/s)	u Pos1 6cm (m/s)	u Pos33 19cm (m/s)	u Pos33 6cm (m/s)			
0.0	-	-0.7	-0.7	-0.5	-0.4	-0.5			
5.0	-	2.0	-0.6	0.1	0.3	-0.3			
10.0	-	1.6	-1.4	-1.2	-1.3	-1.3			
15.0	-	1.0	-2.1	-1.9	-2.1	-2.1			
20.0	-	0.3	-0.9	-0.7	-0.9	-1.0			
25.0	-	0.6	-0.7	-0.4	-0.7	-0.9			

Test 6

Table A3.6 Experimental results at selected times for Test 6.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	15.8	15.3	22.5	23.1	23.9	24.0	24.1	23.7	23.4
5.0	26.1	19.9	300.0	321.9	311.4	285.9	278.3	247.7	211.8
10.0	28.0	18.8	328.4	318.2	303.3	275.4	272.4	240.9	215.4
15.0	22.9	18.9	299.2	293.7	283.9	249.0	251.1	217.8	203.7
18.0	19.7	17.6	128.0	130.9	131.5	131.9	141.0	130.7	125.1
25.0	18.8	17.3	76.5	77.7	78.5	78.6	80.1	78.5	76.8

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	23.2	23.1	22.8	22.9	22.6	22.2	21.5	21.6	23.3
5.0	211.9	205.1	195.0	132.1	119.9	105.1	78.7	51.9	203.7
10.0	220.5	217.6	213.5	178.5	149.4	128.2	106.4	80.9	205.5
15.0	208.6	207.0	206.8	163.1	150.4	133.0	112.8	83.0	201.6
18.0	123.0	119.8	114.3	112.0	108.8	102.9	87.2	61.9	134.9
25.0	76.5	76.1	75.4	73.7	70.6	67.8	62.7	53.5	78.9

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	22.7	21.5	23.3	23.2	23.1	23.1	23.2	23.0	22.9
5.0	113.7	49.4	186.1	199.3	198.4	191.4	183.6	176.2	178.1
10.0	146.9	79.3	202.5	211.1	195.2	207.0	198.7	189.3	190.7
15.0	151.0	84.9	193.3	202.4	182.2	195.7	193.0	187.3	187.2
18.0	117.1	67.2	120.7	118.0	113.5	116.9	114.6	114.5	115.9
25.0	72.9	54.6	75.5	75.6	75.6	74.4	72.9	70.5	71.6

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	22.8	23.0	22.7	22.4	22.1	21.9	21.2	23.0	22.9
5.0	177.8	184.8	136.3	110.8	103.9	74.3	46.7	173.8	185.5
10.0	189.7	190.8	161.9	134.2	128.8	108.6	77.7	185.9	195.9
15.0	186.0	185.5	158.9	137.0	132.5	115.0	83.5	185.0	192.5
18.0	117.6	114.1	109.0	105.7	99.3	87.8	64.3	123.9	126.3
25.0	71.7	70.0	66.7	63.2	61.4	60.3	51.9	71.3	72.6

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	22.6	21.3	22.9	22.7	22.8	22.7	22.6	22.5	22.4
5.0	107.6	42.1	170.8	178.3	168.6	172.0	171.1	165.7	149.0
10.0	134.4	74.5	186.8	189.6	176.8	180.9	182.3	172.9	162.1
15.0	139.5	82.9	183.1	180.9	169.9	178.3	178.6	171.7	162.4
18.0	112.3	66.9	113.9	114.0	108.2	111.0	110.3	108.1	104.9
25.0	64.7	52.4	67.6	68.2	68.1	67.9	68.1	67.6	65.6

Time (min)	TC Pos16	TC Pos16	TC Pos16	TC Pos16	TC Pos16	TC Pos16 100cm	TC Pos16	TC Pos16 190cm	TC Pos17 5cm

	10cm	20cm	40cm	60cm	80cm		140cm		
0.0	22.3	22.3	22.2	22.3	22.0	21.9	21.3	19.7	21.8
5.0	154.6	155.7	137.6	131.3	122.1	106.4	84.0	42.3	141.4
10.0	166.0	165.1	159.7	145.4	140.6	127.9	115.9	76.6	155.7
15.0	163.9	165.0	154.6	146.6	141.5	131.9	121.1	81.9	152.1
18.0	105.3	106.2	105.4	102.3	100.6	97.5	89.0	60.9	100.8
25.0	65.6	66.1	66.5	66.5	65.1	64.9	63.4	52.2	64.8

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	23.6	23.2	23.3	23.3	23.1	23.1	23.8	23.7	23.2
5.0	532.6	826.4	464.0	466.2	375.0	289.1	278.2	250.7	164.8
10.0	572.4	699.0	427.0	442.4	342.5	287.9	284.1	264.2	187.3
15.0	474.3	622.2	386.8	392.0	330.0	274.5	261.0	235.7	180.5
18.0	153.5	158.2	147.7	159.8	139.6	138.8	129.4	122.9	115.3
25.0	87.1	86.6	86.8	90.6	82.5	82.7	78.7	76.3	74.2

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	22.7	22.4	22.5	22.0	22.2	23.7	23.4	22.2	23.4
5.0	143.2	124.6	116.5	103.5	79.1	278.6	122.0	78.0	255.6
10.0	165.7	146.6	135.1	118.9	89.7	286.3	145.5	90.6	266.0
15.0	166.0	150.3	138.8	122.1	91.3	270.5	151.2	94.0	247.4
18.0	110.5	106.2	103.0	89.4	67.1	151.6	115.8	72.8	128.1
25.0	71.8	70.0	68.1	63.0	54.7	84.2	71.9	56.4	78.3

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	23.2	22.8	22.6	22.4	22.8	22.5	22.5	22.2	22.3
5.0	226.6	205.9	187.7	188.9	190.0	163.2	132.4	124.0	110.2
10.0	240.2	217.7	205.2	203.7	204.5	185.6	158.0	144.2	132.0
15.0	224.9	212.0	200.7	199.0	194.7	174.2	154.6	144.2	133.1
18.0	120.8	116.1	113.4	112.9	113.6	109.7	106.0	103.2	99.0
25.0	76.4	75.2	74.0	73.3	72.3	70.8	70.8	70.2	68.2

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	21.7	20.2	22.7	21.8	21.1	22.4	22.4	22.5	22.6
5.0	79.9	52.2	182.6	118.8	49.8	179.4	173.8	170.2	172.6
10.0	106.9	82.0	199.1	140.3	79.7	194.4	184.2	182.2	181.4
15.0	115.2	86.7	198.2	144.4	86.4	186.4	181.4	176.8	177.0
18.0	85.6	62.1	123.4	109.7	65.3	110.3	109.6	109.1	109.5
25.0	58.2	52.0	74.5	70.8	52.7	70.6	68.1	67.7	67.9

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	22.6	22.4	22.3	22.3	22.5	22.3	22.0	22.2	22.2
5.0	155.2	162.7	145.1	150.6	150.5	139.3	128.7	120.7	111.3

10.0	169.5	174.8	160.7	164.3	163.6	153.8	143.8	138.1	130.4
15.0	158.8	172.1	157.3	161.5	161.9	155.6	145.8	139.6	134.2
18.0	108.5	107.7	103.0	104.3	104.5	103.0	101.1	99.8	96.7
25.0	68.0	68.1	65.5	65.8	66.1	65.9	66.3	65.7	63.7
Time (min)	**TC Pos31 140cm**	**TC Pos31 190cm**	**TC Pos32 5cm**	**TC Pos33 19cm**	**TC Pos33 6cm**	**Mass (kg)**	**TC Fuel**	**O2 Pos 11 80cm (vol-%)**	**Smoke Pos11 5cm**
0.0	21.8	20.8	22.6	16.9	16.5	83.6	14.7	20.9	-
5.0	82.6	45.7	134.6	17.5	16.6	79.8	54.8	17.8	-
10.0	115.1	79.1	145.4	28.1	19.0	75.9	182.9	15.8	-
15.0	119.3	85.6	150.3	18.2	17.2	72.7	192.5	14.2	-
18.0	87.9	60.9	100.3	18.2	17.2	72.0	107.4	13.8	-
25.0	62.6	53.3	64.8	17.4	16.6	71.9	61.8	15.6	-
Time (min)	**Smoke Pos11 20cm**	**Smoke Pos11 80cm**	**u Pos1 19cm (m/s)**	**u Pos1 6cm (m/s)**	**u Pos33 19cm (m/s)**	**u Pos33 6cm (m/s)**			
0.0	-	0.0	-0.8	-0.5	-0.5	-0.7			
5.0	-	1.8	-0.8	-0.6	-0.5	-0.8			
10.0	-	1.7	-1.2	-0.8	-0.9	-1.1			
15.0	-	2.2	-1.7	-1.3	-1.5	-1.6			
18.0	-	1.9	-1.4	-1.0	-1.2	-1.4			
25.0	-	3.6	-0.8	-0.2	-0.6	-0.7			

Test 7

Table A3.7 Experimental results at selected times for Test 7.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	14.3	14.1	18.9	18.9	19.0	19.1	19.0	19.0	19.1
5.0	16.2	15.2	135.9	144.2	256.3	125.7	130.4	102.1	97.2
10.0	15.8	14.8	148.3	167.9	315.7	146.1	146.8	112.5	105.6
15.0	16.2	14.9	144.2	157.7	299.5	139.5	143.2	111.6	104.6
20.0	15.9	14.9	146.9	160.6	333.8	140.5	140.8	107.7	102.2
25.0	15.7	14.7	144.5	148.5	288.0	139.0	135.7	108.3	98.7

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	18.9	18.8	18.7	18.3	18.1	17.7	17.3	16.9	18.8
5.0	95.9	84.0	51.7	45.2	40.0	33.9	27.1	25.4	90.5
10.0	102.8	80.8	58.4	54.6	49.9	45.7	37.1	28.6	101.6
15.0	101.7	86.5	60.5	57.2	52.9	50.0	42.3	32.2	100.4
20.0	99.1	82.9	63.2	59.2	57.0	52.9	45.6	33.5	98.2
25.0	96.1	79.1	62.6	59.0	57.9	55.2	47.1	33.7	94.7

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	18.0	16.9	19.0	19.0	18.8	19.0	19.2	18.9	18.9
5.0	39.3	28.3	92.8	76.0	50.0	88.5	84.4	79.5	78.3
10.0	50.8	32.0	98.1	80.6	56.6	93.6	86.5	86.8	84.0
15.0	53.9	35.2	98.8	82.3	58.9	92.3	88.9	85.5	84.2
20.0	57.2	36.3	97.7	81.3	61.2	92.1	91.4	86.8	84.9
25.0	58.3	36.3	93.5	78.0	60.8	86.8	85.7	83.9	82.1

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	18.8	19.1	19.0	18.4	18.0	17.5	17.1	19.0	18.9
5.0	70.0	51.7	39.4	36.9	29.9	23.8	21.8	75.9	71.4
10.0	76.9	57.0	49.5	47.1	41.1	33.1	26.0	84.2	79.3
15.0	78.6	60.1	52.2	50.8	46.4	39.4	29.1	85.0	80.1
20.0	77.5	61.3	55.1	54.7	51.3	43.9	31.5	85.4	80.3
25.0	75.7	60.8	55.9	54.5	52.5	45.8	32.7	82.4	77.5

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	18.6	17.2	19.0	18.9	19.1	19.0	19.0	19.0	19.0
5.0	31.5	21.6	81.5	75.9	72.4	69.6	54.7	68.7	59.4
10.0	45.4	26.2	87.6	81.0	75.2	74.5	59.7	74.7	66.7
15.0	48.7	28.8	84.4	82.0	78.4	75.3	61.6	76.8	67.4
20.0	52.2	31.4	86.4	84.8	78.7	75.6	62.3	77.6	69.5
25.0	52.9	32.7	84.2	82.4	76.3	74.7	61.7	75.7	68.5

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	18.9	18.9	18.8	18.7	18.6	18.4	17.5	17.1	18.9
5.0	60.6	60.6	51.6	47.1	33.8	28.2	22.8	20.8	54.3
10.0	67.4	66.5	57.9	53.6	45.6	40.3	31.7	24.9	57.9
15.0	68.6	69.1	61.2	56.7	49.6	45.9	38.2	28.3	60.4
20.0	70.1	70.0	64.2	59.2	52.2	50.3	43.0	30.4	63.7
25.0	69.6	69.1	63.1	59.4	53.0	50.6	44.3	31.1	64.2

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	19.6	19.6	19.2	19.1	19.1	19.3	19.8	19.7	19.3
5.0	100.6	102.8	89.5	91.3	87.9	82.5	89.4	87.4	49.3
10.0	113.6	119.2	101.9	102.9	97.4	91.4	96.7	92.9	55.3
15.0	113.0	114.8	100.1	103.6	99.6	94.2	97.8	93.2	57.6
20.0	111.1	114.8	101.8	103.0	100.6	92.1	98.9	88.3	60.7
25.0	105.4	108.0	96.5	98.8	94.2	87.8	93.4	88.4	61.3

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	18.8	18.6	18.3	17.6	17.7	19.8	19.0	17.8	19.9
5.0	40.3	36.1	32.4	26.0	24.1	78.6	32.8	23.9	82.0
10.0	50.1	46.9	42.4	35.0	28.7	89.3	45.9	29.3	88.4
15.0	52.5	51.3	48.6	40.3	32.0	92.3	50.1	32.4	90.5
20.0	56.4	54.7	52.1	44.5	33.5	91.7	53.5	34.1	92.1
25.0	56.9	56.4	53.2	46.3	33.8	88.6	55.4	34.5	88.0

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	19.4	19.2	19.3	19.3	19.6	19.4	18.7	18.6	18.4
5.0	78.1	78.5	74.4	76.6	75.6	51.4	41.7	34.3	30.4
10.0	84.9	83.4	82.4	83.3	80.6	54.3	51.1	45.2	41.2
15.0	86.4	85.3	83.9	84.5	83.2	56.2	54.0	49.8	46.1
20.0	87.4	86.6	82.9	84.2	83.8	65.7	54.7	52.5	51.3
25.0	83.4	82.0	80.4	81.7	80.7	60.0	56.3	54.3	52.0

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	17.8	16.9	19.2	18.3	17.5	19.5	19.8	19.7	19.4
5.0	24.4	20.9	68.0	32.2	21.5	71.1	69.8	69.2	66.9
10.0	33.6	25.7	77.4	44.8	26.4	79.9	75.6	75.1	72.5
15.0	39.7	28.8	79.3	49.0	29.6	82.2	77.9	78.1	74.5
20.0	43.9	31.5	80.6	52.2	32.1	81.9	79.1	77.9	76.7
25.0	45.2	32.6	78.0	53.7	33.3	77.9	74.7	73.7	74.8

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	19.1	19.8	19.2	19.1	19.1	18.9	18.9	19.0	18.7

5.0	53.7	64.6	57.7	58.6	59.5	50.1	46.8	33.8	28.5
10.0	58.1	70.1	63.4	64.0	63.8	55.6	52.9	44.4	40.1
15.0	60.3	75.9	65.6	67.0	66.0	58.7	55.6	49.1	45.8
20.0	59.7	75.4	67.4	68.6	67.1	59.7	58.6	53.1	49.0
25.0	60.6	71.7	64.8	66.1	67.3	60.8	57.9	53.3	50.5

Time (min)	TC Pos31 140cm	TC Pos31 190cm	TC Pos32 5cm	TC Pos33 19cm	TC Pos33 6cm	Mass (kg)	TC Fuel	O2 Pos 11 80cm (vol-%)	Smoke Pos11 5cm
0.0	18.1	18.3	20.6	15.1	14.9	61.4	13.3	21.0	0.0
5.0	23.7	21.8	54.7	15.2	15.0	60.8	29.0	20.5	0.5
10.0	32.3	25.7	60.0	15.5	15.1	60.0	54.9	19.7	0.9
15.0	38.0	28.7	61.4	15.2	14.9	59.3	88.2	19.5	0.9
20.0	42.5	31.1	63.6	15.2	15.0	58.6	151.2	19.4	1.0
25.0	43.8	31.9	63.7	15.2	14.9	57.9	161.1	19.1	1.1

Time (min)	Smoke Pos11 20cm	Smoke Pos11 80cm	u Pos1 19cm (m/s)	u Pos1 6cm (m/s)	u Pos33 19cm (m/s)	u Pos33 6cm (m/s)			
0.0	0.0	0.0	-0.6	-0.4	-0.5	-0.6			
5.0	0.0	0.0	-0.7	-0.4	-0.4	-0.6			
10.0	0.2	0.0	-0.9	-0.7	-0.7	-0.8			
15.0	0.5	0.3	-0.8	-0.6	-0.6	-0.8			
20.0	0.9	0.4	-0.9	-0.7	-0.8	-0.9			
25.0	0.9	0.5	-0.8	-0.6	-0.7	-0.9			

Test 8

Table A3.8 Experimental results at selected times for Test 8.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	14.4	14.2	20.6	20.5	21.0	20.9	20.9	20.6	20.7
5.0	30.2	23.2	403.0	533.1	949.8	463.8	451.0	293.9	240.1
10.0	28.6	19.8	419.5	538.0	967.8	460.3	437.6	294.9	249.2
15.0	23.6	18.9	372.2	463.9	750.9	352.4	361.1	254.4	227.5
20.0	18.1	16.5	132.8	132.2	140.4	125.6	141.4	119.5	115.8

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	20.3	20.1	19.9	19.8	19.4	19.2	18.5	18.2	20.5
5.0	232.5	207.7	143.9	131.8	123.7	112.5	85.8	70.0	238.5
10.0	234.6	198.3	163.2	149.4	142.5	134.5	120.2	85.5	248.3
15.0	216.2	190.8	159.7	145.1	139.8	131.7	120.2	84.7	224.8
20.0	111.7	106.8	101.2	99.2	96.9	91.8	79.0	56.1	125.5

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	19.4	18.3	20.6	20.3	20.1	20.3	20.3	20.3	20.1
5.0	124.3	75.9	217.7	197.6	136.6	217.2	209.4	195.4	194.0
10.0	145.0	92.2	226.0	196.7	155.0	218.3	216.2	209.8	208.8
15.0	141.4	89.6	208.7	203.5	151.5	200.7	197.7	187.7	187.6
20.0	104.6	61.8	110.2	104.3	99.7	107.0	105.1	103.6	104.0

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	20.0	20.2	20.1	19.5	19.0	18.9	18.5	20.2	20.1
5.0	181.1	149.6	121.0	114.6	105.6	76.5	48.7	194.5	186.3
10.0	193.3	168.6	148.7	135.1	128.8	119.9	74.3	209.4	194.5
15.0	180.3	159.8	144.4	133.3	128.3	117.6	82.2	190.9	183.2
20.0	103.9	100.8	97.9	93.0	90.7	81.9	62.6	112.3	111.8

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	19.8	18.6	20.1	20.0	20.0	20.0	20.0	20.0	20.0
5.0	109.0	46.9	191.1	185.7	172.1	172.5	137.8	169.0	151.5
10.0	133.6	72.1	211.0	201.0	187.4	182.3	155.6	186.8	171.0
15.0	132.6	82.4	185.1	182.7	171.7	170.8	149.7	172.1	157.8
20.0	99.9	67.7	102.8	101.6	99.0	99.8	98.1	97.3	95.0

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	19.9	19.8	19.8	19.6	19.4	18.9	18.6	18.0	19.5
5.0	155.8	158.2	145.7	129.8	124.5	104.3	71.2	46.2	135.7
10.0	172.3	169.0	148.2	143.0	140.6	133.3	112.1	80.1	153.0

15.0	160.9	162.3	150.3	140.4	137.4	128.6	111.3	80.2	150.0
20.0	94.2	94.9	94.4	93.3	92.2	90.7	81.0	56.5	88.2

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	21.1	21.0	20.9	20.9	20.9	20.4	20.8	20.8	20.6
5.0	274.0	288.8	248.0	249.8	231.7	199.8	218.0	215.7	169.0
10.0	274.5	276.1	232.6	242.4	225.6	201.9	215.5	214.9	186.3
15.0	254.1	263.7	232.5	237.9	225.3	199.4	214.9	208.3	166.6
20.0	114.0	115.4	115.9	126.0	112.8	111.9	109.9	107.2	102.6

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	19.7	18.9	18.8	18.7	19.0	21.1	20.1	19.1	20.5
5.0	128.9	113.0	103.3	80.6	57.7	198.5	106.2	57.2	203.2
10.0	150.0	142.7	131.8	115.2	81.5	204.8	138.9	82.6	203.7
15.0	142.6	137.7	133.3	115.5	84.4	202.1	137.7	86.6	202.6
20.0	99.3	95.7	93.3	81.2	61.1	123.4	103.5	65.3	106.8

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	20.7	20.5	20.1	20.0	20.4	20.3	20.0	19.6	19.3
5.0	188.6	190.0	181.3	187.2	193.2	169.8	123.1	116.3	105.0
10.0	194.6	189.3	181.8	189.0	192.4	164.3	142.9	135.2	127.2
15.0	191.0	186.6	178.3	184.6	183.8	151.1	138.0	135.0	126.9
20.0	104.4	102.9	102.3	102.5	102.9	99.7	96.4	92.7	89.2

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	18.7	18.3	19.9	19.3	18.8	20.2	20.7	20.6	20.2
5.0	76.9	48.9	173.8	107.8	47.9	178.0	171.4	170.9	171.9
10.0	111.2	81.5	180.7	130.9	77.9	182.9	173.5	172.1	175.1
15.0	113.5	83.4	175.8	132.5	83.3	177.1	170.7	170.1	169.5
20.0	80.5	57.6	110.3	99.1	61.7	100.6	99.4	98.8	98.7

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	20.0	20.4	20.0	20.1	20.1	20.0	19.7	19.8	19.7
5.0	133.8	165.2	148.9	152.0	149.7	138.5	128.7	121.8	105.3
10.0	162.4	169.2	155.2	160.3	161.5	154.2	142.2	136.3	128.6
15.0	148.6	166.0	152.0	154.7	154.5	148.2	139.9	135.9	127.2
20.0	97.4	95.7	93.8	94.2	95.1	93.6	93.1	91.5	88.3

Time (min)	TC Pos31 140cm	TC Pos31 190cm	TC Pos32 5cm	TC Pos33 19cm	TC Pos33 6cm	Mass (kg)	TC Fuel	O2 Pos 11 80cm (vol-%)	Smoke Pos11 5cm
0.0	19.4	19.1	20.3	15.0	14.8	83.5	14.1	21.0	0.0
5.0	69.9	46.9	137.3	20.2	15.7	80.3	35.2	17.0	2.3
10.0	113.1	78.4	148.8	25.2	16.5	76.6	102.4	14.8	2.9

15.0	113.0	79.7	146.0	18.9	16.0	73.8	184.4	13.3	3.3
20.0	78.8	52.4	91.5	16.8	16.2	72.4	96.6	13.3	3.8

Time (min)	**Smoke Pos11 20cm**	**Smoke Pos11 80cm**	**u Pos1 19cm (m/s)**	**u Pos1 6cm (m/s)**	**u Pos33 19cm (m/s)**	**u Pos33 6cm (m/s)**			
0.0	0.0	0.0	-0.7	-0.4	-0.4	-0.6			
5.0	1.5	0.0	-0.5	0.1	-0.3	-0.5			
10.0	2.8	1.8	-0.8	-0.6	-0.6	-0.9			
15.0	3.6	2.5	-0.9	-0.7	-0.7	-1.0			
20.0	4.3	0.9	-1.3	-1.0	-1.1	-1.3			

Test 9

Table A3.9 Experimental results at selected times for Test 9.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	14.3	13.9	19.2	19.2	19.5	19.6	19.4	19.4	19.4
5.0	39.7	28.2	395.4	519.5	997.1	497.9	473.7	304.3	253.6
10.0	38.2	22.6	398.6	507.2	898.1	493.1	469.4	331.5	276.7
15.0	27.5	18.4	350.8	435.6	820.5	419.0	408.9	277.8	240.9
20.0	17.6	15.9	122.7	122.2	130.5	119.3	131.1	114.2	110.9
25.0	16.9	15.4	79.7	78.9	82.2	78.4	81.1	75.8	75.5

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	19.2	19.1	18.8	18.8	18.5	18.1	17.6	17.8	19.1
5.0	242.3	207.3	149.2	136.3	128.0	116.7	88.5	72.8	241.1
10.0	257.8	209.3	171.4	154.8	147.3	139.4	123.9	91.0	264.1
15.0	232.2	206.3	162.9	149.8	144.6	136.6	125.0	91.0	239.9
20.0	107.9	103.3	97.7	92.5	90.7	87.1	78.5	57.4	119.5
25.0	73.3	70.5	66.7	64.8	64.0	61.6	57.9	48.6	78.3

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	18.5	17.6	19.3	19.2	19.0	19.2	19.4	19.0	18.9
5.0	128.4	78.5	227.2	199.3	142.0	218.2	211.8	208.2	203.3
10.0	149.2	97.5	246.9	199.6	162.4	237.6	231.6	223.8	218.5
15.0	146.6	96.0	223.8	204.7	157.8	216.1	206.7	198.5	197.4
20.0	98.3	62.5	106.1	100.2	95.2	102.6	101.3	100.2	99.6
25.0	66.5	50.0	72.9	68.8	65.8	71.7	70.5	70.4	70.0

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	18.9	19.2	19.2	18.6	18.2	17.8	17.7	19.0	19.0
5.0	183.2	156.0	126.9	118.3	108.4	75.4	47.0	199.4	187.7
10.0	197.9	173.2	147.5	138.2	132.5	123.9	77.5	219.2	201.0
15.0	182.4	159.9	145.3	136.3	131.4	122.3	86.6	200.4	186.1
20.0	97.9	94.5	91.6	88.9	86.5	80.4	61.5	107.0	104.5
25.0	68.6	66.1	64.5	63.3	63.1	58.7	50.7	73.1	70.4

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	18.7	17.8	19.1	19.1	19.3	19.1	19.1	19.2	19.3
5.0	112.1	44.1	208.2	196.0	179.5	173.8	139.3	175.6	152.7
10.0	136.3	73.2	221.1	210.9	196.8	189.3	154.1	191.7	170.6
15.0	136.4	86.6	198.7	191.0	176.9	174.7	150.4	174.4	164.0
20.0	95.7	67.9	98.7	97.2	94.7	94.8	91.3	93.4	92.0
25.0	66.3	53.6	69.5	69.0	68.0	67.5	64.2	68.0	65.8

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	19.2	19.1	18.9	19.0	18.7	18.5	17.8	17.5	19.0
5.0	156.8	157.8	143.6	131.7	127.1	108.9	71.3	44.7	138.3
10.0	173.8	174.7	156.2	147.4	144.1	138.2	117.4	81.1	157.0
15.0	164.9	164.1	148.1	143.3	141.8	135.7	116.7	85.8	152.2
20.0	91.2	91.3	91.8	89.6	88.3	84.8	77.2	55.6	88.6
25.0	66.0	65.9	63.3	62.9	62.4	60.0	55.4	46.4	63.4

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	19.8	19.5	19.3	19.3	19.5	19.4	20.2	20.1	19.4
5.0	267.1	273.4	231.9	237.4	226.4	195.0	215.0	212.4	162.0
10.0	270.8	273.9	237.0	241.3	223.4	196.4	212.3	212.8	191.4
15.0	242.5	245.7	223.0	229.5	219.2	193.9	208.8	204.4	169.5
20.0	106.3	107.0	108.1	115.6	106.7	105.8	102.9	100.3	95.5
25.0	71.6	70.0	72.5	74.8	72.1	72.8	70.5	68.8	66.4

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	18.9	18.8	18.4	18.2	18.2	19.9	19.2	18.3	19.8
5.0	131.7	118.0	106.0	83.7	59.6	195.5	109.5	58.7	204.3
10.0	153.3	145.1	133.7	117.7	84.8	200.9	141.9	85.7	200.6
15.0	148.2	142.4	136.4	118.9	89.2	197.8	142.2	91.5	197.0
20.0	92.5	89.5	87.5	80.1	59.2	115.0	97.5	64.1	100.7
25.0	64.5	63.2	61.6	58.4	49.6	75.1	65.9	51.4	69.8

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	19.5	19.1	19.3	19.1	19.4	19.2	18.8	18.6	18.6
5.0	191.0	188.3	182.8	186.7	191.0	168.2	124.4	118.8	106.6
10.0	192.1	190.3	186.4	187.8	191.6	178.2	149.1	138.2	130.1
15.0	188.7	186.0	176.9	182.6	186.9	158.9	141.7	137.3	129.0
20.0	98.4	97.1	95.6	96.0	96.2	92.0	89.6	87.7	85.3
25.0	68.9	68.8	68.4	67.9	67.3	65.2	62.9	62.0	60.8

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	18.1	17.6	19.1	18.4	18.0	19.4	19.7	19.5	19.4
5.0	77.7	46.3	173.3	109.8	47.7	179.2	169.2	169.3	170.6
10.0	115.6	85.4	180.9	133.8	81.1	179.0	176.9	176.1	176.5
15.0	117.5	89.8	175.7	136.3	88.9	175.5	171.1	169.5	170.5
20.0	78.6	61.5	102.9	94.3	63.1	94.7	93.9	94.1	93.9
25.0	56.7	47.8	70.0	63.5	49.1	67.2	66.6	66.4	66.1

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	19.3	19.7	19.2	19.4	19.5	18.9	18.9	19.1	19.1

5.0	148.5	166.8	144.6	150.1	151.2	141.4	129.6	118.7	104.6
10.0	165.7	165.5	154.9	159.5	161.8	157.2	149.7	142.8	134.6
15.0	155.5	163.7	149.3	153.4	156.0	151.9	144.0	139.1	131.9
20.0	93.6	93.2	90.5	91.5	91.9	91.2	89.4	87.3	85.0
25.0	64.8	66.1	64.5	64.7	65.0	63.7	62.4	61.9	59.9
Time (min)	**TC Pos31 140cm**	**TC Pos31 190cm**	**TC Pos32 5cm**	**TC Pos33 19cm**	**TC Pos33 6cm**	**Mass (kg)**	**TC Fuel**	**O2 Pos 11 80cm (vol-%)**	**Smoke Pos11 5cm**
0.0	18.3	18.4	19.3	15.3	15.2	83.2	13.4	20.9	0.0
5.0	70.9	46.3	137.3	25.2	22.0	79.8	31.9	16.6	2.4
10.0	114.7	80.5	151.4	30.0	18.3	76.1	107.9	14.1	3.5
15.0	116.3	84.4	143.6	22.7	15.7	73.2	177.7	12.6	4.2
20.0	76.2	56.8	88.1	16.7	16.2	72.0	84.3	13.0	4.8
25.0	54.8	45.9	63.7	18.5	15.0	72.0	57.0	13.8	4.7
Time (min)	**Smoke Pos11 20cm**	**Smoke Pos11 80cm**	**u Pos1 19cm (m/s)**	**u Pos1 6cm (m/s)**	**u Pos33 19cm (m/s)**	**u Pos33 6cm (m/s)**			
0.0	0.0	0.0	-0.6	-0.4	-0.4	-0.6			
5.0	1.3	0.1	-0.6	-0.5	-0.5	-0.4			
10.0	2.9	2.1	-0.8	-0.6	-0.7	-0.9			
15.0	3.6	2.8	-0.9	-0.7	-0.9	-1.0			
20.0	4.2	0.7	-1.0	-0.8	-1.0	-1.1			
25.0	2.0	0.6	-0.5	-0.4	-0.3	-0.8			

Test 10

Table A3.10 Experimental results at selected times for Test 10.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	15.1	14.9	23.5	24.0	24.2	24.3	24.2	23.8	23.6
5.0	87.7	61.2	572.2	755.2	933.8	782.2	759.1	592.2	468.3
10.0	19.2	17.5	164.5	161.7	169.6	155.8	168.8	152.7	148.8
15.0	48.6	48.4	54.8	50.6	56.5	56.1	66.6	58.5	60.4
20.0	33.6	34.0	36.3	34.2	36.7	36.1	37.6	38.5	40.3
25.0	27.9	28.2	29.7	28.7	30.6	30.1	31.3	31.0	32.4

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	23.1	22.7	22.2	22.2	21.9	21.6	21.0	20.8	23.5
5.0	450.2	378.9	300.4	261.1	236.1	213.1	186.1	135.5	441.3
10.0	139.8	131.2	121.5	117.1	114.4	107.3	99.9	70.4	160.7
15.0	58.7	57.0	53.9	53.4	52.0	51.1	48.7	46.2	74.8
20.0	38.7	37.7	35.4	34.9	33.9	32.8	32.5	31.8	42.7
25.0	31.2	30.5	29.1	29.0	28.7	28.1	27.3	26.7	33.1

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	22.1	21.2	23.4	22.9	22.6	22.9	23.0	22.9	22.6
5.0	237.3	141.1	385.8	338.9	266.9	341.0	322.5	304.0	305.5
10.0	124.6	79.9	139.4	125.9	118.5	134.0	130.0	129.1	129.1
15.0	58.3	49.3	59.8	56.2	54.4	59.1	58.6	57.9	56.7
20.0	34.8	32.2	38.7	36.5	35.3	38.2	37.9	37.5	37.0
25.0	28.8	27.0	31.9	30.4	29.3	31.3	31.9	31.5	30.8

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	22.4	22.5	22.2	21.8	21.6	21.6	21.1	22.8	22.5
5.0	288.3	261.4	226.1	197.2	186.7	169.3	116.7	298.3	295.1
10.0	125.4	120.6	113.6	109.4	105.4	94.3	72.8	140.2	134.1
15.0	56.2	53.0	50.9	50.1	49.4	46.3	44.8	68.5	64.1
20.0	36.4	35.1	34.1	34.1	33.5	32.8	31.2	38.8	37.1
25.0	30.5	29.9	29.0	28.5	27.9	26.9	26.6	31.5	30.1

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	22.1	21.1	22.5	22.3	22.4	22.3	22.1	22.1	22.1
5.0	197.1	104.5	299.5	279.3	261.2	263.5	242.8	249.0	231.6
10.0	120.6	80.6	125.1	123.3	120.7	120.7	114.0	118.9	117.1
15.0	57.0	48.0	54.3	51.9	51.7	51.3	50.3	53.2	55.8
20.0	34.8	31.8	35.4	35.4	35.4	34.3	33.6	36.0	36.1
25.0	28.9	26.7	29.0	28.3	28.6	28.3	27.8	29.5	29.0

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	22.0	21.9	21.8	21.8	21.4	21.3	21.2	20.7	21.4
5.0	240.6	240.4	224.6	206.0	200.1	195.1	180.0	126.8	205.5
10.0	116.2	115.7	113.7	109.9	108.4	105.3	93.8	70.9	110.3
15.0	55.0	53.7	52.5	51.5	50.9	50.1	49.3	44.0	55.0
20.0	36.1	35.1	34.3	34.0	33.6	33.2	32.5	31.6	35.6
25.0	28.8	28.5	28.2	28.3	28.1	27.8	27.3	26.9	28.6

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	23.6	23.4	23.9	23.9	23.7	23.2	23.8	23.5	22.8
5.0	390.5	413.1	384.7	391.2	365.7	317.6	337.4	319.6	289.1
10.0	137.3	136.8	139.0	148.9	138.3	137.0	134.6	129.3	123.1
15.0	57.8	54.4	60.4	70.1	58.4	62.0	57.9	56.6	55.6
20.0	37.2	35.4	38.6	39.3	37.5	38.5	37.3	36.2	35.5
25.0	31.1	29.8	32.4	33.6	32.1	33.0	31.3	30.8	29.8

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	21.9	21.8	21.6	21.8	21.7	23.7	22.7	21.8	23.5
5.0	250.2	220.8	203.6	178.7	125.5	322.8	213.7	125.5	317.4
10.0	118.4	111.6	107.6	98.2	77.4	150.0	124.8	83.1	132.8
15.0	55.8	54.1	54.0	53.2	54.7	74.5	62.7	57.0	59.2
20.0	35.3	34.7	34.3	34.4	34.9	40.5	36.4	35.8	37.5
25.0	29.3	28.8	28.9	28.9	29.8	33.4	30.2	30.1	31.7

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	23.2	22.7	22.5	22.4	22.8	22.5	21.9	21.7	21.6
5.0	294.8	280.3	264.3	273.8	273.7	244.1	223.1	202.4	190.1
10.0	128.3	124.6	123.6	123.3	123.4	117.9	113.4	109.0	103.6
15.0	59.0	59.4	57.3	55.7	54.5	53.2	52.1	51.3	49.6
20.0	36.5	36.2	35.6	35.2	35.2	34.4	33.8	33.5	33.3
25.0	30.0	29.8	30.0	29.3	29.2	28.8	28.5	28.4	28.0

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	21.3	20.8	22.3	21.4	21.3	21.8	21.7	21.8	21.8
5.0	170.0	126.8	258.9	200.9	117.9	260.8	252.0	243.6	254.9
10.0	92.9	71.5	132.3	119.0	74.2	120.7	118.9	118.4	118.5
15.0	47.4	45.3	66.8	55.7	48.6	55.3	56.3	56.0	52.8
20.0	32.4	32.0	36.7	34.3	33.1	35.9	36.6	36.0	34.6
25.0	28.0	27.2	29.8	28.4	27.3	29.5	29.4	29.0	28.6

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	21.9	22.0	22.0	22.2	22.2	21.9	21.7	21.9	21.9

5.0	236.8	244.6	222.9	230.8	231.0	220.4	214.1	200.9	192.7
10.0	115.9	115.5	112.5	113.8	114.4	113.0	109.9	107.6	105.1
15.0	51.4	54.9	55.1	53.9	53.2	51.5	50.8	50.6	50.1
20.0	34.6	35.6	36.6	35.7	35.0	34.1	33.9	34.0	33.8
25.0	28.6	29.6	29.5	29.4	29.2	28.9	28.5	28.6	28.5
Time (min)	**TC Pos31 140cm**	**TC Pos31 190cm**	**TC Pos32 5cm**	**TC Pos33 19cm**	**TC Pos33 6cm**	**Mass (kg)**	**TC Fuel**	**O2 Pos 11 80cm (vol-%)**	**Smoke Pos11 5cm**
0.0	21.7	21.6	22.0	15.9	15.7	108.8	16.6	20.9	0.0
5.0	166.5	129.9	208.5	58.1	29.6	101.1	219.5	12.2	5.3
10.0	91.4	68.2	110.0	17.7	17.0	97.7	90.0	9.5	6.2
15.0	49.8	47.5	56.0	49.4	49.0	97.6	52.9	15.3	3.3
20.0	33.3	32.8	36.9	33.9	33.3	97.7	34.4	20.7	1.4
25.0	28.4	28.5	29.3	28.1	28.1	97.4	28.9	20.9	1.2
Time (min)	**Smoke Pos11 20cm**	**Smoke Pos11 80cm**	**u Pos1 19cm (m/s)**	**u Pos1 6cm (m/s)**	**u Pos33 19cm (m/s)**	**u Pos33 6cm (m/s)**			
0.0	0.0	0.0	-0.8	-0.6	-0.6	-0.7			
5.0	4.9	12.8	-0.2	-0.2	-0.5	-0.6			
10.0	5.6	5.0	-1.1	-0.9	-1.2	-1.2			
15.0	2.5	1.7	-0.5	0.5	-1.3	-1.7			
20.0	1.0	0.4	-0.5	0.5	-0.8	-1.4			
25.0	0.6	0.3	-0.5	0.5	0.7	0.8			

Test 11

Table A3.11 Experimental results at selected times for Test 11.

Time (min)	TC Pos1 19cm	TC Pos1 6cm	TC Pos2 5cm	TC Pos3 5cm	TC Pos4 5cm	TC Pos5 5cm	TC08mm Pos5 5cm	TC Pos6 5cm	TC Pos7 5cm
0.0	15.0	14.5	22.3	23.0	24.1	24.4	24.2	24.4	23.8
5.0	49.2	23.9	1025.5	661.4	431.4	336.2	316.7	280.0	264.6
10.0	51.1	18.8	1002.4	619.7	411.7	322.0	315.8	282.1	268.7
15.0	18.4	16.1	196.8	190.4	186.7	172.4	189.7	165.6	160.7
20.0	41.5	40.0	45.3	44.3	49.5	50.4	53.6	53.1	57.2
25.0	31.6	31.3	35.1	33.5	36.8	35.3	36.6	35.9	37.9

Time (min)	TC Pos7 10cm	TC Pos7 20cm	TC Pos7 40cm	TC Pos7 60cm	TC Pos7 80cm	TC Pos7 100cm	TC Pos7 140cm	TC Pos7 190cm	TC08mm Pos7 5cm
0.0	23.6	23.2	22.6	22.7	22.3	21.7	21.4	21.7	23.6
5.0	264.8	226.8	162.6	149.7	140.8	131.4	105.5	81.0	254.0
10.0	268.6	236.8	187.5	172.0	164.4	156.0	139.7	107.3	263.5
15.0	154.4	142.9	136.1	132.2	129.6	123.5	111.6	75.2	178.6
20.0	51.6	48.6	46.1	46.0	45.2	43.8	42.3	39.1	59.7
25.0	35.5	33.8	32.0	32.1	31.8	32.1	31.9	31.2	38.7

Time (min)	TC08mm Pos7 80cm	TC08mm Pos7 190cm	TC Pos8 5cm	TC Pos8 20cm	TC Pos8 40cm	TC Pos9 5cm	TC Pos10 5cm	TC Pos11 5cm	TC Pos11 10cm
0.0	22.2	21.8	23.4	23.1	22.9	23.0	23.0	22.8	22.5
5.0	139.8	88.0	251.5	204.2	152.8	240.8	235.8	215.1	217.1
10.0	165.0	110.5	257.9	226.1	174.6	253.1	247.9	231.1	229.8
15.0	138.0	86.2	153.2	138.9	133.8	146.3	143.7	139.3	139.4
20.0	47.2	40.3	49.9	47.7	45.5	49.3	47.5	48.7	47.9
25.0	32.6	31.5	35.6	33.9	32.2	35.4	35.4	35.4	34.2

Time (min)	TC Pos11 20cm	TC Pos11 40cm	TC Pos11 60cm	TC Pos11 80cm	TC Pos11 100cm	TC Pos11 140cm	TC Pos11 190cm	TC08mm Pos11 5cm	TC08mm Pos11 20cm
0.0	22.4	22.5	22.3	21.9	21.7	21.7	21.1	22.7	22.5
5.0	189.0	154.0	136.8	130.1	121.7	98.4	62.5	217.2	195.4
10.0	207.8	174.4	159.6	152.6	146.8	140.0	99.6	232.2	214.6
15.0	137.4	131.7	127.0	124.3	120.0	108.5	85.3	156.7	152.7
20.0	48.6	44.5	42.2	42.6	41.4	40.1	39.0	55.8	50.4
25.0	34.0	33.1	32.5	32.7	32.3	30.9	31.1	36.9	34.9

Time (min)	TC08mm Pos11 80cm	TC08mm Pos11 190cm	TC Pos12 5cm	TC Pos13 5cm	TC Pos14 5cm	TC Pos14 20cm	TC Pos14 40cm	TC Pos15 5cm	TC Pos16 5cm
0.0	22.1	21.2	22.4	22.4	22.5	22.4	22.3	22.3	22.1
5.0	125.2	57.6	222.3	204.6	189.2	187.9	152.5	177.7	160.0
10.0	152.3	97.4	228.1	215.0	199.2	200.4	176.4	191.9	176.2
15.0	132.4	89.7	133.0	131.2	127.5	130.3	129.5	125.5	123.3
20.0	45.9	41.7	45.4	42.5	43.1	41.3	40.1	45.7	44.5
25.0	34.3	32.0	32.7	32.1	32.0	31.0	30.6	32.2	32.5

Time (min)	TC Pos16 10cm	TC Pos16 20cm	TC Pos16 40cm	TC Pos16 60cm	TC Pos16 80cm	TC Pos16 100cm	TC Pos16 140cm	TC Pos16 190cm	TC Pos17 5cm
0.0	22.1	22.1	22.0	22.1	21.9	21.7	21.6	21.0	21.6
5.0	163.4	166.2	160.7	141.6	137.0	129.5	96.3	58.7	146.3
10.0	179.6	184.1	179.0	163.8	160.3	156.6	133.5	102.0	163.0
15.0	123.1	124.4	125.2	124.9	123.3	118.9	111.7	80.0	121.0
20.0	42.8	41.3	40.5	40.2	40.3	39.9	39.6	36.3	45.7
25.0	32.1	31.3	30.9	30.6	30.4	30.2	29.9	28.5	32.2

Time (min)	TC Pos18 5cm	TC Pos19 5cm	TC Pos20 5cm	TC08mm Pos20 5cm	TC Pos21 5cm	TC Pos22 5cm	TC Pos22 10cm	TC Pos22 20cm	TC Pos22 40cm
0.0	23.6	23.4	23.7	23.7	23.6	22.8	23.5	23.3	22.8
5.0	325.0	326.9	288.5	292.0	273.0	228.6	251.4	230.2	176.7
10.0	334.2	323.3	280.1	287.0	265.6	232.5	247.4	239.6	215.0
15.0	160.1	160.0	157.6	176.4	152.3	147.9	147.6	144.5	138.6
20.0	50.2	46.2	51.0	54.8	50.0	53.8	49.4	47.6	45.7
25.0	36.0	34.0	37.1	38.4	36.1	37.1	35.6	34.3	33.1

Time (min)	TC Pos22 60cm	TC Pos22 80cm	TC Pos22 100cm	TC Pos22 140cm	TC Pos22 190cm	TC08mm Pos22 5cm	TC08mm Pos22 80cm	TC08mm Pos22 190cm	TC Pos23 5cm
0.0	22.4	22.0	21.9	22.1	22.1	23.5	23.1	22.0	23.0
5.0	152.4	137.2	123.0	105.8	76.2	222.3	129.0	73.8	228.2
10.0	176.0	165.0	153.1	136.5	104.4	231.8	162.8	106.1	232.1
15.0	135.2	128.5	121.7	112.6	84.7	165.1	137.3	91.7	144.6
20.0	44.0	42.6	42.0	41.0	42.2	58.7	48.2	44.7	52.3
25.0	32.4	31.6	31.5	31.5	31.8	39.0	33.8	32.7	36.8

Time (min)	TC Pos24 5cm	TC Pos25 5cm	TC Pos26 5cm	TC Pos26 10cm	TC Pos26 20cm	TC Pos26 40cm	TC Pos26 60cm	TC Pos26 80cm	TC Pos26 100cm
0.0	23.3	23.1	22.6	22.4	22.9	22.4	21.9	21.9	22.0
5.0	214.6	210.0	194.6	206.7	211.8	171.7	142.3	127.8	123.0
10.0	220.1	213.3	200.6	208.3	216.9	207.8	175.3	162.1	149.1
15.0	140.6	137.3	136.2	137.1	139.2	134.5	130.7	123.9	120.1
20.0	52.9	51.8	51.0	49.2	47.6	46.5	44.7	44.7	43.5
25.0	36.4	37.0	36.9	34.9	34.1	33.5	32.9	32.7	31.9

Time (min)	TC Pos26 140cm	TC Pos26 190cm	TC08mm Pos26 5cm	TC08mm Pos26 80cm	TC08mm Pos26 190cm	TC Pos27 5cm	TC Pos28 5cm	TC Pos29 5cm	TC Pos29 20cm
0.0	22.0	21.2	22.5	21.7	21.5	22.0	22.0	22.0	22.1
5.0	94.8	63.4	191.7	124.2	61.7	196.0	190.5	186.3	187.2
10.0	133.3	105.7	201.3	159.4	102.9	201.3	198.4	193.8	197.7
15.0	107.8	80.9	151.1	133.3	87.9	134.2	133.3	132.4	132.0
20.0	41.6	40.5	54.1	46.1	42.1	49.2	49.6	46.7	43.8
25.0	31.3	30.7	37.4	33.1	31.5	35.6	35.0	33.1	32.1

Time (min)	TC Pos29 40cm	TC Pos30 5cm	TC Pos31 5cm	TC Pos31 10cm	TC Pos31 20cm	TC Pos31 40cm	TC Pos31 60cm	TC Pos31 80cm	TC Pos31 100cm
0.0	22.2	22.5	22.3	22.4	22.5	22.1	21.8	22.1	22.1

5.0	166.3	183.8	160.2	165.7	168.8	153.0	141.3	133.4	119.5
10.0	191.3	191.0	175.9	179.6	183.3	175.1	161.9	159.1	150.5
15.0	132.4	129.3	124.3	125.3	127.4	127.5	126.9	122.7	118.6
20.0	42.8	44.6	43.2	42.2	41.6	41.1	40.8	40.5	40.0
25.0	31.6	32.6	32.9	32.6	32.3	31.8	31.3	31.3	31.2
Time (min)	**TC Pos31 140cm**	**TC Pos31 190cm**	**TC Pos32 5cm**	**TC Pos33 19cm**	**TC Pos33 6cm**	**Mass (kg)**	**TC Fuel**	**O2 Pos 11 80cm (vol-%)**	**Smoke Pos11 5cm**
0.0	22.1	22.0	22.4	16.2	16.0	83.8	15.4	20.9	0.0
5.0	95.6	60.2	155.0	34.2	24.4	79.2	236.5	15.4	3.6
10.0	135.2	102.4	170.7	40.7	17.7	74.8	243.1	12.6	4.6
15.0	105.2	74.6	122.8	17.8	16.6	72.3	160.9	10.6	5.1
20.0	39.7	39.8	42.9	40.0	39.8	72.2	43.1	19.6	2.0
25.0	31.1	30.8	32.8	31.0	30.7	72.2	32.3	20.8	1.3
Time (min)	**Smoke Pos11 20cm**	**Smoke Pos11 80cm**	**u Pos1 19cm (m/s)**	**u Pos1 6cm (m/s)**	**u Pos33 19cm (m/s)**	**u Pos33 6cm (m/s)**			
0.0	0.0	0.0	-0.8	-0.6	-0.6	-0.7			
5.0	2.8	0.1	-0.4	-0.1	0.3	-0.4			
10.0	4.1	4.0	-0.5	-0.3	-0.1	-0.6			
15.0	4.5	9.4	-1.7	-1.5	-1.6	-1.6			
20.0	1.6	0.8	7.2	6.9	-0.4	-0.7			
25.0	0.9	0.4	6.7	6.7	0.0	-1.0			

Appendix 4 Simulation setup: The base scenario

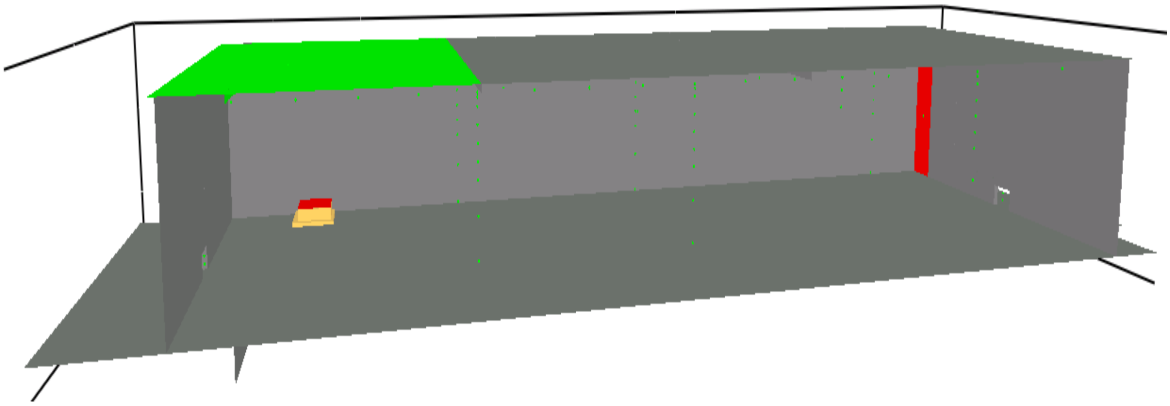

Figure A4.1 *The geometrical setup, the green is the insulation board, the red in the short wall is the door.*

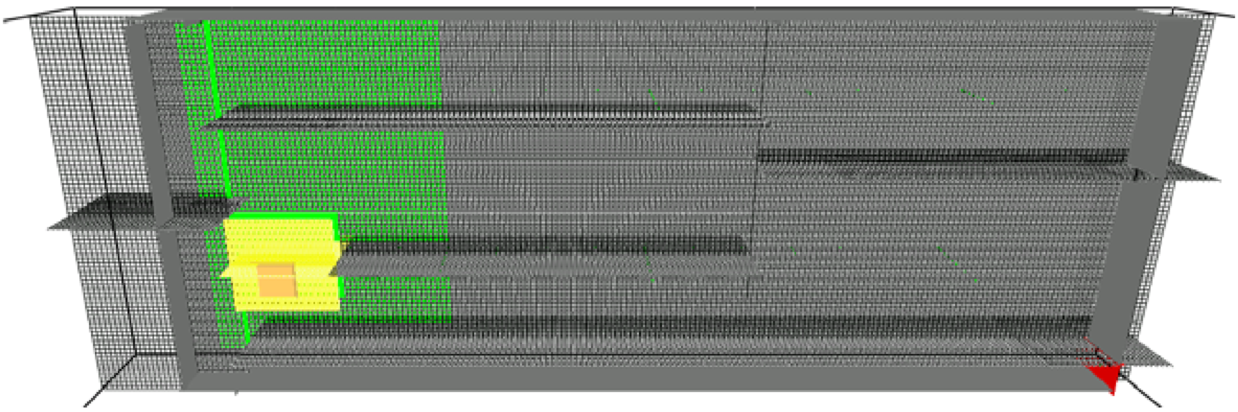

Figure A4.2 *The mesh setup seen from below, the horizontal thick lines are the different meshes.*

Appendix 5 Simulation results for Case 7

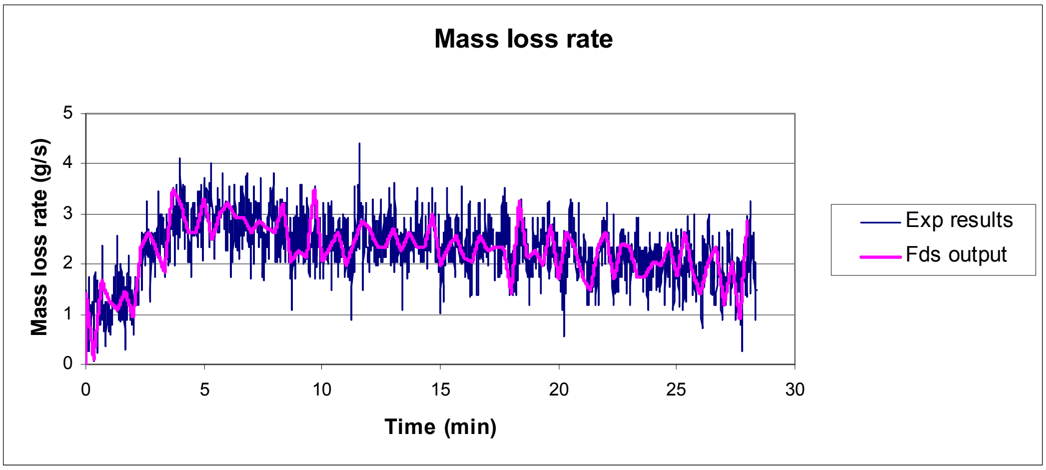

Figure A5.1 Mass loss rate comparison for Case 7.

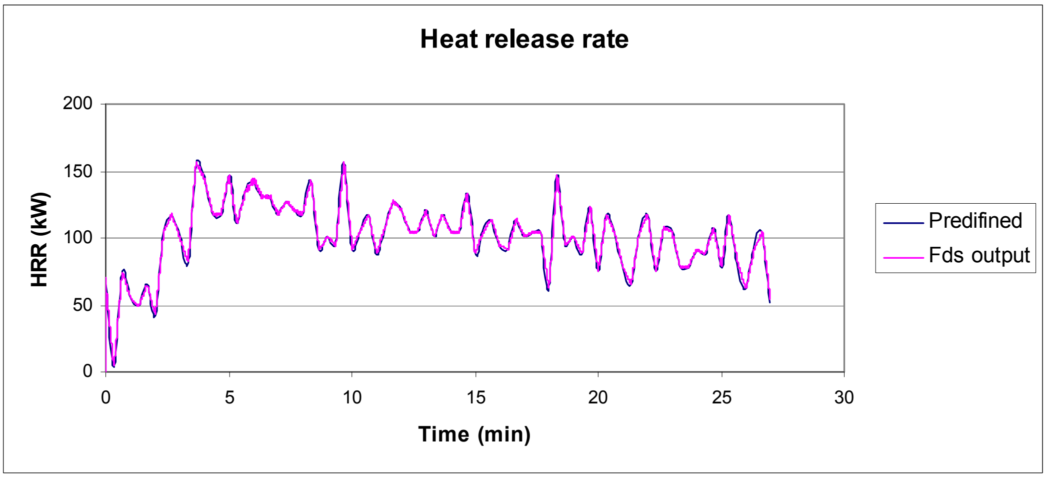

Figure A5.2 Heat release rate comparison for Case 7.

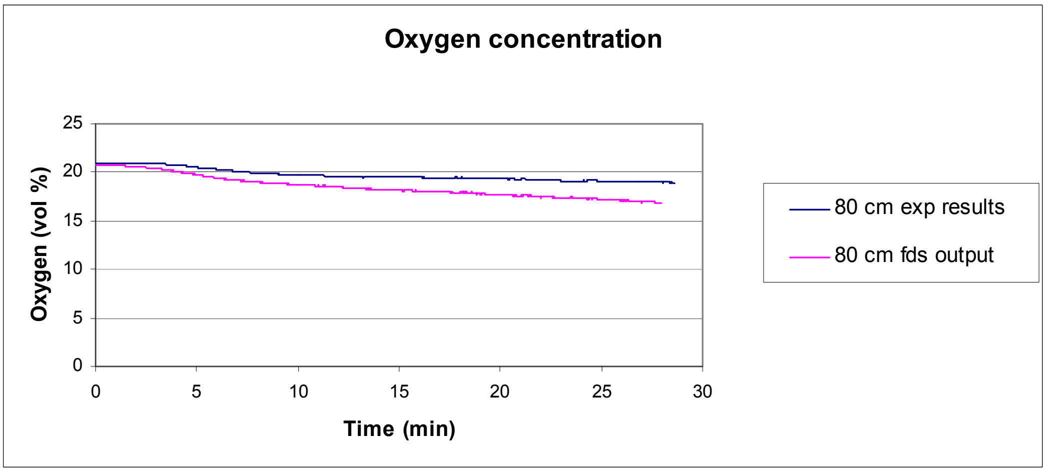

Figure A5.3 Oxygen concentration comparison for Case 7.

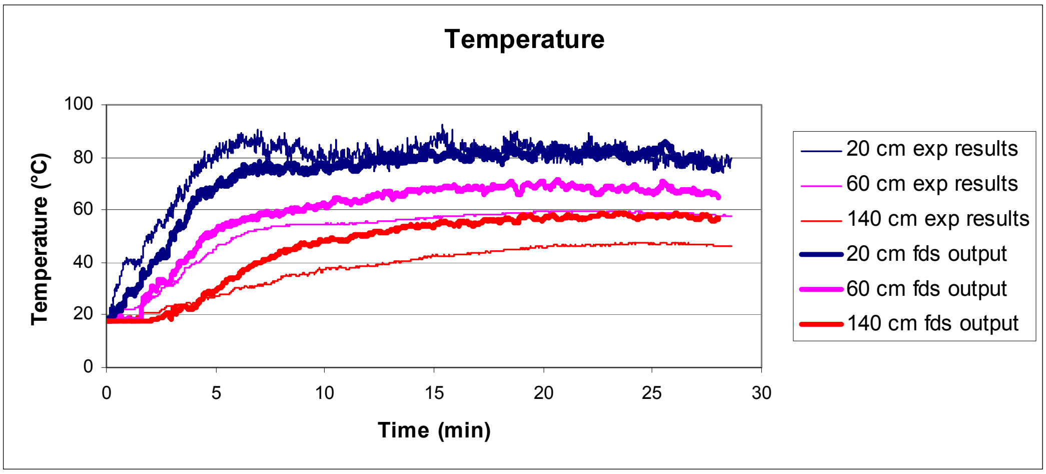

Figure A5.4 Temperature comparison Pos 7 for Case 7.

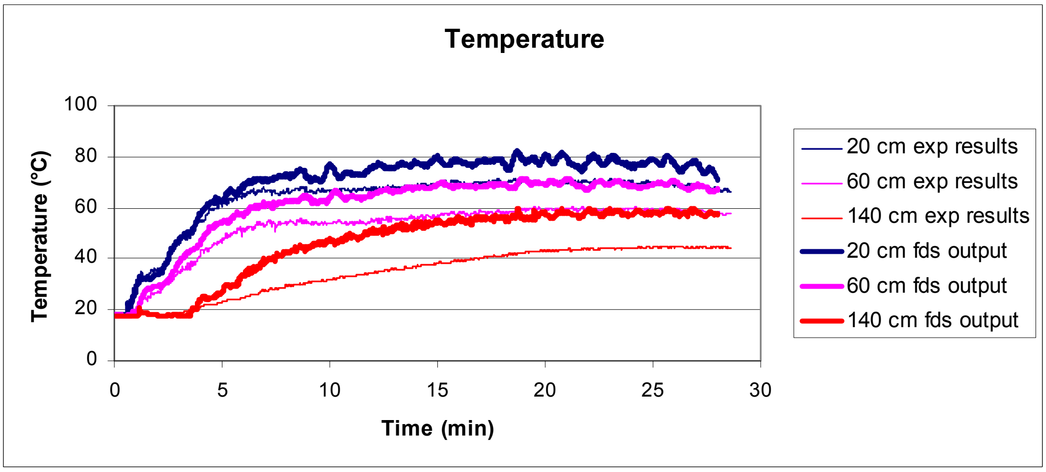

Figure A5.5 Temperature comparison Pos 16 for Case 7.

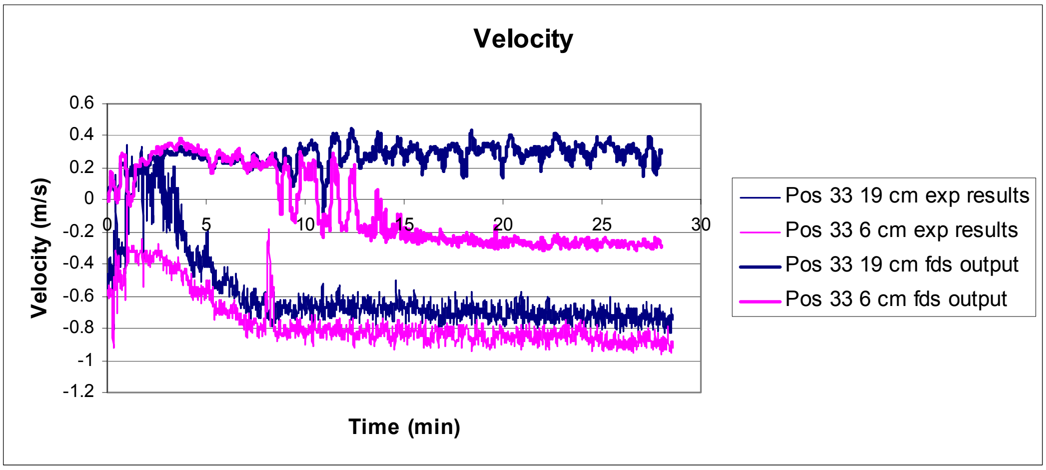

Figure A5.6 Velocity comparison Pos 33 for Case 7.

Appendix 6 Simulation results for Case 10

Case 10 is the reference case and in the following Appendices the cases compared to. It is referred to as the "base scenario".

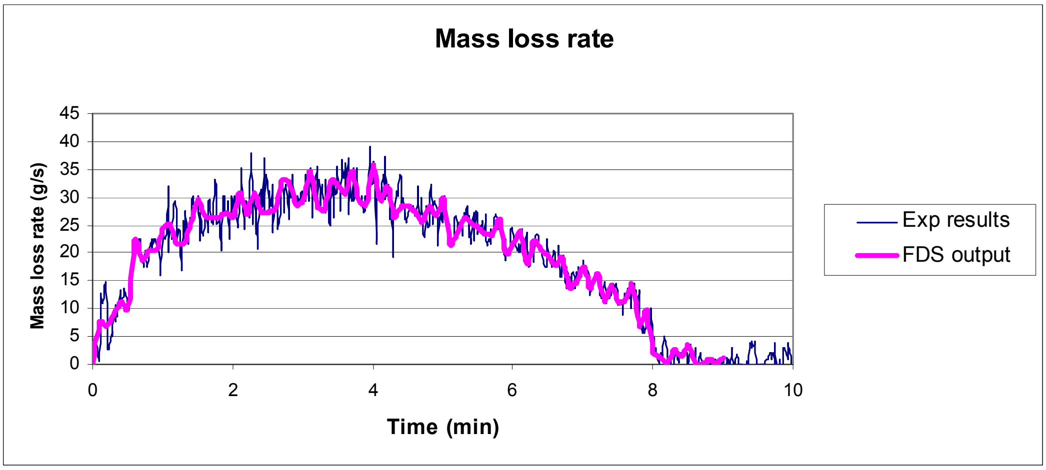

Figure A6.1 Mass loss rate comparison for Case 10.

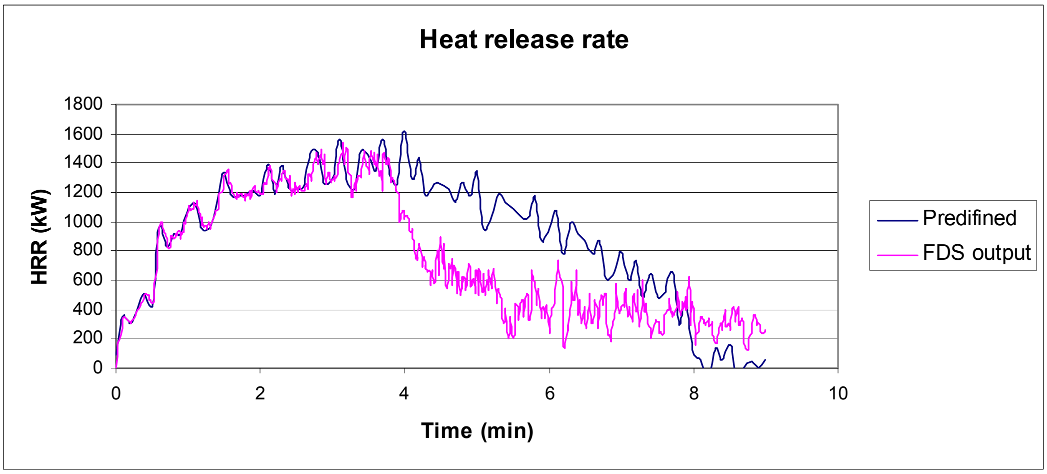

Figure A6.2 Heat release rate comparison for Case 10.

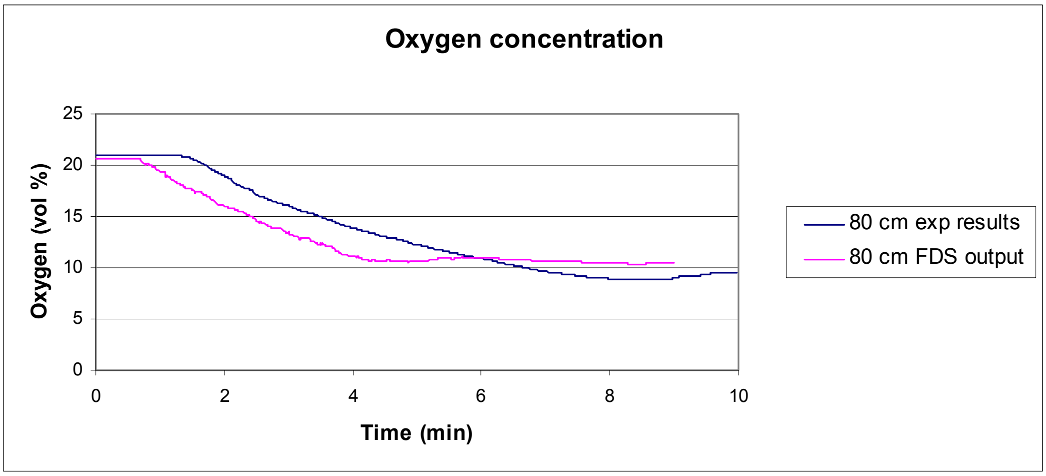

Figure A6.3 Oxygen concentration comparison for Case 10.

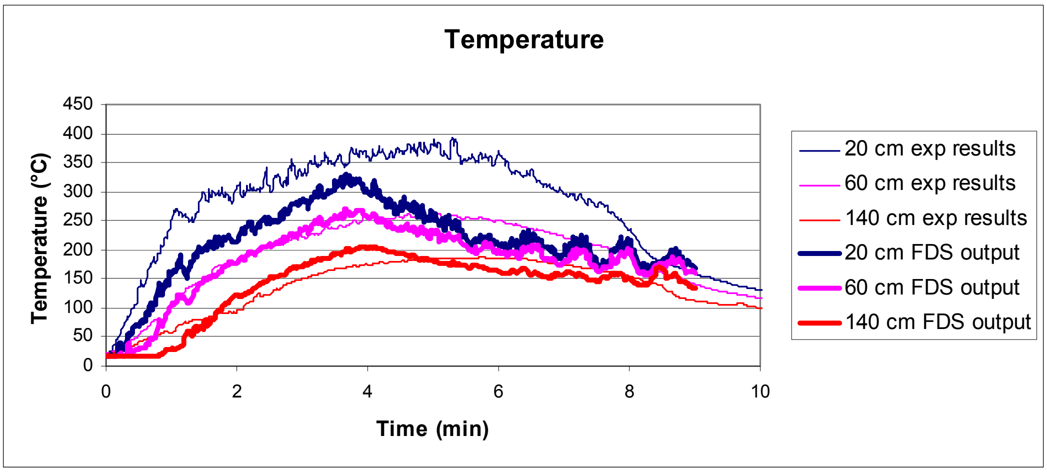

Figure A6.4 Temperature comparison Pos 7 for Case 10.

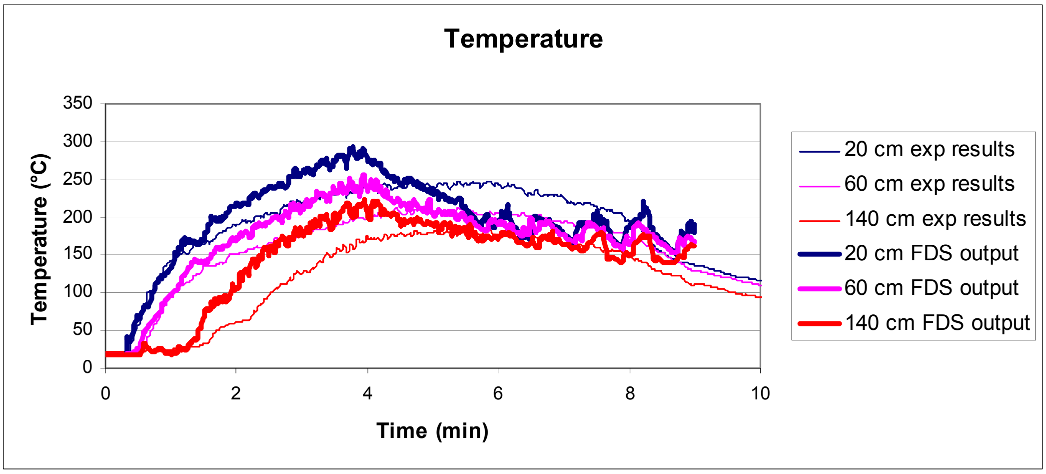

Figure A6.5 Temperature comparison Pos 16 for Case 10.

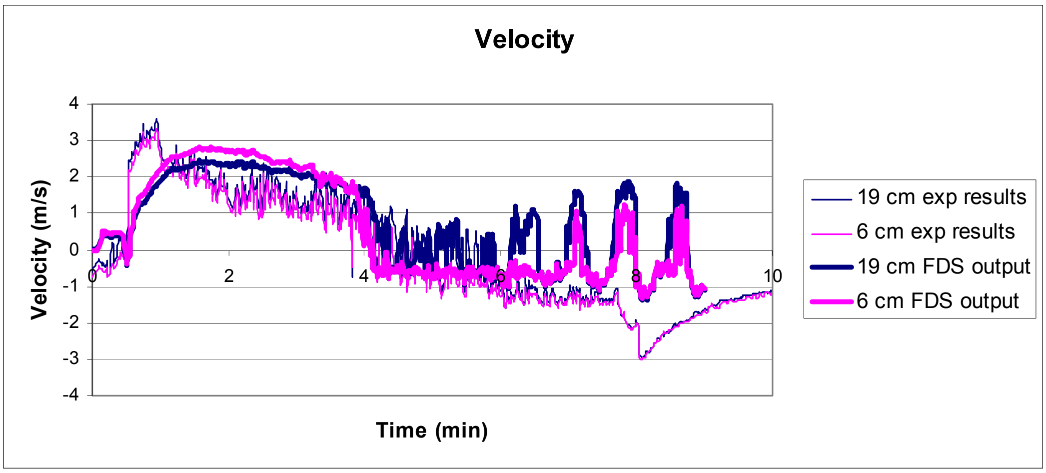

Figure A6.6 Velocity comparison Pos 33 for Case 10.

Appendix 7 Serial run vs. Base scenario

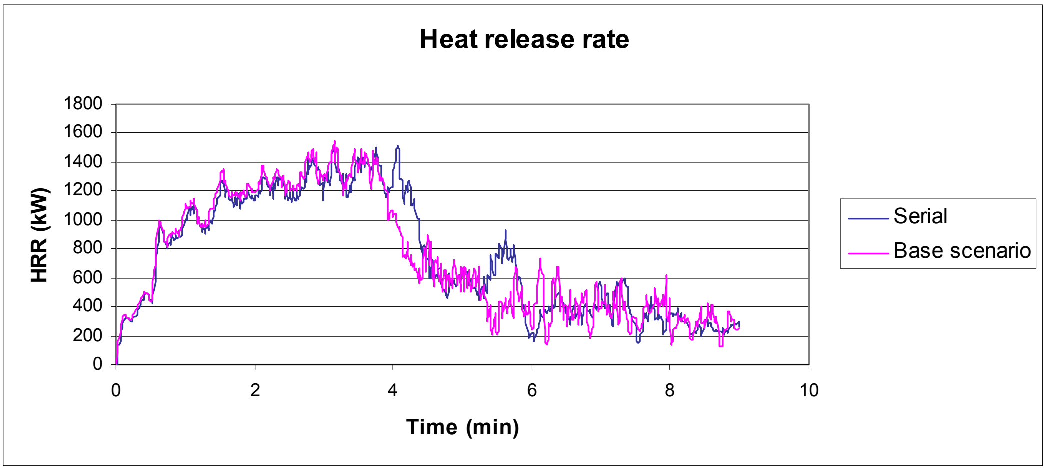

Figure A7.1 Heat release rate comparison for serial and parallel simulation.

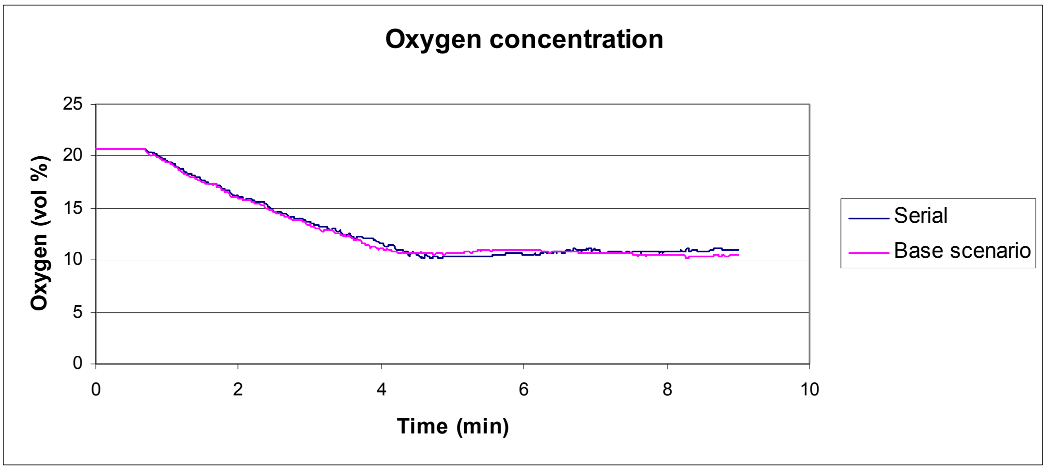

Figure A7.2 Oxygen concentration comparison for serial and parallel simulation (Pos 11).

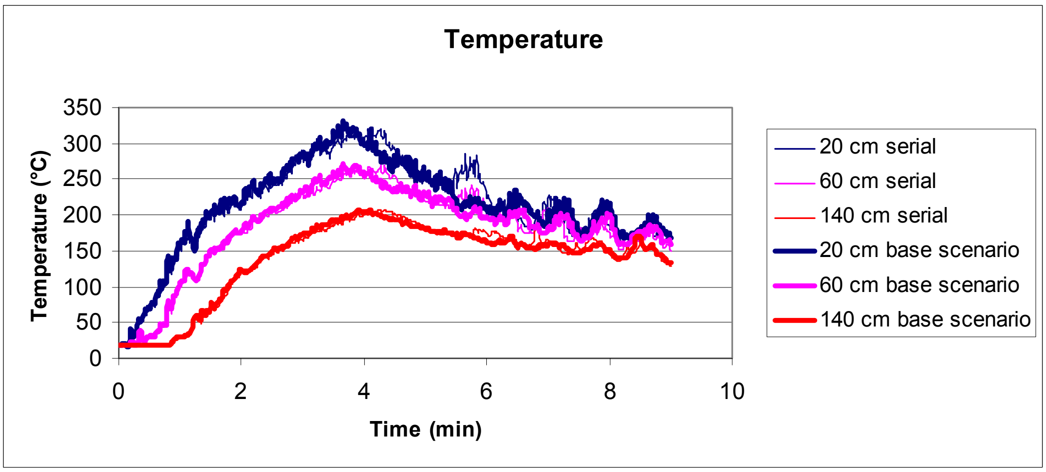

Figure A7.3 Temperature profiles comparison for serial and parallel simulation (Pos 7).

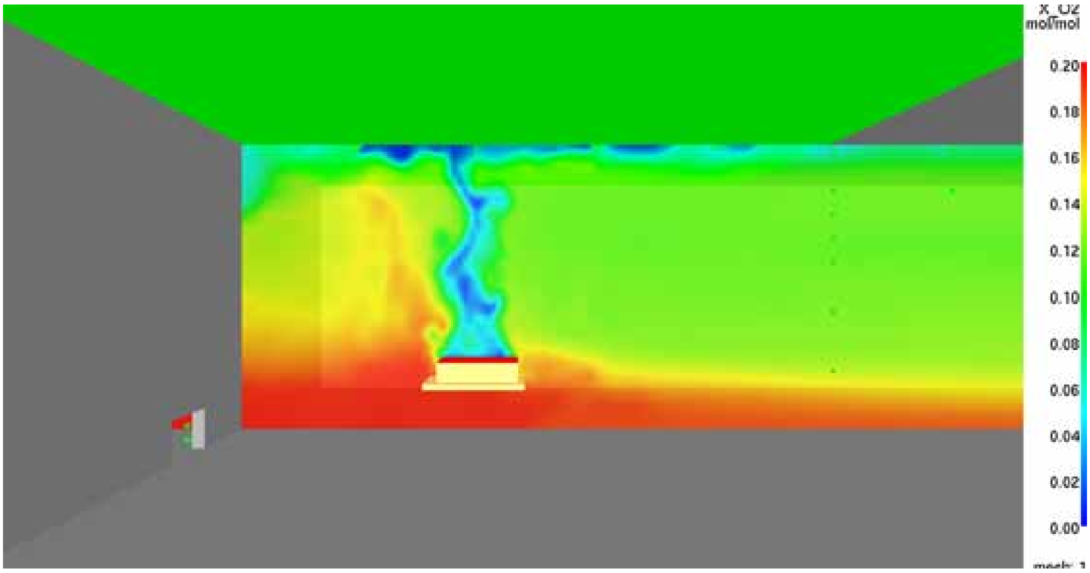

Figure A7.4 *Slice file for the O_2 profile for the serial simulation (through the fire; Time = 239 s).*

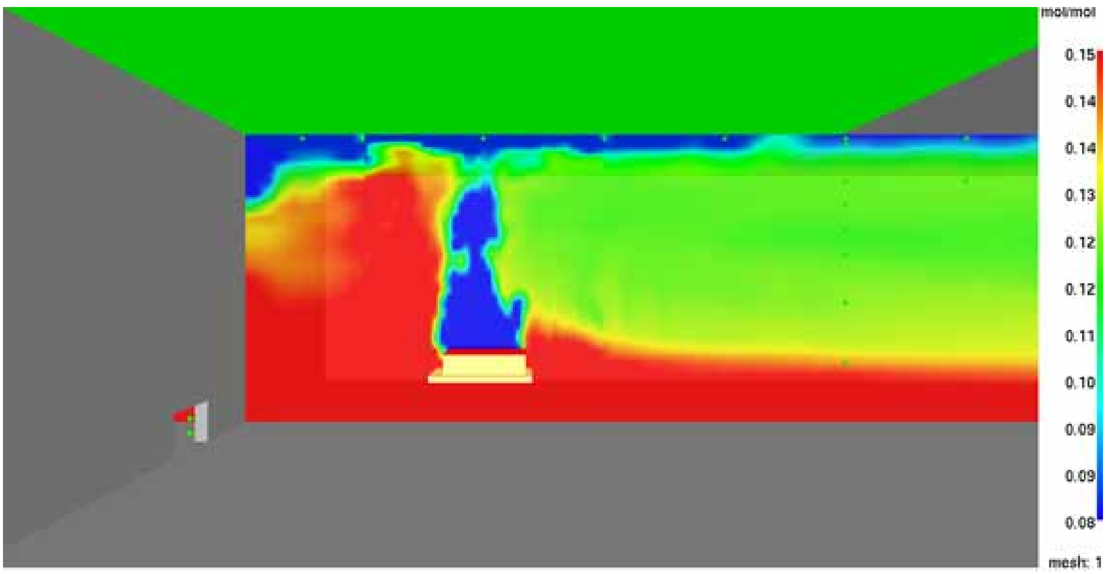

Figure A7.5 *Slice file for the O_2 profile for the base scenario (through the fire; Time = 240 s).*

Appendix 8 One fire mesh vs. Base scenario

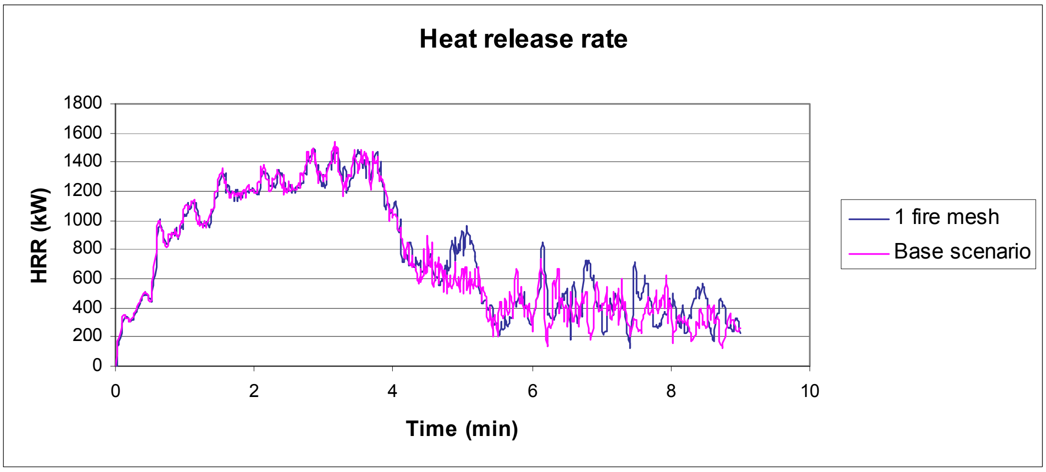

Figure A8.1 Heat release rate comparison for 1 fire mesh and the base scenario.

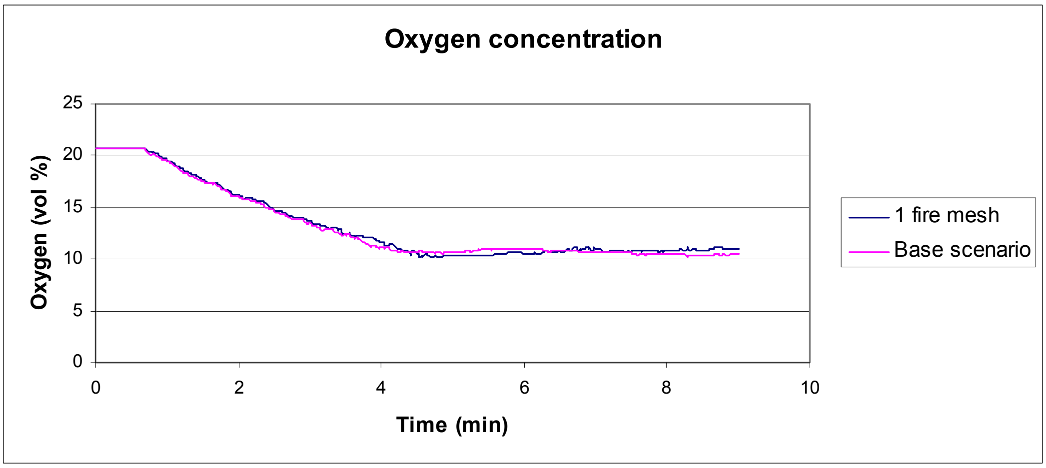

Figure A8.2 Oxygen concentration comparison for 1 fire mesh and the base scenario.

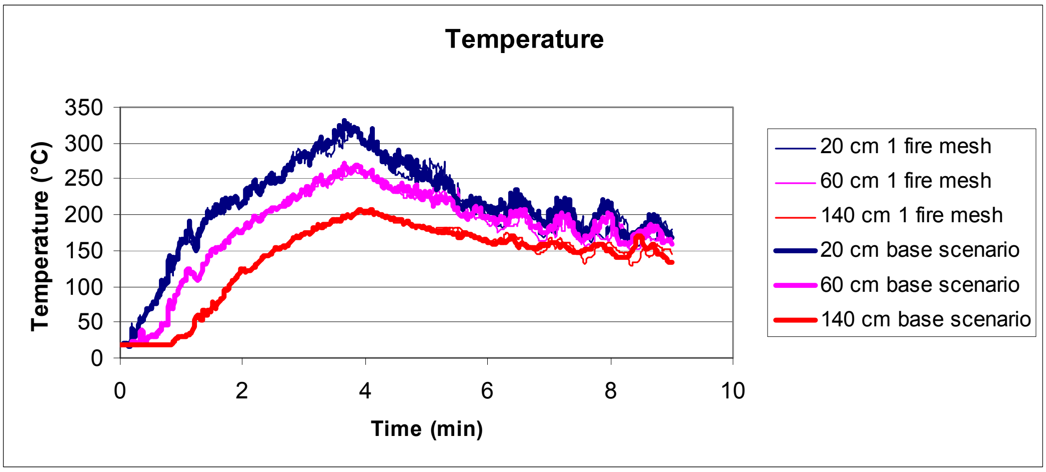

Figure A8.3 Temperature profile comparison for 1 fire mesh and the base scenario (Pos 7).

Appendix 9 Small fire mesh region vs. Base scenario

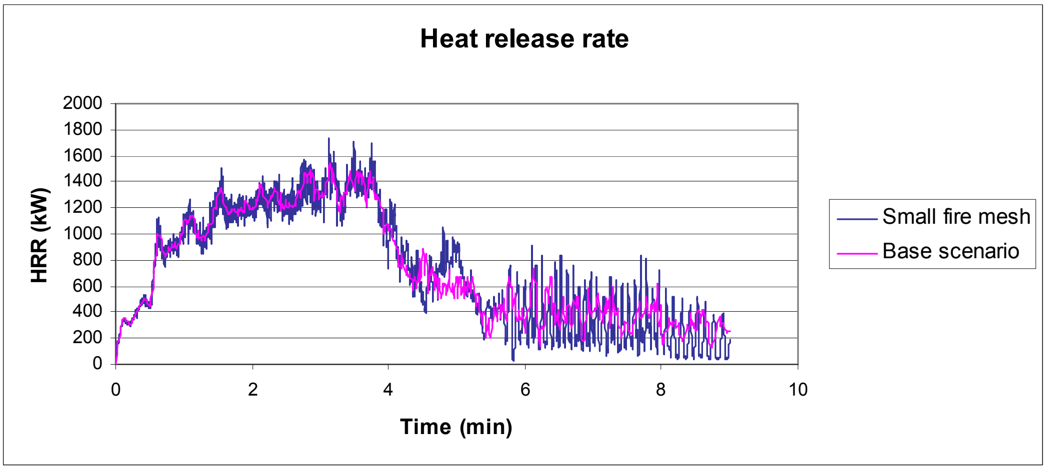

Figure A9.1 *Heat release rate comparison for the small fire mesh and the base scenario.*

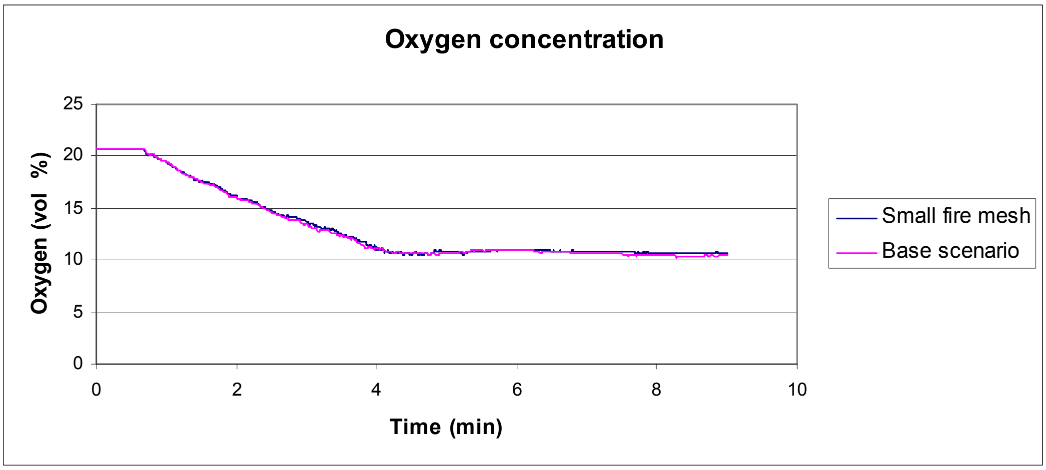

Figure A9.2 *Oxygen concentration comparison for the small fire mesh and the base scenario (Pos 11).*

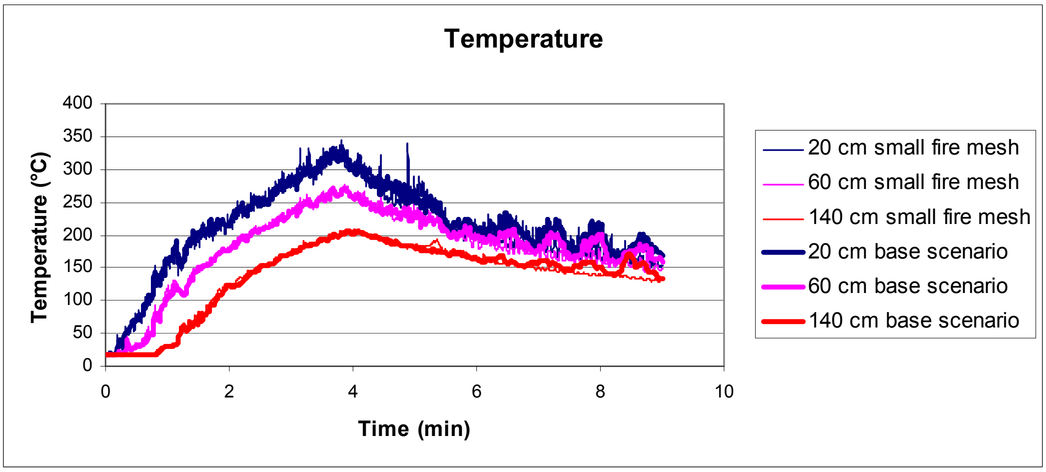

Figure A9.3 *Temperature profile comparison for the small fire mesh and the base scenario (Pos 7).*

Appendix 10 - Synchronized meshes vs. Base scenario

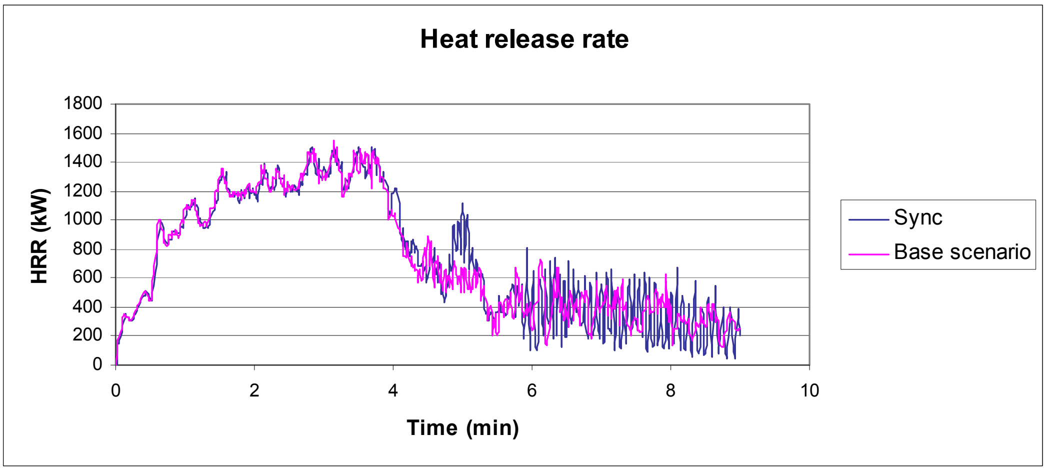

Figure A10.1 *Heat release rate comparison for the synchronized and the base scenario.*

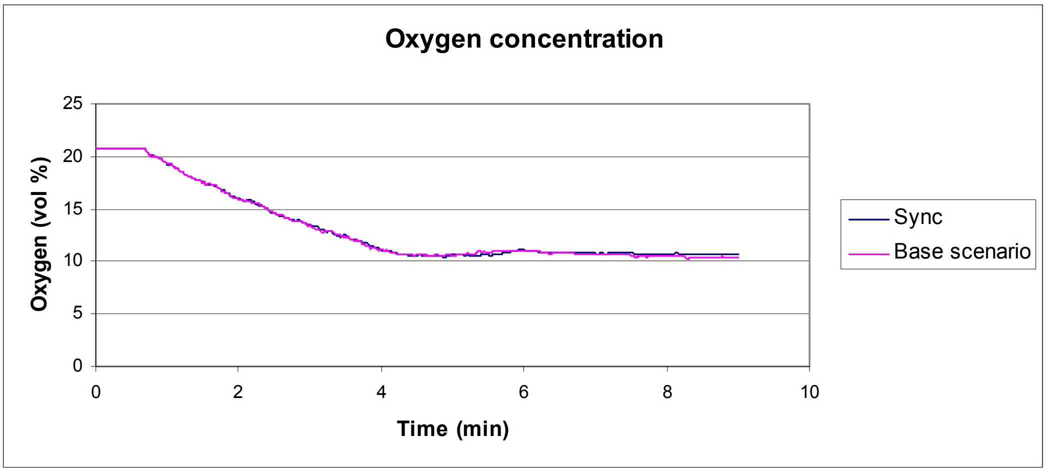

Figure A10.2 *Oxygen level comparison for the synchronized and the base scenario (Pos 11).*

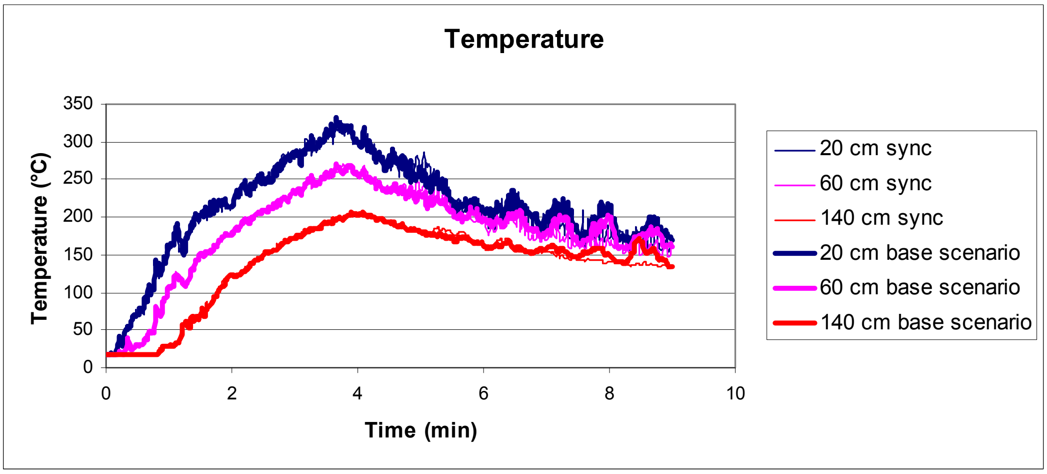

Figure A10.3 *Temperature profile comparison for the synchronized and the base scenario (Pos 7).*

Appendix 11 8n scenario vs. base scenario

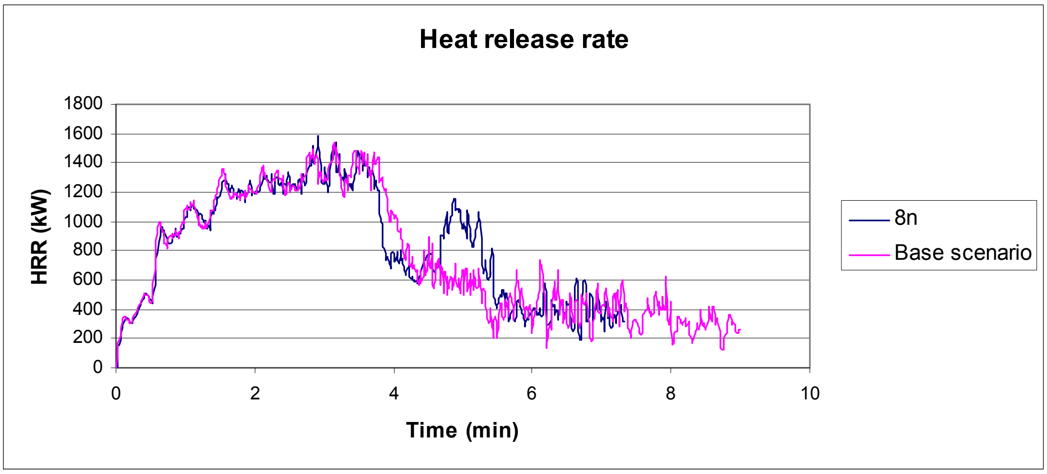

Figure A11.1 Heat release rate comparison for the 8n scenario and the base scenario.

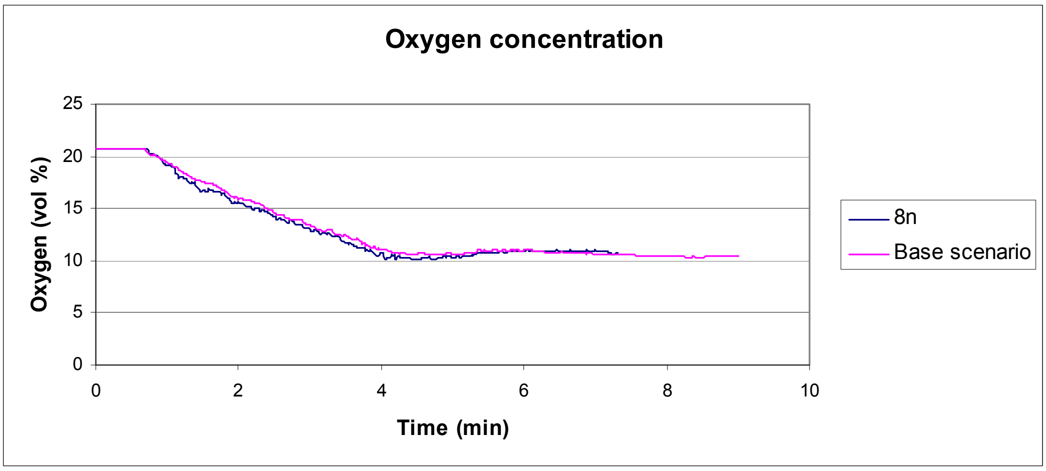

Figure A11.2 Oxygen level comparison for the 8n scenario and the base scenario (Pos 11).

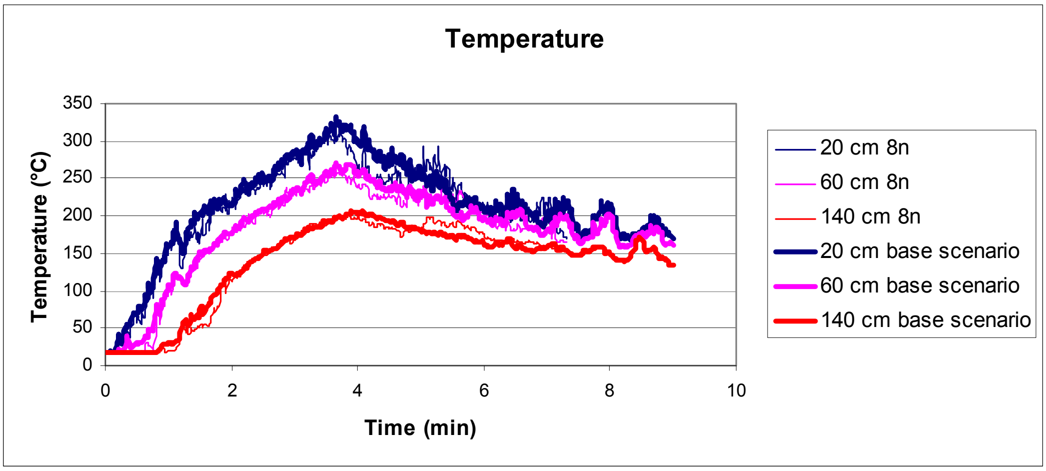

Figure A11.3 Temperature profile comparison for the 8n scenario and the base scenario (Pos 7).

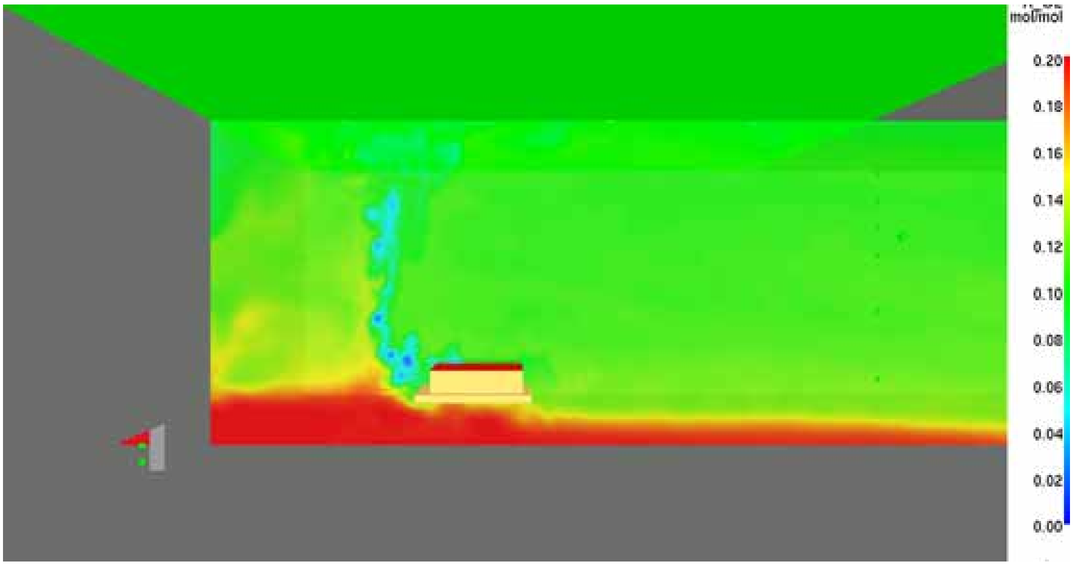

Figure A11.4 *Slice file for the oxygen concentration in scenario 8n (through the fire; Time = 300 s).*

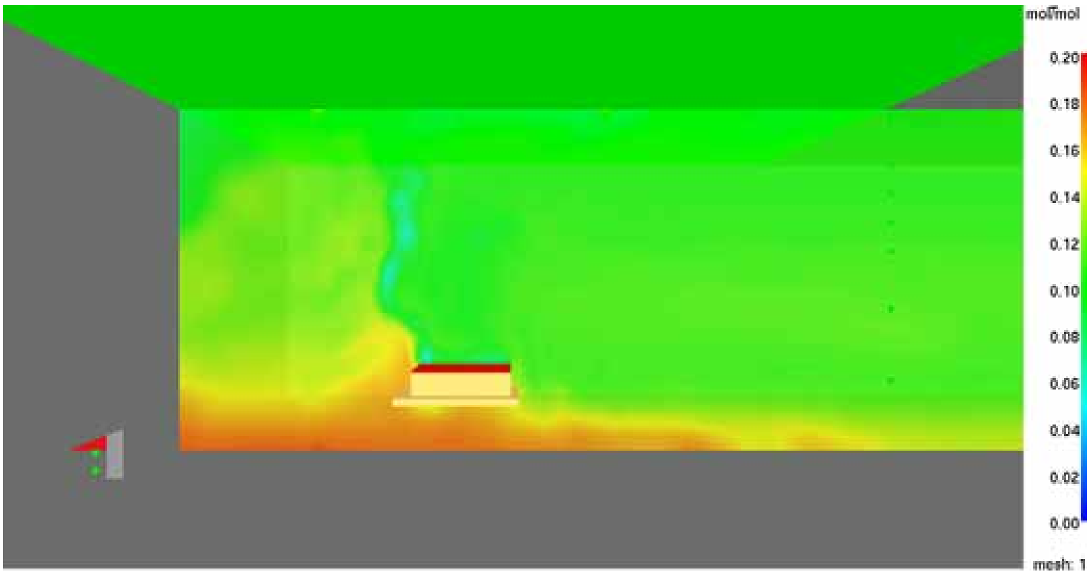

Figure A11.5 *Slice file for the oxygen concentration in base scenario (through the fire; Time = 300 s).*

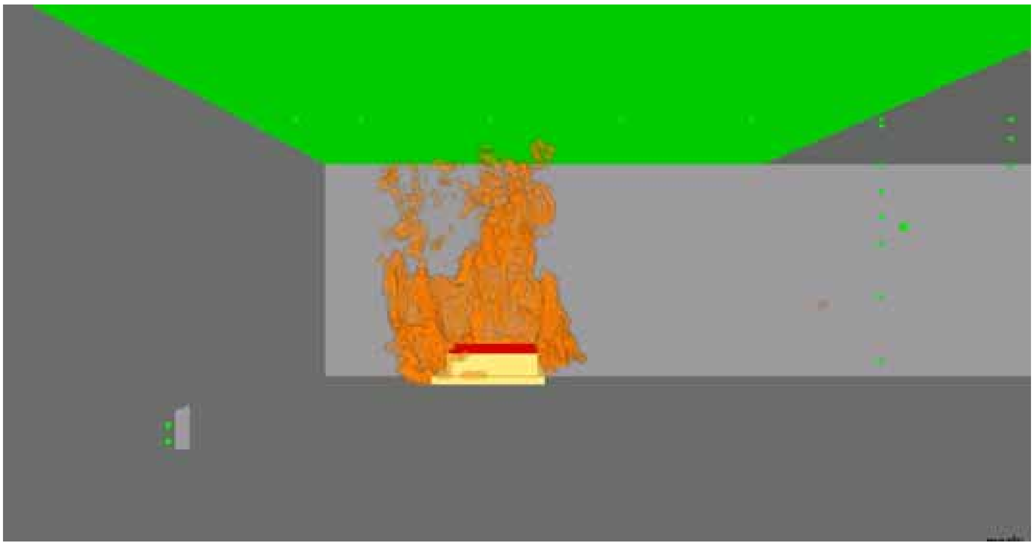

Figure A11.6 HRRPUA for all meshes in scenario 8n (Time = 280 s).

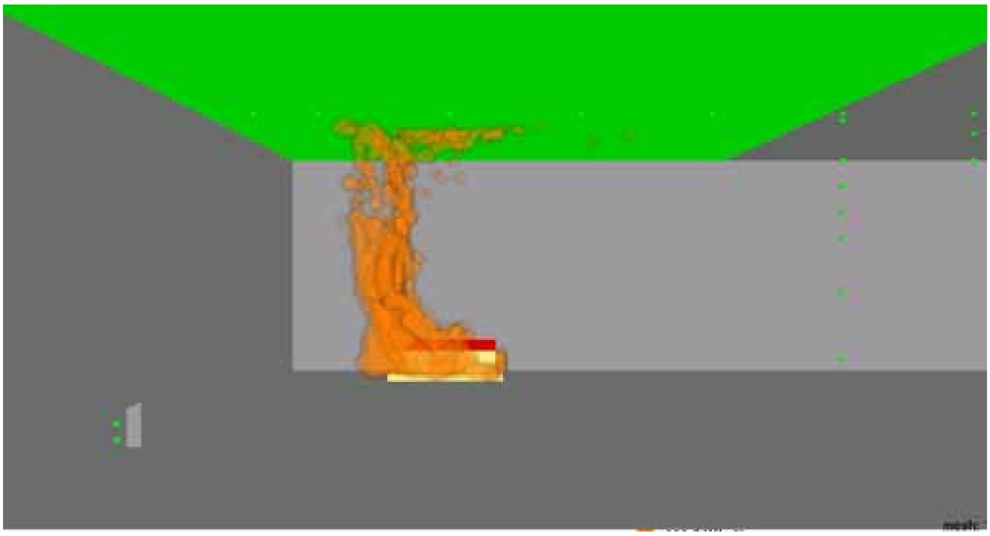

Figure A11.7 HRRPUA for all meshes in the base scenario (Time = 279 s).

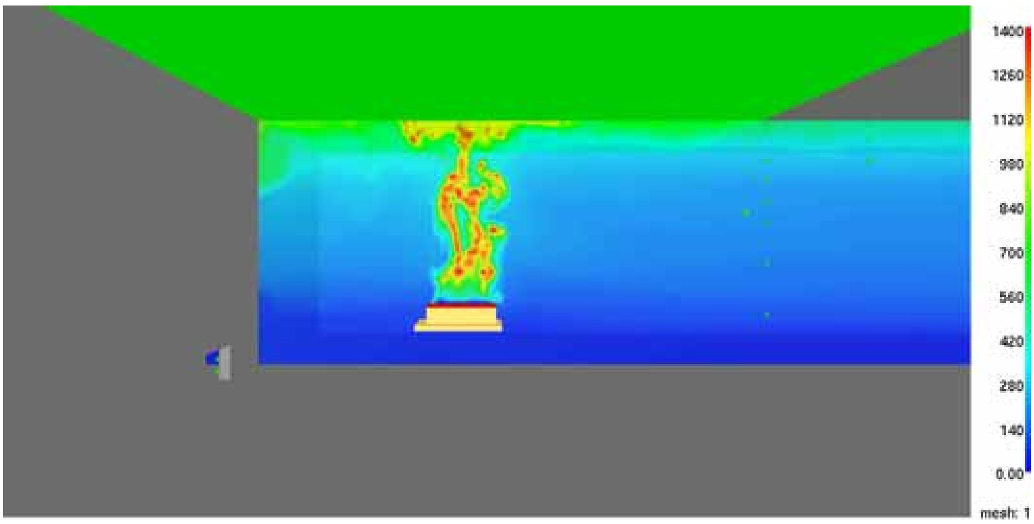

Figure A11.8 Temperature in the flame at 3 min in the 8n scenario (Time = 179 s).

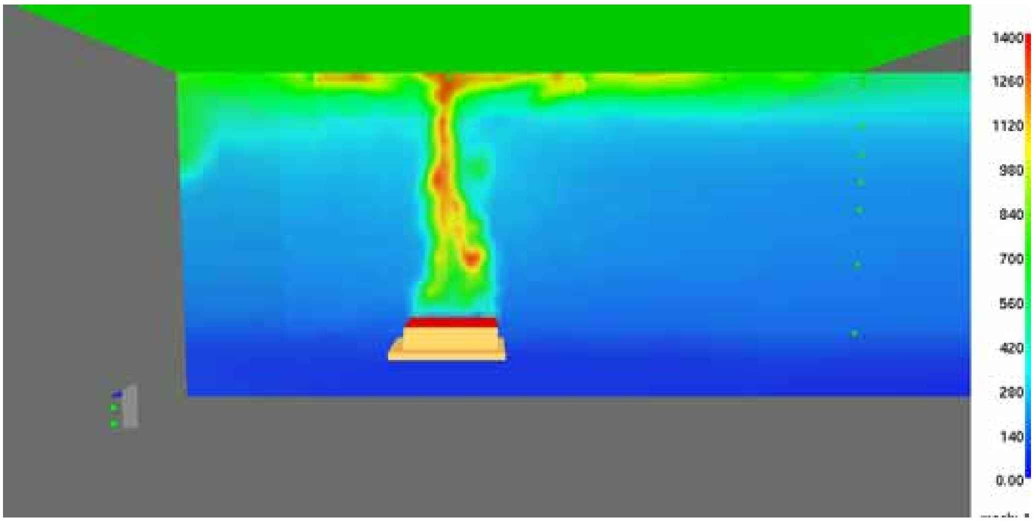

Figure A11.9 Temperature of the flame at 3 min in the base scenario (Time = 181 s)

Appendix 12 0.7 x Mass loss rate compared to Test 10

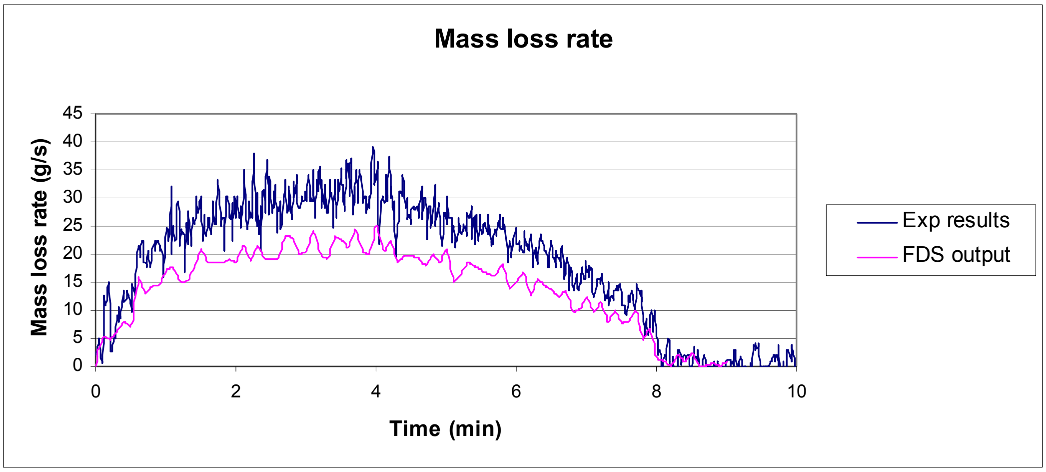

Figure A12.1 Mass loss rate comparison for the 0.7xMLR case.

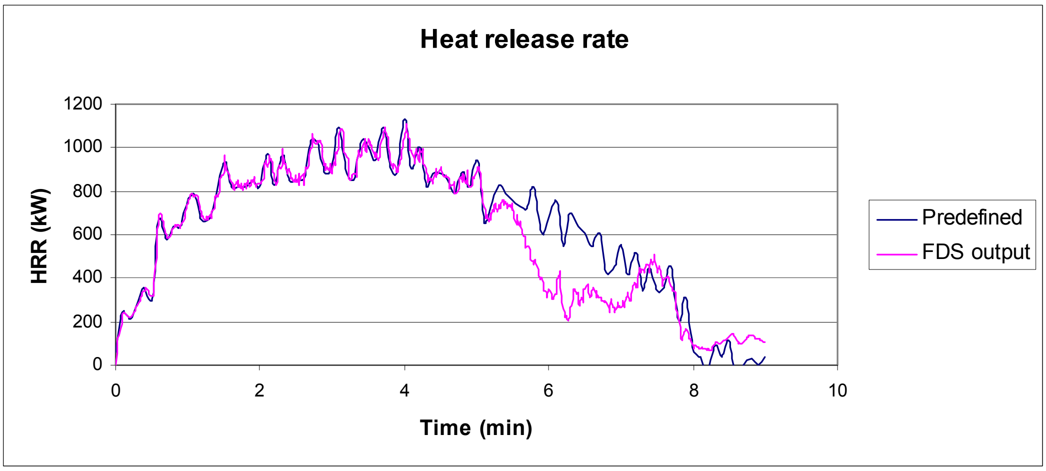

Figure A12.2 Heat release rate comparison for the 0.7xMLR case.

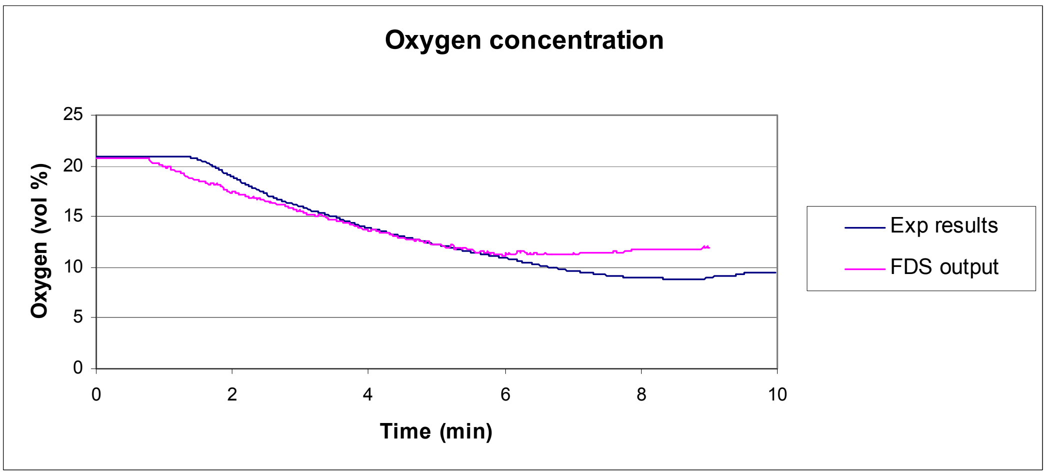

Figure A12.3 Oxygen level comparison (Pos 11) for the 0.7xMLR case.

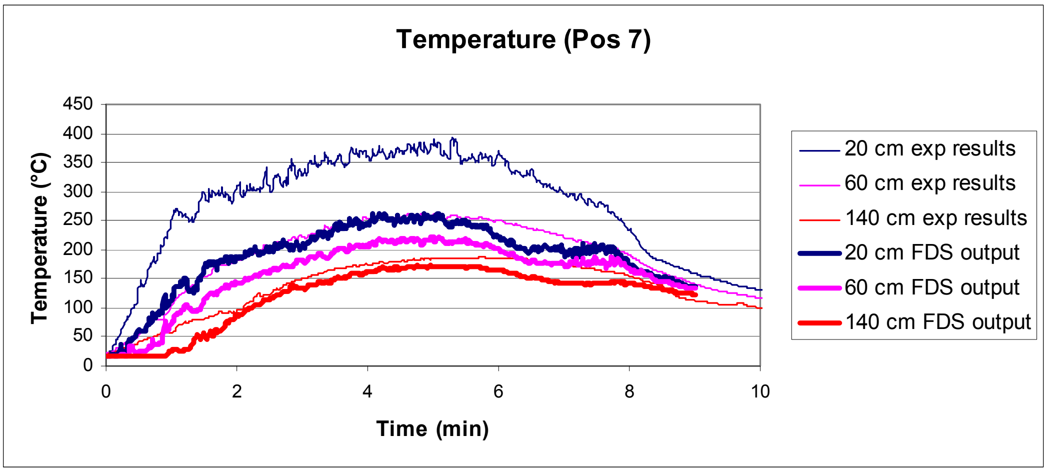

Figure A12.4 Temperature profile comparison (Pos 7) for the 0.7xMLR case.

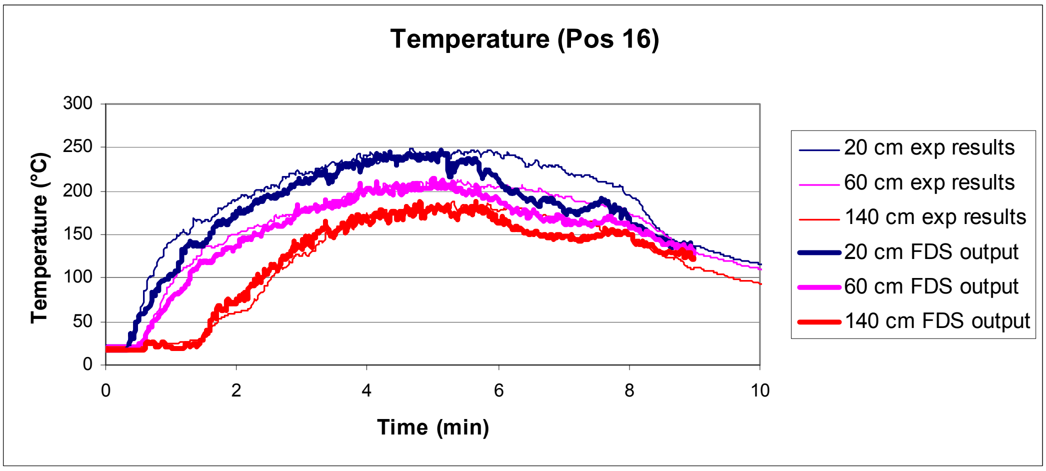

Figure A12.5 Temperature profile comparison (Pos 16) for the 0.7xMLR case.

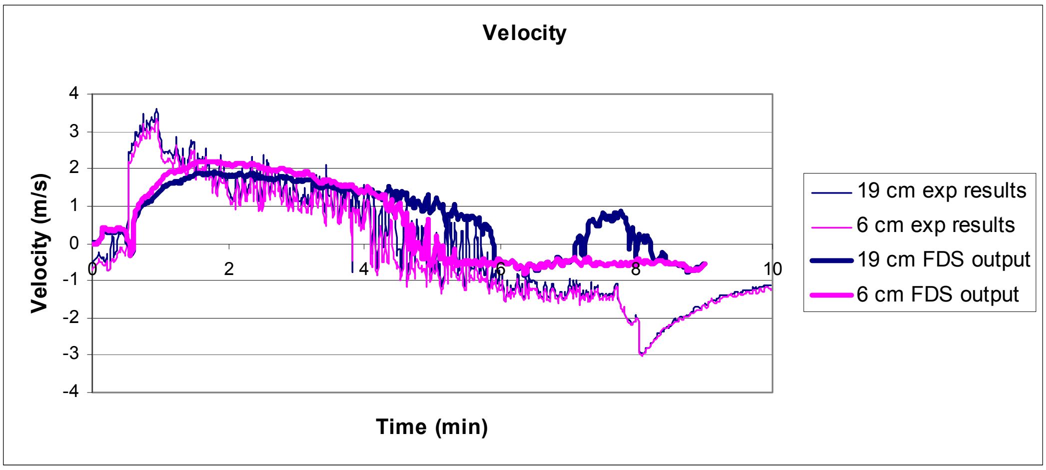

Figure A12.6 Velocity profile comparison (Pos 33) for the 0.7xMLR case.

Appendix 13 Number and sizes of the grids in the Base scenario

Table A13.1 Description of the different meshes used in the CFD simulations (Dimensions in m).

Mesh 1	**Length**	**Grids**	**Grid size**		**Mesh 5**	**Length**	**Grids**	**Grid size**
X	2	40	0.05		X	3	30	0.1
Y	2	40	0.05		Y	8	80	0.1
Z	1.2	24	0.05		Z	3.2	32	0.1
		38400					76800	
Mesh 2	**Length**	**Grids**	**Grid size**		**Mesh 6**	**Length**	**Grids**	**Grid size**
X	2	40	0.05		x	8	80	0.1
Y	2	40	0.05		y	2	20	0.1
Z	1.2	24	0.05		z	2.4	24	0.1
		38400					38400	
Mesh 3	**Length**	**Grids**	**Grid size**		**Mesh 7**	**Length**	**Grids**	**Grid size**
X	10	100	0.1		x	8	80	0.1
Y	4	40	0.1		y	6	60	0.1
Z	2.4	24	0.1		z	2.4	24	0.1
		96000					115200	
Mesh 4	**Length**	**Grids**	**Grid size**		**Mesh 8**	**Length**	**Grids**	**Grid size**
X	18	180	0.1		x	18	180	0.1
Y	2	20	0.1		y	8	80	0.1
Z	2.4	24	0.1		z	0.8	8	0.1
		86400					115200	
					Totalt		604800	

Appendix 14 FDS script for the Base scenario case 10

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names beginning with "".

&TIME T_END=540.0, SYNCHRONIZE=.FALSE. / Time when finished (length of simulation)

&MESH ID='Brand', COLOR='YELLOW', IJK=40,40,24,  XB= 1.00, 3.00,  4.00, 6.00, 0.40,
1.60/
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2.80/
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&MESH ID='Norr om brand',         IJK=180,20,24,  XB= 1.00, 19.00,  6.00, 8.00, 0.40,2.80/
&MESH ID='Bakom brand',           IJK=30,80,32,  XB= -2.00, 1.00,  0.00, 8.00, -0.40,2.80/
&MESH ID='Hyllvolym',            IJK=80,20,24, XB= 3.00, 11.00, 4.00, 6.00,  0.40,2.80/
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CO_PRODUCTION=.FALSE. /

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    DENSITY=910. /

&MATL ID='ROXULL INSULATION'
    CONDUCTIVITY=0.039
    SPECIFIC_HEAT=0.79
    DENSITY=180. / kg/m3

&MATL ID='CONCRETE'
    CONDUCTIVITY=1.0
    SPECIFIC_HEAT=0.88
    DENSITY=2100. /

&MATL ID='HEPTANE'
     DENSITY=680./

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    THICKNESS=0.010,/

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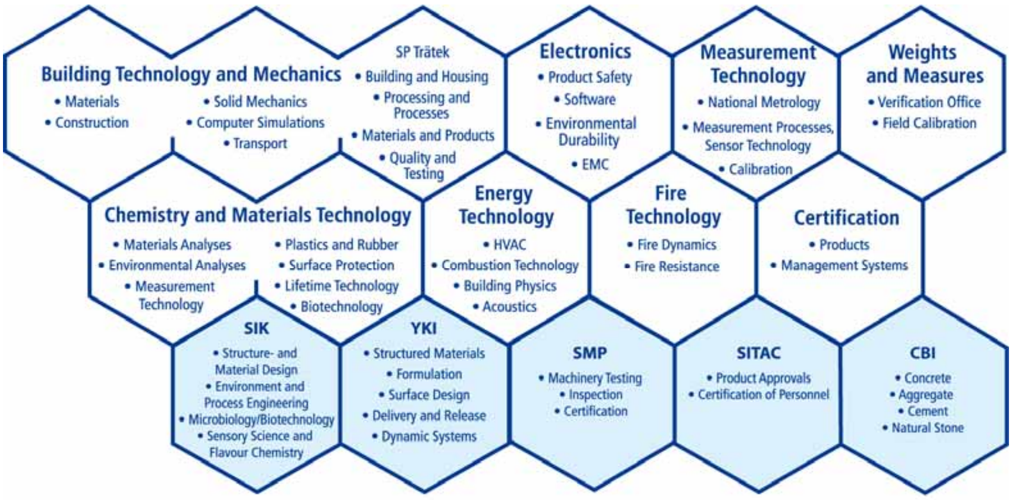

SP is organised into eight technology units and five subsidaries

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Fire Technology
SP Report 2008:55
ISBN 978-91-86319-16-8
ISSN 0284-5172