Initial backdraft experiments

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Abstract
A number of large scale backdraft experiments are decribed in this report. A total of 13 experiments have been carried out. During the experiments have several physical properties such as temperature, pressure, gas concentration have been measured. Example graphs are shown in the report.

The experimental apparatus as well as the measurments are described in detail in this report.

It is difficult to describe the backdraft phenomena strictly in quantitative terms, mut the measurements give a good description of the phenomena in a qualitative way.

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Summary

This report is a compilation of a series of backdraft experiments carried out as a part of the project “Backdraft and Underventilated Fire”, a three year project carried out for Räddningsverket (The Swedish National Rescue Service Agency)

The purpose of the project is partly to develop a backdraft scenario that can be used in the education of fire fighters. A so-called backdraft contrainer has been built to serve as a demonstratoin device as well as an experimental apparatus.

A total of 13 backdraft experiments have been carried out in the backdraft container, 8 of the experiments were successful and backdraft occured. Natural gas has served as fuel during the experiments. Gas temperatures, gas concentrations as well as dynamic and static pressures were measured measured in the experiments. It has been hard to get reliable results from the measurements mainly due to the fact that there are two time-scales involved in a backdraft situation. First there is a long time scale when the container is heated and a combustible gas concentration is built up. Next is there a short time scale when fresh air enters the compartment and ignition occurs.

Even though some of the quantitative results may have a large margin of error, the experiments give a reasonable qulitative explanation of the backdraft phenomena. As an example, the gas measurements show that the oxygen concentration will be as low as 3 % when the flame goes out. This is not a very reasonable value, a value of 12 % would seem more appropriate. However, when looking at the oxygen concentration versus time curve the backdraft event can be well understood. First, the oxygen level decreases while burning occurs in the compartment. When the flame goes out, the oxygen level decreases further at a much slower rate due to dilution. When an opening is made to the compartment, the oxygen level increases until ignition of the combustible mixture occurs. At this point, all the combustible gas in the compartment ignites suddenly and is combusted in a dramatic fireball. This makes the oxygen concentration drop very suddenly to a very low level. Finally when the combustion has taken place, the oxygen level is restored to its ambient value.

To continue the reseach on backdraft the measurement techniques must be refined. The fuel used in future experiments should be "normal" fuel such as wood and plastic products in order to make a connection to a real-case backdraft scenario.

Contents

Introduction

This report is a compilation of a series of backdraft experiments carried out as a part of the project “Backdraft and Underventilated Fire”. The backdraft project is funded by “Statens Räddningsverk” (SRV) and is carried out in close co-operation with “Räddningsverkets skola i Revinge”

Background

During the last few years Lund University has in very close co-operation with SRV, been working on a project regarding backdraft, flashover and smoke gas explosion. The final report [1] of that project suggested that a so-called backdraft container should be built and that educational material in the field of backdraft should be developed. The purpose of the backdraft container would be twofold. First, it would serve as an experimental device, where backdraft experiments could be carried out for research purposes. Second, the container would serve as a demonstration device where fire fighters in training could see how a backdraft develops.

During the last decades the fire research has concentrated on the well-ventilated fire. Research regarding the under ventilated fire has evolved slower, mainly due to the complex physical and chemical processes that occur during this type of fire.

The under ventilated fire is a very common type of fire, actually it is the most common fire the fire brigade face when arriving at the scene of a fire. When burning occurs in a lack of oxygen, at least four final outcomes of the fire development are possible [2]

1. The fire dies out
2. Auto-ignition of the smoke gases at direct contact with oxygen
3. Backdraft
4. Smoke gas explosion

Some numerical and theoretical work such as CFD modelling regarding backdraft can be found in the litterature. [5][6]. The outcome of this theoretical work is mainly concentrated on the mixing process between fresh air and combustible gas, the so-called gravity current.

Also some small-scale experiments involving backdraft can be found in the litterature. The most elaborate work has been carried out by Fleischmann [7][8]. But also the Fire Research Station in England [9] as well as Hokkaido University in Japan [10] have carried out small-scale backdraft experiments. Notable is that the experiments carried out in Japan used natural fuels, such as wood, during their experiments. However, it is questionable if it is a backdraft phenomena that occurs during these experiments since there no sudden opening to the enclosure, the opening is present during the whole experiments.

Finally, has some full-scale experiments also been carried out. These include the ones carried out by The University of Canterbury in New Zealand [4]. These experiments will be discussed further in this chapter. Full-scale experiments using diesel spray as fuel has also been carried out. [11][12]. These experimets has focused on backdraft behaviour onboard naval ships.

Of these four final outcomes the first one, the fire dies out, is the most common. In 75% of all fires in Sweden the fire is limited to the initially burning item when the fire brigade arrives at the scene. In Sweden only a few cases of backdraft and smoke gas explosion are reported every year. However, one could expect that cases of backdraft do occur more often than reported. This due to several reasons. First, it can be hard to distinguish a fast flashover from a slowly propagating backdraft, there is a “grey-zone” in which we cannot clearly distinguish different phenomena. Secondly, the statistics are based on “incident report forms”, these forms do not include a checkbox for backdraft or any type of explosion.

The backdraft is a special case of a room fire and is a transient event that can occur when air is introduced in a compartment where burning has occurred in a lack of oxygen. There is no ISO definition of the backdraft phenomena but the Institution of Fire Engineers (IFE) and the National Fire Protection association (NFPA) [3] give the following definitions.

The IFE definition of backdraft is:
"An explosion of greater or lesser degree, caused by the inrush of fresh air from any source or cause, into a burning building, where combustion has been taking place in a shortage of air."

The NFPA definition is:
“The explosive or rapid burning of heated gases that occurs when oxygen is introduced into a building that has not been properly ventilated and has a depleted supply of oxygen due to fire.”

A real case backdraft scenario could happen as follows:
Normal dwellings contain combustible material, like furniture and wall linings. When a fire starts somewhere, e.g. in a bed or in the TV, the fire might spread and grow. The temperature rises in the room and the room will fill with smoke. If the room is rather airtight, i.e. the window glass remains intact and the doors are closed, the fire will die out due to oxygen starvation. However, even though the fire has died out the temperature may be high enough to maintain the pyrolosys process. This will generate a build-up of combustible gas that not will be able to burn until the oxygen concentration in the room increases.

If an opening is made in the compartment fresh air will be able to mix with the combustible gas, creating a flammable region. If any type of ignition source ignites this region the temperature and the pressure in the compartment will rise rapidly. This pushes the yet unburnt gases outside the compartment. Once outside the compartment, the gases will be combusted in a dramatic fireball.

Objectives and application

The purpose of the backdraft experiments was to create a scenario that can be used when the backdraft container will be used as a demonstration device. One of the end-use purposes of the backdraft container is to show fire fighters in training what a backdraft might look like and at what explosive force it might occur. Since many people, both students and teachers, are involved in such a demonstration it is important that a scenario which has a high rate of reproducibility is used. Also it is important that the whole demonstrations is rather easy to set-up and does not take too long.

The University of Canterbury in New Zealand [4] has carried out experiments that are qualitatilvely similar to the ones discussed in this report even though the scope of our experiments is much wider and the quantitative measurements more elaborate. It is the backdraft container used in their experiments that has served as a model for the container used in our work.

Acknowledgements

This report is a part of a project funded by SRV. I would like to express my gratitude to Stefan Svensson, Jan Tapani and Staffan Persson at “Räddningsverkets skola i Revinge” for helping me with all the practical matters. I would also like to thank Per Werling (FOA) for sharing his experience in measurement techniques with me.

Experiments

This chapter describes the experimental apparatus used and the measurements that were made during the experiments. In the chapter the experimental procedure is also described. Other chapters describes the results obtianed. A total of 13 experiments have been carried out. In the table below is a short summary of the experiments carried out.

Experiment number	Backdraft	Comments
1	No	No measurements made
2	Yes	No weight measurements made
3	No	
4	Yes	
5	No	
6	No	No weight measurements made
7	Yes	
8	No	
9	Yes	Successful pressure measurements
10	Yes	
11	Yes	
12	Yes	
13	Yes	Gas concentration measurements made

Experimental apparatus

As mentioned earlier a backdraft container described by Bollinger [4] served as a model for the one used in these experiments.

The backdraft container is built from a standard shipping container, measuring 5.5x2.2x2.2 m (length x width x height). The shipping container has been modified in several ways to fulfil its purpose as a experimental apparatus.

First of all the container has been sealed and insulated properly in order to keep the heat and the unburnt gases in the container. The container is not 100% air- tight, several leakages exist mainly around the pressure relief panel. The container’s walls have been insulated with glassfibre insulation. The floor has been covered by concrete.

A pressure relief panel is placed on one of the short ends of the container as seen in Figure 1.

Figure 1. The pressure relief panel in closed position at the container's short side.

The function of this panel is to vent any unwanted pressure build-up that might occur during the experiments. This is in order to protect the construction from severe damage. The panel is kept in place by plastic wires that are attached to both the panel and the container itself. The amount of straps used and the strength of the straps determines the overpressure that triggers the opening of the hatch. A metal wire can also be attached to the panel so the panel can be lowered to the ground for easier entry/exit to the container. Figure 2 shows the relief panel at its lowered position.

Figure 2. The pressure relief panel at its lowered position, making entry and exit to the container easier.

The area around the panel has been hard to seal properly so during the experiments will some heat and gases escape around the perimeter of the panel.

To allow better visualisation of the backdraft during demonstrations a window has been installed in the container. The glass in the container is fire-rated and withstands high temperature changes as well as pressure changes.

To control the introduction of air into the container an opening was made at the other short side of the container. The opening covers the whole width of the container and is 0,8 m high. The opening is placed at mid-height of the container. A hatch that can be opened by pulling a wire from a safe distance covers the opening. Figure 3 shows the opening from the inside of the container.

Figure 3. The opening that allows fresh air to enter the container seen from the inside.

The reason for choosing this specific opening geometry is that it creates a more 2-dimensional flow than a door or window-opening geometry would do. This eases the modelling of the experiments using e.g. CFD models.

In addition to the modifications to the container mentioned above a few smaller instalments were made in the container. Along the centreline of the container at the rear end (near the pressure relief panel) a gas burner is situated on the floor. The burner measures 0.3x0.3m and is filled with sand. A hole in the concrete floor allows gaseous fuel to enter the burner. An electrical spark igniter is placed at the rind of the burner.

To be able to ignite the combustible mixture in the container an electrically heated metal wire is used as an ignition source. The wire is approximately 1 m long and is vertically oriented. The wire can be moved vertically.

A roof protects the container from precipitation.

Measuring devices

In order to evaluate the experiments in a quantitative and qualitative way, several physical quantities were measured during the experiments. These measurements include:

- Temperature
- Gas concentrations
- Pressure

Temperature

The temperature in the container has been measured at several locations. Two thermocoupletrees (TCT) are positioned in the container according to Figure 4.

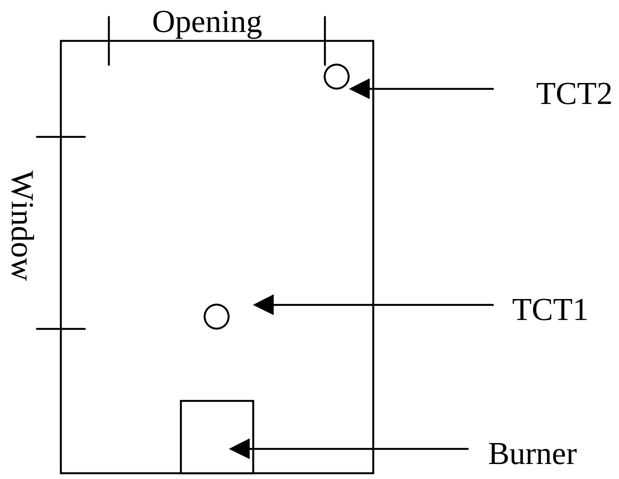

Figure 4. A plan view of the TCTs positions.

The TCTs contain 5 thermoelements each, separated by a distance of 40 cm. The topmost thermocouple is positioned 20 cm under the ceiling.

During some of the experiments 3 thermocouples were placed on the wall opposite the window. The purpose of placing the thermocouples on the wall is to ease the verification of a CFD-model against the experiments. No results from the wall-attached thermocouples are presented in this report.

If the velocity of the in- and outflowing gases is to be calculated at some point is it necessary to obtain both the temperature (density) as well as the dynamic pressure at that point. 3 bi-directional pitot tubes, placed in the opening register the pressure. On each pitot tube a thermocouple is placed as well.

The temperature of the inflowing gas is also measured by a thermocouple.

All thermocouples are 0,25 mm thick, bare type K.

Pressure

A piezoresistive pressure sensor is installed in the container. The purpose of this pressure sensor is to track the static pressure build-up. The sensor scans the pressure in the container during the whole experiment. When the pressure build-up reaches a pre-determined trigger-value the sensor is triggered and the pressure history is logged for a total of 6 seconds, 1 second before the trigger level is reached and 5 seconds after the sensor has triggered.

Most of the measurements made with the pressure sensor have been unsuccessful. The trigger level must be set quite low (70 Pa) for the sensor to trigger. When opening the hatch the vibration caused by the falling hatch is enough to trigger the sensor. Therefore the pressure profile only exists for 1 experiment (number 9).

3 bi-directional pitot tubes are placed in the opening. These tubes record the change in dynamic pressure. A thermocouple is placed on each tube. Knowing the pressure and the temperature (density) of the flowing gas is it possible to calculate the velocity of the gas. Since the tubes are bi-directional the direction of the gas-flow is also given.

<u>Gas measurements</u>

The main parameter that determines the outcome of a possible backdraft situation is the amount of combustible gas in the enclosure. During these experiments have natural gas has been used as fuel. Using a gaseous fuel eases the control of the amount of gas, which has entered the container. Three different methods have been used to measure the amount of fuel in the container:

- Simply by looking at the pressure sensor on the tank originally containing the natural gas. The pressure change in the tank corresponds to a specific amount of gas that has entered the container.
- By weighting the tank. The tank is placed on a scale and therefore the mass loss rate can be calculated.
- By using a Dräger Multiwarn II gas instrument. The Dräger instrument is equipped with one infrared sensor for measurements of methane gas concentrations (0-100 vol %), but also with 2 electrochemical sensors for measurements of carbon dioxide as well as oxygen.

Experimental procedure

A real-case backdraft event is described in the Background chapter. The purpose of the experiments was to simulate a real backdraft scenario using natural gas. Using natural gas for such a purpose might seem strange since it is not very likely that a backdraft would occur in reality due to natural gas. When a backdraft occurs it is due to pyrolosys of solid fuels. However, natural gas has the same physical qualities as products of pyrolosys, such as a density lower than air and flammability within certain limits. The main reason for using natural gas is that when using a gaseous fuel is it much easier to control the amount of fuel released in the enclosure. It would be much harder to control the amount of gaseous fuel produced in a pyrolosys process of a solid fuel.

The experiment starts by closing the hatch and the pressure relief panel. At this stage the container is rather airtight. A small ventilation hole is opened. The small spark igniter, located at the burner, is ignited. Next the gas is led to the burner. The spark igniter ignites the gas. A 2 m high flame is produced by the burner, the heat release rate is approximately 600 kW. When the flame is stabilised the small ventilation hole is covered by a hatch. The reason for opening a ventilation hole is to vent the overpressure created when igniting the flame. The flame dies out due to oxygen vitiation after approximately 1 minute.

Even though the flame has gone out the natural gas is kept flowing through the burner. This procedure is followed to simulate a pyrolosys process where a high concentration of combustible gas is generated. When the desired concentration is reached the gasflow is turned off. The hatch that covers the slot opening is opened and fresh air is allowed to enter the container. The ignition source is turned on. The air mixes with the natural gas, creating a flammable region. When the flammable region reaches the ignition source the gas mixture is ignited (Figure 5). The temperature rises very quickly in the container causing a volumetric expansion. The yet unburnt gases are expelled outside the container (Figure 6). The flame propagates through the container and finally the unburnt gases outside the container are combusted in a dramatic fireball (Figure 7).

Figure 5. The gases inside the container are ignited.

Figure 6. The heat generated causes a thermal expansion and the yet unburnt gases are expelled out of the container.

Figure 7. The unburnt gases are combusted in a dramatic fireball outside the container.

Results

This chapter will discuss the results from the experiments. Example graphs from the measurements will also be shown.

Temperature

As mentioned earlier the gas temperature in the container was measured by two thermocouple trees (TCT1 and TCT2). Figure 8 and Figure 9 show how the temperature differs between these two trees at different distances from the ceiling.

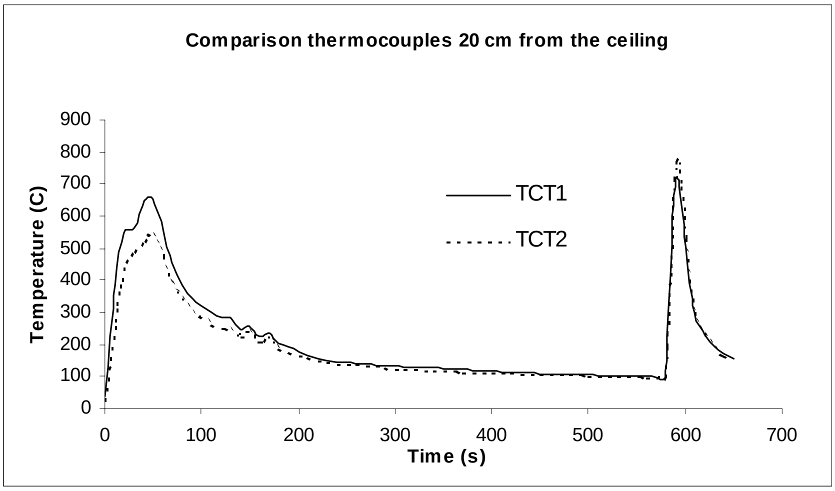

Figure 8 Comparison between the two thermocouples located 20 cm from the ceiling.

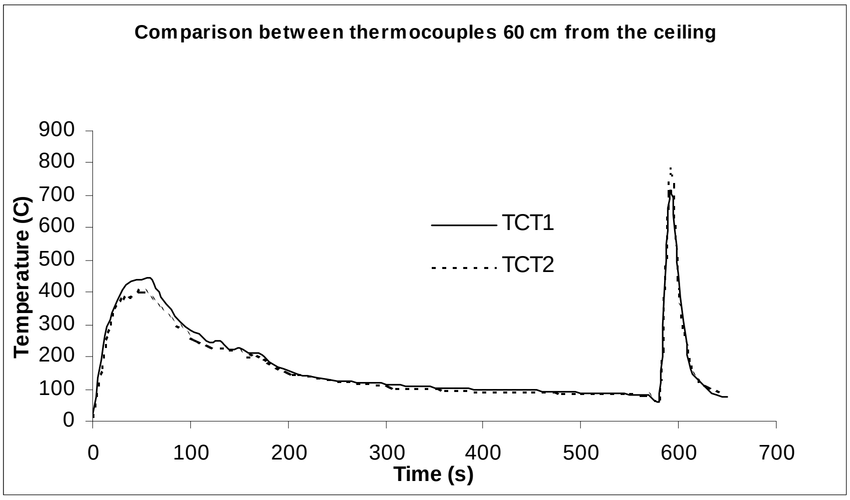

Figure 9 Comparison between the two thermocouples located 60 cm from the ceiling.

It can be clearly seen that the difference between the temperature at the two thermocouple trees is very small. The largest difference is found in the beginning of the experiment. The reason for the larger difference is probably due to the fact that the flame reaches the uppermost thermocouple at TCT1. Temperature comparison between thermocouples located more than 60 cm from the ceiling are shown in the Appendix.

The next graph, Figure 10, shows the temperature profile inside the container at different times after ignition. The temperature curves are taken from TCT1 in experiment number 2.

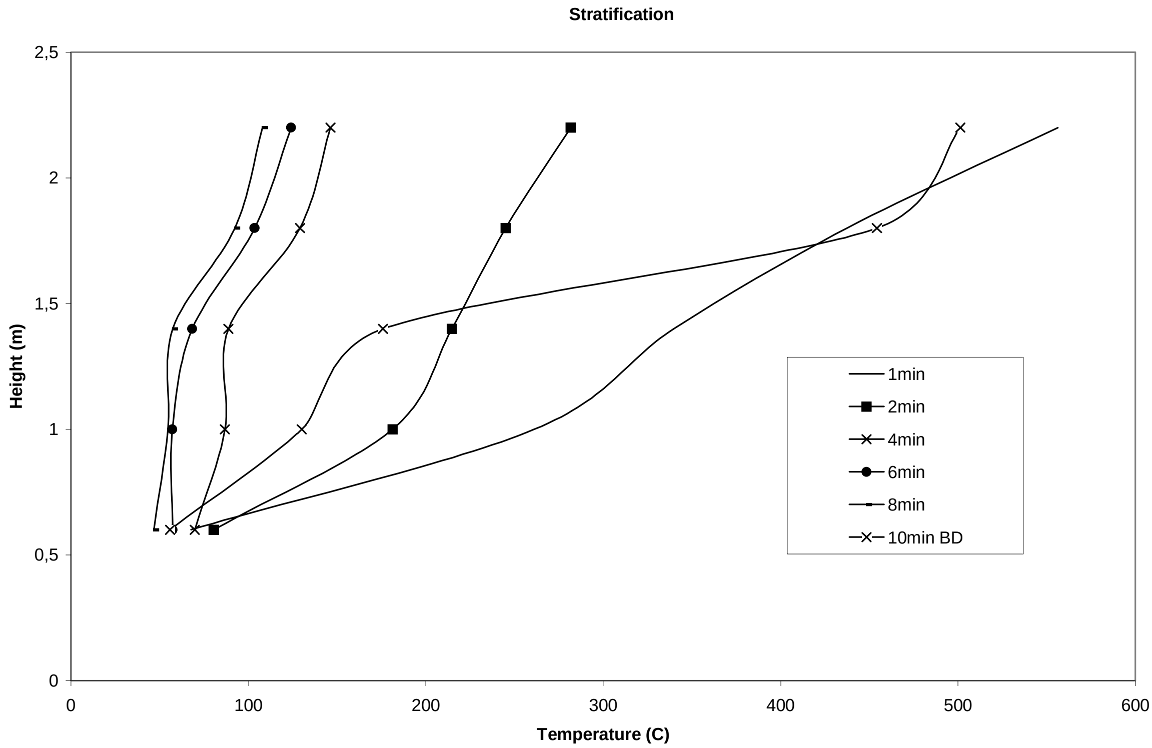

Figure 10. The temperature profile inside the container at different times after ignition. After 10 minutes does backdraft occur

Figure 10 shows how the temperature rises quickly in the upper region of the container shortly after the burner ignition. However, when the flame dies out due to oxygen starvation the temperature decreases very quickly. This is mainly due to 2 reasons:

- Leakages. Heat will escape by conduction through the construction but also through the leagages around the pressure relief panel.
- Cold gas entering the container. When the flame dies out the gas is kept flowing. The temperature of the natural gas is -4°C. This will also lower the temperature in the container.

10 minutes after ignition backdraft occurs in this experiments. This can be clearly seen in Figure 10 since the temperature rises again in the upper part of the container.

Figure 11 shows a typical temperature graph as registrered by TCT2. This particular figure is taken from experiment number 7, which is a case where backdraft did occur.

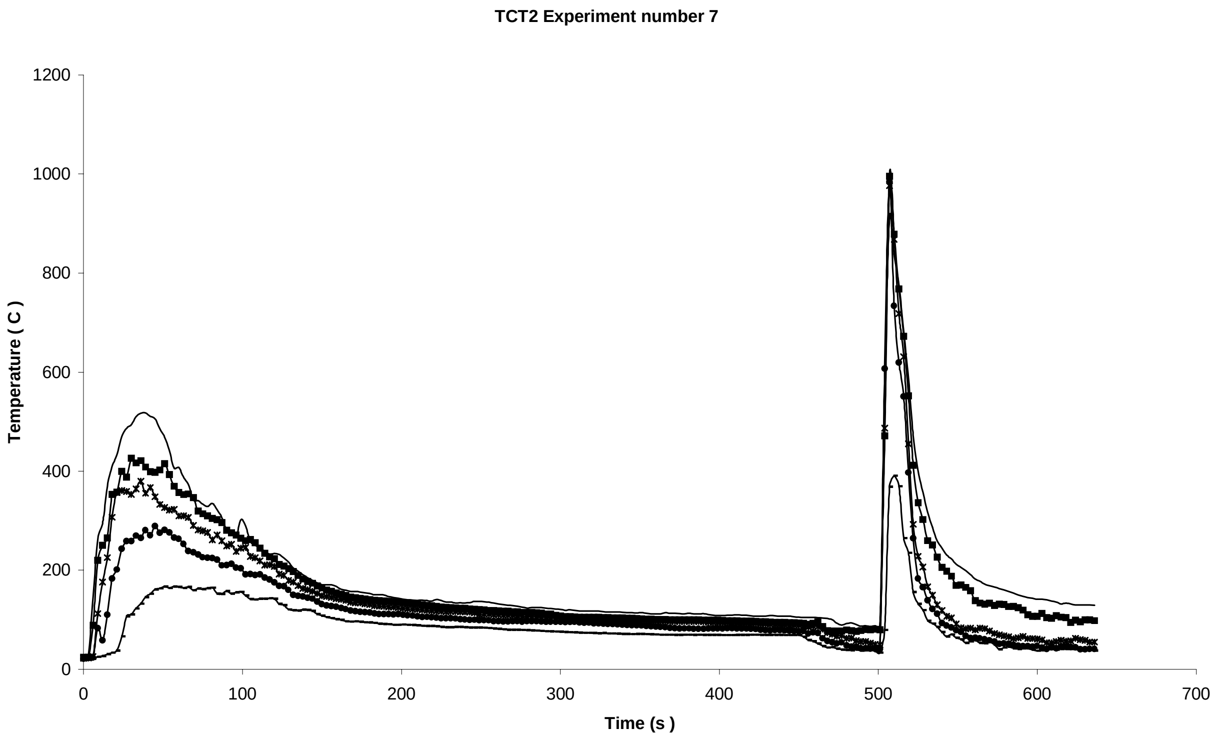

Figure 11. A typical temperature graph for the case when backdraft occurs.

The results are rather clear. The temperature in the container rises quickly when the burner is ignited, the temperature is higher in the upper part of the container than in the lower part. After approximately 60 seconds the flame will go out due to the lack of oxygen. The temperature will then gradually decrease in the container due to the reasons given above. When the hatch is opened, at 470 seconds, the temperature in the lower part of the room decreases even more due to the effect of the gravity current. Finally the fuel/air mixture is ignited and the temperature increases very quickly in the container. The temperature registered during the deflagration is probably not the correct one since the thermocouples are too slow to register this fast event. After the backdraft has occurred the temperature decreases again.

Temperature graphs from all the experiments can be found in the Appendix.

Gas concentration

This part of the chapter will concentrate on the natural gas concentration build-up. The experiment starts when the gas burner is ignited. The reason for this procedure is mainly twofold:

- Consuming the oxygen in the container. Consuming the oxygen will have the effect that combustion cannot take place in the container until the hatch is opened and fresh air is allowed to enter the container.
- Heating the contents of the container. When the gases in the container are heated their density will decrease. This is important to create a gravity current once the hatch is opened.

When the flame from the burner dies the natural gas is kept flowing. This will cause a concentration build-up of natural gas in the container. It is hard during the experiments to estimate what the gas concentration is within the container. The only way to do an estimate of the amount of gas released in the container is to control the pressure gauge on the natural gas tank. Knowing the tank volume and the change in pressure, the total amount of gas released in the container can be calculated. However, this procedure does not take the effect of leakage into account. To allow better control of the gas concentration the gas tank is placed on a scale. The mass loss rate may then be calculated. Figure 12 and Figure 13 show typical graphs that result from the weight measurements. The two graphs look quite different. This is due to the effect of wind. Figure 12 is from experiment number 3 that took place on a very calm day while Figure 13 is from experiment number 7 that took place on a windy day. The wind appears to affect the gas tank, making the mass curve fluctuate. Therefore, a straight line has been inserted into the graphs that corresponds to the best linear fit.

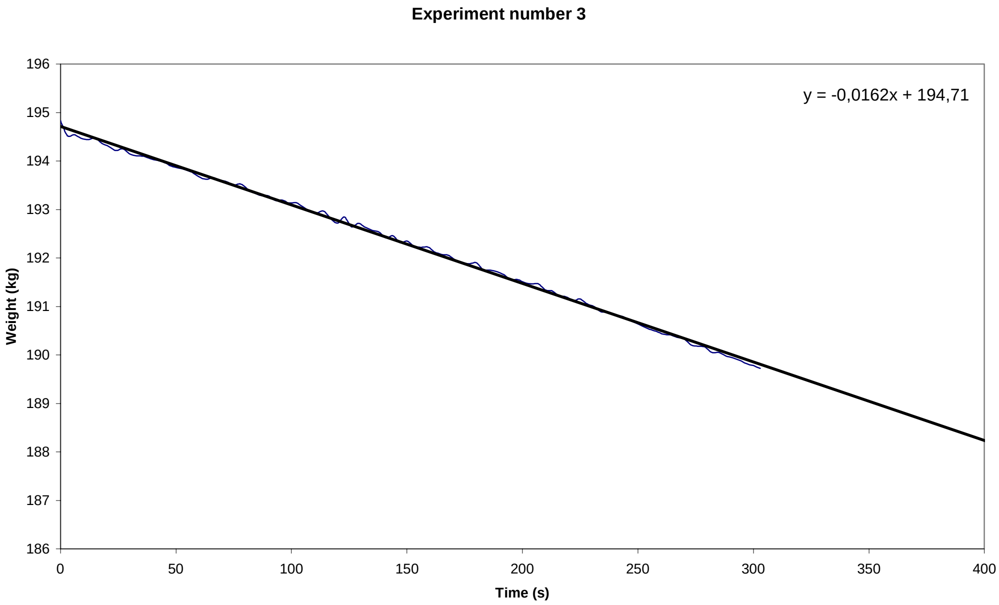

Figure 12. The mass of the natural gas tank on a calm day.

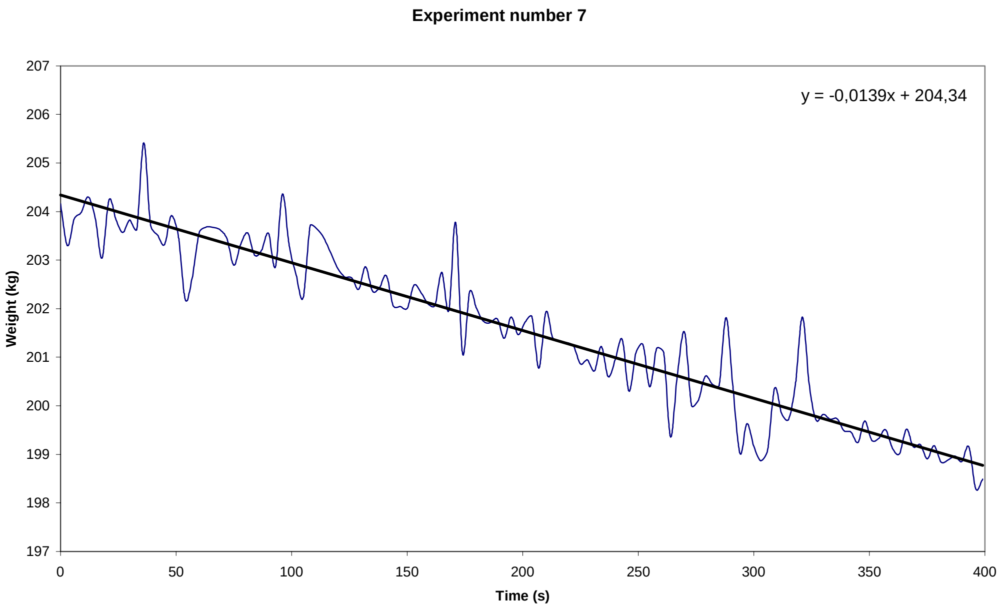

Figure 13 The mass of the natural gas tank on a windy day .

The graphs above also display the equation of the straight line. The slope coefficient corresponds to the mass loss rate expressed in kg/s. Knowing the mass loss rate, the maximum heat release rate from the burner can be calculated. The mass-loss rate can also be converted to a volumetric flow rate since the gas density is known. Integrating the volumetric flow rate over time gives the total amount of natural gas released in the container. However, no consideration is taken to leakage. This information is given in the table below.
Also, the table displayes the volume of natural gas released in the container, calculated by reading the pressure gauge on the tank.

Calculations based on the best fit curve as displayed in Figure 11 and Figure 12

Calculations base upon reading the gas tank's pressure gauge

Experiment number	Mass flow rate	Energy release rate	Volume flow rate	Time[1]	Volume (1)	vol%	Loss in tank pressure	Volume (2)	vol %	Backdraft
	(kg/s)	(kW)	(m^3/s)	(s)	(m^3)		(bar)	(m^3)		
1	*	*	*	*	*	*	*	*	*	No
2	*	*	*	*	*	*	*	*	*	Yes
3	0,016	646	0,019	357	6,9	26	70	5,6	21	No
4	0,017	690	0,021	450	9,3	35	70	5,6	21	Yes
5	0,014	566	0,017	339	5,7	22	80	6,4	24	No
6	*	*	*	*	*	*	80	6,4	24	No
7	0,014	554	0,017	453	7,5	28	80	6,4	24	Yes
8	0,016	618	0,018	453	8,4	31	80	6,4	24	No
9	0,017	658	0,020	417	8,2	31	80	6,4	24	Yes
10	0,016	638	0,019	372	7,1	27	70	5,6	21	Yes
11	0,010	399	0,012	450	5,4	20	70	5,6	21	Yes
12	0,013	534	0,016	450	7,2	27	60	4,8	18	Yes
13	0,016	642	0,019	318	6,1	23	70	5,6	21	Yes

* The weight of the tank was not measured during these experiments.
[1] The amount of time elapsed until the gas flow was turned off.

As seen in the table the two methods of estimating the gas concentration do not correspond very well. There are several sources of error in the calculations.

- One part of the calculated volume is combusted. No consideration is taken to this fact.
- No consideration is taken of leakage.

However, the same assumptions are made in both of the methods, i.e. it is actually the amount of gas that has left the tank that is being calculated not the gas concentration inside the container upon ignition. Therefore, the two methods should give the same result. The correspondence is shown in Figure 14.

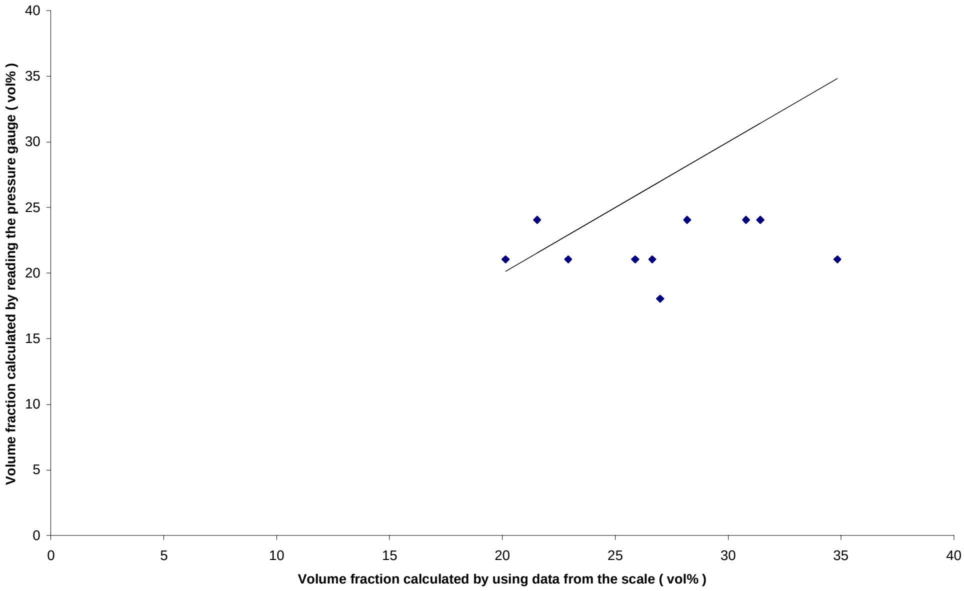

Figure 14 Comparison between two different methods of measuring the amount of fuel which has entered the container.

As seen in Figure 14, the results from the calculations should be gathered around the straight line. However, this is not the case. This makes it very hard to estimate the actual amount of gas in the container.

In addition to the above calculations a gas-measuring device has been installed in the container. The results from this device are not very good though. A typical result is shown in Figure 15.

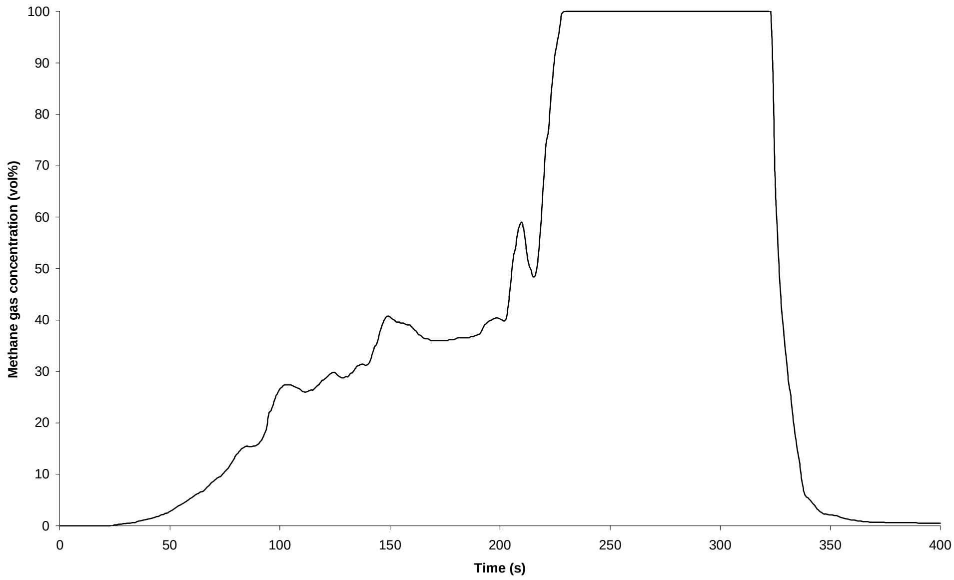

Figure 15 The methane gas concentration as measured by the Dräger measuring device in experiment number 13.

The results shown in Figure 15 are not very reliable, the gas concentration is way too high. One of the reasons for the incorrect values might be the temperature of the measured gas. The temperature could be outside the range of the measuring device. This will be evaluated further.

As mentioned in an earlier chapter the Dräger device also measures the CO_2 and the O_2 concentrations. The results of these measurements are presented in Figure 16.

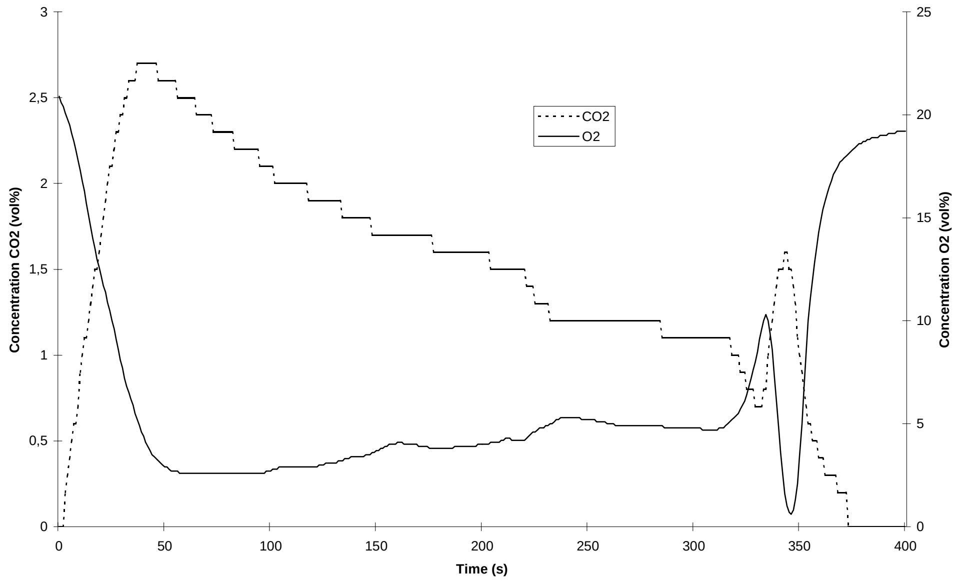

Figure 16. Concentrations of CO_2 and O_2 as measured by the Dräger measuring device.

As seen in Figure 16 the quantitative results are somewhat incorrect, i.e. is an oxygen concentration of 3% is probably way too low. However, the graph gives a very good qualitative description of the chemistry in a backdraft. Figure 16 is reproduced below as Figure 17 with corresponding explanations.

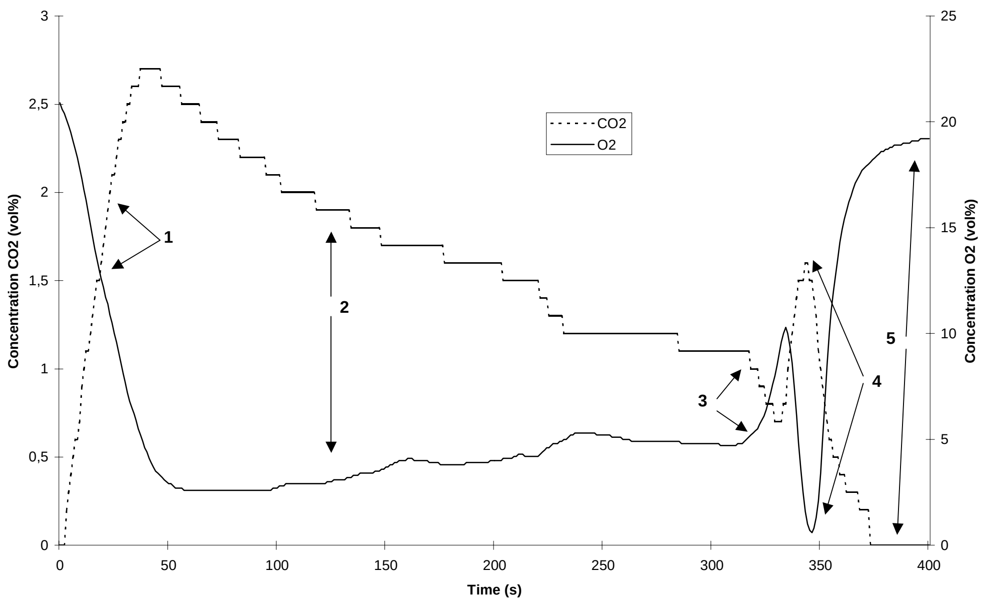

Figure 17. Gas concentrations with referrals to qualitative explanations.

1. During this phase of the experiment the oxygen concentration decreases due to the combustion. The carbon dioxide level will increase since it is a product of combustion. This phenomenon will occur as long the burner produces a flame. When the oxygen level reaches a level where combustion won't occur the flame goes out and no more carbon dioxide will be produced.
2. During the second phase of the experiment when natural gas is kept flowing into the container the carbon dioxide concentration will be reduced further due to the dilution from the natural gas. The oxygen concentration will increase since fresh air enters the container through leakage.
3. When the hatch is opened at 310 seconds the oxygen level increases rapidly since fresh air enters the container as a gravity current. The carbon dioxide concentration is reduced even further due to dilution.
4. Once the ignition source ignites the flammable mixture combustion takes place once again and backdraft occurs. The effect of the combustion process can be seen since the carbon dioxide concentration increases rapidly and the oxygen concentration decreases.
5. Finally when the backdraft is over the gas concentrations will be restored to their ambient values.

Ignition

The time from opening the hatch until ignition occurs is strongly dependent on the gravity current. A gravity current occurs since the density of the fresh air is higher than the density of the gases inside the container. CFD simulations can be carried out to investigate the behaviour of such a gravity current. Example pictures are given in Figure 18 and 19.

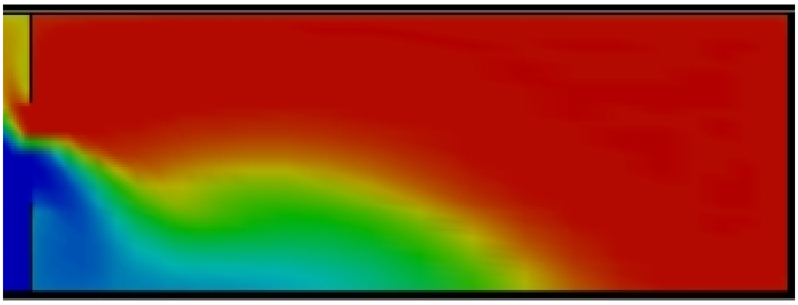

Figure 18. 2 seconds after the hatch is opened. Fresh air (blue) will enter the container and mix with the combustible gas (red).

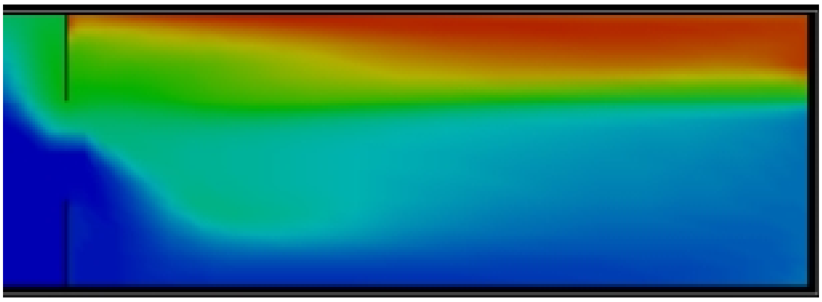

Figure 19 10 seconds after the hatch is opened. The air and the gas mixes, creating a combustible region (green).

The time to achieve ignition should be dependent of the gas concentration inside the container. A higher gas concentration requires more fresh air in order for the mixture to get within the flammable region and therefore the time from hatch opening until ignition will increase with increasing gas concentration. In Figure 20 and Figure 21 the time to ignition (calculated from the hatch opening) is plotted against the concentration of natural gas in the container.

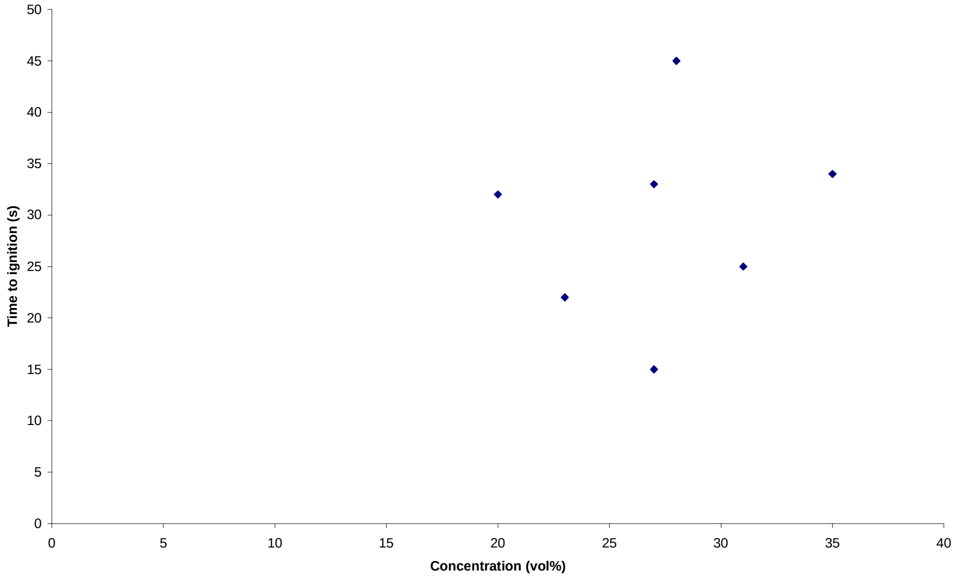

Figure 20. Time to ignition as a function of gas concentration for the cases when backdraft occured. The gas concentration has been calculated using data from the weight measurements of the gas tube.

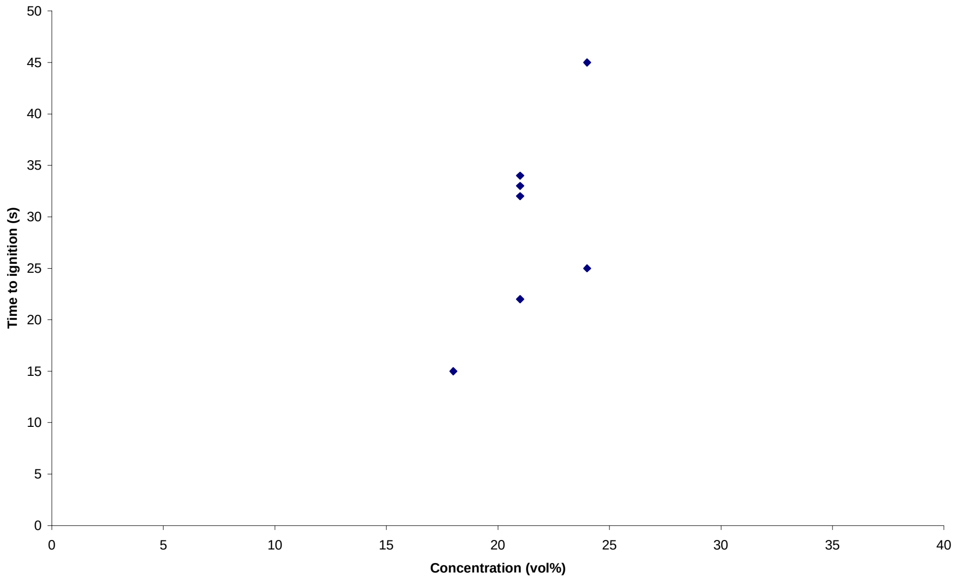

Figure 21. Time to ignition as a function of gas concentration for the cases when backdraft occurred. The gas concentration has been calculated using data from the pressure gauge.

As seen in Figures 20 and 21 no clear conclusions on the relationship between gas concentration and time to ignition can be drawn. The following statements can explain this.

- It has been shown in this report that the gas concentration has been difficult to calculate.
- The ignition source is not reliable. The voltage on the heated wire is not high enough to instantaneously ignite the gas mixture

However, Figure 21 seems to indicate that higher gas concentration requires longer ignition time, but no clear statement on this can be made due to the above reasons.

Pressure

Once ignition occurs the pressure in the compartment will rise due to the thermal expansion. When the overpressure is vented through the opening is an underpressure generated in the compartment. Only a few successful pressure measurements have been made. In Figure 22 such a measurement can be seen. The pressure history is taken from experiment number 9.

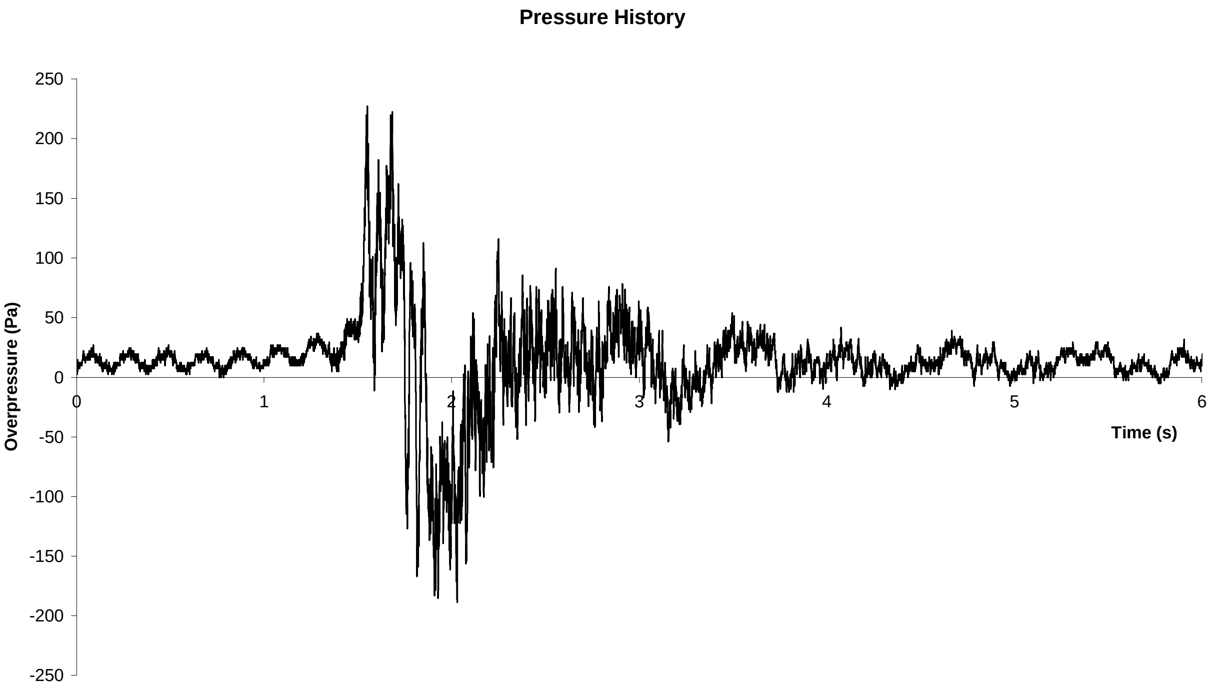

Figure 22. The pressure history when the gas mixture ignites

The pressure has also been measured using the pitot tubes placed in the opening. The pitot tubes are placed at 0,2 m, 0,4m and 0,6 m distances from the opening sill. Some typical results are shown in Figure 23. The data is taken from experiment number 7. The quantitative values should be considered uncertain since the time-scale is very short during the backdraft. As seen in Figure 23, three different stages of the backdraft can be described using the data from the pitot tubes.

1. The first stage is found between the opening of the hatch and prior to ignition . During this stage fresh air will enter the compartment at the lower part of the opening while hot gases escape through the opening's upper part. This is characterised in Figure 23 as an overpressure (flow coming out of the container) in the upper part (height > 0,45 m) and an underpressure in the lower part of the opening
2. This stage is the actual backdraft. Ignition has occured , pushing the gases out of the container. This generates an overpressure across the whole opening.
3. The next few seconds after the backdraft, the pressure inside the container is equalised. This causes fresh air to once again enter the container. This is characterised by an underpressure across the whole opening, yet not as great as the overpressure in the previous stage.

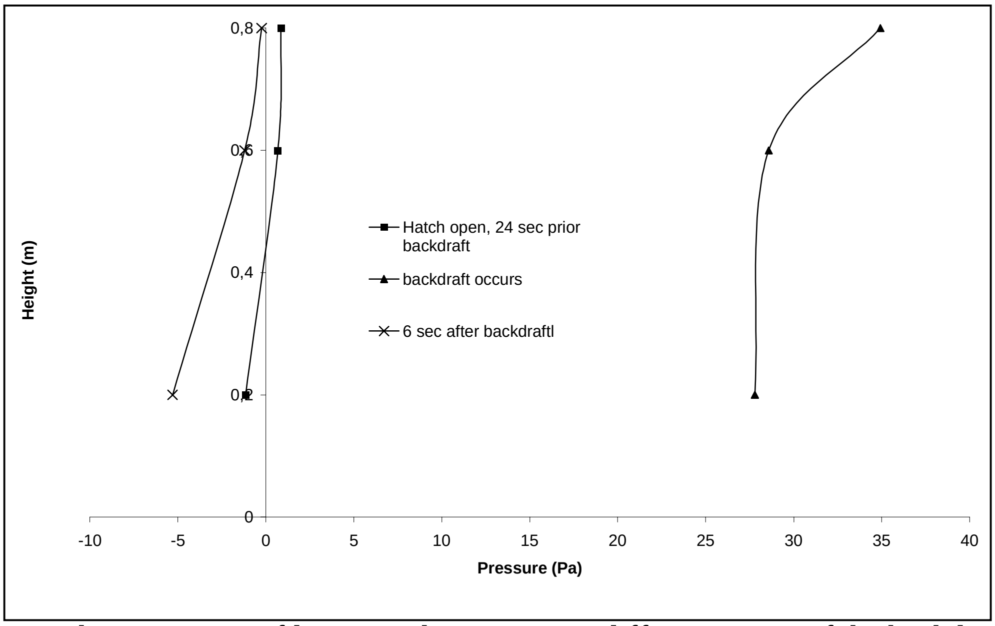

Figure 23. The pressure profile across the opening at different stages of the backdraft.

Conclusions

The purpose of the experiments was to produce a backdraft scenario for demonstrations. There is no problem making a backdraft occur as long as enough fuel is used and the ignition source is powerful enough to ignite the gas/air mixture. Consideration should be taken to the weather since the wind appears to have a major effect on the behaviour of the gravity current.

However, if scientific conclusions are to be drawn the measurement techniques must be refined since the techniques used during these experiments appeared to be non-reliable. One of the most important parameters that control the backdraft situation is the concentration of combustible gas in the enclosure. A reliable method of measuring this parameter must be developed. But even if such a method were used the wind would still have a major effect on the outcome of the experiment. It would have been favourable to perform the experiments indoors where the ambient conditions would be easier to control.

During the experiments was natural gas used as fuel. In forthcoming experiments should solid material, such as wooden and plastic products be used instead to increase the connection to a real case backdraft scenario.

The behaviour of the gravity current is dependent on several factors such as wind, opening geometry and the temperature of the gases. CFD modelling can be used to clarify these issues. During the experiments only a slot opening was used. The experience gained when performing these experiments indicate that the behaviour of the backdraft would probably have been quite different if another type of opening, such as a door opening, had been used.

From the experimental data the backdraft can be rather well explained in a qualitative way. The temperature profiles show clearly how the temperature increases in the compartment as long as there is enough oxygen. After a while the flame will die out and the temperature starts to decrease. When an opening is made the temperature in the lower part of the container will drop further due to the inrush of fresh air. If backdraft occurs a short, but intensive, temperature peak is seen in the temperature-time graphs.

The same course of events can be seen when looking at the gas concentration measurements. The oxygen will decrease during the early stage of the fire. At the same time carbon dioxide will be produced. When fresh air enters the compartment the oxygen concentration increases rapidly. If backdraft occurs the oxygen concentration will decrease once again, at the same time as carbon dioxide is prodeuced. Finally, the gas concentrations are restored to their respective ambient values.

Also the pressure measurements show the backdraft event quite well. During backdraft there is a great over pressure in the compartment and just after the backdraft event is there a minor under pressure.

This document has described some initial backdraft experiments. The main purpose has been to establish a backdraft scenario for demonstration purposes and to highlight some of the problems with measurements that were expected. Future work will concentrate on refining the measurement techniques and, once this is done, carry out systematic experiments, varying such factors as fuel, opening geometry and ignition sorce.

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Appendix

Most of the measurement data from the experiments has been gathered here in this appendix. Figure A1-A4 show the comparison between thermocouples located at the same height between TCT1 and TCT2. The result show that there is very little difference between the temperature measured by the two thermocoupletrees (TCT1 and TCT2). The height of the compared thermocouples is displayed in the figures.

Figure A5-A16 show the temperature's time dependence. 13 experiments were carried out, but during experiment number 1 was the temperature not measured. The experiment number is displayed in the figure. For several cases did backdraft occur. This can be clearly seen as a peak in the temperature after a few minutes. Just prior the temperature peak will the temperature drop slightly since the hatch is released and fresh air is entering the compartment. For the cases when backdraft did not occur will there be no temperature peak.

Finally, Figure A17-A26 show the mass of the natural gas tank as a function of time. Since gas is released from the tank will the mass decrease with time. All graphs have the same length of their scales, i.e. all graphs have 10 kilos mass loss on the y-axis and 400 seconds on the x-axis. In the upper right corner of the figures is the straight line equation of the best fit curve. The best fit curve is also displayed in the graphs. For some experiments did the measuring cell malfunction. The graphs from these experiments are not displayed

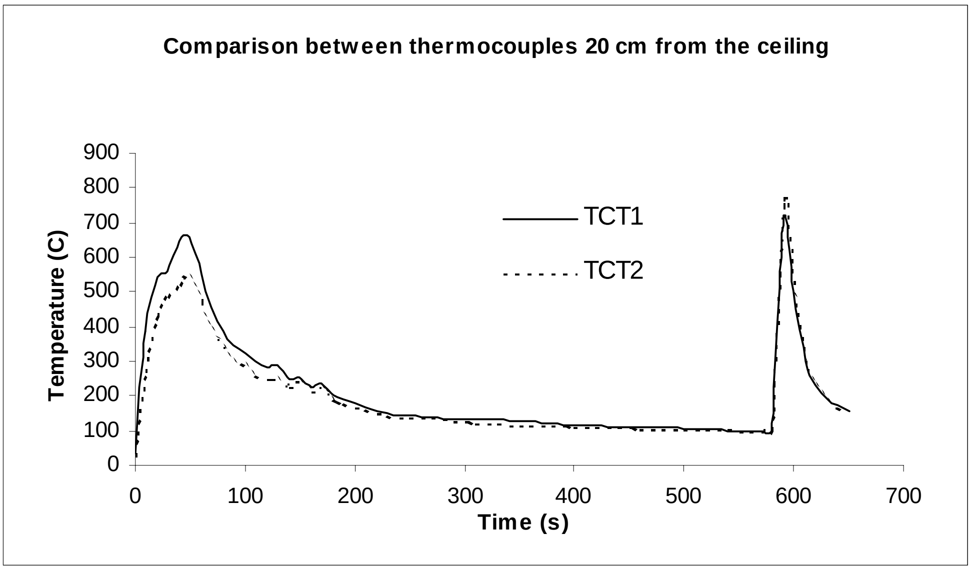


Figure A1. Comparison between thermocouples located 20 cm from the ceiling.

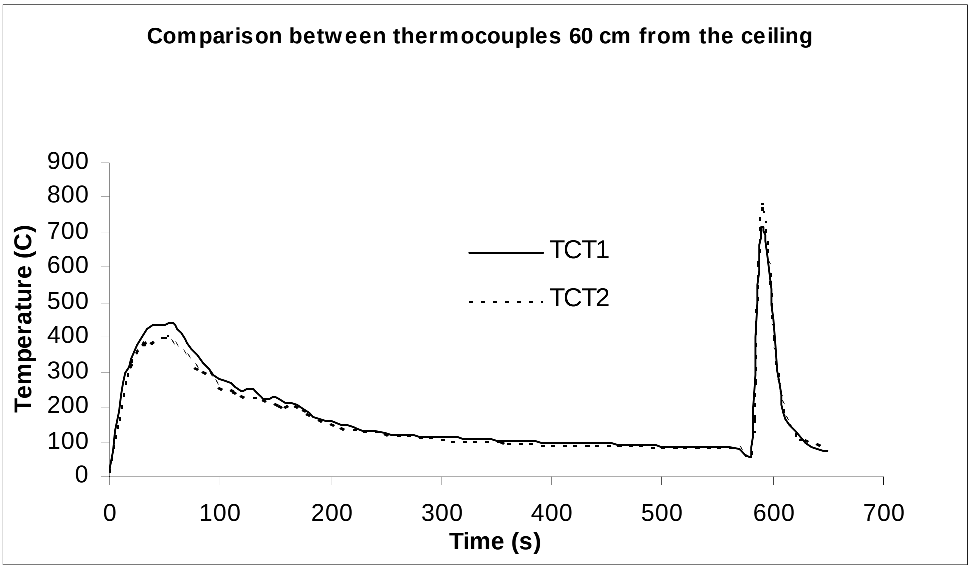


Figure A2. Comparison between thermocouples located 60 cm from the ceiling.

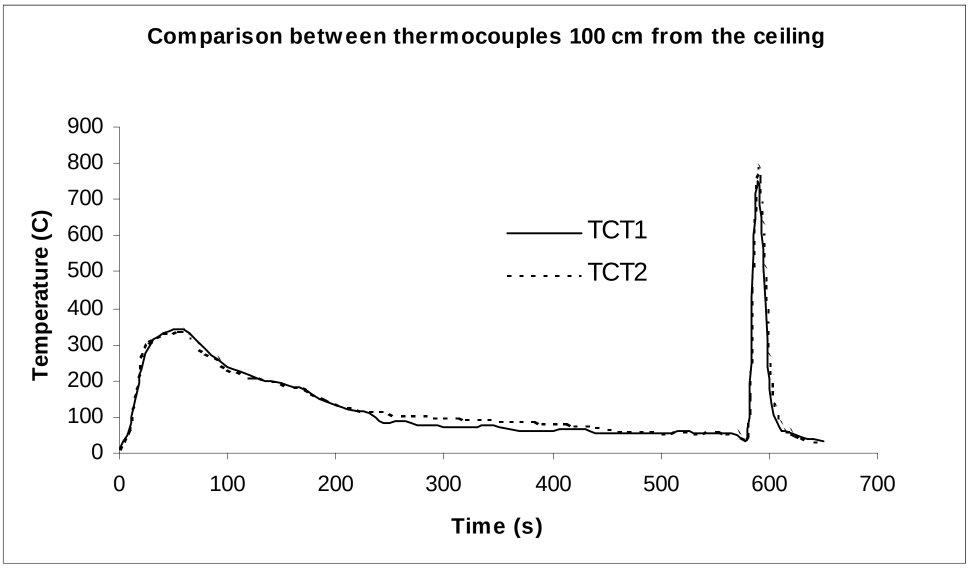


Figure A3. Comparison between thermocouples located 100 cm from the ceiling.

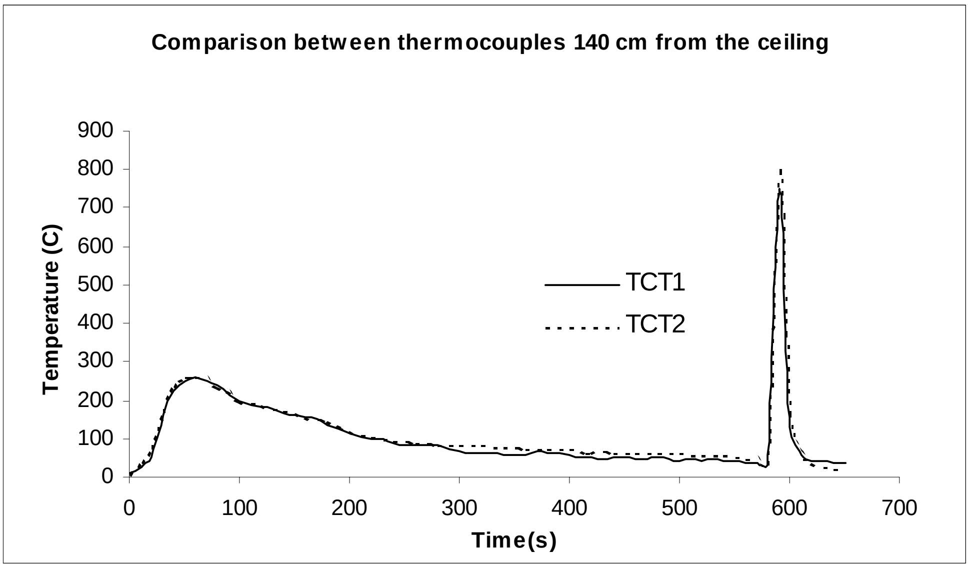


Figure A4. Comparison between thermocouples located 140 cm from the ceiling.

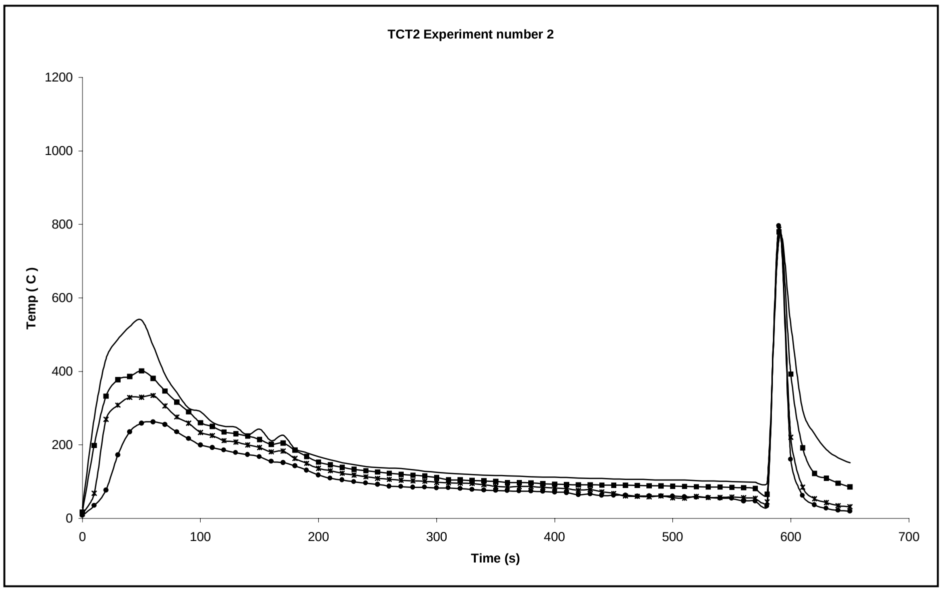


Figure A5. Temperature-time graph for experiment number 2.

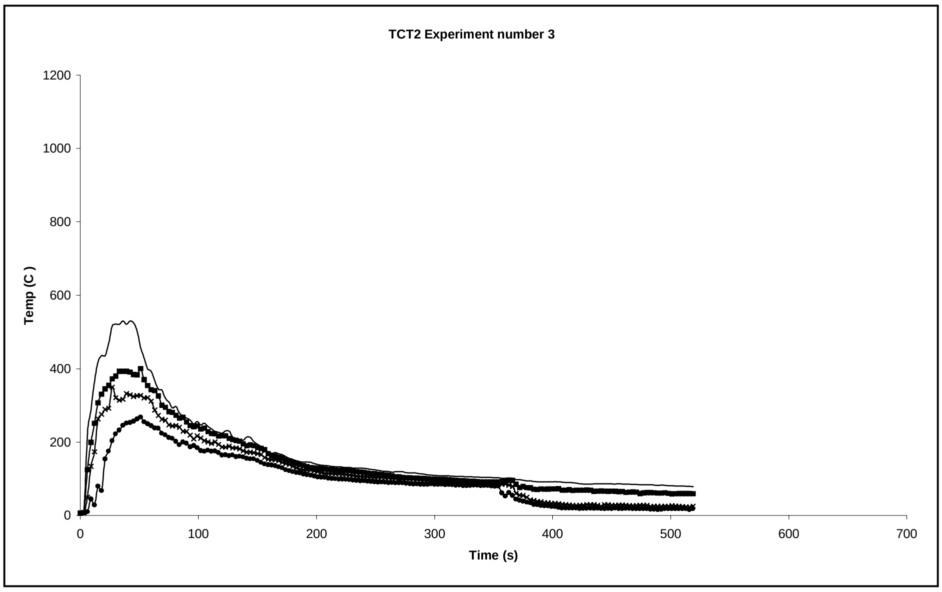


Figure A6. Temperature-time graph for experiment number 3.

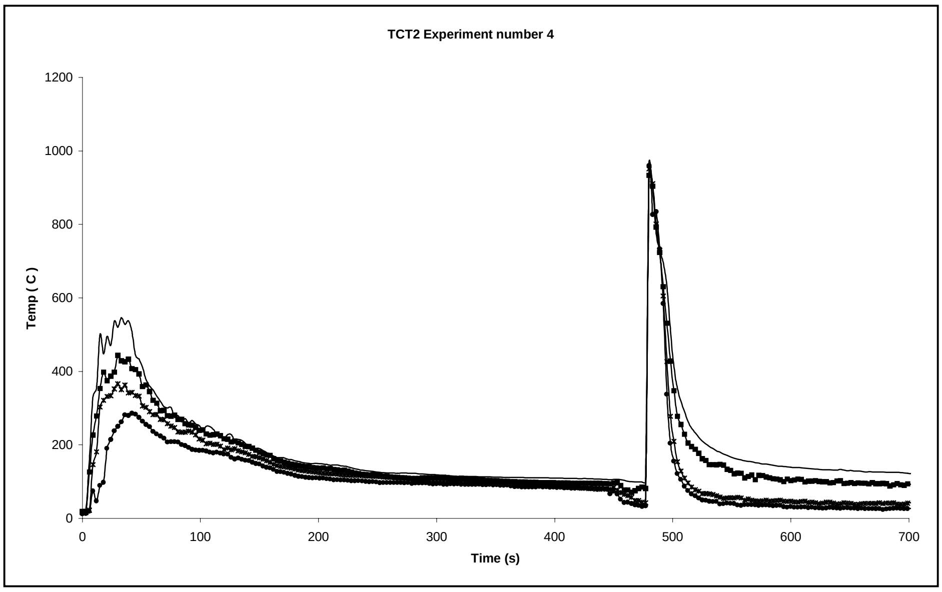


Figure A7. Temperature-time graph for experiment number 4.

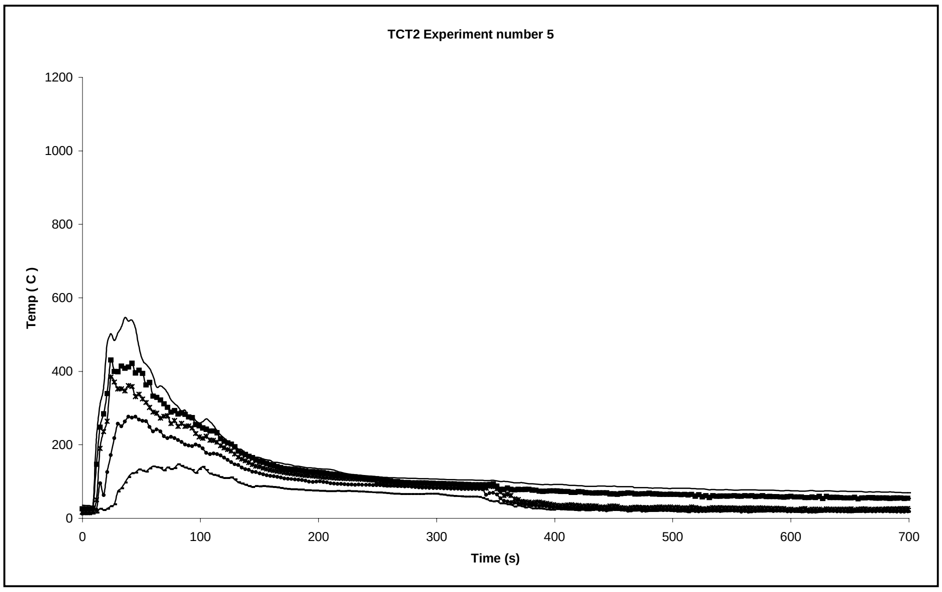


Figure A8. Temperature-time graph for experiment number 5.

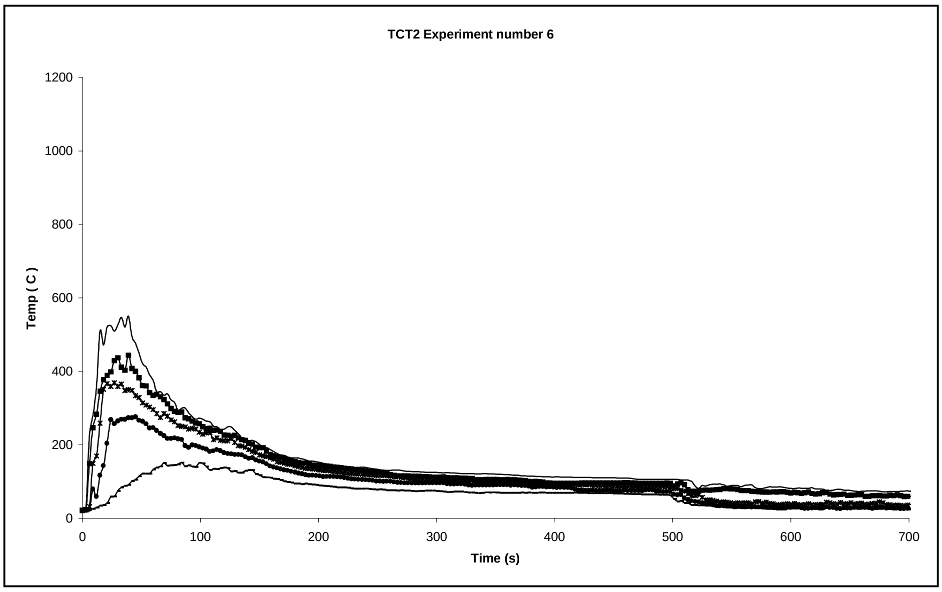


Figure A9. Temperature-time graph for experiment number 6.

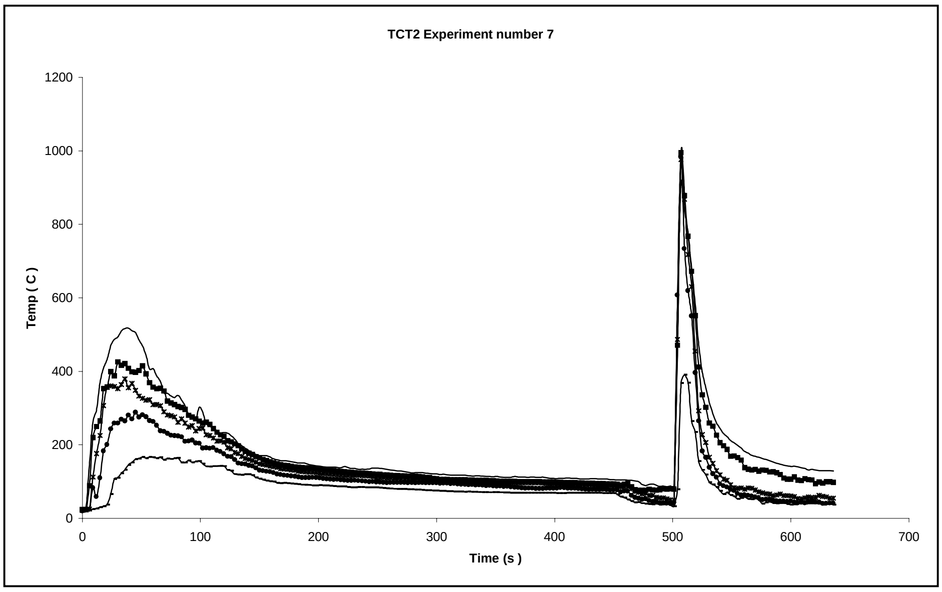


Figure A10. Temperature-time graph for experiment number 7.

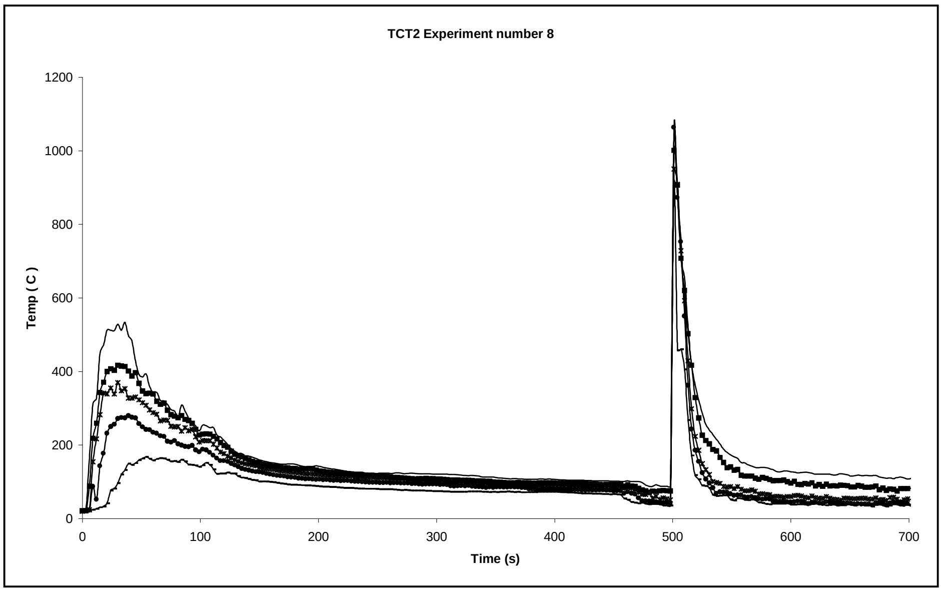


Figure A11. Temperature-time graph for experiment number 8.

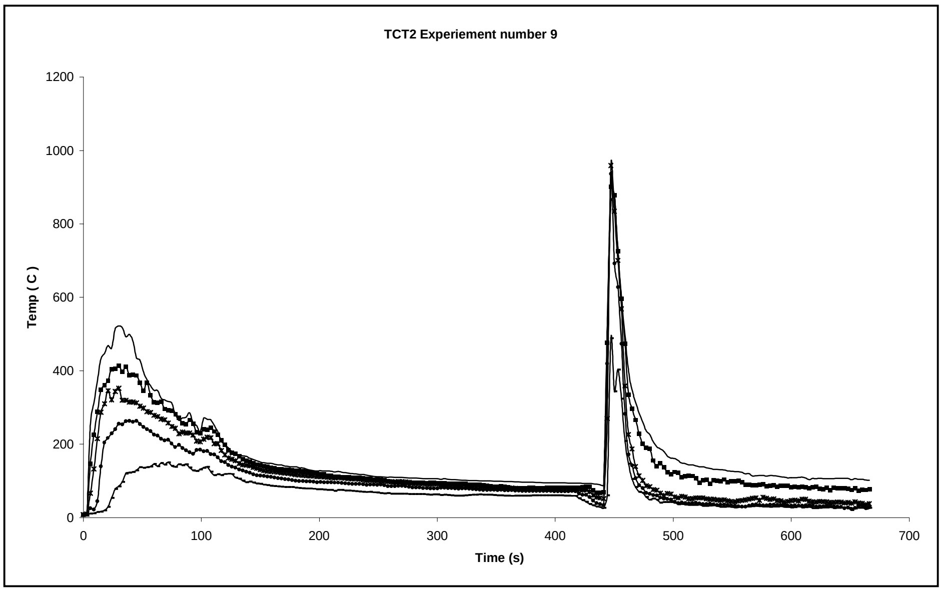


Figure A12. Temperature-time graph for experiment number 9.

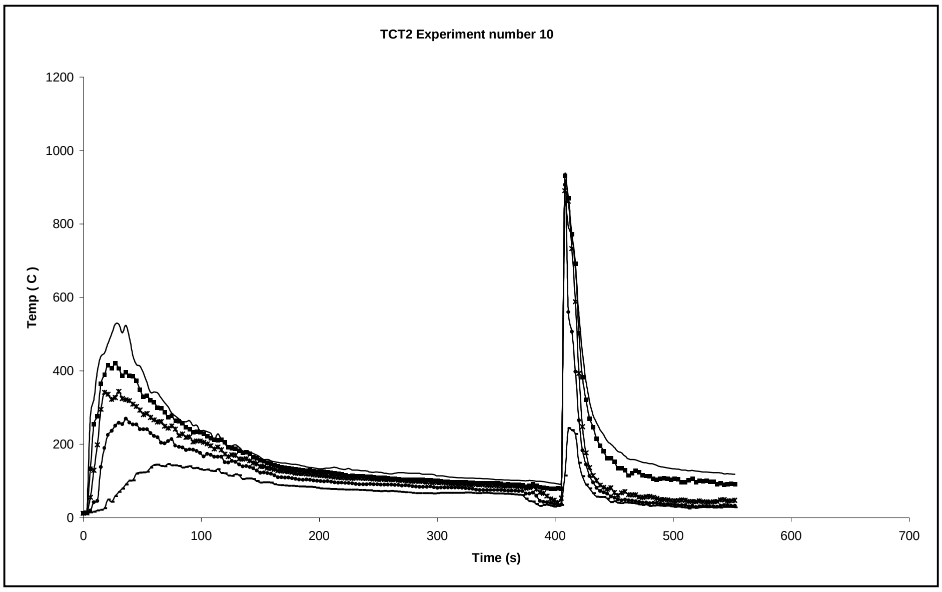


Figure A13. Temperature-time graph for experiment number 10.

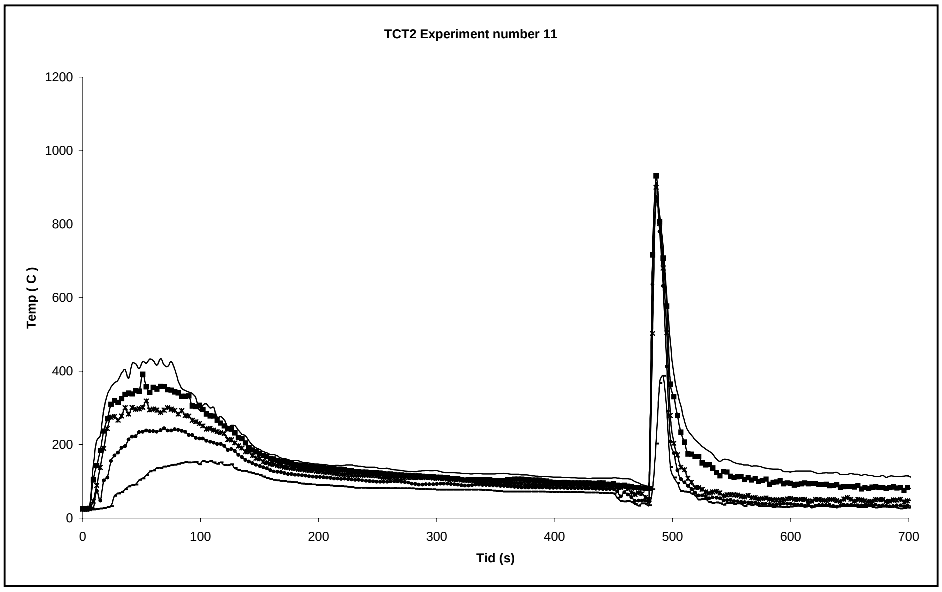


Figure A14. Temperature-time graph for experiment number 11.

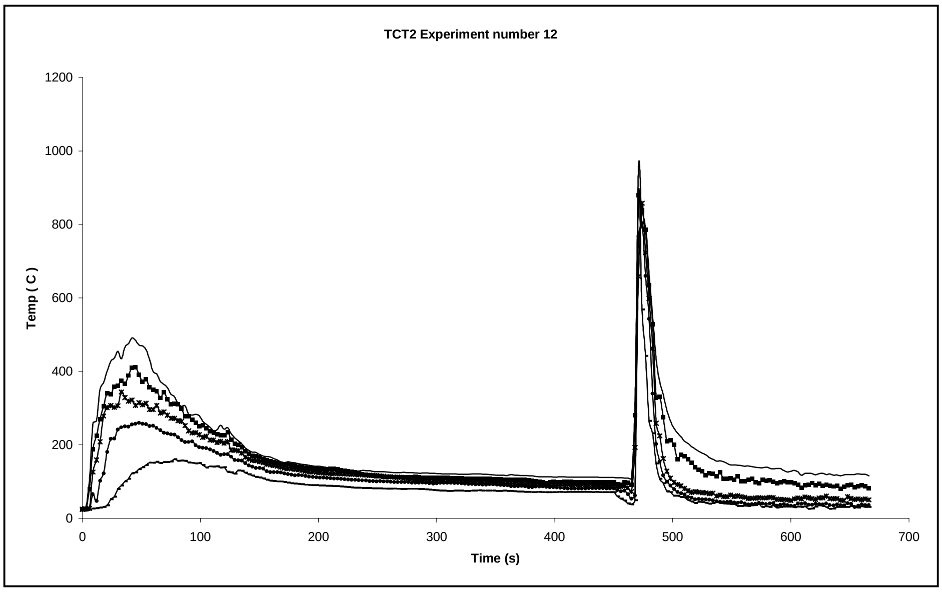
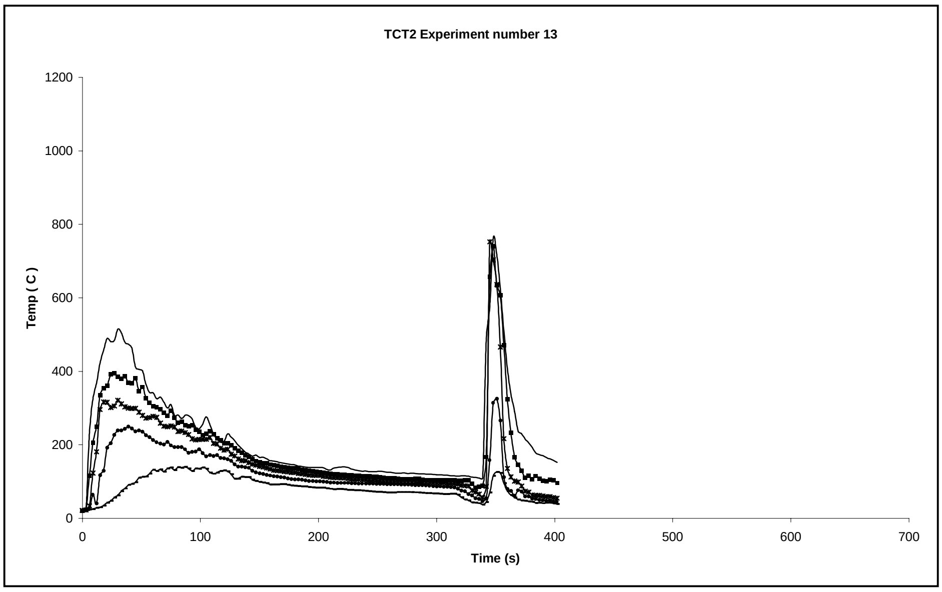


Figure A15. Temperature-time graph for experiment number 12.



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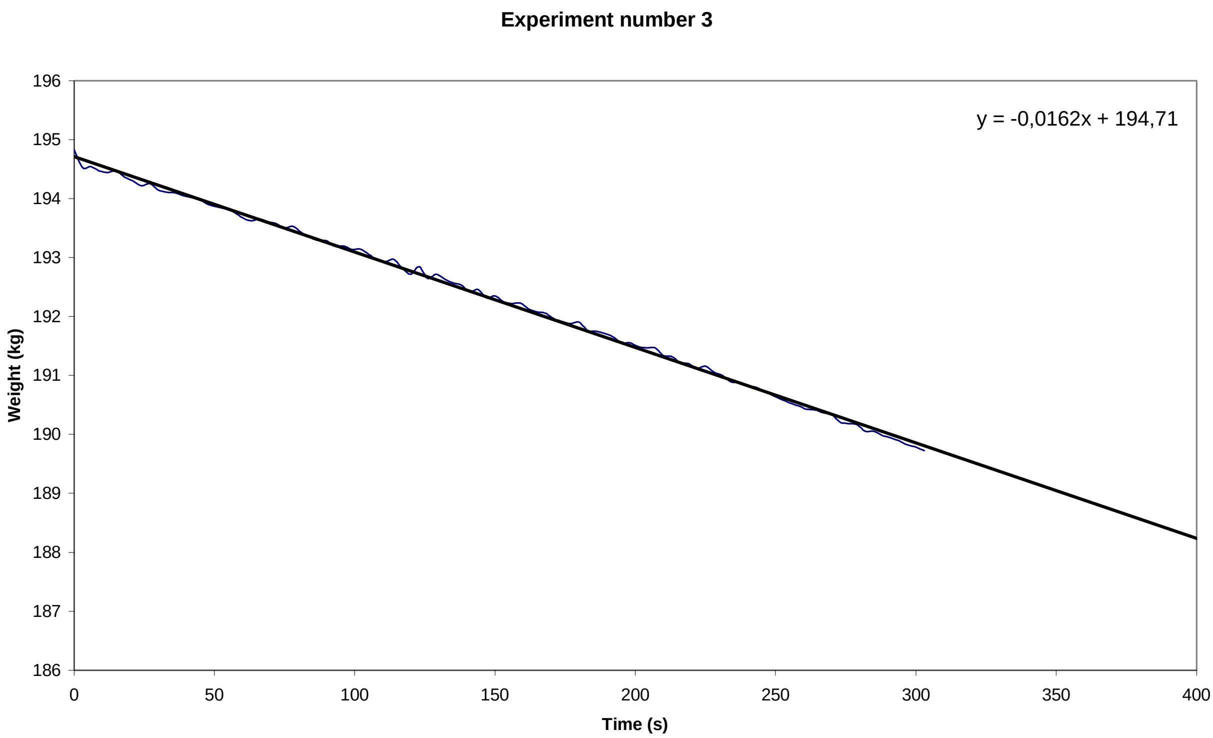

Figure A17. Mass-time graph for the gas tank. Experiment number 3.

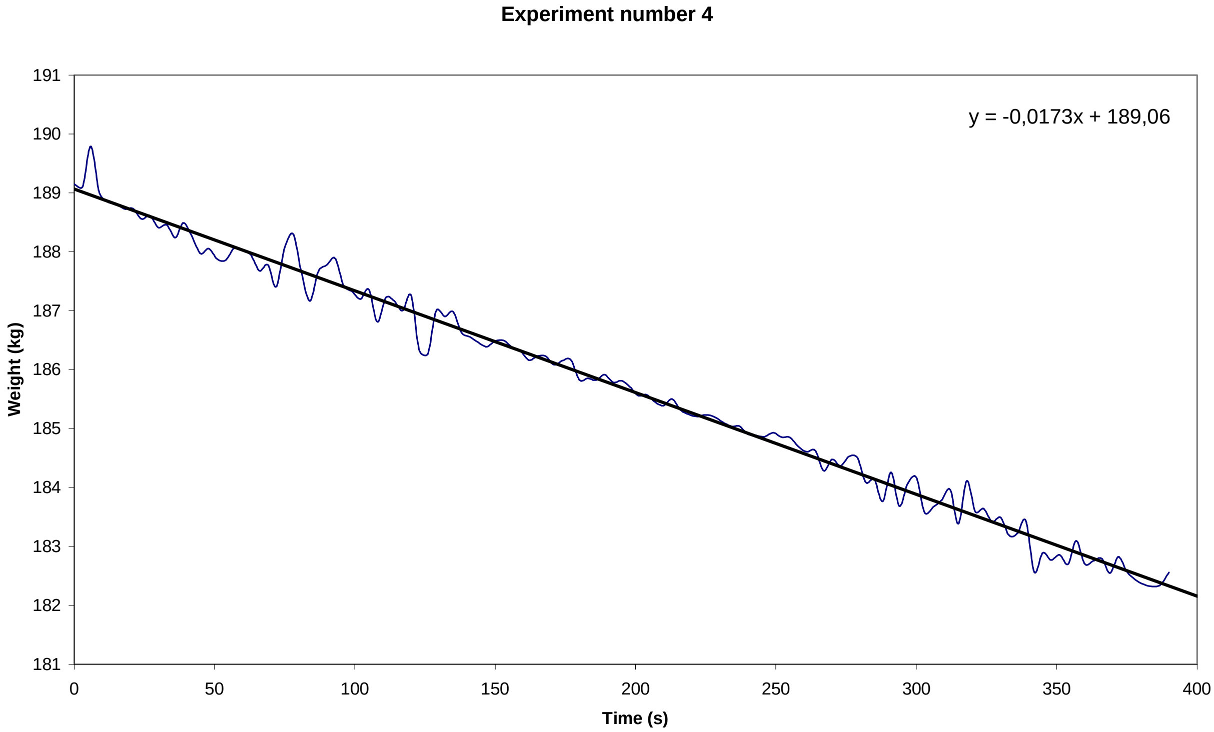

Figure A18. Mass-time graph for the gas tank. Experiment number 4.

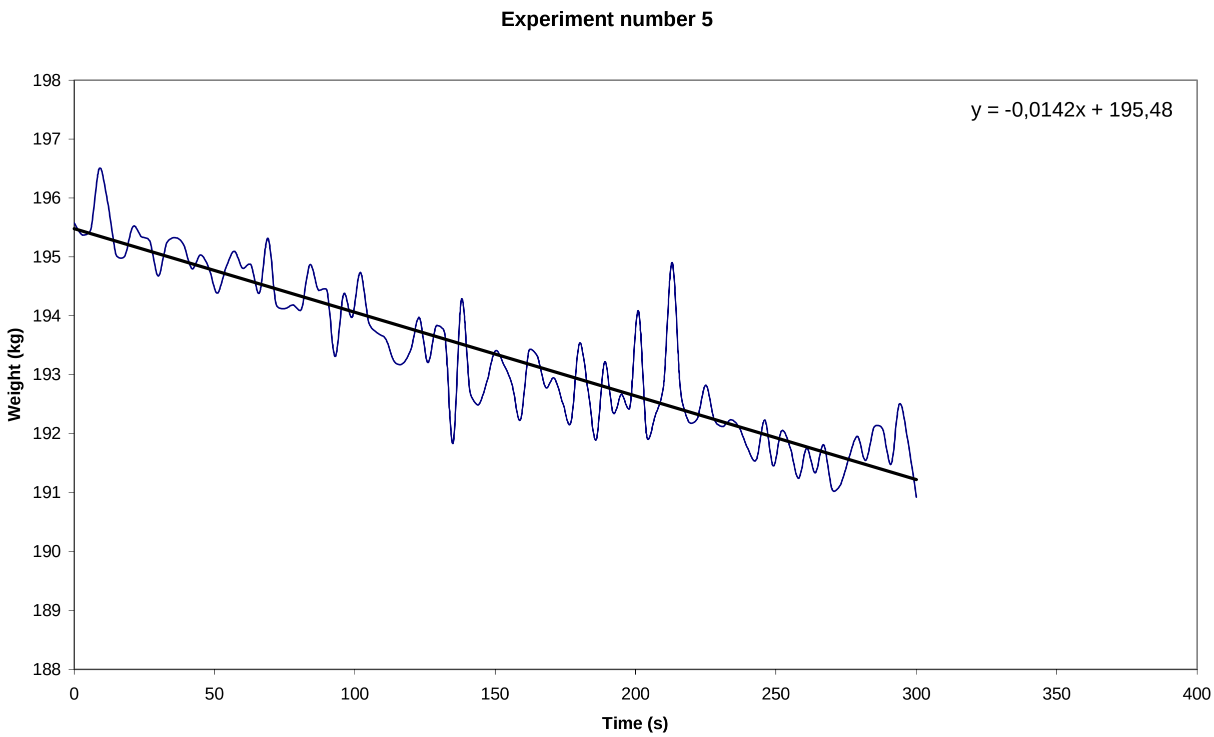

Figure A19. Mass-time graph for the gas tank. Experiment number 5.

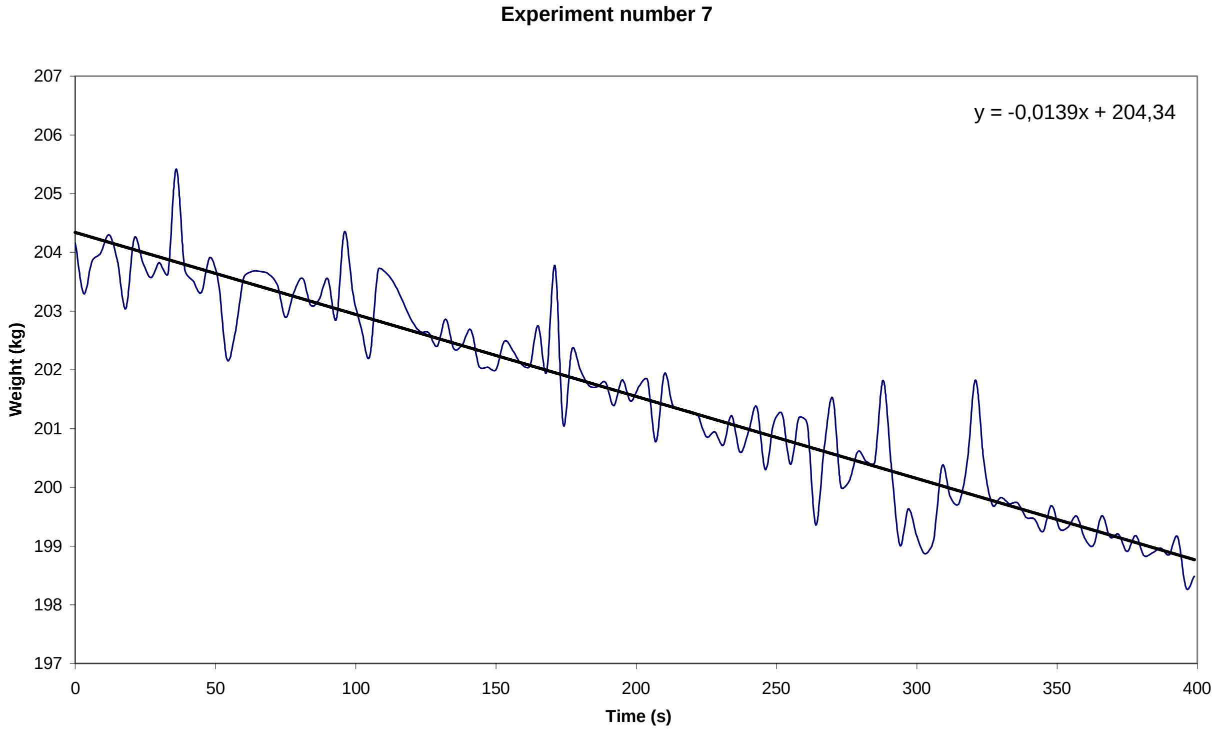

Figure A20. Mass-time graph for the gas tank. Experiment number 7.

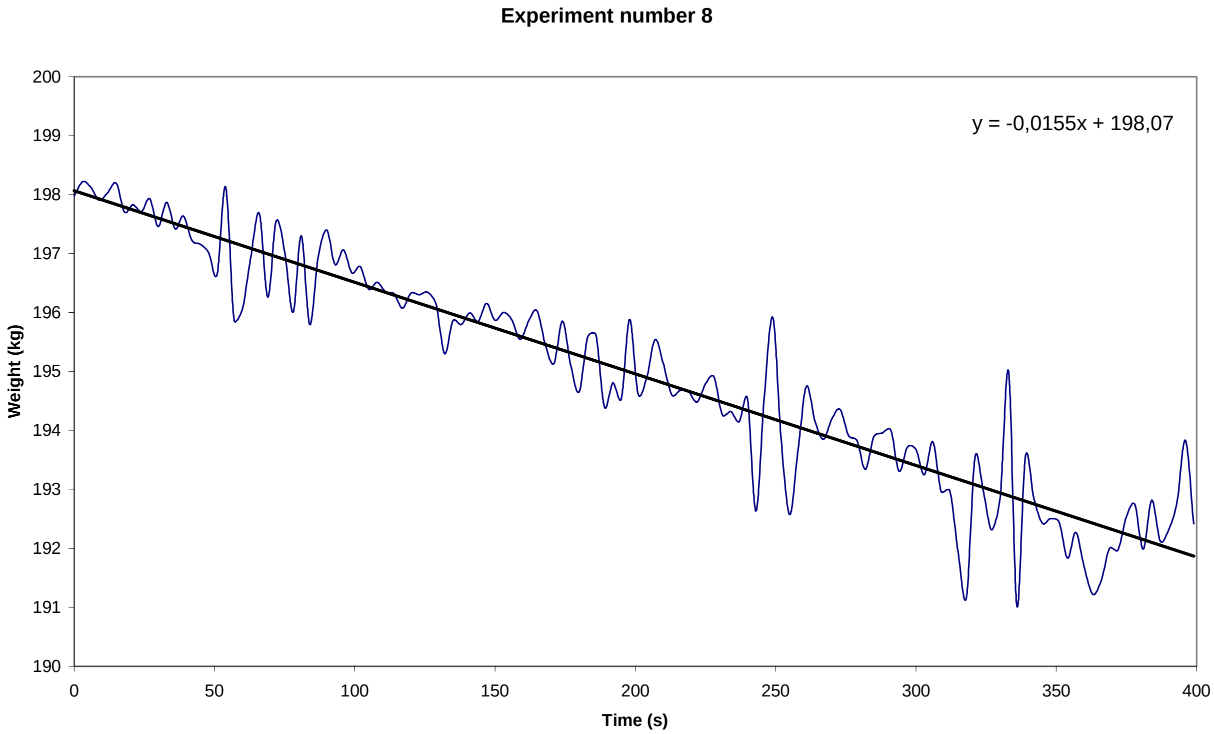

Figure A21. Mass-time graph for the gas tank. Experiment number 8.

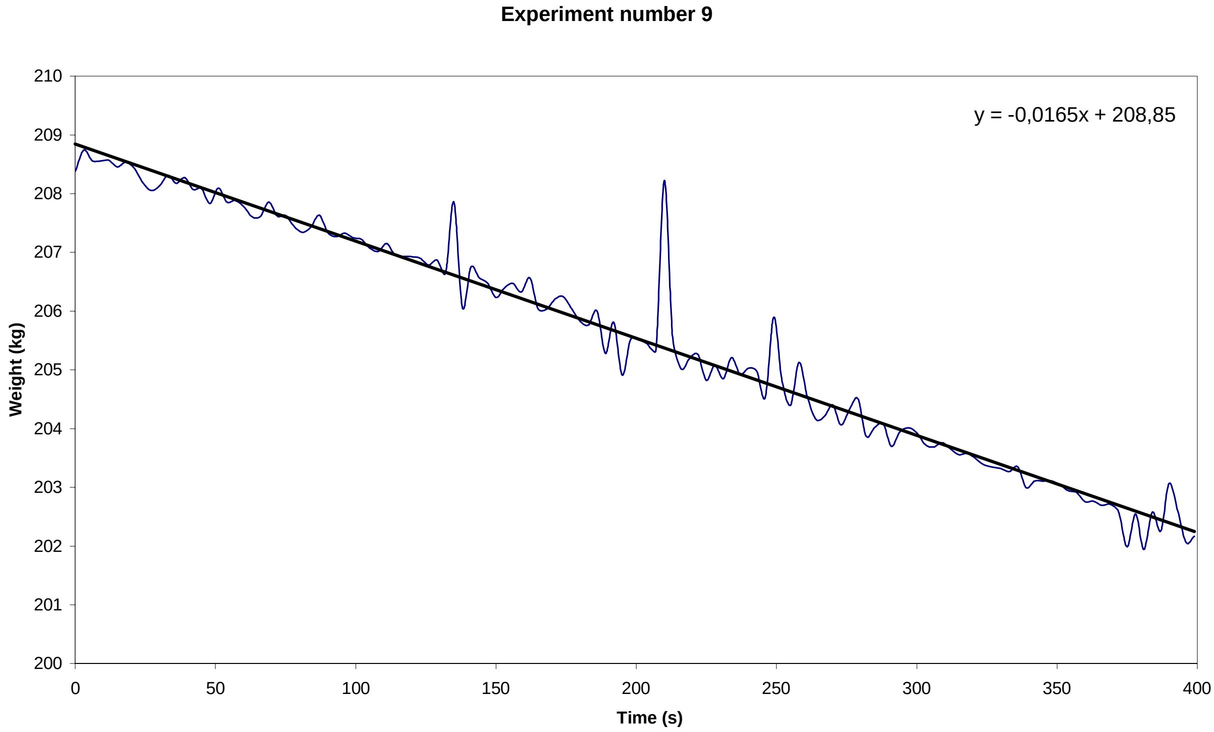

Figure A22. Mass-time graph for the gas tank. Experiment number 9.

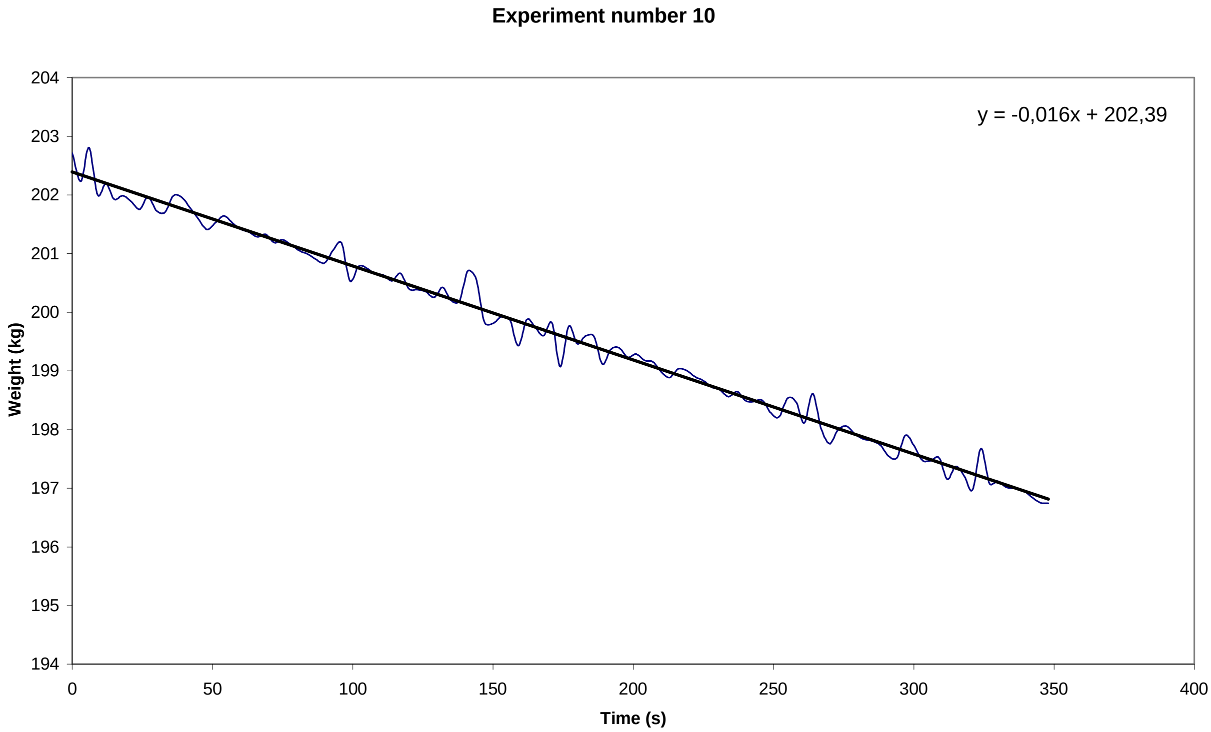

Figure A23. Mass-time graph for the gas tank. Experiment number 10.

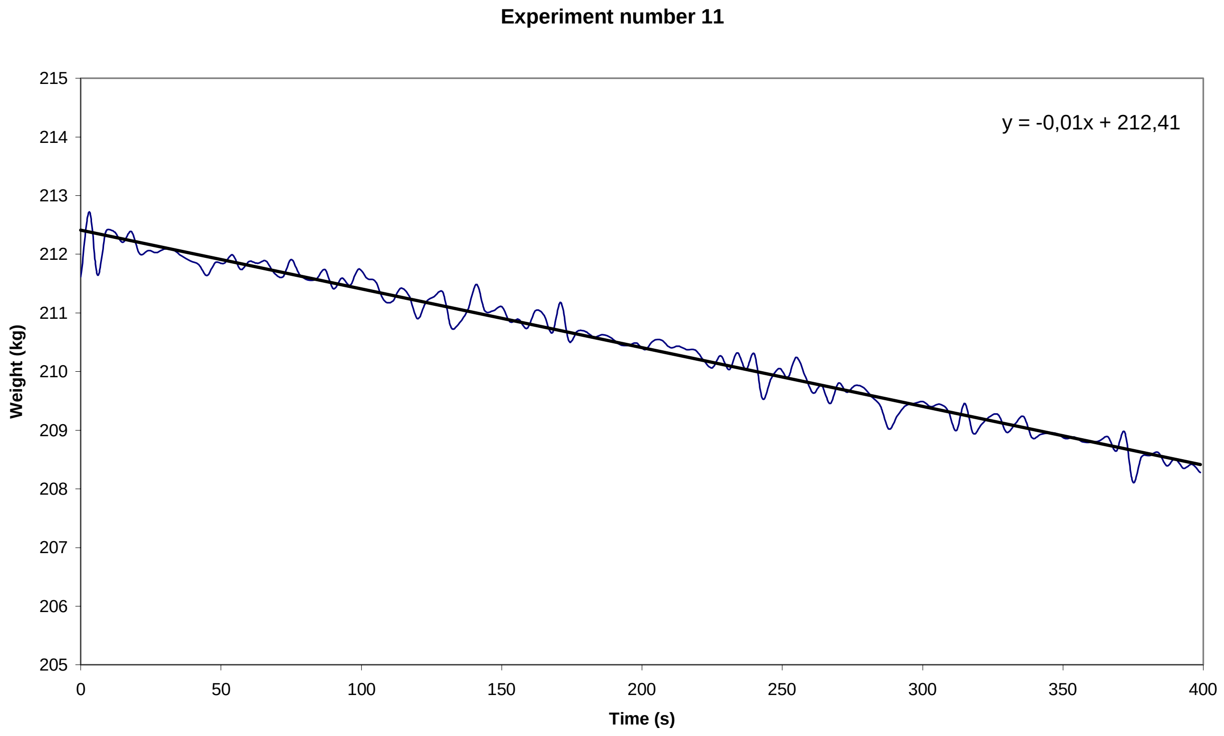

Figure A24. Mass-time graph for the gas tank. Experiment number 11.

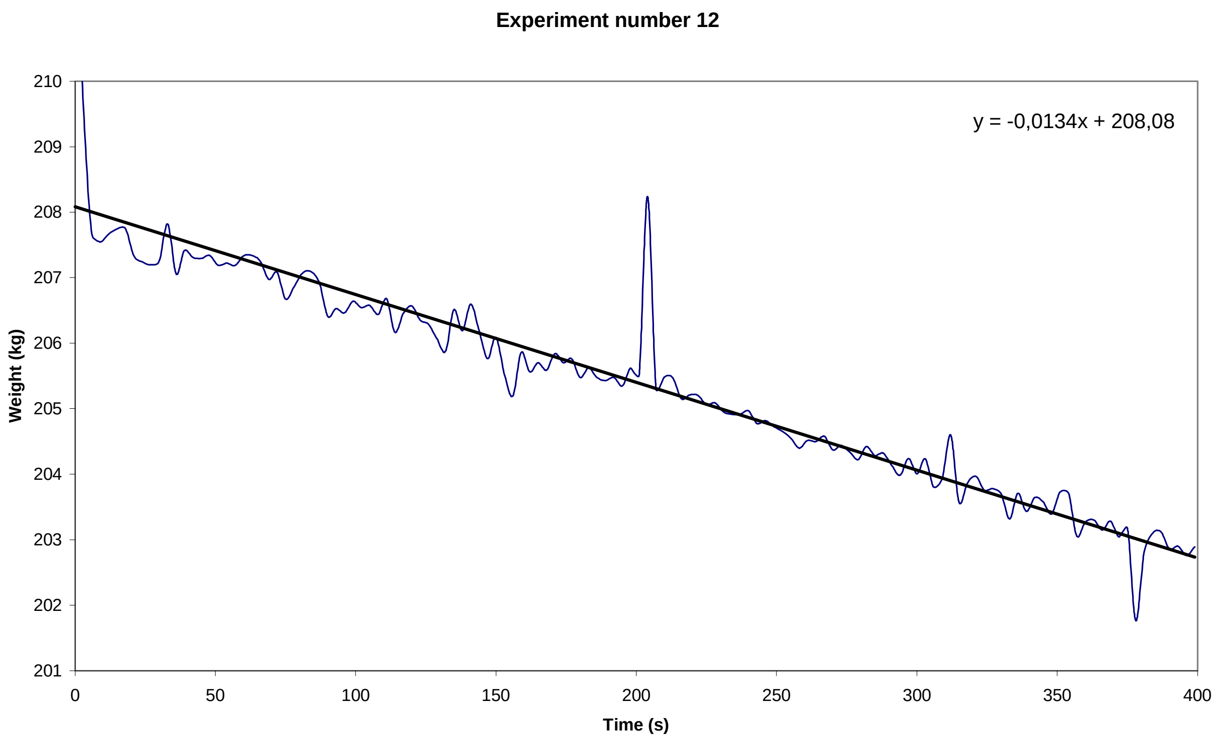

Figure A25. Mass-time graph for the gas tank. Experiment number 12.

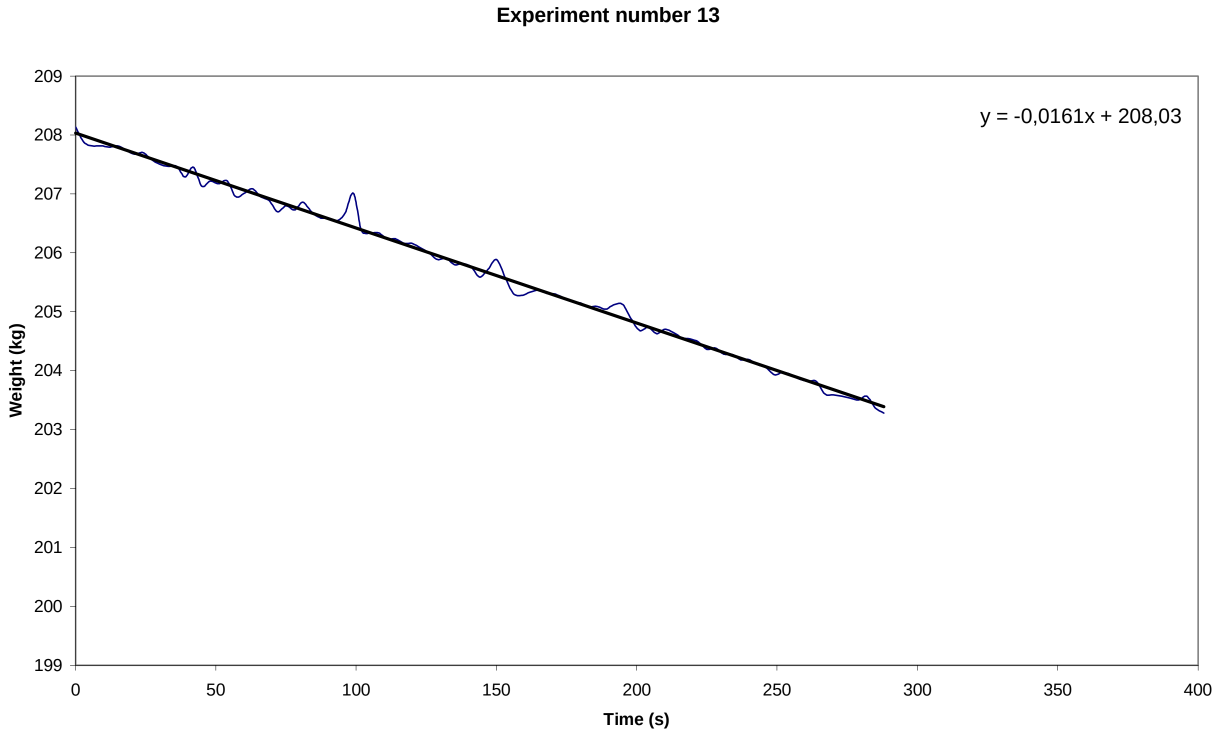

Figure A26. Mass-time graph for the gas tank. Experiment number 13.

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