Investigation of the principle of flame rectification in order to improve detection of the propane flame in absorption refrigerators

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LiTH - IFM - EX - - 05 / 1467 - - SE

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Sammanfattning
Abstract

Electrical properties of a propane flame was investigated to improve detection of the flame in absorption refrigerators. The principle of flame rectification, which uses the diode property of the flame, was studied. A DC voltage in the range 0–130V was applied, between the burner and an electrode in the flame, and the current through the flame in the forward and reverse direction was measured. This measurements were performed with the electrode top in different horizontal and vertical positions. AC voltages at various frequencies was also applied and the average current through the flame was measured.

A linear relation was found between the applied DC voltage and the current through the flame which means that the resistance, in the investigated voltage range, is independent of the applied voltage. The resistance in the forward direction was almost constant for different electrode positions but the reverse resistance varied many hundred $M\Omega$ when the electrode was moved vertically away from the burner. The gas flow also influenced the reverse resistance to a large extent.

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Flame detection, flame rectification, combustion

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Electrical properties of a propane flame was investigated to improve detection of the flame in absorption refrigerators. The principle of flame rectification, which uses the diode property of the flame, was studied. A DC voltage in the range 0–130V was applied, between the burner and an electrode in the flame, and the current through the flame in the forward and reverse direction was measured. This measurements were performed with the electrode top in different horizontal and vertical positions. AC voltages at various frequencies was also applied and the average current through the flame was measured.

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Keywords: Flame detection, flame rectification, combustion

Sammanfattning

Elektriska egenskaper hos en propanlåga undersöktes i syfte att förbättra detekteringen av lågan i absorptionskylskåp. Rektifieringsprincipen, vilken utnyttjar lågans diodegenskap, undersöktes. En likspänning i intervallet 0–130V lades på, mellan brännaren och en elektrod i lågan, och strömmen genom lågan i fram- och backriktningen mättes. Dessa mätningar gjordes med elektroden i olika horisontella och vertikala positioner. Växelspänning med olika frekvenser lades också på och medelvärdet av strömmen genom lågan mättes.

Ett linjärt samband upptäcktes mellan pålagd likspänning och strömmen genom lågan vilket betyder att resistansen, i det undersökta spänningsintervallet, är oberoende av pålagd spänning. Resistansen i framriktningen var i princip konstant vid olika elektrodplaceringar medan backresistansen varierade flera hundra $M\Omega$ när elektroden flyttades bort från brännaren vertikalt. Gasflödet påverkade också backresistansen i stor utsträckning.

Nyckelord: Lågdetektering, rektifieringsprincipen, förbränning

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Abbreviations

The abbreviations used in this thesis are explained here.

Abbreviation	Meaning
DC	Direct current
AC	Alternating current
EMF	Electromotive force
RMS	Root mean square
TRMS	True RMS
UI-graph	Graph showing current plotted against voltage
UI-curve	The curve in an UI-graph

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Chapter 1

Introduction

In this chapter the background to the thesis will be explained. The host company will be presented and the problem stated.

1.1 Background

The host company, Dometic AB, and its products are presented in this section. Dometic produce absorption refrigerators in which the gas burner, that is investigated in this thesis, is used.

1.1.1 Dometic AB

Production of refrigerators in Motala started 1923 under the name of AB Arctic. Electrolux purchased the company in 1925. Dometic AB was established in 2001 when Electrolux sold its leisure product division to the venture capital company EQT. The name Dometic was taken since it earlier had been the Electrolux trademark in the USA. EQT sold Dometic in April 2005 and the buyer was the British venture capital company BC Partners. Dometic's main product is refrigerators used in recreation vehicles, hotels and for medical purposes. One of Dometic's largest production facilities is the Motala factory at which the work with this thesis has been carried out. Dometic has about 800 employees in Motala today. Refrigerators, water purificators and wine cellars are the products that are manufactured in the Motala factory. All refrigerators that are made by Dometic in Motala are based on the absorption technology.

1.1.2 Absorption technology

The refrigerators produced by Dometic are based on the absorption technology which was the principle of cooling used in the first commercial refrigerators. The absorption technology [8, 9] was invented by Ferdinand Carré about 1860. The Swedish students Baltzar von Platen and Carl Munters invented the first absorption refrigerator without movable mechanical parts as a thesis work at KTH (Royal Institute of Technology) in 1922. They also protected their invention by patent [6, 7]. von Platen's and Munters' invention is still the base for the absorption refrigerators which are made by Dometic today.

The absorption cooling unit is the device where the cooling takes place in an absorption refrigerator. It mainly consists of a boiler, a condenser, an evaporator and an absorber. How the cooling unit works will be described here. The capital letters, used to show various parts of the cooling unit, refer to figure 1.1. The cooling unit can be run either on gas, kerosene or electricity. When the unit runs on gas or kerosene the heat is supplied by a burner located under the chimney tube[1] (tube A) and when it runs on electricity a heating element is inserted into the tube B.

The cooling unit contains a quantity of ammonia, water and hydrogen at a sufficient pressure to condense ammonia at room temperature. The unit is a closed system which never needs to be opened after manufacturing.

The boiler system produces bubbles of ammonia gas when heat is supplied to it. The ammonia gas bubbles carry weak[2] ammonia solution through the siphon pump (tube C). This weak solution falls back into the tube D but the ammonia vapour rises into the vapour pipe (tube E). Then the ammonia vapour continues to the water separator where the water vapour is condensed and runs back into the boiler system. The ammonia vapour continues to the condenser where air circulation over the fins of the condenser removes heat from it. It condenses to liquid ammonia and flows into the evaporator. The evaporator is supplied with hydrogen and the hydrogen passes across the surface of the ammonia and lowers the ammonia gas pressure enough to allow the liquid ammonia to evaporate. Heat is extracted from the evaporator when the ammonia evaporates and that heat is taken from the food storage space in the refrigerator. The mixture of ammonia and hydrogen gas continues to the absorber. A continuous trickle of weak ammo-

[1] The chimney tube acts as a chimney for the burnt gas when the refrigerator runs on gas or kerosene and its purpose is to transfer the heat from the flame to the coolant.

[2] There are principally two kinds of ammonia solution inside the cooling unit; a strong one with a higher ammonia concentration and a weak one with a lower ammonia concentration.

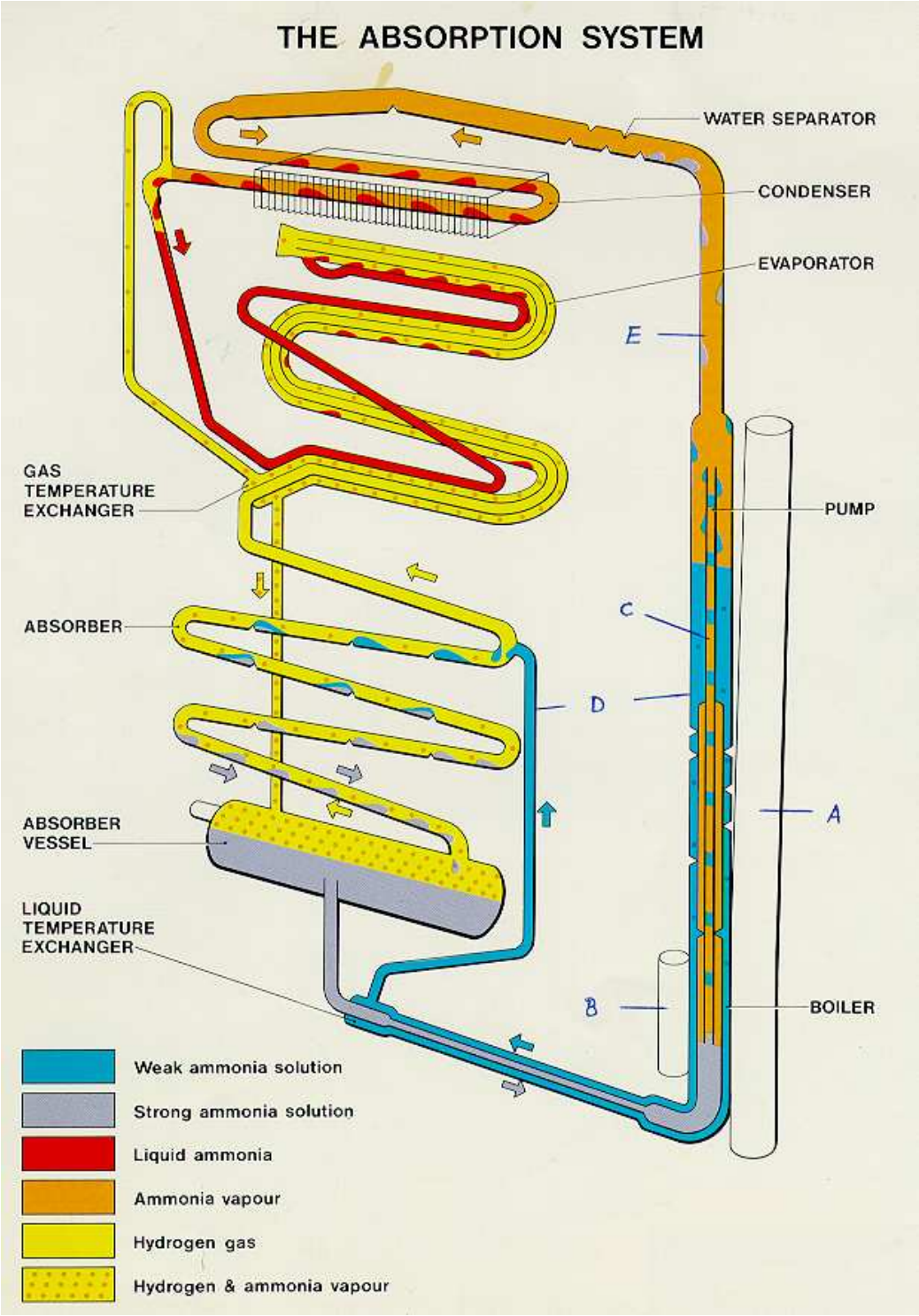

Figure 1.1: The absorption cooling unit.

nia solution enters the absorber from the tube D. This weak solution flows down through the absorber and absorbs the ammonia from the ammonia and hydrogen gas mixture. This leaves the hydrogen ammonia free and it can rise back to the evaporater. The hydrogen runs continuously between the evaporator and the absorber in this way. The strong ammonia solution which is produced in the absorber flows down to the absorber vessel and the boiler. In this way an operation cycle of the absorption cooling unit is completed.

It should be observed that the liquid circulation in the unit is purely gravitational. This implies that the absorption cooling unit needs to be orientated with the boiler in a vertical direction to work properly. It is improtant to have a good air circulation around the absorber to remove the heat which is generated there. The condenser has to be encircled by free air circulation in order for the ammonia to be cooled enough to condense.

1.2 Problem formulation

The problem that will be investigated in this thesis is presented in this section and the thesis statement is given.

1.2.1 Flame detection

When running a product (for example a refrigerator) with gas it is important to know if the flame is present. If the flame is not present Dometic's system tries to reignite and if this does not succed the gas valve has to be closed to prevent excessive gas flow. Gas flowing out in a closed space is an explosion hazard and it is therefore very important that the flame detection system works properly.

Different ways of detecting small gas flames exists. As mentioned in [3, 4] for example thermocouple, the electrical properties of flames and their infrared and ultraviolet radiation are methods used in detection systems. This thesis will focus on flame rectification which is a detection method that uses the electrical properties of the flame. Thermocouple has been used for a long time. Dometic still uses thermocouple in the majority of their refrigerators despite that there are disadvantages. The thermocouple generates a current when it is heated and in former days that current was used to power an electromagnet that kept the gas valve open. No external voltage had to be applied so this method was robust. It was, however, hard to control the gas valve[3] electronically with this solution so today all

[3]The old mechanical solution required manual start and stop.

Dometic's refrigerators have a gas valve which is electronically controlled but the flame detector is still a thermocouple. Flame detection with thermocouple requires an extra probe (the thermocouple probe) inserted into the flame. This is not the case when flame rectification is used because then the spark probe can be used for detection as well. It is favourable to remove the thermocouple probe since it decreases the production cost for the refrigerators. To cut costs is always important when manufacturing consumer products in large numbers. Another disadvantage of a thermocouple is when the flame flickering (due to for example draught in the caravan) makes the average temperature of the thermocouple too low to sense the flame and therefore the refrigerator is turned off even if the flame is present. The slow response of a thermocouple is another weaknes. It takes about 5–10 seconds for the thermocouple to react, and close the gas valve, when the flame is quenched. Flame rectification is a much faster detection method.

1.2.2 Thesis statement

The objective of this thesis is to analyze the principle of flame rectification in Dometic's burner system experimentally. This will provide deeper knowledge on how to place the electrode and what voltage to apply in order to optimize flame detection. The purpose is to increase the knowledge and understanding of what happens when different parameters are changed and not to design a new burner system.

1.2.3 Delimitations

There was no suitable variable voltage source available at Dometic to generate the voltages being applied to the flame. To avoid dangerous currents during the experiments the voltage used was stepped up from the 12V output of a signal generator via a transformer. This construction only allowed voltage output in the range of 0–130V for DC and 0–100V for AC. Due to this fact the applied voltages were restricted to these ranges.

Only sine waves were used in the AC measurements and the upper limit of the frequencies was 1 kHz because the voltmeter (Fluke 76 TRMS) used was only able to stand frequencies up to this limit.

Another delimitation concerns the accuracy when the electrode was positioned relative to the burner. An accuracy on approximately ± 0.3 mm was achieved since the electrode was manually positioned and the position was measured by measurement pins and slide-calliper. This delimited the accuracy.

Chapter 2

Theory

This chapter contains a review of the theory of ionization in flames and how it makes the principle of flame rectification possible.

2.1 Ionization in flames

Different flames conduct current to a different extent but it is the property of conduction that makes flame detection with applied voltage possible on the whole. Propane flames are investigated in this thesis so this theory section will give a short review why such flames conduct current.

The current through the flame is conducted by free carriers created in the flame. Ions in flames have been studied for a long time which can be seen in [5]. A lot of ideas about what causes the ionization have been tested. At an early stage of the investigations of hydrocarbon flames, the thermal process[1] of ionization was the most common explanation. This is however not the explanation that applies today. Many good arguments indicates that the chemi-ionization is responsible for the ions in hydrocarbon flames[2]. The following reaction is considered to create the main part of the ions in these flames [2, 10].

$$\mathrm{CH} + \mathrm{O} \longrightarrow \mathrm{CHO}^{+} + \mathrm{e}^{-}$$

There is also other chemi-ionization processes that contribute to the concentration of ions in the flame but the process above is suggested to be the main reason.

[1] A *thermal process* is any process that utilizes heat, without the aid of a catalyst, to accomplish chemical change.

[2] More about hydrocarbon flames can be read in [1].

2.2 Flame rectification

The fact that a flame conducts current can be used to detect if the flame is present or not. One can think of a very simple system that just applies a voltage between the burner and an electrode, located above the burner, and measure if there is any current passing. If current passes then the flame is present. This works in principle but it is not a secure system because some dust or soot between the burner and the probe might conduct a current and always indicate that the flame is present even if it is not. Such a system will not fulfill the requirements of a secure saftey system. Another interesting property of flames is that if the two electrodes, that the voltage is applied between, do not have the same sizes and geometrical positions different amount of current passes depending on the sign of the voltage. This means that a flame behaves like a diode. It conducts in one direction and stops the current in the other. The direction of conduction is from the smaller electrode (the probe) to the larger electrode (the burner).[3] The flame is after all not a perfect diode since there is a back current.

The rectification property of a flame makes it possible to detect the flame in a more reliable way. An AC voltage is applied between the burner and a probe and this results in a net current in the forward direction if the flame is present but no current at all if the flame is not present. This method is much safer than just to apply a DC voltage and sense a current since the rectification method will just measure an AC if it is a short between the burner and the probe. An AC is not enough to detect the flame since the detection system requires an average net current in the forward direction.

The method of flame rectification is only used in systems with small gas flames since the temperature cannot be too high. There is a risk of misdetection [4] in the temperature range between 900°C and 1300°C and a sure misdetection above 1300°C. The misdetection occurs during a time period after that the flame has gone out. This depends on the fact that gas is emitted from the electrode. The temperature range is dependent on the material in the electrode.

[3] In all other chapters the small electrode (probe) is called *the electrode* and the larger electrode is called *the burner*.

Chapter 3

Experimental details

In this chapter the experimental setup is described. The equipment used and the measurements are explained.

3.1 Equipment

The equipment used for the experiments is described in this section. Modifications of the burner is explained and the two boxes made to perform the voltage measurements are explained. A photo of the burner used in this thesis work can be seen in figure 3.1.

3.1.1 The modified burner

The idea of this work was to make measurements on the burner that is used by Dometic today. The attachment point of the electrode had to be sligtly modifed allowing the position of the electrode to be changed. Nine holes were made allowing the electrode to be moved in nine discrete vertical positions. The electrode was moved[1] 3.0 mm closer to the burner in the horizontal plane which probly gave other measurement values than if it had not been moved. None of the other changes are supposed to affect the measurements because the changes are done so far from the flame. Please note that the burner house itself was not modified at all[2]. The dimensions of the modified burner can be seen in figure 3.2 and figure 3.3. A photo can be seen in figure 3.4.

As can be seen in figure 3.2 the six slits were labeled $\mathrm{S1}, \ldots, \mathrm{S6}$. The nine discrete

[1] The electrode was moved in the horizontal plane just to make it easier to move it in the vertical direction.

[2] It was only the attachment point for the electrode which was modified.

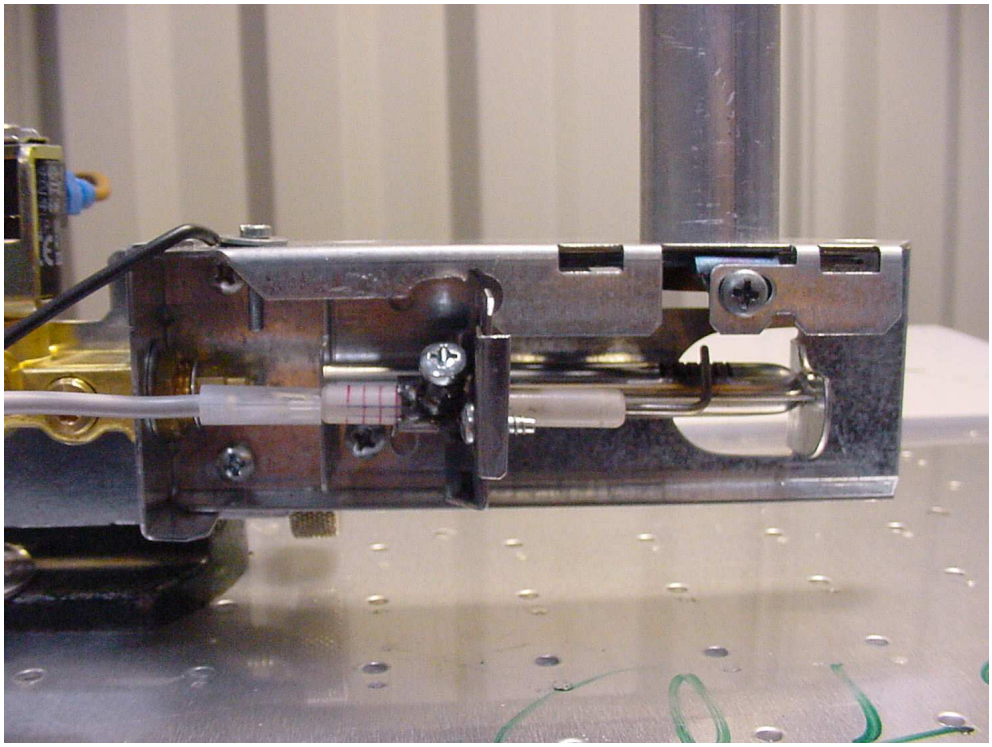

Figure 3.1: The Dometic burner used in this thesis work.

Label	d2 (mm)
V1	9.0
V2	11.0
V3	13.0
V4	15.0
V5	17.0
V6	19.0
V7	21.0
V8	23.0
V9	25.0

Table 3.1: Description of the discrete vertical positions of the attachment point of the electrode. The distance d2 refers to figure 3.2.

vertical positions of the electrode were labeled $\mathrm{V1}, \ldots, \mathrm{V9}$ as described in table 3.1. The distance d2 in table 3.1 refers to figure 3.2. In the text the position of the electrode is described like $(\mathrm{V5}, \mathrm{S4}, 4.5\mathrm{mm})$. In this case it means that the vertical discrete position of the electrode was V5, the electrode top was located above slit S4 and the distance between the electrode top and the burner was 4.5 mm.

3.1.2 Materials in the burner

The type of electrodes used in this thesis can be seen in figure 3.2 and 3.3. The conducting part of the electrode, which is in the flame, consists of a ferritic nickel free stainless steel. Even the burner house is made of a ferritic stainless steel.

3.1.3 The DC–box

A signal generator was selected to vary the voltage being applied to the flame. The signal generator only gave an output voltage with a maximum value of 12V peak to peak for a sine wave and therefore a transformer had to be used. A rectifier had to be used to rectify the AC output from the transformer. A box was designed and built to contain the electronics needed when doing the DC measurements. It was called the DC–box and a circuit diagram of it can be seen in figure 3.5. The transformer gave an output in the range of 0–130V[3] DC when the peak value of the input AC voltage was in the range 0–12V. The DC–box was equiped with three connection points; an input connection for the input AC voltage, a connection for

[3]The maximum output voltage of the transformer varied a bit depending on the frequency of the input AC voltage.

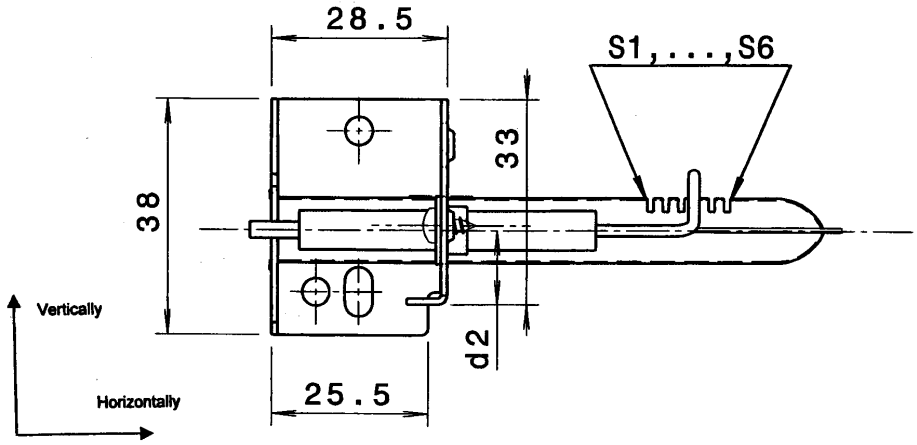

Figure 3.2: Drawing of the Dometic burner from one side.

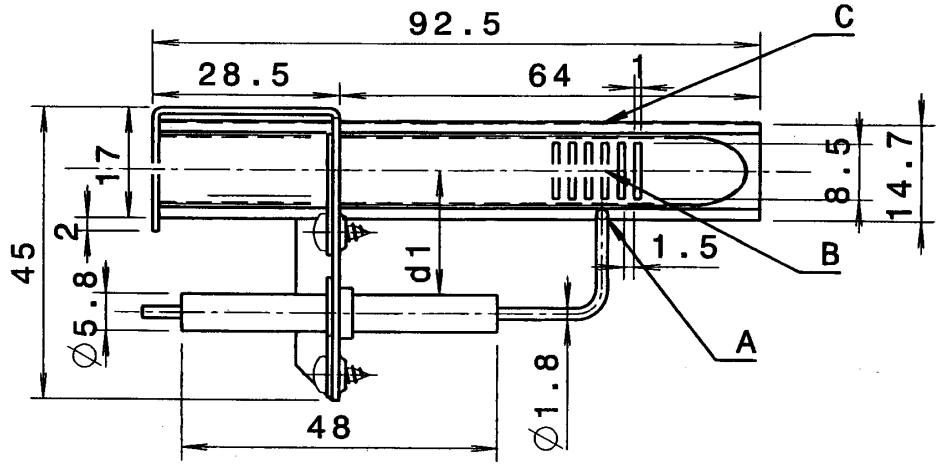

Figure 3.3: Drawing of the Dometic burner, in the horizontal plane, from above.

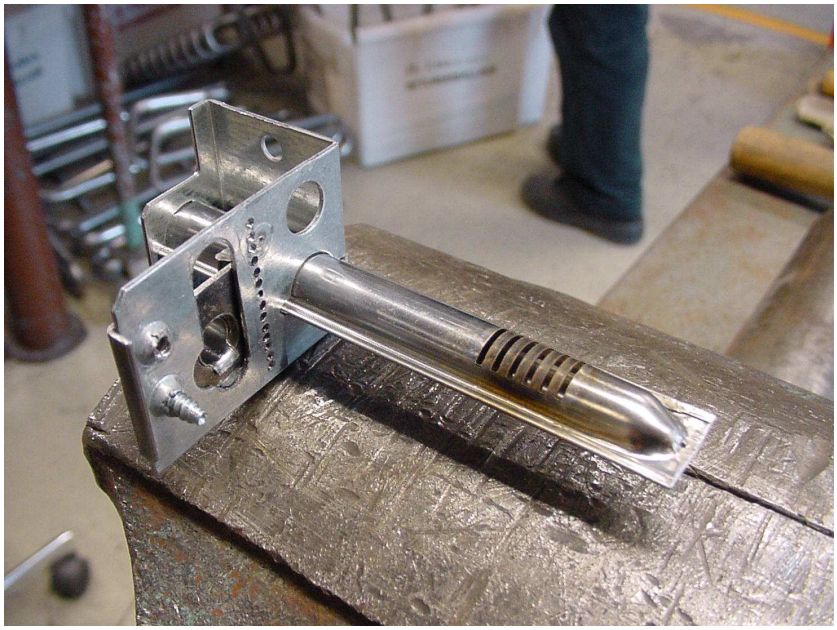

Figure 3.4: Photo of the burner house used in the experiments.

the voltmeter and a connection for the output DC voltage. The purpose of the two switches S1 and S2 was to change the polarity of the output voltage. These two switches were connected so that both had to switch at the same time. The purpose of the switch S3 was to choose whether the voltage over the flame or the voltage over the resistance R1 would be measured by the voltmeter. The voltage over R1 was measured to determine the current passing through it and hence the flame.

3.1.4 The AC–box

Another box was built to make the AC measurements. It was called the AC–box and a circuit diagram of it can be seen in figure 3.6. It contained a transformer just as the DC–box does. The AC–box also had three connection points; a connection for the input AC voltage, a connection for the voltmeter and a connection for the output AC voltage. It gave an output in the range of 0–100V AC (RMS value) when the peak to peak value of the input AC voltage from the signal generator was in the range of 0–12V and sine wave was used. The switch S1 decided whether the output AC voltage over the flame or the DC voltage over the capacitor C2 would be measured. The DC voltage over the capacitor C2 was measured to calculate the rectified current.

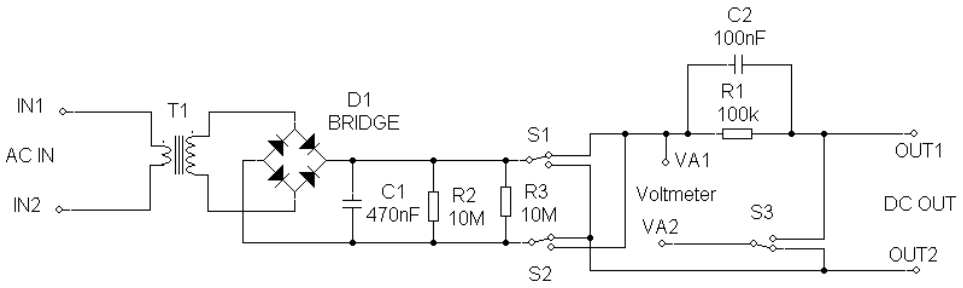

Figure 3.5: Circuit diagram of the DC–box.

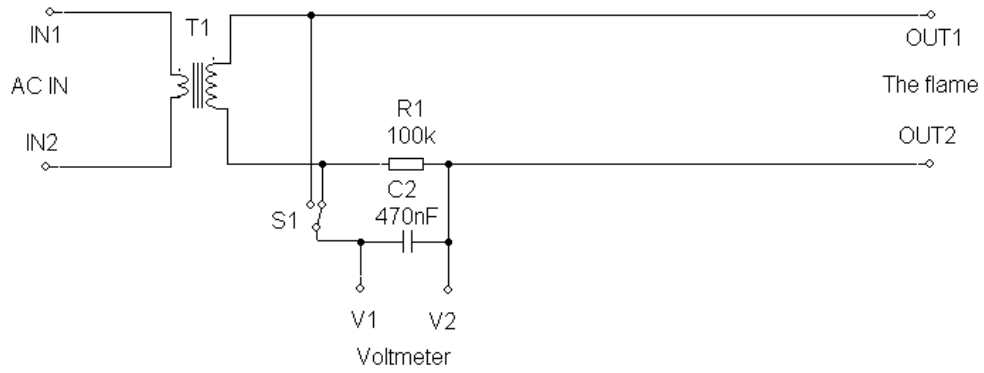

Figure 3.6: Circuit diagram of the AC–box.

3.2 Measurements

This section describes the different measurements and how they were performed.

3.2.1 Labeling of measurements

The measurements are labeled in a system with the date and a number. The system is: MYYYYMMDDN. The first M just indicates that it is a measurement. The number N specify chronologically the measurements made the day given by the date part of the label. The measurement M200503302 for example was the second measurement made on the 30:th of March 2005.

3.2.2 Electrode positions

DC measurements were made with the electrode in 19 different positions in the flame. The electrode was positioned to imitate the angle which it has in the Dometic burner. The electrode top is located above the horizontal plane which contains the attachment point of the electrode and makes approximately[4] an angle of 24° with the horizontal plane. The electrode was positioned with measurement pins and slide–calliper. The electrode top was positioned by eye along the burner, i.e. which slit it was above.

3.2.3 The chimney tube

It was interesting to know if the chimney tube[5] affected the rectified current through the flame. The chimney tube is the tube that transfers the heat from the flame to the cooling unit and it is located right above the flame. This means that the electrode comes closer to the chimney tube the larger the distance is to the burner. Measurements in different positions were performed with and without the chimney tube present to see if it affected the rectified current.

3.2.4 The penetration depth of the electrode into the flame

As mentioned in section 2.2 the size of the electrodes plays an important role for flame rectification. Therefore it was intresting to see how the measurements were affected if the penetration depth of the electrode into the flame was varied. The theory predicts that there will be a decrease in the rectified current if more of the electrode is in the flame.

[4]The uncertainty in the angle measurement was approximately 5°.

[5]The chimney tube is described in section 1.1.2.

The modifed burner did not allow the electrode to be moved closer to the burner in the horizontal plane so an electrode was modified to do this experiment. The top of the electrode was bent to point in a direction which was parallel with the slit in the burner and located in the horizontal plane. Different amount of the electrode was put into the flame to see if it was any difference in the direct current.

3.2.5 Contaminated electrode

There were strong suspicions that a contaminated electrode gives an rectified current that differs compared to that of a new electrode. These suspicions gave rise to measurments with two types of contaminated electrodes. The two types used were electrodes which had been spark-tested and electrodes which had been in a flame previously.

3.2.6 Frequencies

Different AC frequencies were used in some of the AC measurements to see if that affected the direct component of the current.

3.2.7 Flame temperature

Measurements were performed to get an indication of typical flame temperature. The flame temperature was measured with a K-type thermocouple which was connected to a *Fluke 51 K/J Thermometer*. No detailed temperature measurements were done.

3.2.8 Ignition and extinction of the flame

AC measurements were performed at flame ignition and extinction and the average current was plotted against time. An AC voltage with a RMS value of 50.0 V was applied. During the ignition and extinction measurements the voltage over the resistance R1 in figure 3.6 was measured with a *Fluke 123 ScopeMeter*.

3.2.9 Gas flows

To change the gas flow implies to change to power of the flame. The gas flow was changed by substituting the jet at the gas outlet. Four different jets were used. The jets used and the flow through them are described in tabel 3.2.

Jet number	Flow (litre/hour)
32	9.5
43	12.2
58	18.0
73	21.5

Table 3.2: Description of the jets used in the flow experiments.

3.2.10 Electromotive force of the flame

The flame causes a electromotive force. It was measured at different electrode positions to see how it varies in the flame. The electromotive force was measured with a voltmeter (Fluke 76 TRMS) without any applied voltage and a capacitor of 470nF was connected over the input pins to avoid disturbances.

Chapter 4

Results

The results of the measurements are published in this chapeter.

4.1 DC measurements

The DC measurements were performed by first applying a DC voltage in the forward direction to the flame and then applying a DC voltage in the reverse direction. The flame acts as an diode, though not perfect, and the forward direction is when the electrode has the highest potential and the current flows from the electrode to the burner through the flame. The reverse direction is hence when the electrode has the lowest potential and the current flows from the burner to the electrode. The diode property is obvious from all results of the DC measurements. Currents have been measured in both the forward and the reverse direction. A solid line is used for forward currents and a dashed for back currents in all UI-graphs. The current through the flame was measured for different voltages with an interval of 5V. The measurement points are marked with a dot. The line between the dots are there only to guide the eye.

The flame has different resistances in the forward and reverse direction but the resistance seems to be independant of voltage for a given position and direction. There is essentially only one exception and that is when the electrode is close to the chimney tube. More about this in section 4.1.2. Measurement M200503092 has a typical graph that shows the linear relation between applied voltage and the current through the flame. This measurement is performed in the $(\mathrm{V3}, \mathrm{S6}, 2.5\mathrm{mm})$ position and is visaulized in figure 4.1. Resistance values are calculated as the linear cofficient when the data was fitted to a straight line in a least square sense.

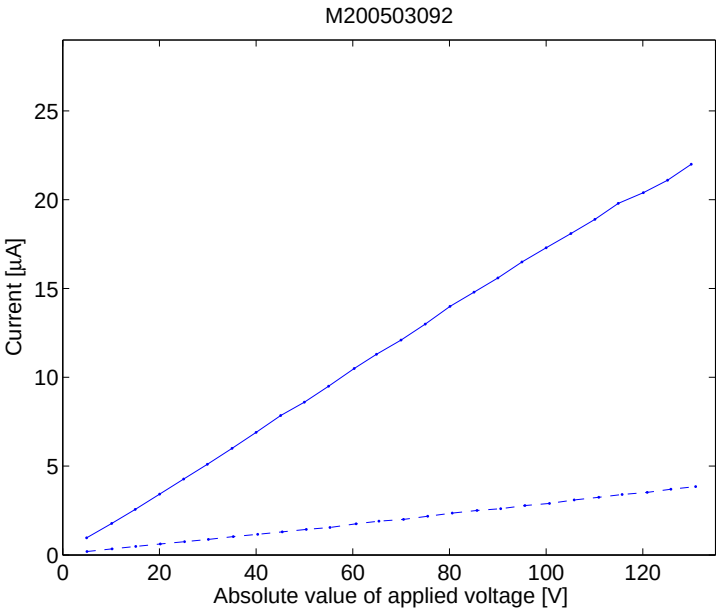

Figure 4.1: DC measurement which shows the linear relation between applied voltage and current through the flame. The measurement was performed in the $(\mathrm{V3}, \mathrm{S6}, 2.5\mathrm{mm})$ position. The solid line shows current through the flame in the forward direction and the dashed line current through the flame in the reverse direction.

4.1.1 Electrode positions

The measurements, to investigate if the current through the flame was influenced by the electrode position, were performed as described in section 3.2.2. Measurements were performed in 19 different positions which are illustrated in figure 4.2. The centre of the circles in figure 4.2 shows were the lower part of the electrode top was located during the measurements. This distance was measured with measurement pins.

Measurements with the electrode in different positions were performed in the flame in both the horizontal and vertical directions. Measurements in the horizontal direction were performed at two levels. At those levels the electrode top was positioned 2.5 mm and 7.6 mm above the burner. The forward current was approximately constant in the horizontal direction so the ratio between the resistances in the forward and reverse direction has been plotted in the horizontal direction. The forward current was approximately constant at 6 $M\Omega$ at both the 2.5 mm and 7.6 mm level. See figure 4.5. Plots for the two different horizontal levels are visualized in figure 4.3 and 4.4. In figure 4.4 it is clear that the ratio decreases when the electrode is moved to the right in the burner, i.e. when the electrode is moved to a warmer part of the flame. It should be observed that the flame burns leaning to the right. Lower ratio between the resistance in the forward and reverse directions means that the difference between forward and back current decrease. The tendency from the 7.6 mm level is not as obvious at the 2.5 mm level. This probably depends on that the electrode is colder at the 2.5 mm level compared with the 7.6 mm level. It might also depends on the fact that there are less electrons avaliable in the region with much unburnt gas.

Measurements in the vertical direction was performed above slit S4. Both the resistance in the forward and reverse direction varied vertically so the results for the forward and reverse direction are presented in different graphs. The resistances in the forward direction are presented in figure 4.5 and the resistances in the reverse direction in figure 4.6.

4.1.2 The chimney tube

Measurements with and without the chimney tube present were performed as described in section 3.2.3. These measurements were made with the electrode in the $(\mathrm{V3}, \mathrm{S2}, 2.5\mathrm{mm})$ and $(\mathrm{V9}, \mathrm{S4}, 14.5\mathrm{mm})$ positions. In the $(\mathrm{V3}, \mathrm{S2}, 2.5\mathrm{mm})$ position no significant difference was observed between the measurements with and without the chimney tube. An interesting result was however observed when the measurements were repeated in the $(\mathrm{V9}, \mathrm{S4}, 14.5\mathrm{mm})$ position. When about 80V

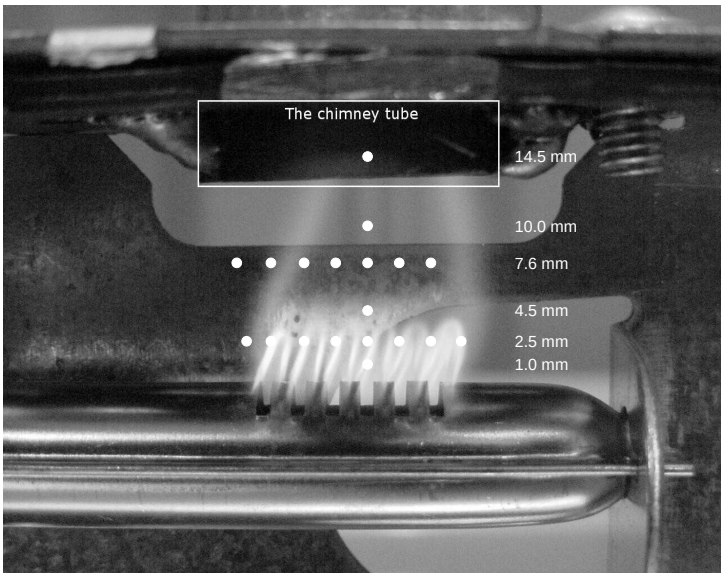

Figure 4.2: Photo of the Dometic burner with the flame present. Centre of circles indicates the electrode top positions for which measurements were performed. The lower part of the chimney tube, into which the burnt gas rises, is marked with a box.

DC was applied the UI-curve lost its linearity. The results are visulized in figure 4.7 and 4.8.

4.1.3 The penetration depth of the electrode into the flame

Measurements with different penetration depth of the electrode into the flame were performed as described in section 3.2.4. Three different positions of the electrode were used. In the first position the electrode top was located just above the long side of the burner (position A in figure 3.3) which was nearest to the attachment point of the electrode. This was the position with least of the electrode in the flame. In the second position the electrode top was located above the middle of the burner (position B in figure 3.3) and in the third position it reached across the burner (position C in figure 3.3) to the other long side. The third position was hence the position when most of the electrode was in the flame. The positioning of the electrode was not the usual in this experiment because the electrode top was bent. The electrode top was located above slit S4 and the vertical position of the attachment point of the electrode was positioned at V8.

The results from these measurements are visualized in figure 4.9 and 4.10. Just

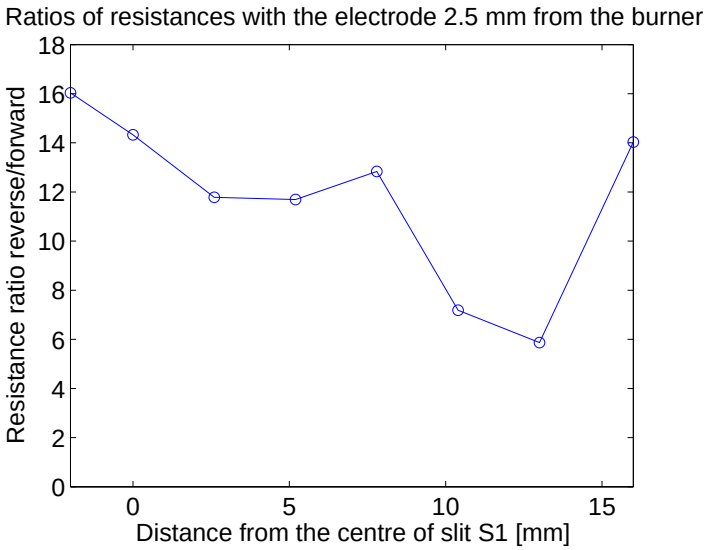

Figure 4.3: Plot of the ratio between the resistance in the forward and reverse direction at a horizontal level with the electrode top 2.5 mm above the burner.

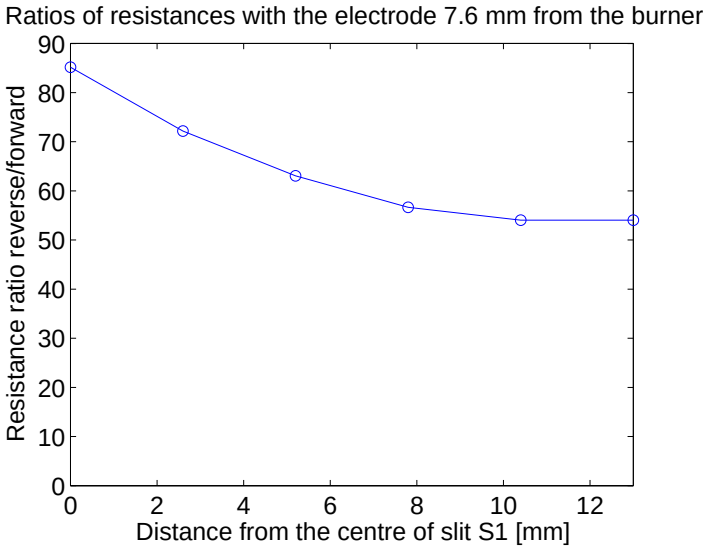

Figure 4.4: Plot of the ratio between the resistance in the forward and reverse direction at a horizontal level with the electrode top 7.6 mm above the burner.

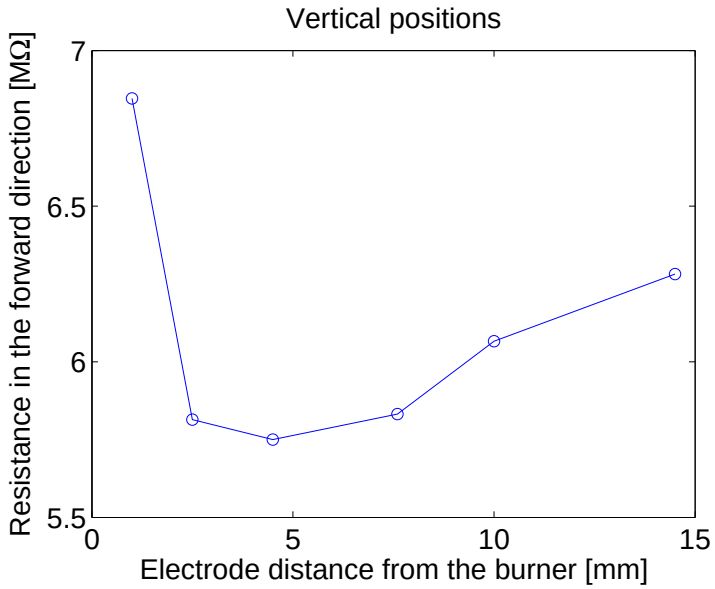

Figure 4.5: Plot of forward resistances for different vertical positions, above slit S4.

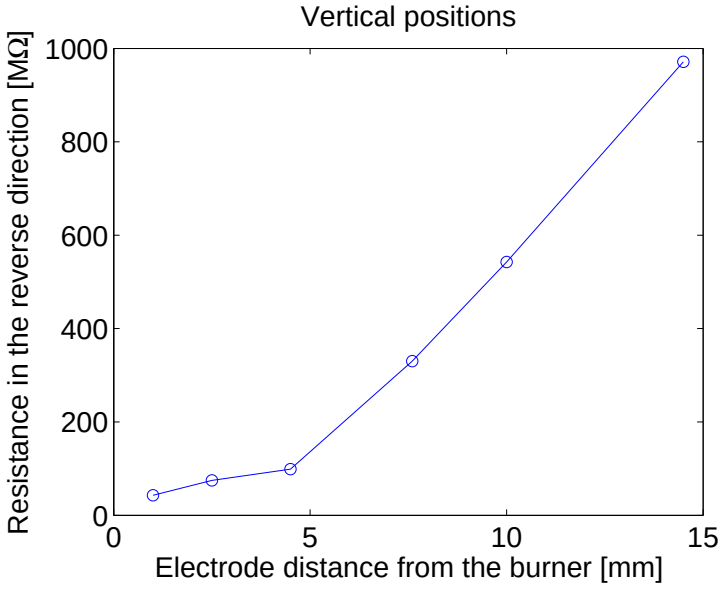

Figure 4.6: Plot of reverse resistances for different vertical positions, above slit S4.

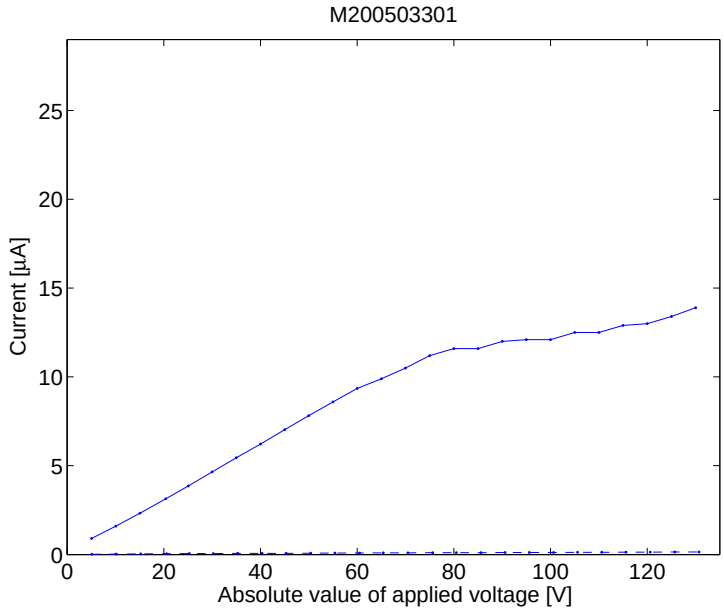

Figure 4.7: Measurement, in the $(\mathrm{V9}, \mathrm{S4}, 14.5\mathrm{mm})$ position, with the chimney tube present.

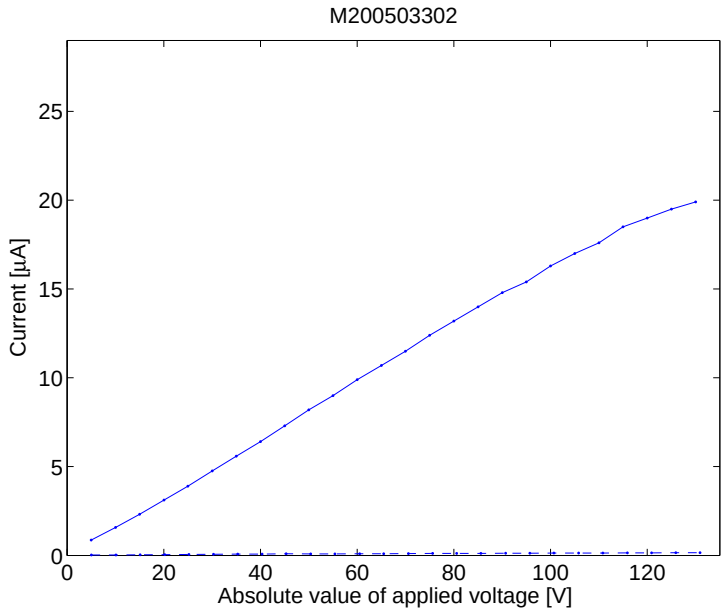

Figure 4.8: Measurement, in the $(\mathrm{V9}, \mathrm{S4}, 14.5\mathrm{mm})$ position, without the chimney tube present.

as the theory predicts the reverse resistance decreases when more of the electrode is in the flame. However, this effect can also be caused by the fact that the electrode is warmer when more of it is inside the flame. The resistance in the forward direction is close to constant.

4.1.4 Contaminated electrode

Measurements with different kind of contaminated electrodes were performed as described in section 3.2.5. Electrode #3 was a new electrode which had been exposed to a propane flame for about 19 hours before it was measured on. Electrode #2 was new and never exposed to a flame before. The same measurement was repeated with this electrode. Electrode #4 had been spark tested. It had sparked about one million times. The purpose of the spark test was to simulate all sparks during a refrigerators life time. The measurements with those different electrodes are presented in table 4.1.

Electrode	Forward resistance $(M\Omega)$	Reverse resistance $(M\Omega)$
New (#2)	5.8	119.9
Exposed in flame (#3)	5.7	85.6
Spark tested (#4)	5.9	137.5

Table 4.1: Resistance values from measurements on different electrodes.

There are no significant differences between the resistances in the forward direction but in the reverse direction. This fact is further discussed in section 5.2.4.

4.1.5 Gas flows

Measurements at different gas flows were performed as described in section 3.2.9. The resistance in the forward direction, through the flame, with different gas flows is presented in figure 4.11 and the resistance in the reverse direction in figure 4.12.

4.2 AC measurements

The results of the AC measurements are described in this section.

4.2.1 Frequencies

Three different frequencies were used to investigate its influence on the rectification. The measurements are visualized in figure 4.13.

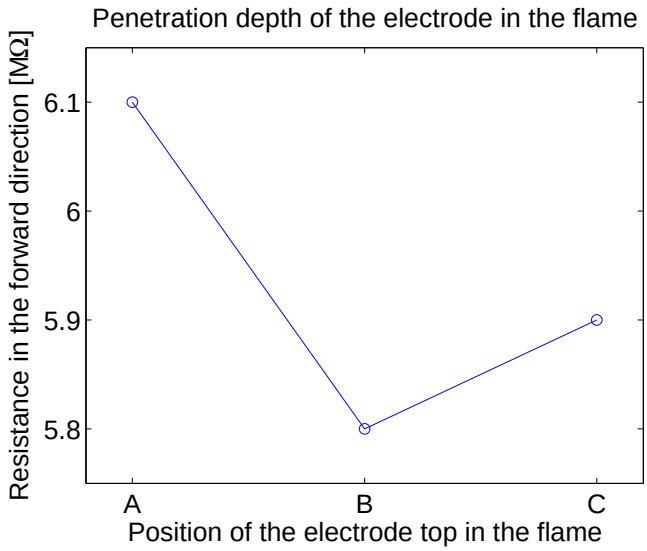

Figure 4.9: Resistance in the forward direction with the electrode top differently deep into the flame.

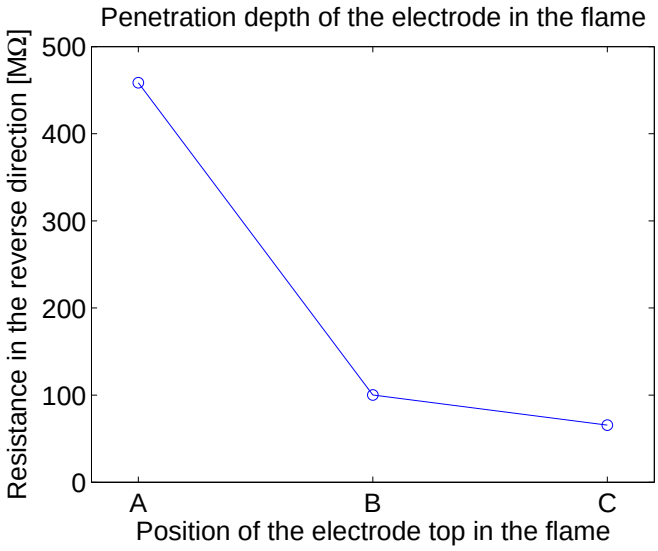

Figure 4.10: Resistance in the reverse direction with the electrode top differently deep into the flame.

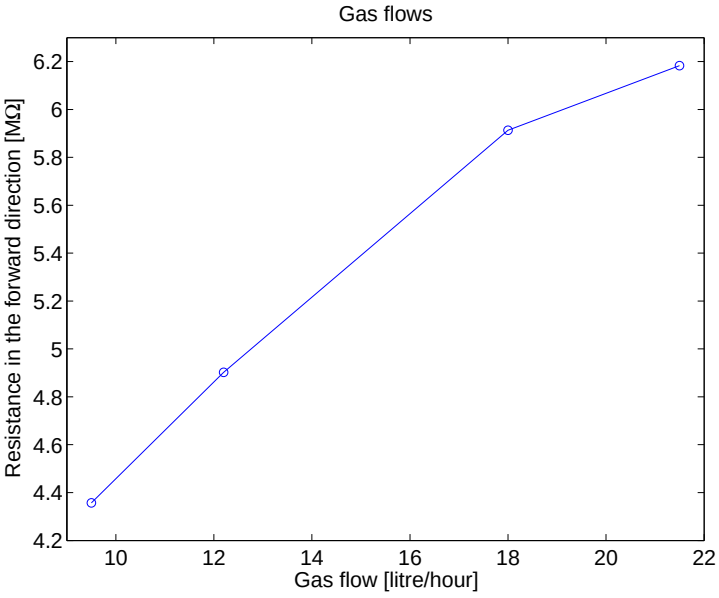

Figure 4.11: Measurements at different gas flows with the electrode top in the $(\text{V5}, \text{S4}, 4.5\text{mm})$ position.

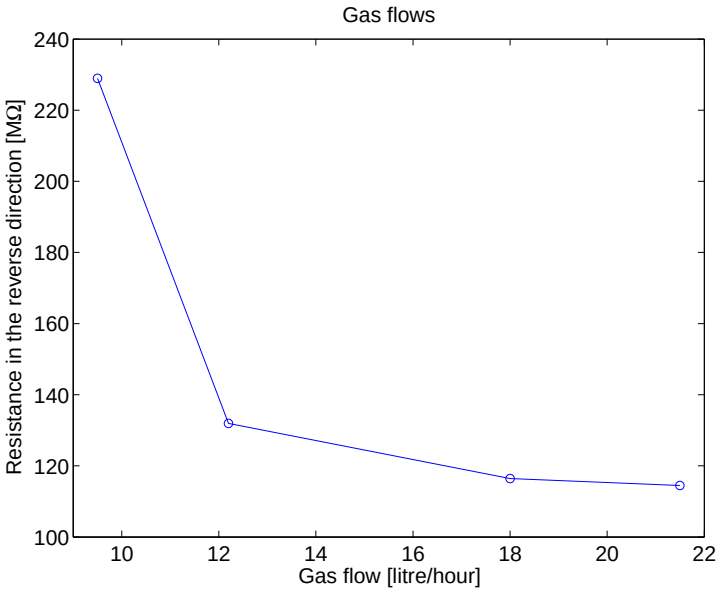

Figure 4.12: Measurements at different gas flows with the electrode top in the $(\text{V5}, \text{S4}, 4.5\text{mm})$ position.

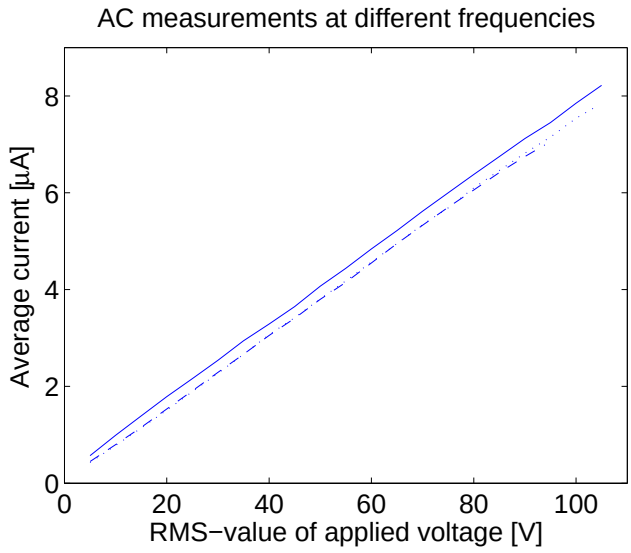

Figure 4.13: AC measurements at different frequencies performed with the electrode in the $(\mathrm{V5}, \mathrm{S4}, 4.5\mathrm{mm})$ position. The solid line shows the measurement performed at 1000 Hz, the dotted line shows the measurement performed at 600 Hz and the dashed line shows the measurement performed at 50 Hz. The dots that have been used to show measurement points in other plots has been omitted to make the plot less confusing.

4.2.2 Agreement between the AC and DC measurements

It is, of course, possible to calculate the rectified current through the flame when the resistance of the flame in the forward and reverse direction is known. It is especially easy since the resistance is constant in the used voltage range 0–130V. We have one constant resistance in the forward direction and another constant resistance in the reverse direction. This is a result from the DC measurements. See section 4.1.

The resistance in the forward direction is called R_f and the resistance in the reverse direction is called R_r with $R_f < R_r$. Let

$$u(t) = \hat{u} \sin\left(\frac{2\pi t}{T}\right) \tag{4.1}$$

where $\hat{u}$ is the top value of the AC voltage. Ohms law now gives that

$$i(t) = \frac{\hat{u}}{R} \sin\left(\frac{2\pi t}{T}\right) \tag{4.2}$$

and hence the average current, I, is

$$\begin{aligned}
I &= \frac{1}{T}\int_0^T i(t)dt \\
&= \frac{1}{T}\int_0^{T/2} i(t)dt + \frac{1}{T}\int_{T/2}^T i(t)dt \\
&= \frac{1}{T}\int_0^{T/2} \frac{\hat{u}}{R_f}\sin\left(\frac{2\pi t}{T}\right)dt + \frac{1}{T}\int_{T/2}^T \frac{\hat{u}}{R_r}\sin\left(\frac{2\pi t}{T}\right)dt \\
&= \frac{\hat{u}}{2\pi R_f}\left[-\cos\left(\frac{2\pi t}{T}\right)\right]_0^{T/2} + \frac{\hat{u}}{2\pi R_r}\left[-\cos\left(\frac{2\pi t}{T}\right)\right]_{T/2}^{T} \\
&= \frac{\hat{u}}{\pi}\left(\frac{1}{R_f} - \frac{1}{R_r}\right).
\end{aligned} \tag{4.3}$$

Let u_{RMS} be the RMS-value of the AC voltage. For a harmonic voltage it is valid that

$$u_{\text{RMS}} = \frac{\hat{u}}{\sqrt{2}} \tag{4.4}$$

and equation 4.3 and 4.4 finally gives that

$$I = \frac{\sqrt{2}}{\pi} u_{\text{RMS}} \left(\frac{1}{R_f} - \frac{1}{R_r} \right). \tag{4.5}$$

Measurement M200503217 was performed with the electrode in the $(\text{V5}, \text{S4}, 4.5\text{mm})$ position. For this measurement $R_f \approx 5.8\,\text{M}\Omega$ and $R_r \approx 98.7\,\text{M}\Omega$. See figure 4.14. In figure 4.15 the measured AC values for the same electrode position are compared with those calculated, from the DC measurements, with equation 4.5. The measured values corresponds fairly well with the calculated.

4.2.3 Ignition and extinction of the flame

Plots of the current through the flame at ignition and extinction were made with the electrode in the $(\text{V5}, \text{S4}, 4.5\text{mm})$ position. The applied AC voltage was fixed at 50.0 V (RMS value) and the average current during a time period after ignition or extinction was plotted as a function of time.

4.3 Flame temperature

The flame temperature was measured as described in section 3.2.7. No detailed measurements were performed but temperatures between 900°C and 1100°C were observed in the flame. The top of the electrode had a temperature of approximately 900°C.

4.4 Electromotive force of the flame

The electromotive force of the flame was measured at different electrode positions before that the relatively large time variations was observed. Instead the time dependene of the electromotive force (e.m.f) was investigated with the electrode top in the $(\text{V5}, \text{S4}, 4.5\text{mm})$ position. The results from this measurement is visualized in figure 4.18. Observ that the electromotive force of the flame was measured without any applied voltage.

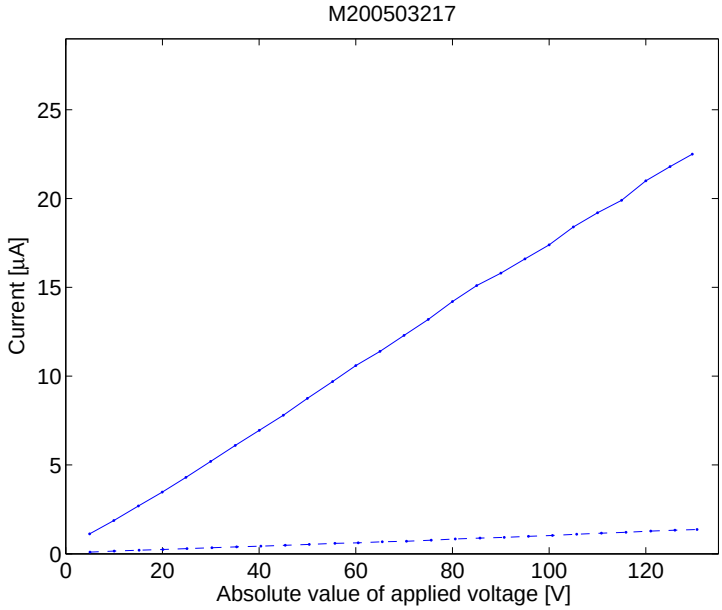

Figure 4.14: Applied DC voltage with the electrode in the $(\mathrm{V5}, \mathrm{S4}, 4.5\mathrm{mm})$ position.

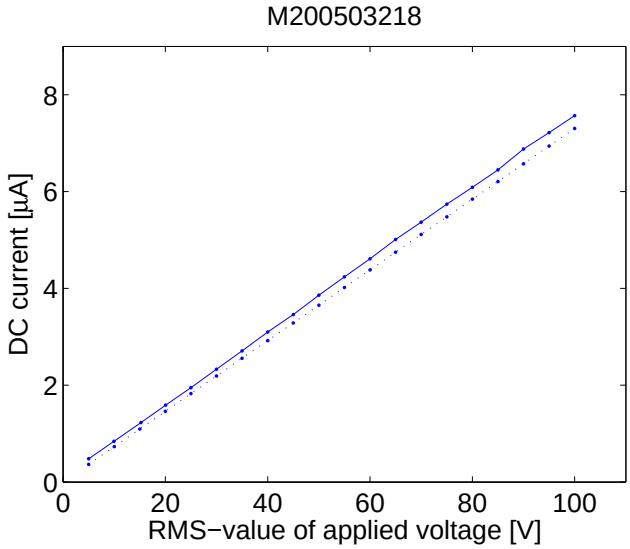

Figure 4.15: Applied AC voltage with the electrode in the $(\mathrm{V5}, \mathrm{S4}, 4.5\mathrm{mm})$ position. The dotted line shows the values calculated from equation 4.5 with $R_1 = 5.8$ MΩ and $R_2 = 98.7$ MΩ.

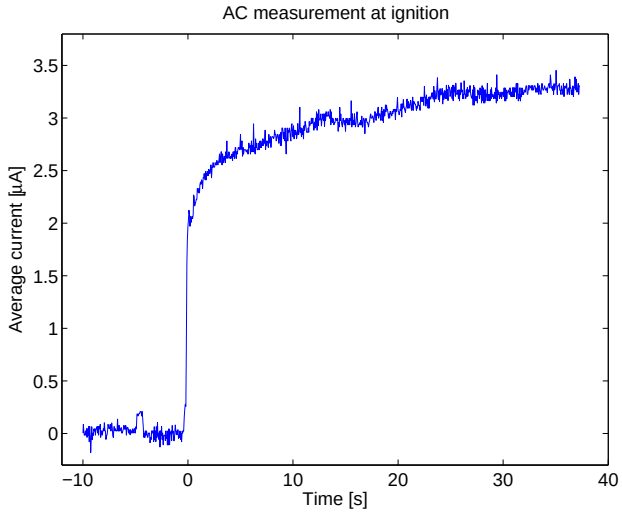

Figure 4.16: The average current through the flame plotted during approximately 38 s after ignition. The electrode top was in the $(\mathrm{V5}, \mathrm{S4}, 4.5\mathrm{mm})$ position and an AC voltage of 50.0V (RMS value) was applied.

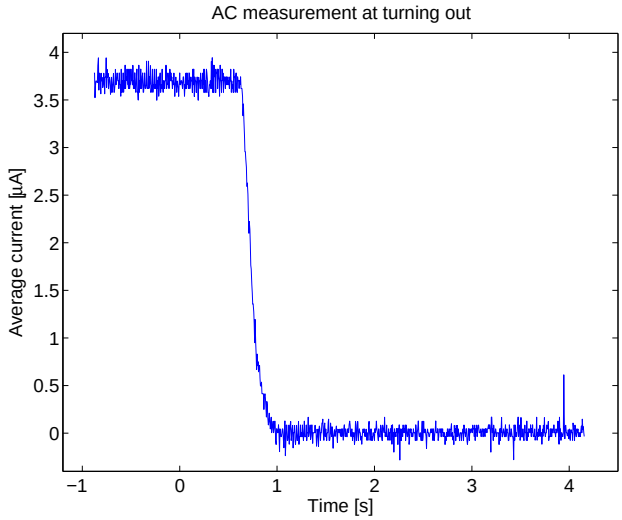

Figure 4.17: The average current through the flame plotted during approximately 4 s after extinction. The electrode top was in the $(\mathrm{V5}, \mathrm{S4}, 4.5\mathrm{mm})$ position and an AC voltage of 50.0V (RMS value) was applied.

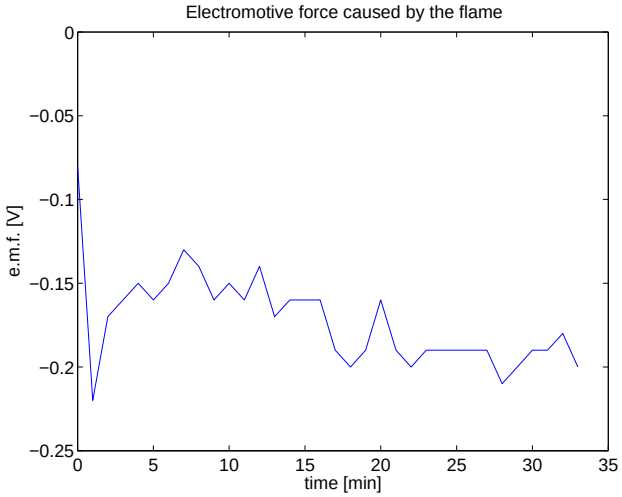

Figure 4.18: The time dependence of the electromotive force caused by the flame. The electrode top was in the $(\mathrm{V5}, \mathrm{S4}, 4.5\mathrm{mm})$ position.

Chapter 5

Discussion

The results and methods are discussed in this chapter.

5.1 General approach

The aim of this thesis has been to analyze the principle of flame rectification experimentally. The experimental approach was chosen since there was not much to find about this topic in scientific databases. The fact that there was not much to find in scientific databases is probably because of the geometry dependence of the rectification principle. Calculation on the rectification probably has to be made with some numerical method and that will be unnecessarily complicated.

5.2 DC measurements

In this section the results of the DC measurements are discussed.

5.2.1 Electrode positions

It is not easy to explain the observations from the measurements with the electrode in different positions. This depends on the fact that it is more than one factor which affects the resulting rectified current. The distance between the electrode top and the burner and how much of the electrode that is in the flame are supposed to be important factors. It is relatively easy to measure the distance between the electrode top and the burner but it is not as obvious to measure how much of the electrode that is in the flame. This thesis does not focus on how much of the electrode that is in the flame, but some hints for further studies are given in chapter 7. It can be seen from the results presented in section 4.1.3 that the penetration depth of the electrode into the flame strongly influence the DC. No

measurements of how much of the electrode that was in the flame was performed during the position measurements.

As illustrated in figure 4.4 there is a slightly decreasing ratio between the resistances in the forward and reverse direction when the electrode top is moved horizontally in the flame. The most probable explanation to this seems to be that the electrode top becomes warmer when it is moved to the right. This happens because the flame burns litted to the right. The forward direction is when the electrode is positive and the burner negative and this means that the electrode captures electrons and the burner neutralizes the positive ions. See figure 5.1 for an illustration. The reverse direction is hence when the burner is positive and the electrode negative. This means that the electrode neutralizes positive ions and the burner captures electrons. See figure 5.2 for an illustration. The decreasing ratio in figure 4.4 means that the reverse resistance is decreased when the electrode top is moved to the right in the flame, since the resistance in the forward direction is close to constant. The conclusion of this has to be that a warmer electrode neutralizes more positive ions than a colder electrode. The same effect can be seen in the measurements performed with the electrode top 2.5 mm from the burner. See figure 4.3. The tendency in this measurement is however not as clear as in that performed at the 7.6 mm level. This is supposed to depend on the fact that the electrode top at the 2.5 mm level is both in the region with unburnt and burnt gas.

The largest influence on resistance in any experiment was observed when the electrode was moved vertically away from the burner. Both the resistances in the forward and the reverse direction varied when the position of the electrode was moved vertically. They were therefore plotted in separate graphs. The resistance in the forward direction did not vary much compared with the variation of the resistance in the reverse direction. The resistance in the forward direction is plotted in figure 4.5. It increases except for measurements performed with the electrode top close (approximately 4 mm) to the burner. This effect has to be explained by the fact that the electrode top then is in a region of the flame with unburnt gas. No free carriers are avaliable in that region because they are created in the burning process. The resistance in the reverse direction varies more and is plotted in figure 4.6. The values differ many hundred $M\Omega$ and the resistance increases when the electrode top is moved away from the burner. This depends on the fact that it becomes more difficult for the positive ions to reach the electrode. The ions are heavier and do not travel as easy as the electrons so it is harder for them to reach the electrode when it is moved away from the burner.

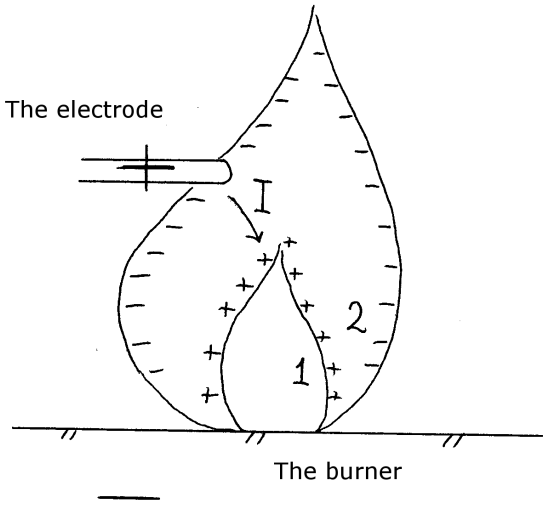

Figure 5.1: Principle drawing of carrier transport through the flame in the forward direction. Region 1 is the region with unburnt gas and region 2 the region with burnt gas.

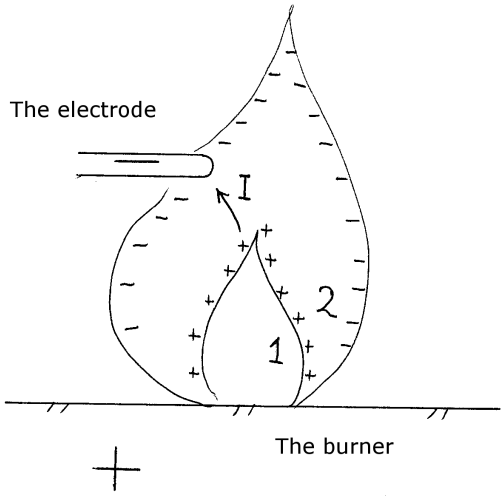

Figure 5.2: Principle drawing of carrier transport through the flame in the reverse direction. Region 1 is the region with unburnt gas and region 2 the region with burnt gas.

5.2.2 The chimney tube

If the chimney tube was present or not did not affect the measured values when the electrode top was 4.5 mm above the burner. This seems natural because the distance from the electrode top to the chimney tube is relatively large. As can be seen in figure 4.7 and 4.8 the situation was different when the electrode top was closer to the chimney tube. In the measurements that are visualized in figure 4.7 and 4.8 the distance from the electrode top to the burner was 14.5 mm and the distance from the electrode to the chimney tube 2.9 mm. The linear form of the UI-curve was broken when about 80V was applied. No detailed investigation about what happens have been carried out but an explanation might be that the flame comes in better contact with the chimney tube.

5.2.3 The penetration depth of the electrode into the flame

The back current through the flame is increased if more of the electrode is exposed to the flame. This fact was predicted by the theory in section 2.2 and confirmed by the results presented in section 4.1.3.

5.2.4 Contaminated electrode

No significant differences were observed when the clean electrode was compared with the spark tested electrode and the electrode that had been in a flame for approximately 19 hours. The differences in the forward direction were less than 0.3 $M\Omega$ which is considered to be insignificant. The observed differences in the reverse direction were in the order of 30 $M\Omega$ which is small compared to the differences observed when the electrode was moved vertically (se figure 4.6). It should be observed that it was not possible to position the electrodes in exactly the same position when they were substituted. The positioning is supposed to be the largest source of error in this experiment. It can be seen that the contaminated electrodes do not seem to deteriorate the flame detection, i.e. the difference between the forward and the reverse resistance.

A statistical investigation of different electrodes would be necessary in order to draw definite conclusions.

5.2.5 Gas flows

There was interesting differences in the resistances when the gas flow was changed. Increasing of the gas flow affects the measured values in the same way as if the

electrode top was moved closer to the burner because the size of the flame increases when the gas flow increases. This is also what has been observed. The resistance in the reverse direction, when the gas flow is increased, is visualized in figure 4.12. The resistance decreases, as expected, when the gas flow is increased.

5.3 AC measurements

In this section the results of the AC measurements are discussed.

5.3.1 Agreement with the DC measurements

There is a good agreement between the AC measurements and the values calculated from the DC measurements. The resistances from the DC measurements were assumed to be constant and used to calculate the average current through the flame with equation 4.5 on page 31. In figure 4.15 the calculated values, of the average current, were compared with those measured with the AC–box. As seen in the figure the calculated and measured values are almost equal.

5.3.2 Frequenies

No significant differences have been observed between the measurements at different frequences. As can be seen in figure 4.13, on page 29, there was a very small frequency dependence on the average current through the flame. The lines at 50 Hz and 600 Hz overlap almost everywhere and the line at 1000 Hz is just slightly above the other two.

5.3.3 Ignition and extinction of the flame

A plot of how the average current through the flame varies just after the ignition is shown in figure 4.16 and a similar plot for extinction is presented in figure 4.17. It can be seen that it takes approximately 30 seconds after ignition before the average current reach its stable value. It should be observed that the electrical filter in the AC–box probably affect the extinction plot in figure 4.17. However, the average current goes to zero in less than one second. It should be observed that all other DC and AC measurements have been made when the gas flame has been present for several minutes.

5.4 Electromotive force of the flame

As can be seen in figure 4.18 the electromotive force caused by the flame varies a lot over time. This fact was observed after a long time of measuring and hence no detalied investigation of the electromotive force could be made.

Chapter 6

Conclusions

The conclusions of this thesis work are presented in this chapter.

The largest difference between currents in the forward and reverse direction was observed when the electrode top was moved vertically away from the burner. The explanation is that the heavier positive ions travel much slower through the flame compared to the negative electrons. The ionization occurs at the base of the flame so the electrode top has harder to attract the positive ions when its moved away from the burner. The forward direction of current through the flame is hence when the electrode is positive and attract negative electrons. Today the electrode top in the refrigerators is positioned approximately 4 mm from the burner but the results given above show that the detection should be safer if that distance was increased. The electrode cannot, however, be moved as one would like since its other purpose is to generate ignition sparks.

A very large difference between the forward and the reverse current was also seen when the gas flow was changed. This difference is, however, most likely to be explained by the same arguments as when the electrode top is moved vertically away from the burner. A low gas flow causes a smaller flame than a high gas flow. This means that a fix position of the electrode and increasing gas flow can be compared to a fix gas flow and a decreasing distance between the burner and the electrode top.

It should be observed that the resistance in the forward direction is almost constant at all locations compared to the variations in the reverse resistance so it is the reverse resistance that causes the resistance difference. As mentioned above the explanation is that the negative electrons travel easy in the flame but the heavier positive ions do not.

The chimney tube did not affect the resistances in the forward and reverse direction except when the electrode was positioned very close to it[1]. Measurements at different frequencies did not even affect the average current through the flame.

[1] Approximately 2.9 mm between the electrode and the chimney tube.

Chapter 7

Recommendations

Recommendations for futher work are given in this chapter.

7.1 Methods

The size of the part of the electrode that is in the flame affects the rectified current as explained in the theory section 2.2. How much of the electrode that was in the flame was not measured in this investigation. If this could be measured in some way, it would be possible to say to which extent this affects the rectification. The temperature of the electrode top should at least be possible to measure and that might be a measure of how much of the electrode that is in the flame.

7.2 Measurements

Only propane gas was used in this study. It would be of considerable value to use other gases since different gas mixtures are used in different countries. Butane and natural gas should be tested.

During this thesis work there was only time to make AC measurements with sine waves. One of the electronic boxes that Dometic uses to detect the flame by flame rectification applies a square wave to the flame. Therfore, at least square waves, and preferable even other wave forms, should be tested.

The test of contaminated electrodes should be improved. Only one electrode of each kind was tested in this thesis work and no sure conclusions can be drawn from that. A statistical investigation of different kind of contaminated electrodes should be performed. Different electrodes should be repeatedly tested to see if there are any differences between them.

The electromotive force of the flame varied over time as described in section 4.4. The variations in time should be further investigated and the average of the electromotive force, with the electrode in different positions, should be measured.

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Appendix A

Measurements

All DC, AC and EMF measurements performed during this thesis work are presented in this appendix.

A.1 DC

Tables of the DC measurements are presented here. The fields that explains the measurements will be described here. The field *measurement* just tells the label of the measurement. The field *date* tells which date the measurement was performed. The field *applied voltage* tells if DC or AC voltage was applied. The field *electrode* describes which electrode that was used in the measurement. The field *vertical position of electrode* tells which vertical position the attachment point of the electrode had. The discrete vertical positions are explained in table 3.1 on page 11. The field *electrode above slit* tells which slit the electrode top was above. The field *distance to electrode top* tells the shortest distance between the lower part of the electrode top and the burner. The field *chimney tube present* tells wether the chimney tube was present or not. The field *gas pressure* tells the gas pressure. The pressure was regulated with a pressure governor and measured with a liquid-column gage that was filled with water. The field *jet number* finally explains what jet that was used. The different jets used are explained in table 3.2 on page 17.

U+ is the DC voltage that was applied in the forward direction and U- the DC voltage that was applied in the reverse direction. They differ because of the different amount of current that passes the flame and hence there is diffrent voltage drop over the flame. I+ and I- are not currents, as the names indicate, but voltages which are associated with currents. They measure the voltage drop over a $100k\Omega$ resistance so the current can easily be calculated.

Measurement:	**M200503031**
Date:	2005–03–03
Applied voltage:	DC
Vertical position of electrode:	V3
Electrode top above slit:	S1
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.02	-5.07	0.104	-0.011
12.02	-12.12	0.214	-0.021
24.01	-24.21	0.415	-0.036
30.03	-30.28	0.521	-0.043
35.00	-35.29	0.610	-0.050
40.08	-40.42	0.700	-0.056
45.0	-45.4	0.787	-0.062
50.0	-50.3	0.868	-0.068
55.0	-55.4	0.962	-0.073
60.0	-60.5	1.045	-0.080
65.0	-65.5	1.130	-0.085
70.0	-70.5	1.220	-0.091
75.0	-75.5	1.302	-0.097
80.0	-80.7	1.387	-0.102
85.0	-85.6	1.470	-0.108
90.0	-90.7	1.550	-0.114
95.0	-95.7	1.630	-0.117
100.0	-100.8	1.715	-0.125
105.0	-105.8	1.790	-0.132
110.0	-110.9	1.872	-0.137
115.0	-115.9	1.950	-0.143
120.0	-120.9	2.020	-0.149
125.0	-125.9	2.098	-0.155
130.0	-130.9	2.175	-0.160

Measurement:	**M200503081**
Date:	2005–03–08
Applied voltage:	DC
Vertical position of electrode:	V3
Electrode top above slit:	S2
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.07	-5.12	0.103	-0.012
10.13	-10.21	0.181	-0.019
15.02	-15.14	0.261	-0.027
20.06	-20.22	0.346	-0.034
24.99	-25.19	0.430	-0.042
30.04	-30.28	0.519	-0.049
35.04	-35.32	0.604	-0.056
40.13	-40.46	0.696	-0.064
45.0	-45.3	0.780	-0.072
50.0	-50.3	0.869	-0.079
55.0	-55.4	0.96	-0.086
60.0	-60.5	1.05	-0.095
65.0	-65.5	1.13	-0.103
70.0	-70.5	1.22	-0.110
74.9	-75.4	1.30	-0.117
80.0	-80.6	1.39	-0.125
85.0	-85.6	1.47	-0.127
90.0	-90.6	1.55	-0.136
95.1	-95.8	1.65	-0.141
100.0	-100.7	1.74	-0.150
105.0	-105.8	1.80	-0.157
110.0	-110.9	1.90	-0.163
114.9	-115.8	1.97	-0.170
120.0	-120.9	2.07	-0.182
125.0	-126.0	2.13	-0.190
130.0	-130.9	2.22	-0.199

Measurement:	**M200503082**
Date:	2005–03–08
Applied voltage:	DC
Vertical position of electrode:	V3
Electrode top above slit:	S2
Distance to electrode top:	2.5 mm
The chimney tube present:	No
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.05	-5.09	0.092	-0.011
10.00	-10.07	0.167	-0.018
15.02	-15.13	0.247	-0.025
20.07	-20.23	0.33	-0.032
24.97	-25.17	0.415	-0.039
30.09	-30.33	0.50	-0.046
35.04	-35.32	0.59	-0.054
39.95	-40.27	0.68	-0.060
44.9	-45.2	0.765	-0.068
50.1	-50.4	0.86	-0.075
55.0	-55.4	0.94	-0.081
60.1	-60.6	1.03	-0.089
65.0	-65.5	1.11	-0.096
70.0	-70.5	1.19	-0.104
75.0	-75.5	1.29	-0.110
80.0	-80.6	1.38	-0.118
85.0	-85.6	1.46	-0.123
90.0	-90.7	1.53	-0.132
100.0	-100.7	1.70	-0.150
105.0	-105.8	1.78	-0.158
110.0	-110.8	1.86	-0.164
115.0	-115.9	1.92	-0.168
119.9	-120.8	2.03	-0.176
125.1	-126.0	2.11	-0.185
129.9	-130.8	2.16	-0.192

Measurement:	**M200503083**
Date:	2005–03–08
Applied voltage:	DC
Vertical position of electrode:	V3
Electrode top above slit:	S3
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.03	-5.07	0.093	-0.012
9.98	-10.06	0.168	-0.020
15.08	-15.19	0.25	-0.028
20.09	-20.24	0.335	-0.042
24.96	-25.15	0.415	-0.042
29.94	-30.18	0.50	-0.049
35.02	-35.30	0.59	-0.056
40.03	-40.35	0.68	-0.063
44.9	-45.2	0.77	-0.069
50.0	-50.3	0.86	-0.078
55.0	-55.3	0.945	-0.084
59.9	-60.3	1.03	-0.093
65.0	-65.5	1.125	-0.099
70.0	-70.5	1.21	-0.106
75.0	-75.6	1.30	-0.115
80.0	-80.6	1.385	-0.120
85.0	-85.6	1.46	-0.127
90.0	-90.7	1.55	-0.136
95.0	-95.7	1.64	-0.145
99.9	-100.6	1.72	-0.154
105.0	-105.8	1.81	-0.163
110.0	-110.8	1.87	-0.168
115.0	-115.9	1.97	-0.175
119.9	-120.7	2.03	-0.184
125.2	-126.1	2.12	-0.190
130.0	-131.0	2.20	-0.195

Measurement: **M200503084**
Date: 2005–03–08
Applied voltage: DC
Vertical position of electrode: V3
Electrode top above slit: S4
Distance to electrode top: 2.5 mm
The chimney tube present: Yes
Gas pressure: 27.5 mbar
Jet number: 58
Electrode: #1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.07	-5.11	0.093	-0.012
9.98	-10.06	0.166	-0.019
15.03	-15.15	0.249	-0.026
20.03	-20.19	0.330	-0.031
24.98	-25.18	0.418	-0.039
30.09	-30.33	0.505	-0.045
35.00	-35.28	0.59	-0.051
40.04	-40.37	0.68	-0.059
45.0	-45.3	0.77	-0.063
50.1	-50.4	0.865	-0.073
55.0	-55.4	0.95	-0.078
60.1	-60.6	1.04	-0.085
65.0	-65.5	1.13	-0.092
70.0	-70.6	1.22	-0.097
75.0	-75.6	1.30	-0.105
80.0	-80.6	1.39	-0.112
85.0	-85.7	1.485	-0.120
90.0	-90.6	1.56	-0.125
95.2	-95.9	1.63	-0.128
100.1	-100.8	1.74	-0.140
105.0	-105.8	1.80	-0.144
110.2	-111.0	1.90	-0.151
114.9	-115.7	1.98	-0.160
119.9	-120.8	2.05	-0.165
124.7	-125.7	2.12	-0.176
130.1	-131.0	2.20	-0.184

Measurement: **M200503091**
Date: 2005–03–09
Applied voltage: DC
Vertical position of electrode: V3
Electrode top above slit: S5
Distance to electrode top: 2.5 mm
The chimney tube present: Yes
Gas pressure: 27.5 mbar
Jet number: 58
Electrode: No data

U+ (V)	U- (V)	I+ (V)	I- (V)
5.03	-5.08	0.107	-0.017
9.99	-10.07	0.185	-0.029
15.01	-15.13	0.267	-0.041
19.98	-20.13	0.350	-0.052
24.99	-25.19	0.435	-0.064
30.00	-30.24	0.526	-0.078
34.98	-35.25	0.61	-0.088
40.00	-40.30	0.70	-0.101
45.0	-45.3	0.785	-0.113
50.0	-50.4	0.88	-0.125
55.0	-55.4	0.96	-0.138
60.0	-60.4	1.05	-0.148
65.0	-65.4	1.135	-0.160
69.9	-70.4	1.22	-0.172
75.0	-75.5	1.31	-0.185
80.0	-80.6	1.395	-0.196
85.0	-85.6	1.48	-0.207
90.0	-90.7	1.565	-0.220
95.2	-95.9	1.63	-0.231
100.0	-100.7	1.73	-0.238
105.1	-105.9	1.805	-0.252
110.0	-110.8	1.88	-0.263
115.0	-115.8	1.96	-0.277
120.2	-121.0	2.03	-0.290
125.1	-126.0	2.10	-0.300
129.9	-130.8	2.16	-0.310
130.5	-131.4	2.19	-0.312

Measurement: **M200503092**
Date: 2005–03–09
Applied voltage: DC
Vertical position of electrode: V3
Electrode top above slit: S6
Distance to electrode top: 2.5 mm
The chimney tube present: Yes
Gas pressure: 27.5 mbar
Jet number: 58
Electrode: #1

U+ (V)	U- (V)	I+ (V)	I- (V)
4.97	-5.01	0.096	-0.019
10.14	-10.21	0.177	-0.034
15.00	-15.10	0.256	-0.048
20.04	-20.18	0.342	-0.062
25.03	-25.22	0.427	-0.075
29.93	-30.15	0.51	-0.087
35.04	-35.31	0.60	-0.103
40.02	-40.32	0.69	-0.116
45.1	-45.4	0.785	-0.130
50.0	-50.4	0.86	-0.144
55.0	-55.3	0.95	-0.155
60.3	-60.7	1.05	-0.175
64.9	-65.4	1.13	-0.190
70.0	-70.5	1.21	-0.200
75.0	-75.5	1.30	-0.218
80.1	-80.6	1.40	-0.236
85.1	-85.7	1.48	-0.250
90.0	-90.6	1.56	-0.260
95.0	-95.6	1.65	-0.278
100.0	-100.7	1.73	-0.290
105.1	-105.8	1.81	-0.310
110.1	-110.9	1.89	-0.325
114.9	-115.7	1.98	-0.340
120.1	-120.9	2.04	-0.352
125.1	-125.8	2.11	-0.370
130.0	-130.9	2.20	-0.385

Measurement: **M200503093**
Date: 2005–03–09
Applied voltage: DC
Vertical position of electrode: V3
Electrode top above slit: S1-1.5 mm
Distance to electrode top: 2.5 mm
The chimney tube present: Yes
Gas pressure: 27.5 mbar
Jet number: 58
Electrode: #1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.24	-5.29	0.092	-0.004
10.03	-10.11	0.158	-0.006
15.18	-15.29	0.233	-0.009
19.95	-20.10	0.304	-0.012
24.97	-25.16	0.382	-0.015
30.17	-30.41	0.46	-0.019
35.01	-35.27	0.53	-0.022
39.92	-40.22	0.61	-0.027
44.9	-45.2	0.685	-0.031
50.0	-50.4	0.76	-0.035
55.0	-55.4	0.84	-0.039
60.0	-60.4	0.92	-0.043
65.0	-65.5	0.99	-0.047
70.0	-70.5	1.06	-0.051
75.1	-75.6	1.10	-0.061
80.0	-80.5	1.18	-0.064
85.3	-85.8	1.27	-0.069
90.0	-90.6	1.34	-0.074
95.1	-95.8	1.42	-0.079
99.9	-100.6	1.49	-0.083
104.9	-105.6	1.57	-0.089
110.2	-110.9	1.64	-0.094
115.0	-115.8	1.72	-0.099
120.1	-121.0	1.79	-0.105
125.0	-125.9	1.86	-0.111
130.0	-130.9	1.91	-0.115

Measurement:	**M200503101**
Date:	2005–03–09
Applied voltage:	DC
Vertical position of electrode:	V6
Electrode top above slit:	S1
Distance to electrode top:	7.6 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.01	-5.05	0.091	-0.0019
10.03	-10.12	0.161	-0.0029
15.00	-15.12	0.235	-0.0036
20.03	-25.24	0.302	-0.0043
25.04	-25.24	0.385	-0.0052
30.11	-30.35	0.460	-0.0060
35.00	-35.28	0.545	-0.0067
40.10	-40.42	0.635	-0.0076
45.0	-45.4	0.71	-0.0084
50.0	-50.4	0.79	-0.0092
55.0	-55.4	0.87	-0.0100
60.0	-60.4	0.935	-0.0108
70.0	-70.5	1.12	-0.0125
75.0	-75.6	1.20	-0.0133
79.9	-80.5	1.27	-0.0142
85.0	-85.7	1.36	-0.0151
90.0	-90.7	1.46	-0.0162
95.0	-95.8	1.54	-0.0171
100.1	-100.8	1.58	-0.0179
105.0	-105.8	1.64	-0.0188
110.0	-110.8	1.67	-0.0199
114.9	-115.6	1.69	-0.0206
120.1	-120.9	1.73	-0.0217
125.0	-125.8	1.80	-0.0225
130.1	-130.9	1.89	-0.0237
130.7	-131.6	1.85	-0.0240

Measurement:	**M200503102**
Date:	2005–03–10
Applied voltage:	DC
Vertical position of electrode:	V6
Electrode top above slit:	S2
Distance to electrode top:	7.6 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.07	-5.12	0.101	-0.0034
10.03	-10.12	0.176	-0.0049
14.98	-15.11	0.255	-0.0062
19.98	-20.16	0.340	-0.0074
25.05	-25.27	0.426	-0.0085
30.04	-30.30	0.513	-0.0096
35.02	-35.33	0.596	-0.0107
40.04	-40.39	0.685	-0.0118
45.0	-45.3	0.775	-0.0129
50.0	-50.4	0.860	-0.0140
55.1	-55.6	0.955	-0.0152
60.0	-60.4	1.04	-0.0162
65.0	-65.5	1.125	-0.0175
70.0	-70.6	1.21	-0.0186
75.0	-75.6	1.30	-0.0198
80.0	-80.7	1.38	-0.0208
85.0	-85.7	1.47	-0.0220
89.9	-90.6	1.56	-0.0233
95.0	-95.8	1.63	-0.0244
100.0	-100.8	1.71	-0.0258
104.9	-105.7	1.79	-0.0270
110.0	-110.8	1.89	-0.0284
115.0	-115.9	1.96	-0.0300
120.0	-121.0	2.04	-0.0313
125.0	-126.0	2.14	-0.0325
130.1	-131.2	2.20	-0.0338

Measurement:	**M200503103**
Date:	2005–03–10
Applied voltage:	DC
Vertical position of electrode:	V6
Electrode top above slit:	S3
Distance to electrode top:	7.6 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
4.94	-5.00	0.105	-0.0043
10.00	-10.09	0.176	-0.0065
15.04	-15.17	0.254	-0.0083
20.04	-20.21	0.334	-0.0099
25.00	-25.21	0.416	-0.0113
30.03	-30.27	0.499	-0.0127
35.06	-35.36	0.589	-0.0141
40.05	-40.40	0.677	-0.0151
45.0	-45.4	0.765	-0.0164
50.0	-50.4	0.852	-0.0176
55.0	-55.5	0.945	-0.0188
60.0	-60.5	1.04	-0.0200
65.1	-65.6	1.12	-0.0215
70.0	-70.5	1.215	-0.0228
75.0	-75.6	1.30	-0.0241
79.9	-80.6	1.38	-0.0255
85.0	-85.7	1.47	-0.0268
90.0	-90.8	1.56	-0.0282
95.0	-95.8	1.63	-0.0298
100.0	-100.8	1.72	-0.0310
105.0	-105.8	1.81	-0.0326
110.0	-110.9	1.89	-0.0340
115.0	-115.9	1.97	-0.0354
120.0	-121.0	2.06	-0.0370
125.0	-126.0	2.13	-0.0387
130.0	-131.0	2.22	-0.0403

Measurement:	**M200503104**
Date:	2005–03–10
Applied voltage:	DC
Vertical position of electrode:	V6
Electrode top above slit:	S4
Distance to electrode top:	7.6 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.05	0.099	-0.0036
9.97	-10.05	0.175	-0.0055
14.98	-15.11	0.255	-0.0071
20.01	-20.18	0.340	-0.0087
24.98	-25.20	0.423	-0.0102
30.00	-30.26	0.510	-0.0117
35.00	-35.31	0.600	-0.0131
40.01	-40.36	0.687	-0.0146
45.1	-45.5	0.778	-0.0161
50.0	-50.3	0.865	-0.0175
55.0	-55.4	0.95	-0.0190
60.0	-60.5	1.04	-0.0205
65.0	-65.6	1.14	-0.0221
70.0	-70.6	1.22	-0.0234
75.0	-75.6	1.31	-0.0249
80.0	-80.7	1.40	-0.0266
85.0	-85.7	1.48	-0.0281
90.0	-90.8	1.57	-0.0295
95.0	-95.8	1.66	-0.0312
100.0	-100.8	1.74	-0.0327
105.0	-105.9	1.81	-0.0342
110.2	-111.1	1.89	-0.0361
115.0	-115.9	1.97	-0.0373
120.0	-121.0	2.05	-0.0390
124.9	-125.9	2.13	-0.0409
130.0	-131.1	2.20	-0.0425

Measurement:	**M200503105**
Date:	2005–03–10
Applied voltage:	DC
Vertical position of electrode:	V6
Electrode top above slit:	S5
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
4.97	-5.02	0.096	-0.0037
9.99	-10.07	0.171	-0.0058
14.99	-15.12	0.251	-0.0076
20.02	-20.19	0.335	-0.0094
25.06	-25.28	0.426	-0.0110
30.01	-30.27	0.507	-0.0125
34.98	-35.29	0.595	-0.0141
40.00	-40.34	0.683	-0.0155
45.0	-45.3	0.77	-0.0172
50.0	-50.4	0.865	-0.0186
55.0	-55.4	0.95	-0.0201
60.0	-60.5	1.045	-0.0213
65.0	-65.5	1.135	-0.0231
70.0	-70.6	1.22	-0.0247
75.0	-75.6	1.31	-0.0261
80.0	-80.6	1.40	-0.0278
85.0	-85.7	1.48	-0.0296
90.0	-90.8	1.56	-0.0312
95.0	-95.8	1.64	-0.0328
100.0	-100.9	1.73	-0.0345
105.0	-105.8	1.81	-0.0360
110.0	-110.9	1.90	-0.0379
115.0	-115.9	1.99	-0.0392
119.9	-120.9	2.06	-0.0413
125.0	-126.0	2.13	-0.0432
130.0	-131.0	2.20	-0.0450

Measurement:	**M200503111**
Date:	2005–03–11
Applied voltage:	DC
Vertical position of electrode:	V6
Electrode top above slit:	S6
Distance to electrode top:	7.6 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.02	-5.07	0.092	-0.0045
9.96	-10.04	0.162	-0.0068
15.03	-15.15	0.240	-0.0085
19.97	-20.13	0.320	-0.0102
25.03	-25.24	0.404	-0.0119
30.10	-30.35	0.494	-0.0136
34.97	-35.25	0.58	-0.0148
40.01	-40.35	0.67	-0.0164
45.0	-45.3	0.755	-0.0175
50.0	-50.4	0.84	-0.0192
55.0	-55.5	0.93	-0.0205
60.0	-60.4	1.01	-0.0217
65.0	-65.5	1.10	-0.0240
70.0	-70.6	1.19	-0.0250
75.0	-75.6	1.27	-0.0267
80.0	-80.6	1.36	-0.0280
85.0	-85.7	1.44	-0.0302
90.0	-90.8	1.53	-0.0322
95.1	-95.8	1.62	-0.0333
100.0	-100.8	1.70	-0.0344
105.0	-105.8	1.79	-0.0358
110.0	-110.9	1.85	-0.0378
115.0	-115.9	1.93	-0.0400
120.0	-120.9	2.01	-0.0420
124.9	-125.9	2.09	-0.0435
130.0	-131.0	2.16	-0.0449

Measurement:	**M200503112**
Date:	2005–03–11
Applied voltage:	DC
Vertical position of electrode:	V6
Electrode top above slit:	S1-2.0 mm
Distance to electrode top:	7.6 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-4.98	0.002	-0.0002
10.04	-10.04	0.016	-0.0005
14.99	-14.99	0.025	-0.0007
20.08	-20.10	0.05	-0.0009
25.06	-25.08	0.04	-0.0011
30.08	-30.11	0.06	-0.0013
34.99	-35.03	0.06	-0.0017
40.17	-40.21	0.11	-0.0020
45.0	-45.1	0.13	-0.0022
50.0	-50.1	0.15	-0.0024
55.0	-55.0	0.15	-0.0028
60.0	-60.0	0.18	-0.0031
65.1	-65.1	0.18	-0.0034
70.1	-70.1	0.24	-0.0039
75.0	-75.2	0.20	-0.0040
80.0	-80.1	0.18	-0.0044
85.0	-85.1	0.27	-0.0047
90.0	-90.1	0.35	-0.0051
95.1	-95.2	0.30	-0.0057
100.2	-100.3	0.35	-0.0058
105.0	-105.2	0.35	-0.0060
109.9	-109.9	0.40	-0.0065
115.0	-115.1	0.45	-0.0070
119.8	-120.0	0.45	-0.0070
125.0	-125.2	0.45	-0.0077
130.0	-130.3	0.55	-0.0080

Measurement:	**M200503216**
Date:	2005–03–21
Applied voltage:	DC
Vertical position of electrode:	V2
Electrode top above slit:	S4
Distance to electrode top:	1.0 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
4.94	-4.96	0.070	-0.011
10.09	-10.14	0.132	-0.021
14.96	-15.04	0.196	-0.031
20.07	-20.18	0.264	-0.042
25.01	-25.15	0.33	-0.053
30.05	-30.22	0.40	-0.065
34.95	-35.15	0.475	-0.076
40.00	-40.23	0.55	-0.087
45.0	-45.2	0.62	-0.100
49.9	-50.1	0.69	-0.111
54.9	-55.1	0.76	-0.123
60.0	-60.3	0.845	-0.135
65.0	-65.3	0.92	-0.146
70.0	-70.4	0.99	-0.160
75.0	-75.4	1.08	-0.171
80.0	-80.4	1.14	-0.180
85.0	-85.5	1.22	-0.195
90.0	-90.5	1.29	-0.205
95.0	-95.5	1.36	-0.212
100.0	-100.6	1.43	-0.225
105.0	-105.6	1.51	-0.236
110.0	-110.6	1.58	-0.253
115.0	-115.6	1.65	-0.268
120.0	-120.7	1.73	-0.278
125.1	-125.8	1.80	-0.293
129.8	-130.5	1.87	-0.298

Measurement:	**M200503217**
Date:	2005–03–21
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
4.97	-5.02	0.112	-0.009
9.95	-10.04	0.187	-0.015
15.04	-15.17	0.269	-0.020
19.97	-20.13	0.347	-0.024
24.89	-25.10	0.43	-0.029
29.98	-30.23	0.52	-0.034
35.06	-35.36	0.61	-0.039
40.04	-40.37	0.695	-0.043
45.0	-45.4	0.78	-0.048
50.0	-50.4	0.875	-0.053
55.2	-55.7	0.97	-0.059
60.0	-60.5	1.06	-0.062
65.0	-65.5	1.14	-0.068
70.0	-70.5	1.23	-0.071
75.0	-75.6	1.32	-0.077
80.0	-80.6	1.42	-0.083
85.0	-85.7	1.51	-0.088
90.0	-90.7	1.58	-0.092
95.0	-95.7	1.66	-0.098
100.0	-100.7	1.74	-0.103
105.0	-105.7	1.84	-0.110
110.0	-110.8	1.92	-0.116
115.0	-115.9	1.99	-0.121
120.0	-121.0	2.10	-0.128
125.0	-126.0	2.18	-0.133
129.6	-130.6	2.25	-0.137

Measurement:	**M200503222**
Date:	2005–03–22
Applied voltage:	DC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	10.0 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.04	-5.11	0.105	-0.0029
10.03	-10.12	0.178	-0.0044
15.02	-15.15	0.255	-0.0057
20.09	-20.25	0.336	-0.0067
25.02	-25.23	0.418	-0.0078
30.04	-30.29	0.502	-0.0088
34.97	-35.27	0.589	-0.0100
40.02	-40.36	0.673	-0.0108
45.0	-45.4	0.761	-0.0118
50.0	-50.4	0.849	-0.0128
55.0	-55.5	0.935	-0.0137
60.0	-60.4	1.023	-0.0146
65.0	-65.6	1.110	-0.0157
70.0	-70.5	1.196	-0.0166
75.0	-75.6	1.28	-0.0174
80.0	-80.6	1.37	-0.0180
85.0	-85.7	1.45	-0.0190
90.0	-90.7	1.53	-0.0199
95.0	-95.7	1.61	-0.0207
100.0	-100.8	1.69	-0.0218
104.9	-105.8	1.77	-0.0224
110.0	-110.9	1.84	-0.0233
115.0	-115.9	1.91	-0.0240
120.1	-121.1	1.97	-0.0248
125.0	-125.9	2.04	-0.0260
129.7	-130.7	2.10	-0.0270

Measurement:	**M200503231**
Date:	2005–03–23
Applied voltage:	DC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	10.0 mm
The chimney tube present:	No
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.01	-5.05	0.091	-0.0027
10.00	-10.08	0.165	-0.0040
15.00	-15.11	0.243	-0.0052
20.06	-20.22	0.327	-0.0062
25.00	-25.21	0.410	-0.0072
30.00	-30.24	0.493	-0.0082
35.00	-35.30	0.578	-0.0090
40.00	-40.33	0.666	-0.0101
45.0	-45.3	0.755	-0.0109
50.0	-50.4	0.842	-0.0119
55.0	-55.4	0.93	-0.0127
60.0	-60.5	1.01	-0.0135
65.0	-65.5	1.10	-0.0145
70.0	-70.5	1.19	-0.0152
75.0	-75.6	1.27	-0.0161
80.0	-80.7	1.36	-0.0170
85.0	-85.6	1.44	-0.0179
90.0	-90.7	1.53	-0.0188
95.0	-95.8	1.61	-0.0196
100.0	-100.8	1.69	-0.0205
105.0	-105.9	1.77	-0.0213
110.0	110.8	1.85	-0.0221
115.0	-115.9	1.93	-0.0231
120.0	-121.0	2.00	-0.0240
125.0	-126.0	2.08	-0.0247
129.6	-130.6	2.15	-0.0255

Measurement:	**M200503301**
Date:	2005–03–30
Applied voltage:	DC
Vertical position of electrode:	V9
Electrode top above slit:	S4
Distance to electrode top:	14.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.06	-5.10	0.090	-0.0019
10.07	-10.16	0.160	-0.0029
15.09	-15.21	0.233	-0.0036
20.42	-20.58	0.314	-0.0043
25.06	-25.26	0.386	-0.0050
30.01	-30.24	0.465	-0.0054
35.00	-35.28	0.545	-0.0062
40.00	-40.32	0.622	-0.0064
45.0	-45.3	0.703	-0.0069
50.0	-50.4	0.782	-0.0075
55.0	-55.4	0.859	-0.0080
60.0	-60.5	0.935	-0.0083
65.0	-65.4	0.990	-0.0089
70.0	-70.5	1.05	-0.0091
75.0	-75.6	1.12	-0.0099
80.0	-80.5	1.16	-0.0103
85.0	-85.6	1.16	-0.0105
90.0	-90.6	1.20	-0.0112
95.0	-95.6	1.21	-0.0114
100.0	-100.6	1.21	-0.0118
105.0	-105.6	1.25	-0.0122
110.0	-110.6	1.25	-0.0128
115.0	-115.6	1.29	-0.0133
120.0	-120.6	1.30	-0.0134
125.0	-125.7	1.34	-0.0139
130.0	-130.7	1.39	-0.0145

Measurement:	**M200503302**
Date:	2005–03–30
Applied voltage:	DC
Vertical position of electrode:	V9
Electrode top above slit:	S4
Distance to electrode top:	14.5 mm
The chimney tube present:	No
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.04	0.086	-0.0021
10.02	-10.10	0.158	-0.0029
15.00	-15.12	0.232	-0.0036
20.04	-20.20	0.312	-0.0044
25.00	-25.20	0.390	-0.0053
30.02	-30.27	0.476	-0.0062
35.00	-35.29	0.559	-0.0071
40.00	-40.33	0.641	-0.0074
45.0	-45.3	0.73	-0.0089
50.0	-50.4	0.82	-0.0080
55.0	-55.4	0.90	-0.0085
60.0	-60.5	0.99	-0.0090
65.0	-65.5	1.07	-0.0097
70.0	-70.6	1.15	-0.0100
75.0	-75.6	1.24	-0.0109
80.0	-80.6	1.32	-0.0114
85.0	-85.6	1.40	-0.0116
90.0	-90.7	1.48	-0.0125
95.0	-95.7	1.54	-0.0124
100.0	-100.7	1.63	-0.0130
105.0	-105.8	1.70	-0.0130
110.0	-110.8	1.76	-0.0132
115.0	-115.9	1.85	-0.0139
120.0	-120.9	1.90	-0.0148
125.0	-125.9	1.95	-0.0153
130.0	-130.9	1.99	-0.0155

Measurement:	**M200504011**
Date:	2005–04–01
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.04	0.093	-0.0113
10.00	-10.08	0.165	-0.0171
15.01	-15.12	0.246	-0.0225
20.00	-20.16	0.327	-0.028
25.00	-25.20	0.413	-0.033
30.00	-30.24	0.502	-0.039
35.00	-35.28	0.59	-0.045
40.00	-40.32	0.68	-0.050
45.0	-45.3	0.77	-0.055
50.0	-50.4	0.86	-0.061
55.0	-55.4	0.95	-0.067
60.0	-60.4	1.04	-0.072
65.0	-65.5	1.13	-0.079
70.0	-70.5	1.22	-0.083
75.0	-75.6	1.30	-0.090
80.0	-80.6	1.40	-0.095
85.0	-85.7	1.49	-0.100
90.0	-90.7	1.57	-0.109
95.0	-95.8	1.66	-0.114
100.0	-100.8	1.74	-0.121
105.0	-105.8	1.83	-0.128
110.0	-110.9	1.91	-0.133
115.0	-115.9	2.00	-0.138
120.0	-120.9	2.09	-0.146
125.0	-125.9	2.16	-0.153
130.0	-131.0	2.23	-0.159

Measurement:	**M200504013**
Date:	2005–04–01
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.06	0.113	-0.008
10.00	-10.09	0.188	-0.013
15.00	-15.12	0.266	-0.016
20.00	-20.16	0.350	-0.020
25.00	-25.21	0.430	-0.024
30.00	-30.25	0.52	-0.028
35.00	-35.30	0.61	-0.032
40.00	-40.33	0.69	-0.036
45.0	-45.4	0.785	-0.040
50.0	-50.4	0.87	-0.044
55.0	-55.4	0.96	-0.048
60.0	-60.5	1.05	-0.052
65.0	-65.5	1.12	-0.056
70.0	-70.5	1.23	-0.060
75.0	-75.6	1.32	-0.064
80.0	-80.6	1.41	-0.069
85.0	-85.7	1.50	-0.073
90.0	-90.7	1.57	-0.077
100.0	-100.8	1.73	-0.086
105.0	-105.8	1.84	-0.090
110.0	-110.8	1.93	-0.096
115.0	-115.9	1.99	-0.100
120.0	-120.9	2.09	-0.104
125.0	-125.9	2.15	-0.109
129.6	-130.6	2.24	-0.114

Measurement:	**M200504071**
Date:	2005–04–07
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#4

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.03	0.093	-0.007
10.02	-10.10	0.162	-0.011
14.95	-15.07	0.238	-0.014
20.00	-20.16	0.319	-0.018
25.00	-25.20	0.401	-0.021
30.01	-30.25	0.489	-0.024
40.00	-40.33	0.655	-0.031
45.0	-45.4	0.746	-0.035
50.0	-50.4	0.830	-0.038
55.0	-55.4	0.918	-0.042
60.0	-60.4	1.00	-0.045
65.0	-65.5	1.10	-0.049
70.0	-70.6	1.19	-0.053
75.0	-75.5	1.27	-0.056
80.0	-80.6	1.35	-0.059
85.0	-85.7	1.44	-0.064
90.0	-90.8	1.52	-0.067
95.0	-95.8	1.61	-0.071
100.0	-100.7	1.69	-0.076
105.0	-105.8	1.78	-0.080
110.0	-110.9	1.86	-0.083
115.0	-115.9	1.95	-0.087
120.0	-121.0	2.03	-0.091
125.0	-126.2	2.12	-0.095
130.0	-131.0	2.19	-0.099

Measurement:	**M200504073**
Date:	2005–04–07
Applied voltage:	DC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#5

U+ (V)	U- (V)	I+ (V)	I- (V)
5.07	-5.11	0.094	-0.002
10.07	-10.15	0.159	-0.003
15.01	-15.12	0.227	-0.004
20.00	-20.15	0.299	-0.006
25.02	-25.21	0.378	-0.007
30.00	-30.24	0.455	-0.008
35.10	-35.37	0.534	-0.009
40.00	-40.31	0.614	-0.010
45.0	-45.3	0.700	-0.011
50.0	-50.4	0.785	-0.012
55.0	-55.4	0.87	-0.013
60.0	-60.4	0.95	-0.014
65.0	-65.4	1.04	-0.015
70.0	-70.5	1.12	-0.016
75.0	-75.6	1.20	-0.017
80.0	-80.6	1.29	-0.018
85.0	-85.7	1.37	-0.019
90.0	-90.7	1.46	-0.020
95.0	-95.7	1.54	-0.021
100.0	-100.8	1.62	-0.022
105.0	-105.8	1.70	-0.024
110.0	-110.9	1.79	-0.025
115.0	-115.9	1.87	-0.027
120.0	-121.0	1.95	-0.028
125.0	-121.0	1.95	-0.028
130.0	-131.0	2.11	-0.030

Measurement:	**M200504073**
Date:	2005–04–07
Applied voltage:	DC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#5

U+ (V)	U- (V)	I+ (V)	I- (V)
5.07	-5.11	0.094	-0.002
10.07	-10.15	0.159	-0.003
15.01	-15.12	0.227	-0.004
20.00	-20.15	0.299	-0.006
25.02	-25.21	0.378	-0.007
30.00	-30.24	0.455	-0.008
35.10	-35.37	0.534	-0.009
40.00	-40.31	0.614	-0.010
45.0	-45.3	0.700	-0.011
50.0	-50.4	0.785	-0.012
55.0	-55.4	0.87	-0.013
60.0	-60.4	0.95	-0.014
65.0	-65.4	1.04	-0.015
70.0	-70.5	1.12	-0.016
75.0	-75.6	1.20	-0.017
80.0	-80.6	1.29	-0.018
85.0	-85.7	1.37	-0.019
90.0	-90.7	1.46	-0.020
95.0	-95.7	1.54	-0.021
100.0	-100.8	1.62	-0.022
105.0	-105.8	1.70	-0.024
110.0	-110.9	1.79	-0.025
115.0	-115.9	1.87	-0.027
120.0	-121.0	1.95	-0.028
125.0	-121.0	1.95	-0.028
130.0	-131.0	2.11	-0.030

Measurement:	**M200504074**
Date:	2005–04–07
Applied voltage:	DC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#5

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.06	0.107	-0.010
9.99	-10.08	0.176	-0.015
15.00	-15.11	0.250	-0.021
20.00	-20.16	0.329	-0.025
25.00	-25.19	0.411	-0.029
30.00	-30.22	0.495	-0.035
35.00	-35.28	0.58	-0.039
40.00	-40.32	0.67	-0.044
45.0	-45.3	0.755	-0.049
50.0	-50.4	0.84	-0.053
55.0	-55.5	0.935	-0.059
60.0	-60.4	1.025	-0.064
65.0	-65.5	1.11	-0.068
70.0	-70.5	1.20	-0.073
75.0	-75.6	1.29	-0.078
80.0	-80.6	1.37	-0.083
85.0	-85.7	1.46	-0.088
90.0	-90.7	1.54	-0.094
95.0	-95.8	1.63	-0.099
100.0	-100.8	1.72	-0.104
105.0	-105.8	1.80	-0.109
110.0	-110.8	1.88	-0.115
115.0	-115.9	1.97	-0.121
120.0	-121.0	2.05	-0.126
125.0	-125.9	2.13	-0.131
130.0	-130.9	2.20	-0.137

Measurement:	**M200504075**
Date:	2005–04–07
Applied voltage:	DC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#5

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.05	0.111	-0.014
10.00	-10.09	0.186	-0.022
15.00	-15.11	0.268	-0.030
20.00	-20.16	0.350	-0.038
25.00	-25.20	0.436	-0.044
30.00	-30.24	0.519	-0.051
35.00	-35.28	0.61	-0.059
40.00	-40.32	0.70	-0.065
45.0	-45.3	0.79	-0.073
50.0	-50.4	0.88	-0.080
55.0	-55.4	0.96	-0.087
60.0	-60.5	1.05	-0.096
65.0	-65.5	1.14	-0.103
70.0	-70.6	1.23	-0.110
75.0	-75.6	1.32	-0.118
80.0	-80.6	1.40	-0.124
85.0	-85.6	1.49	-0.133
90.0	-90.7	1.57	-0.141
95.0	-95.8	1.66	-0.150
100.0	-100.8	1.75	-0.159
105.0	-105.8	1.82	-0.168
110.0	-110.8	1.91	-0.174
115.0	-115.9	1.99	-0.183
120.0	-120.9	2.07	-0.193
125.0	-126.0	2.12	-0.199
130.0	-131.0	2.18	-0.205

Measurement: **M200504141**
Date: 2005–04–14
Applied voltage: DC
Vertical position of electrode: V5
Electrode top above slit: S4
Distance to electrode top: 4.5 mm
The chimney tube present: Yes
Gas pressure: 31.9 mbar
Jet number: 58
Electrode: #2

U+ (V)	U- (V)	I+ (V)	I- (V)
4.96	-5.01	0.094	-0.008
10.08	-10.15	0.162	-0.013
15.00	-15.11	0.235	-0.017
20.00	-20.15	0.310	-0.021
25.00	-25.19	0.390	-0.025
30.00	-30.23	0.47	-0.029
35.00	-35.27	0.555	-0.032
40.00	-40.37	0.64	-0.037
45.0	-45.3	0.73	-0.040
50.0	-50.3	0.81	-0.044
55.0	-55.4	0.90	-0.048
60.0	-60.5	0.99	-0.052
65.0	-65.5	1.08	-0.056
70.0	-70.5	1.165	-0.060
75.0	-75.5	1.25	-0.064
80.0	-80.6	1.34	-0.067
85.0	-85.7	1.43	-0.072
90.0	-90.7	1.52	-0.075
95.0	-95.7	1.62	-0.079
100.0	-100.8	1.70	-0.084
105.0	-105.8	1.79	-0.087
110.0	-110.9	1.88	-0.092
115.0	-115.8	1.96	-0.096
120.0	-121.0	2.04	-0.101
125.0	-126.0	2.14	-0.106
130.0	-131.0	2.21	-0.110

Measurement: **M200504142**
Date: 2005–04–14
Applied voltage: DC
Vertical position of electrode: V5
Electrode top above slit: S4
Distance to electrode top: 4.5 mm
The chimney tube present: Yes
Gas pressure: 27.5 mbar
Jet number: 58
Electrode: #2

U+ (V)	U- (V)	I+ (V)	I- (V)
5.07	-5.12	0.091	-0.006
10.00	-10.08	0.162	-0.009
15.00	-15.12	0.239	-0.012
20.00	-20.16	0.322	-0.015
25.00	-25.20	0.403	-0.018
30.00	-30.24	0.488	-0.021
35.00	-35.28	0.57	-0.024
40.00	-40.33	0.66	-0.028
45.0	-45.3	0.75	-0.031
50.0	-50.4	0.83	-0.034
55.0	-55.4	0.92	-0.037
60.0	-60.5	1.00	-0.040
65.0	-65.5	1.09	-0.043
70.0	-70.6	1.18	-0.046
75.0	-75.6	1.26	-0.050
80.0	-80.6	1.34	-0.052
85.0	-85.6	1.42	-0.056
90.0	-90.7	1.51	-0.059
95.0	-95.8	1.59	-0.063
100.0	-100.8	1.68	-0.066
105.0	-105.8	1.76	-0.069
110.0	-110.9	1.83	-0.073
115.0	-115.9	1.91	-0.077
120.0	-121.0	1.99	-0.080
125.0	-125.9	2.06	-0.084
130.0	-131.0	2.13	-0.088

Measurement: **M200504143**
Date: 2005–04–14
Applied voltage: DC
Vertical position of electrode: V5
Electrode top above slit: S4
Distance to electrode top: 4.5 mm
The chimney tube present: Yes
Gas pressure: 29.4 mbar
Jet number: 58
Electrode: #2

U+ (V)	U- (V)	I+ (V)	I- (V)
4.96	-5.00	0.087	-0.007
10.00	-10.08	0.158	-0.011
15.00	-15.11	0.234	-0.015
20.00	-20.14	0.313	-0.018
25.00	-25.19	0.394	-0.021
30.00	-30.24	0.48	-0.025
35.00	-35.29	0.565	-0.028
40.00	-40.32	0.65	-0.032
45.0	-45.3	0.74	-0.035
50.0	-50.3	0.82	-0.039
55.0	-55.5	0.915	-0.042
60.0	-60.5	1.00	-0.046
65.0	-65.4	1.08	-0.049
70.0	-70.6	1.18	-0.053
75.0	-75.6	1.27	-0.057
80.0	-80.7	1.35	-0.061
85.0	-85.6	1.44	-0.064
90.0	-90.7	1.53	-0.069
95.0	-95.8	1.62	-0.072
100.0	-100.8	1.70	-0.076
105.0	-105.9	1.78	-0.080
110.0	-110.9	1.87	-0.085
115.0	-115.9	1.96	-0.088
120.0	-120.9	2.03	-0.092
125.0	-126.0	2.11	-0.096
130.0	-131.0	2.21	-0.102

Measurement: **M200504201**
Date: 2005–04–20
Applied voltage: DC
Vertical position of electrode: V9
Electrode top above slit: S4
Distance to electrode top: 14.5 mm
The chimney tube present: Yes
Gas pressure: 27.5 mbar
Jet number: 73
Electrode: #2

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.04	0.090	-0.0017
10.00	-10.08	0.155	-0.0024
15.00	-15.12	0.229	-0.0032
20.00	-20.16	0.303	-0.0038
25.00	-25.20	0.380	-0.0042
30.00	-30.24	0.460	-0.0047
35.00	-35.28	0.536	-0.0052
40.00	-40.32	0.614	-0.0055
45.0	-45.3	0.692	-0.0061
50.0	-50.4	0.77	-0.0063
55.0	-55.4	0.85	-0.0069
60.0	-60.4	0.92	-0.0072
65.0	-65.5	1.00	-0.0077
70.0	-70.5	1.07	-0.0078
75.0	-75.5	1.14	-0.0082
80.0	-80.6	1.21	-0.0088
85.0	-85.6	1.28	-0.0090
90.0	-90.6	1.33	-0.0094
95.0	-95.6	1.39	-0.0099
100.0	-100.7	1.36	-0.0104
105.0	-105.6	1.39	-0.0105
110.0	-110.7	1.41	-0.0109
115.0	-115.7	1.42	-0.0114
120.0	-120.7	1.45	-0.0115
125.0	-125.7	1.46	-0.0121
130.0	-130.7	1.45	-0.0120

Measurement:	**M200504202**
Date:	2005–04–20
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	32
Electrode:	#2

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.07	0.142	-0.003
10.00	-10.14	0.258	-0.005
15.00	-15.19	0.381	-0.007
20.00	-20.26	0.505	-0.009
25.00	-25.32	0.632	-0.011
30.00	-30.38	0.761	-0.013
35.00	-35.45	0.894	-0.015
40.00	-40.52	1.02	-0.017
45.0	-45.6	1.16	-0.018
50.0	-50.6	1.28	-0.020
55.0	-55.7	1.41	-0.022
60.0	-60.7	1.54	-0.024
65.0	-65.8	1.66	-0.026
70.0	-70.9	1.81	-0.029
75.0	-75.9	1.92	-0.031
80.0	-81.0	2.02	-0.031
85.0	-86.0	2.16	-0.036
90.0	-91.1	2.28	-0.038
95.0	-96.2	2.39	-0.040
100.0	-101.2	2.51	-0.042
105.0	-106.2	2.56	-0.045
110.0	-111.3	2.67	-0.048
115.0	-116.3	2.61	-0.051
120.0	-121.3	2.70	-0.053
125.0	-126.3	2.75	-0.056
130.0	-131.3	2.80	-0.059

Measurement:	**M200504203**
Date:	2005–04–20
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	43
Electrode:	#2

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.06	0.110	-0.006
10.00	-10.10	0.207	-0.009
15.00	-15.15	0.307	-0.013
20.00	-20.21	0.410	-0.016
25.00	-25.26	0.513	-0.019
30.00	-30.31	0.621	-0.022
35.00	-35.37	0.73	-0.025
40.00	-40.41	0.84	-0.028
45.0	-45.5	0.95	-0.032
50.0	-50.5	1.06	-0.036
55.0	-55.5	1.17	-0.039
60.0	-60.6	1.28	-0.043
65.0	-65.7	1.38	-0.047
70.0	-70.7	1.49	-0.051
75.0	-75.8	1.59	-0.055
80.0	-80.8	1.69	-0.058
85.0	-85.9	1.80	-0.066
90.0	-90.9	1.90	-0.066
95.0	-95.9	2.00	-0.070
100.0	-101.0	2.10	-0.075
105.0	-106.0	2.16	-0.078
110.0	-111.1	2.25	-0.084
115.0	-116.0	2.35	-0.087
120.0	-121.1	2.46	-0.092
125.0	-126.1	2.52	-0.097
130.0	-131.1	2.59	-0.102

Measurement:	**M200504204**
Date:	2005–04–20
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	73
Electrode:	#2

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.04	0.085	-0.008
10.00	-10.07	0.152	-0.013
15.00	-15.11	0.223	-0.018
20.00	-20.14	0.303	-0.022
25.00	-25.19	0.384	-0.027
30.00	-30.22	0.464	-0.031
35.00	-35.27	0.545	-0.035
40.00	-40.31	0.63	-0.039
45.0	-45.3	0.71	-0.043
50.0	-50.3	0.79	-0.047
55.0	-55.4	0.88	-0.051
60.0	-60.5	0.97	-0.057
65.0	-65.5	1.05	-0.061
70.0	-70.5	1.11	-0.066
75.0	-75.5	1.21	-0.069
80.0	-80.5	1.29	-0.072
85.0	-85.6	1.38	-0.078
90.0	-90.7	1.47	-0.083
95.0	-95.7	1.54	-0.088
100.0	-100.7	1.62	-0.092
105.0	-105.8	1.69	-0.097
110.0	-110.8	1.77	-0.101
115.0	-115.8	1.85	-0.105
120.0	-120.8	1.92	-0.110
125.0	-125.9	1.99	-0.114
130.0	-130.9	2.06	-0.119

Measurement:	**M200504205**
Date:	2005–04–20
Applied voltage:	DC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	29.4 mbar
Jet number:	58
Electrode:	#2

U+ (V)	U- (V)	I+ (V)	I- (V)
5.00	-5.04	0.090	-0.007
10.00	-10.07	0.165	-0.012
15.00	-15.12	0.243	-0.016
20.00	-20.15	0.327	-0.020
25.00	-25.20	0.410	-0.024
30.00	-30.23	0.497	-0.028
35.00	-35.28	0.59	-0.032
40.00	-40.33	0.67	-0.037
45.0	-45.3	0.76	-0.041
50.0	-50.4	0.85	-0.045
55.0	-55.4	0.94	-0.049
60.0	-60.5	1.02	-0.053
65.0	-65.5	1.11	-0.056
70.0	-70.5	1.20	-0.061
75.0	-75.6	1.28	-0.065
80.0	-80.6	1.37	-0.070
85.0	-85.7	1.46	-0.075
90.0	-90.7	1.53	-0.079
95.0	-95.7	1.62	-0.083
100.0	-100.7	1.71	-0.089
105.0	-105.9	1.78	-0.094
110.0	-110.8	1.85	-0.097
115.0	-115.9	1.93	-0.103
120.0	-120.9	2.02	-0.106
125.0	-126.0	2.10	-0.111
130.0	-130.9	2.17	-0.116

A.2 AC

Tables of the AC measurements are presented here. The fields *measurement*, *date*, *applied voltage*, *vertical position of electrode*, *electrode above slit*, *distance to electrode top*, *chimney tube present*, *gas pressure*, *jet number* and *electrode* are the same as in the DC measurements. Those fields are explained on page 47. The fields *frequency* and *wave form* are specific for the AC measurements. The field *frequency* tells the frequency of the applied AC voltage. The field *wave form* tells what kind of wave form the applied AC voltage had. Only sine wave has been used.

U is the RMS value of the applied AC voltage and I is a measure of the direct component of the current through the flame. Observ that I is not a current but a DC voltage measured over the $100k\Omega$ resistance in figure 3.6 on page 14. Hence the value given by I in the tables has to be divided by 10^5 to get the current through the flame.

Measurement:	**M200503181**
Date:	2005–03–18
Applied voltage:	AC
Vertical position of electrode:	V6
Electrode top above slit:	S1
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.03	0.034
10.10	0.064
15.04	0.094
20.04	0.126
24.97	0.158
30.08	0.192
35.00	0.226
40.07	0.261
45.0	0.298
50.0	0.333
55.0	0.370
59.9	0.403
65.1	0.439
70.0	0.477
75.0	0.511
80.0	0.543
85.0	0.578
90.0	0.614
95.0	0.649
100.0	0.672
102.4	0.695

Measurement:	**M200503182**
Date:	2005–03–18
Applied voltage:	AC
Vertical position of electrode:	V6
Electrode top above slit:	S2
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.06	0.042
10.02	0.072
15.20	0.106
20.01	0.137
25.01	0.170
30.03	0.204
35.01	0.240
40.00	0.274
45.0	0.308
50.0	0.341
55.0	0.376
60.0	0.413
65.0	0.448
70.0	0.482
75.0	0.516
80.0	0.553
85.0	0.587
90.0	0.619
95.0	0.653
100.0	0.684

Measurement:	**M200503183**
Date:	2005–03–18
Applied voltage:	AC
Vertical position of electrode:	V3
Electrode top above slit:	S3
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	500 Hz
Wave form:	Sine

U (V)	I (V)
4.99	0.036
9.92	0.066
15.06	0.099
19.94	0.130
25.02	0.164
30.06	0.198
35.04	0.233
39.97	0.266
45.0	0.299
50.0	0.333
55.0	0.366
60.0	0.402
65.0	0.436
70.0	0.468
75.0	0.501
80.0	0.535
85.1	0.570
90.0	0.604
95.1	0.639
100.0	0.669

Measurement:	**M200503184**
Date:	2005–03–18
Applied voltage:	AC
Vertical position of electrode:	V3
Electrode top above slit:	S4
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.06	0.039
10.03	0.069
14.98	0.100
20.07	0.132
25.03	0.165
29.94	0.198
35.00	0.231
40.02	0.266
45.0	0.296
50.0	0.331
55.0	0.365
60.0	0.402
65.0	0.435
70.0	0.468
75.0	0.500
79.9	0.537
85.0	0.570
90.0	0.599
95.0	0.633
100.0	0.660

Measurement:	**M200503211**
Date:	2005–03–21
Applied voltage:	AC
Vertical position of electrode:	V3
Electrode top above slit:	S2
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.00	0.041
10.00	0.070
15.00	0.101
20.00	0.134
25.00	0.167
30.00	0.201
35.00	0.235
40.00	0.272
45.0	0.306
50.0	0.342
55.0	0.378
60.0	0.414
65.0	0.450
70.0	0.484
75.0	0.517
80.0	0.553
85.0	0.587
90.0	0.622
95.0	0.657
100.0	0.688
102.4	0.705

Measurement:	**M200503212**
Date:	2005–03–21
Applied voltage:	AC
Vertical position of electrode:	V3
Electrode top above slit:	S4
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.00	0.039
10.05	0.067
15.04	0.097
20.09	0.127
24.99	0.156
30.00	0.188
35.07	0.221
40.04	0.255
45.0	0.284
50.0	0.318
55.0	0.351
60.0	0.384
65.0	0.416
70.0	0.449
75.1	0.485
80.1	0.517
85.0	0.547
90.0	0.578
95.0	0.611
100.0	0.643

Measurement:	**M200503213**
Date:	2005–03–21
Applied voltage:	AC
Vertical position of electrode:	V3
Electrode top above slit:	S5
Distance to electrode top:	2.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.07	0.041
10.02	0.067
14.96	0.098
20.14	0.129
25.00	0.160
30.00	0.190
35.00	0.222
40.00	0.257
45.0	0.286
50.0	0.320
55.0	0.352
60.0	0.386
65.0	0.420
70.0	0.452
75.0	0.484
80.0	0.515
85.0	0.550
90.0	0.582
95.0	0.614
100.0	0.643

Measurement:	**M200503214**
Date:	2005–03–21
Applied voltage:	AC
Vertical position of electrode:	V3
Electrode top above slit:	S6
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.02	0.045
10.06	0.075
15.05	0.104
20.00	0.131
24.99	0.160
30.00	0.191
35.04	0.224
40.10	0.255
45.0	0.287
50.0	0.317
55.0	0.351
60.0	0.386
65.0	0.417
70.0	0.449
75.0	0.480
80.0	0.511
85.0	0.545
90.0	0.575
95.0	0.607
100.0	0.639

Measurement:	**M200503215**
Date:	2005–03–21
Applied voltage:	AC
Vertical position of electrode:	V2
Electrode top above slit:	S4
Distance to electrode top:	1.0 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.03	0.034
10.06	0.058
15.06	0.083
20.00	0.107
25.03	0.132
30.00	0.156
35.00	0.182
40.10	0.212
45.0	0.238
50.0	0.266
55.0	0.293
60.0	0.323
65.0	0.352
70.0	0.382
75.0	0.410
80.0	0.441
85.0	0.469
90.1	0.499
95.0	0.528
100.0	0.557

Measurement:	**M200503218**
Date:	2005–03–21
Applied voltage:	AC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.02	0.048
9.95	0.084
15.23	0.123
20.05	0.159
25.00	0.195
30.00	0.233
35.00	0.271
40.00	0.310
45.0	0.346
50.0	0.386
55.0	0.424
60.0	0.461
65.0	0.501
70.0	0.537
75.0	0.574
80.0	0.609
85.0	0.645
90.0	0.688
95.0	0.722
100.0	0.757

Measurement:	**M200503221**
Date:	2005–03–22
Applied voltage:	AC
Vertical position of electrode:	V6
Electrode top above slit:	S4
Distance to electrode top:	7.6 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.08	0.052
10.10	0.088
15.04	0.124
20.05	0.161
24.96	0.198
30.05	0.237
35.06	0.276
40.00	0.313
45.0	0.350
50.0	0.388
55.0	0.427
60.0	0.465
65.0	0.503
70.0	0.542
75.0	0.577
80.0	0.616
85.0	0.655
90.0	0.690
95.0	0.728
100.0	0.763

Measurement:	**M200503223**
Date:	2005–03–22
Applied voltage:	AC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	10.0 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
4.96	0.047
10.09	0.083
14.98	0.118
19.98	0.154
25.06	0.192
30.08	0.228
35.00	0.265
40.02	0.302
45.1	0.337
50.0	0.373
55.0	0.409
60.0	0.445
65.0	0.481
70.0	0.515
75.0	0.550
80.0	0.586
85.0	0.624
90.0	0.661
95.0	0.693
100.0	0.720

Measurement:	**M200503232**
Date:	2005–03–23
Applied voltage:	AC
Vertical position of electrode:	V8
Electrode top above slit:	S4
Distance to electrode top:	10.0 mm
The chimney tube present:	No
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.01	0.044
9.95	0.077
15.00	0.113
20.03	0.150
25.05	0.187
30.03	0.223
35.00	0.261
40.00	0.297
45.0	0.332
50.0	0.371
55.0	0.409
60.0	0.447
65.0	0.484
70.0	0.521
75.0	0.557
80.0	0.595
85.0	0.631
90.0	0.669
95.0	0.704
100.0	0.741

Measurement:	**M200503234**
Date:	2005–03–23
Applied voltage:	AC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	1004 Hz
Wave form:	Sine

U (V)	I (V)
5.01	0.057
10.00	0.099
15.00	0.139
20.02	0.179
25.00	0.216
30.00	0.254
35.00	0.294
40.00	0.329
45.0	0.365
50.0	0.407
55.0	0.444
60.0	0.484
65.0	0.522
70.0	0.562
75.0	0.600
80.0	0.638
85.0	0.675
90.0	0.712
95.0	0.745
100.0	0.785
105.0	0.822

Measurement:	**M200503235**
Date:	2005–03–23
Applied voltage:	AC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	50 Hz
Wave form:	Sine

U (V)	I (V)
5.04	0.045
10.06	0.080
15.07	0.116
19.98	0.153
25.03	0.191
30.01	0.229
34.97	0.266
39.99	0.305
45.0	0.341
50.0	0.380
55.0	0.415
60.0	0.455
65.0	0.495
70.0	0.533
75.0	0.570
80.0	0.606
85.0	0.642
90.0	0.675
93.9	0.699

Measurement:	**M200503236**
Date:	2005–03–23
Applied voltage:	AC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	600 Hz
Wave form:	Sine

U (V)	I (V)
5.00	0.043
10.00	0.078
15.00	0.114
20.00	0.151
25.00	0.189
30.00	0.227
35.00	0.266
40.00	0.307
45.0	0.342
50.0	0.381
55.0	0.418
60.0	0.457
65.0	0.495
70.0	0.534
75.0	0.569
80.0	0.610
85.0	0.646
90.0	0.682
95.0	0.715
100.0	0.754
104.2	0.780

Measurement:	**M200503303**
Date:	2005–03–30
Applied voltage:	AC
Vertical position of electrode:	V3
Electrode top above slit:	S4
Distance to electrode top:	14.5 mm
The chimney tube present:	No
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.00	0.038
10.00	0.068
15.00	0.100
20.00	0.134
25.00	0.167
30.00	0.202
35.00	0.235
40.00	0.269
45.0	0.301
50.0	0.333
55.0	0.366
60.0	0.399
65.0	0.433
70.0	0.463
75.0	0.494
80.0	0.525
85.0	0.557
90.0	0.585
95.0	0.613
100.0	0.641
102.5	0.652

Measurement:	**M200503304**
Date:	2005–03–30
Applied voltage:	AC
Vertical position of electrode:	V9
Electrode top above slit:	S4
Distance to electrode top:	14.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.00	0.041
10.00	0.073
15.00	0.105
20.00	0.138
25.00	0.171
30.00	0.206
35.00	0.239
40.00	0.273
45.0	0.302
50.0	0.335
55.0	0.367
60.0	0.397
65.0	0.428
70.0	0.459
75.0	0.480
80.0	0.517
85.0	0.535
90.0	0.55
95.0	0.56
100.0	0.58

Measurement:	**M200504012**
Date:	2005–04–01
Applied voltage:	AC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.00	0.038
10.00	0.072
15.00	0.107
20.00	0.143
25.00	0.179
30.00	0.217
35.00	0.256
40.00	0.295
45.0	0.331
50.0	0.372
55.0	0.409
60.0	0.445
65.0	0.483
70.0	0.522
75.0	0.560
80.0	0.599
85.0	0.635
90.0	0.679
100.0	0.750

Measurement:	**M200504014**
Date:	2005–04–01
Applied voltage:	AC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#Not1
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.01	0.048
10.02	0.083
15.01	0.120
20.09	0.158
25.00	0.193
30.09	0.232
35.06	0.270
39.99	0.308
45.0	0.345
50.0	0.382
55.0	0.420
60.0	0.460
65.0	0.500
70.0	0.537
75.0	0.578
80.0	0.611
85.0	0.649
90.0	0.685
95.0	0.725
100.0	0.758

Measurement:	**M200504072**
Date:	2005–04–07
Applied voltage:	AC
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
The chimney tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#4
Frequency:	300 Hz
Wave form:	Sine

U (V)	I (V)
5.13	0.047
10.10	0.082
15.04	0.117
20.02	0.153
25.00	0.189
30.00	0.227
35.00	0.264
40.00	0.303
45.0	0.338
50.0	0.376
55.0	0.413
60.0	0.450
65.0	0.486
70.0	0.527
75.0	0.564
80.0	0.598
85.0	0.637
90.0	0.673
95.0	0.710
100.0	0.748

A.3 EMF

The electromotive force (EMF) caused by the flame was measured. The fields *measurement*, *date*, *vertical position of electrode*, *electrode above slit*, *distance to electrode top*, *chimney tube present*, *gas pressure*, *jet number* and *electrode* are the same as in the DC measurements. Those fields are explained on page 47.

Time is the measured time since ignition and U is the measured electromotive force caused by the flame.

Measurement:	**M200504144**
Date:	2005–04–14
Vertical position of electrode:	V5
Electrode top above slit:	S4
Distance to electrode top:	4.5 mm
Central tube present:	Yes
Gas pressure:	27.5 mbar
Jet number:	58
Electrode:	#2

time (minutes)	U (V)
0	-0.08
1	-0.22
2	-0.17
3	-0.16
4	-0.15
5	-0.16
6	-0.15
7	-0.13
8	-0.14
9	-0.16
10	-0.15
11	-0.16
12	-0.14
13	-0.17
14	-0.16
15	-0.16
16	-0.16
17	-0.19
18	-0.20
19	-0.19
20	-0.16
21	-0.19
22	-0.20
23	-0.19
24	-0.19
25	-0.19
26	-0.19
27	-0.19
28	-0.21
29	-0.20
30	-0.19
31	-0.19
32	-0.18
33	-0.20

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