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Laminar burning velocities of methanol mixed with formaldehyde and statistical examination of the heat flux burners

Bachelor thesis

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Abstract

Combustion of methanol is being used widely and the chemistry in the process is therefore important to know. When being mixed with formaldehyde and combusted previous measurements with the heat flux method have shown results not consistent with the theoretical models present today. These experiments are in this paper being repeated. A statistical examination of the burners used for the measurements is also conducted. The results are a calibration of the burners and values of the laminar burning velocity that are consistent with the previous values. This calibration is used on the methanol formaldehyde mixtures and gives a result that, as previous results also do, differs from the model. Large scatter is observed in the temperature distribution as measured by the thermocouples. The experimental values consist of some outliers and this can be the result by water contamination. This conclusion is verified by a density determination of the methanol formaldehyde mixtures.

Keywords

Methanol, formaldehyde, statistical analysis, burner, heat flux method, Matlab, biofuel, combustion, fuel, density, temperature, laminar burning velocity, acetone, thermocouple, equivalence ratio.

1. Introduction

1.1 Background

As the demand for energy increases every year the importance of finding alternatives to combustion of fossil fuels grows larger. Research is therefore widely being done in the area. However, since combustion is so dominating, it is also important to make it more efficient and less pollutant. One of the possibilities being explored is the combustion of bio fuels. Bio fuels are characterized by being renewable and reasonably carbon dioxide neutral since they are made from organic material, commonly corn and wood and recreated within a relatively short time. Since they absorb as much carbon dioxide during their growth as released at the combustion of them [1], the biological cycle can be considered carbon neutral. They have for these reasons become popular. A lot of research has been done on methanol and it is already an alternative to diesel and petrol. The wide use of methanol as a fuel motivates research concerning its combustion characteristics.

The burning velocity is defined as the velocity of the reaction zone front with respect to the unburnt gas. By examining the laminar burning velocity of a fuel, important characteristics about it can be provided. The adiabatic burning velocity for pure methanol has previously been investigated several times by amongst others Metghalchi and Keck (1982), Gulder et al (1982), Saeed and Stone (2004), Liao et al (2006 and 2007) and Veloo et al (2010) [4-9]. When methanol is combusted, before becoming carbon dioxide and water, it becomes formaldehyde. Many hydrocarbon fuels go through formaldehyde in becoming carbon dioxide [3]. A new approach to further increase the understanding is to mix the methanol with formaldehyde to see how it effects the combustion characteristics. The results from the methanol investigation can then be applied on many other substances also going through formaldehyde.

Up till now the laminar burning velocity of methanol-formaldehyde mixtures by the heat flux method has been investigated only once and it is therefore interesting to expand such experiments. The previous experiments were showing results differing from the models [10]. For the fuel lean condition the results were good at matching the model but at high temperatures, concentrations of formaldehyde and equivalence ratios the deviation was considerable. Some reasons for the deviation from the model are errors in the experiment such as contamination of the fuel or errors in the model.

1.2 Motivation

The first step of this experiment will be to try to recreate the previous results. To further test the reliability three different burner heads are going to be used and the measurements are going to be reproduced several times. The consistency of the results of the different burners is then going to be investigated. If the burners show different results a calibration model is to be made.

1.3 Structure

In chapter 2 basic physics and chemistry relevant for the paper is presented, such as the heat flux method, equivalence ratio and the basic combustion. In chapter 3 the experiment is presented as well as the results and a discussion about them. In chapter 3.1 this will be discussed for the statistical analysis of the burner heads and in chapter 3.2 for the formaldehyde methanol combustion. A brief density determination is also presented in chapter 3.2. Finally in chapter 4 some conclusions will be drawn and discussed. As an appendix the written Matlab code is attached.

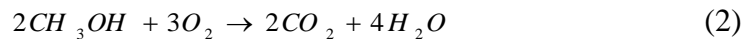
2. Theory

2.1 Basic chemistry

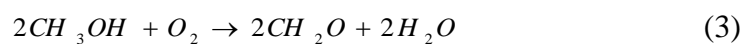
Methanol, CH_3OH , is the simplest alcohol and is in room temperature and pressure a colorless, clear liquid with distinctive odour. It is created either from natural gas or biomass. In the later case gasification of biomass leads to carbon monoxide and hydrogen monoxide which with a catalyst creates methanol [3].



When methanol then is combusted it oxidizes through amongst others formaldehyde to become carbon dioxide and water [11].



Formaldehyde, CH_2O , is the simplest of the aldehydes. It is stable at 80-100 °C but polymerizes into paraformaldehyde at room temperature. A lot of formaldehyde is used in synthesis but it is also used pure as a preservative and disinfectant. Formaldehyde is highly toxic to humans and animals and is presumably carcinogen [12]. Formaldehyde is mainly created by the oxidation of methanol with a catalyst present, usually silver or an iron and molybdenum/vanadium oxide mixture.



Another common way to produce formaldehyde is by dehydrogenation [13]



2.2 Equivalence ratio

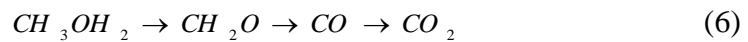
The ratio between the number of moles in the fuel relative to the number of moles of oxygen in a current mixture compared to the same relationship for the stoichiometric solution is called the equivalence ratio Φ . Measurements are usually being done at different equivalence ratios to conclude how the combustion behaves at a shortage or surplus of air.

$$\Phi = \frac{\frac{n_{fuel}}{n_{O_2}}}{\left(\frac{n_{fuel}}{n_{O_2}} \right)_{stochiometric}} \quad (5)$$

For $\Phi > 1.0$ the mixture has a surplus of fuel and is called fuel-rich, for $\Phi < 1.0$ it has a surplus of oxygen and is called fuel-lean [14].

2.3 Combustion model

Combustion is the interplay between a large number of different chemical reactions occurring simultaneously and the transfer of heat and mass. How many and what reactions that are occurring depend on the reactants involved. Combustion is an exothermic chemical reaction, meaning that it releases energy in the form of heat. Whenever there is a difference in temperature in a medium a transfer of heat occurs. This transfer can occur by diffusion, conduction or radiation. In the same way mass must be transferred, either by convective motion or diffusion. This can for example be the transfer of the burnt products from a candle, such as soot, by convection clearing the flame and allowing unburned gas to access and participate in further combustion. In this case the fuel is not premixed [15]. The combustion of methanol can be described by a model involving 84 reversible elementary reactions among 18 species as described by a model by Li et al [15]. The basic combustion chain is



Mainly the methanol reacts with an H , O , OH , O_2 , HCO , HO_2 or CH_3 creating hydroxymethyl radical, CH_2OH , or methoxy radical, CH_3O . These two then decompose or react with an H , O , OH , O_2 , HCO , HO_2 , CH_3O or CH_2OH to become formaldehyde, the second step in the basic chain. The formaldehyde then reacts with H , OH , O or CH_3 becoming formyl radicals, CHO , which then further reacts with H or OH or decomposing to carbon monoxide then becoming carbon dioxide [16].

2.4 Method

There are several methods to measure the adiabatic burning velocity. In some of them a stretched flame is used, for example the counter flow method and the closed vessel method which both are commonly used. These methods need to correct for stretch effect in the flame by using an extrapolation and this leads to uncertainties. Another method is to use a non stretched flame. In this way the flame speed can be determined without any extrapolation for

the stretch. A method to perform this is the heat flux method [17]. In these experiments the heat flux method has been used, as proposed by de Goey and further developed by van Maaren et al [19-20]. To be able to determine the adiabatic burning velocity the flame is supposed to be flat and in the ideal case one dimensional, which can be achieved on a perforated plate burner [19]. In this case there is heat loss to the burner and extrapolation is still needed. However, this problem was solved by K. J. Bosschaart by heating the burner plate and thereby heating the unburned gas [10]. In this way the heat loss can be compensated by the heat gain from the heated burner plate. To achieve a flat flame the velocity of the gas is varied until eight thermocouples, placed in the burner plate at radius 0, 2.1, 4.2, 6.3, 8.4, 10.5, 12.6 and 14.7 mm, show the same temperature and the flame is flat. At higher concentrations a flat flame is harder to achieve.

The relationship between the radius of the burner plate and the temperature is called the parabolic coefficient, and it determines how the temperature depends on the radius of the burner plate and when there are adiabatic burning the temperature should be independent from the radius, meaning the temperature is the same all over the burner plate:

$$T_p(r) = T_{center} - \alpha r^2 \quad (7)$$

where $\alpha = -\frac{q}{4\lambda h}$ is the parabolic coefficient, q is the heat flux and λ and h are the thermal conductivity and the thickness of the burner plate, respectively [14].

The experimental setup is the same as used in the previous experiment [10], see fig 2.1, but in the present work several burners are tested. The three burners are supposed to be identical and thus yield the same result.

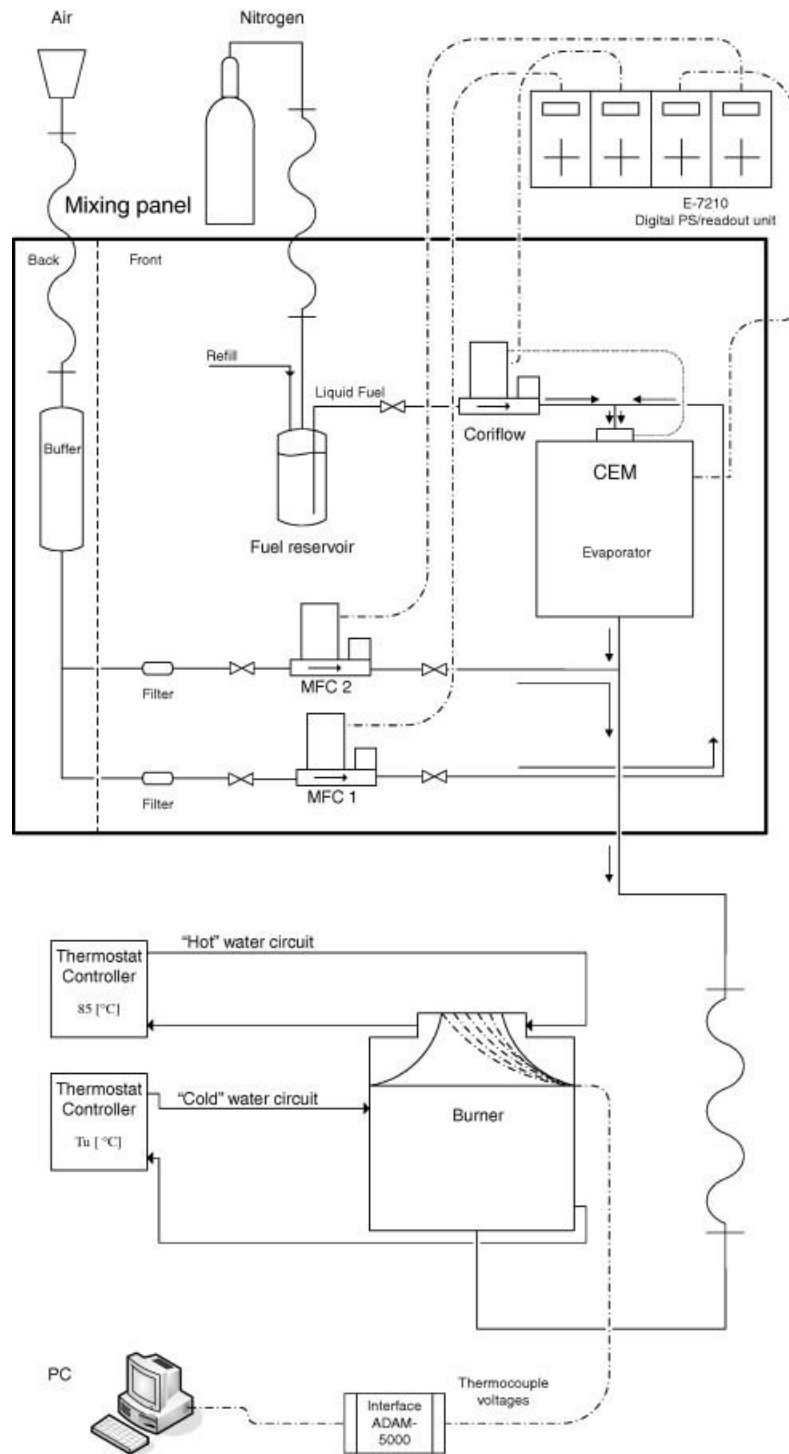


Fig 2.1. The experimental setup [21].

The burner consists of a burner plate with a perforated hexagonal pattern, see fig 2.2. The diameter and distance of the holes are special for which flow velocity that is going to be used and several calculations of the best fit have been performed by de Goey (1995) [19]. Furthermore, the burner is equipped with thermocouples, previously mentioned, a heating jacket and a cooling jacket, the cooling jacket keeping the same temperature as the unburned gas and the heating jacket above this temperature to minimize the heat loss. The part on the

burner that produces a uniform flow to the burner outlet is the plenum chamber, which is achieved by a grid in the lower part of the chamber, fig 2.2.

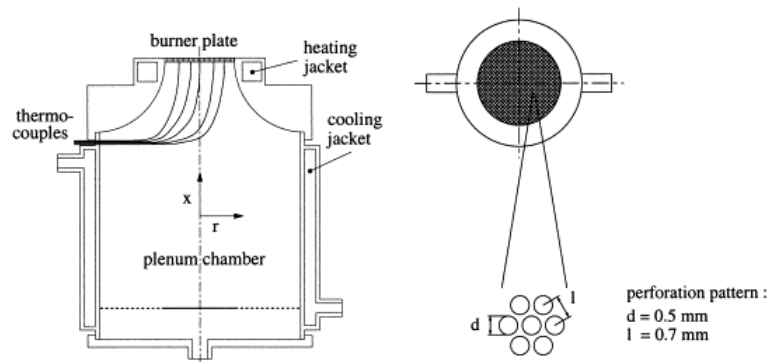


Fig 2.2. To the left the burner chamber and to the right the burner plate and its hexagonal pattern [17].

To control the air to fuel ratio, Φ , two mass flow controllers, MFC, are used. The MFC:s deliver a mass flow rate by determining the temperature decrease of the gas between two points. In this way it is independent of small temperature and pressure variations. Air is mixed into the gas at two different places to get the desired ratio. The uncertainty for MFC:s is one of the largest in the heat flux method. The MFC:s is connected to the Controlled evaporator mixer, CEM, where the gas fuel is vaporized [17].

3. Determination of the laminar burning velocity

3.1 Experimental procedure

The following experimental procedure is applied

- i. A Matlab program is used, taking the air pressure, gas temperature, flame speed, equivalent ratio and the fuel combination and giving the settings for the controller.
- ii. The burning velocity is varied until a stable flame is obtained and the parabolic coefficient is close to zero.
- iii. The achieved value is documented together with about three more surrounding burning velocities.
- iv. The whole procedure is repeated for more equivalence ratios between 0.6 and 1.4.
- v. The burning velocities and parabolic coefficient are abstracted from the documented files by another Matlab program and plotted to obtain the correct burning velocity where alpha equals exactly zero, see fig 3.1.

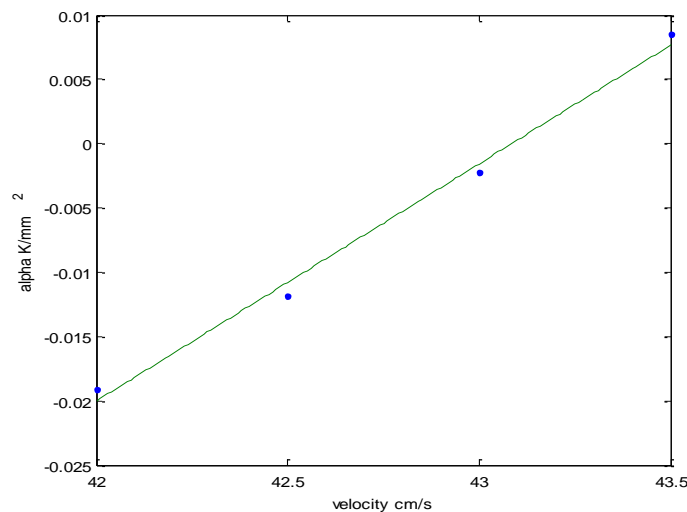


Fig 3.1. A linear regression of the velocity as a function of the alpha value with measurements on 9.7% formaldehyde concentration in methanol and at an initial gas mixture temperature 298 K.

3.2 Statistical analysis of the burners

3.2.1 Background

To test the reliability of previous experiment three different burner heads were used. When the results were analyzed it turned out that the results in fact differed significantly from each other, both in the laminar burning velocity, see fig 3.2 and the sensitivity, see fig 3.3. This led to a side track where an investigation of the results was performed. The three burner heads were tested one by one with methanol and acetone, which both have known laminar burning velocities from previous measurements, and these results analyzed to suggest a calibration for the burners to make them give the same results. A Matlab program was written to perform a statistical analysis of the data.

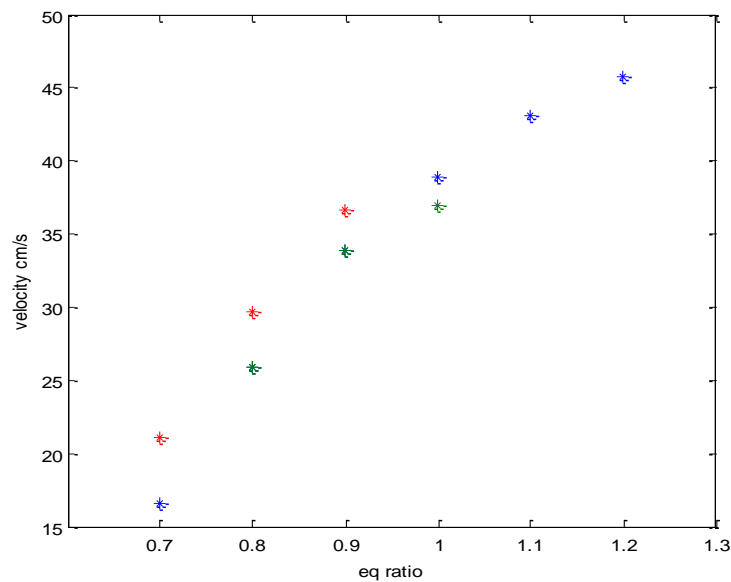


Fig 3.2. The velocity as a function of the equivalence ratio for the three different burners, red=burner 1, blue=burner 2 and green=burner 3 for acetone.

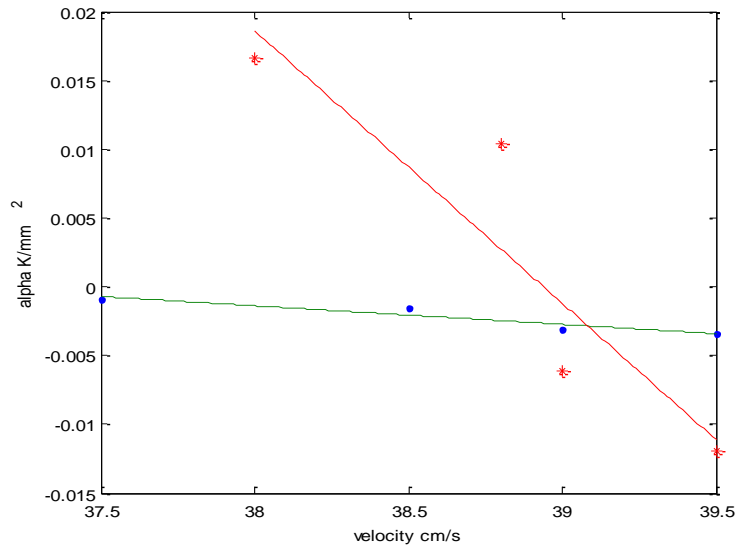


Fig 3.3. The sensitivity of the alpha value as a function of velocity in burner 1, red, versus burner 3, green for 9.7% concentration of formaldehyde in methanol at an initial gas mixture temperature 298 K and $\phi = 0.9$.

By studying the temperature profile without flow of fuel or air, it was seen that in contradiction to what was expected the thermocouples did not show the same temperature. An example can be seen in fig 3.4, when the temperature of the burner plate is suppose to be uniform, but a large scatter in the temperature can be seen. Further investigation of the effect from the different thermocouples turned out to be necessary.

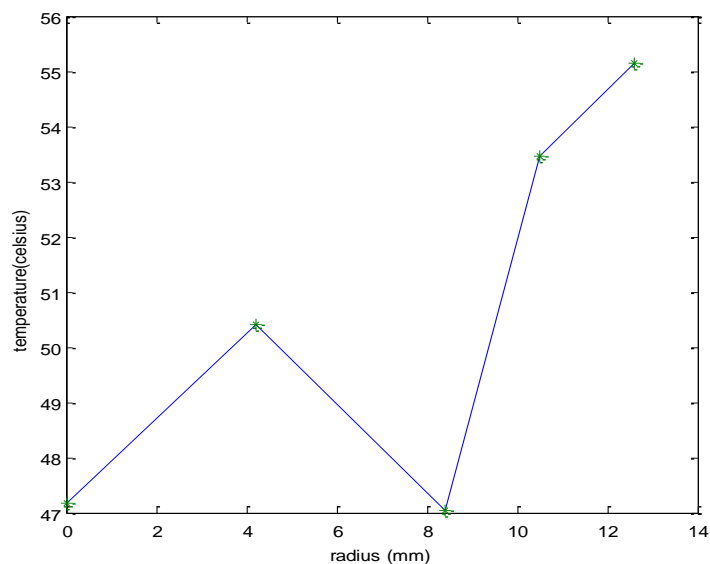


Fig 3.4. No flow on burner 2, temperature is suppose to be uniform but a large scatter can be seen, thermocouple 2,4 and 8 are excluded due to no contact.

3.2.2 Matlab

The new results from the methanol and acetone combustion were analyzed in a Matlab program written for this purpose. The program uses temperature data from the previous measurements and one by one excludes one thermocouple to determine the parabolic coefficient without this particular one. The measurement from the thermocouples that was obviously wrong was also excluded. The program then plotted the different values for the coefficient together and determined how much they differed from each other. In this plot the original coefficient obtained during the experiment was also added. As a second step the correlating velocities at an alpha equal to zero was calculated and plotted together with the equivalence ratios. In this way an error got estimated from the adiabatic burning velocities.

3.2.3 Results and discussion

The temperature distribution for the three burners is illustrated in fig 3.5, 3.6 and 3.7. The same trends for the different burners have been seen in previous measurements. By looking at this some obvious outliers can be found. To have an adiabatic flame the temperature should be the same independent of the radius but from the trends of the plots it can be seen that the thermocouples measure different temperatures. Burner 1 has consistent pattern but still a temperature difference of about 10 degrees. Instead burner 2 has one outlier, thermocouple number six, that, as it looks right now, should be excluded. This will be further discussed later. Burner number 3 already has two thermocouples without connection; that is why only six points can be seen in the plot, and by looking at the temperature distribution at the plot at least two more are extreme outliers. Since so few thermocouples are operational, burner 3 is not investigated further.

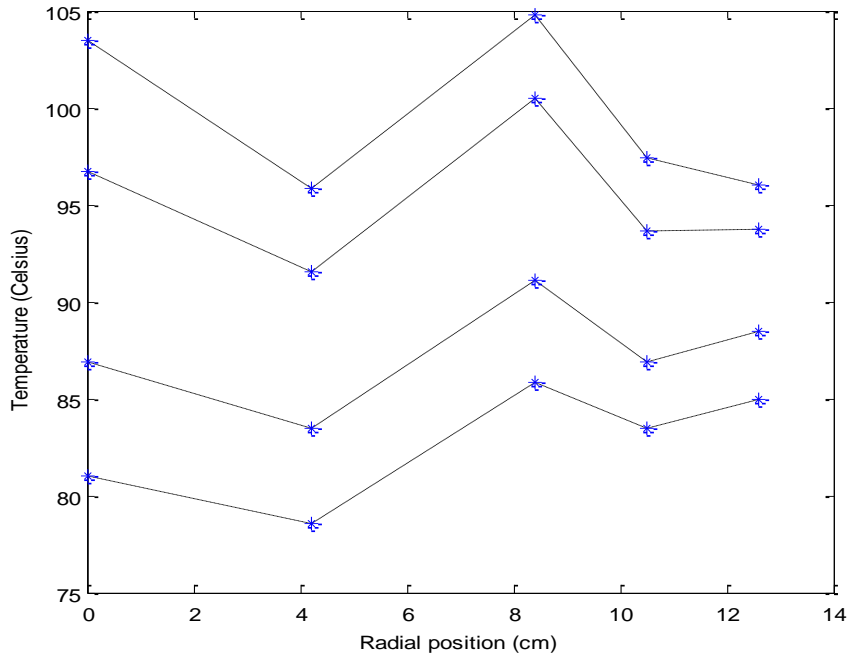


Fig 3.5. The temperature distribution for burner 1 when combustion of methanol at an initial gas mixture temperature 298 K and $\phi = 0.9$, thermocouple 2,4 and 8 being excluded due to no contact.

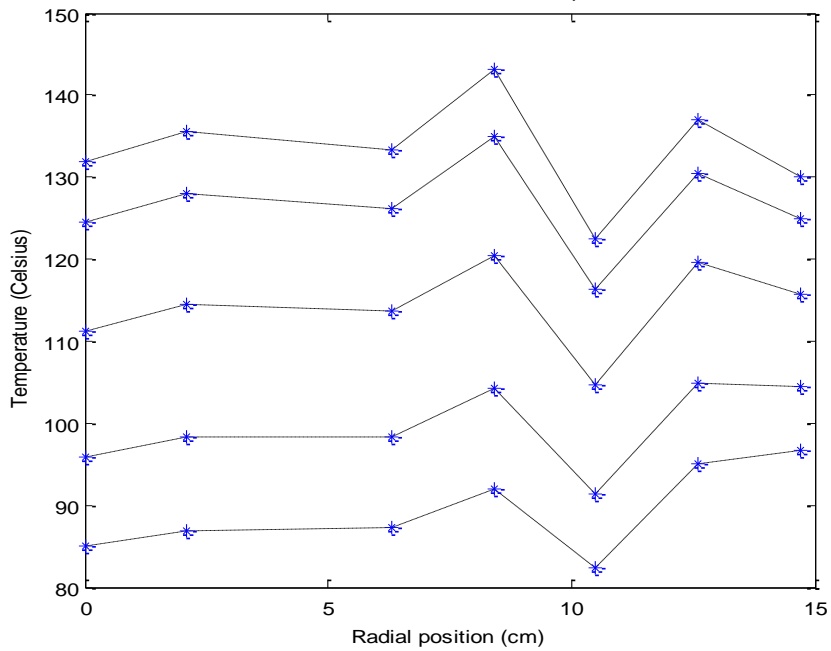


Fig 3.6. The temperature distribution for burner 2 when combustion of methanol at an initial gas mixture temperature 298 K and $\phi = 0.9$, thermocouple 3 being excluded due to no contact.

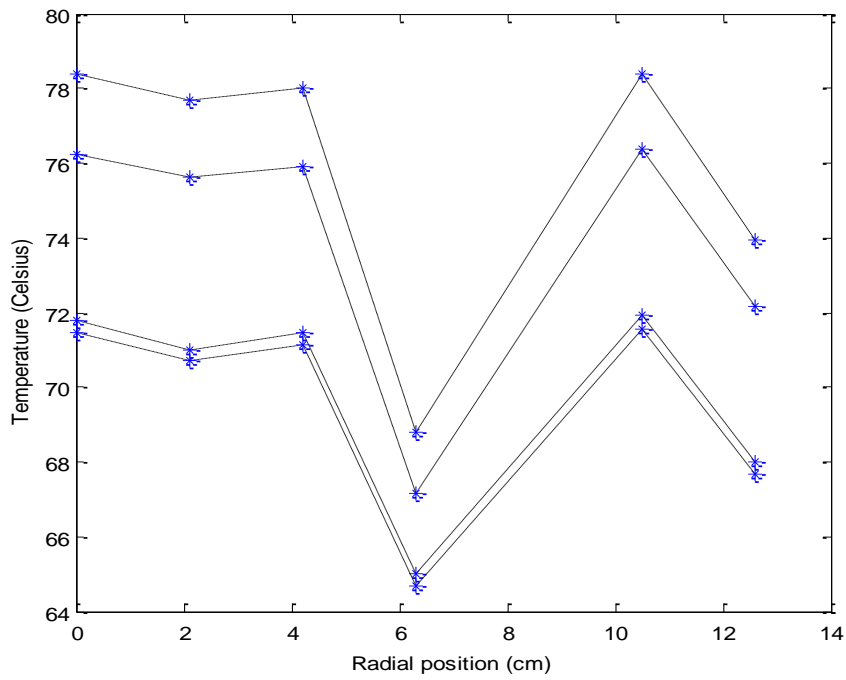


Fig 3.7. The temperature distribution for burner 3 when combustion of methanol at an initial gas mixture temperature 298 K and $\phi=0.9$, thermocouple 5 and 8 being excluded due to no contact.

As discussed earlier, when finding the adiabatic burning velocity, the different alpha values for the different velocities are plotted and the roots are found. Where alpha equals zero the flame is adiabatic and this is where the adiabatic burning velocity can be found. The same is done with the extended plots where each alpha that has been calculated after excluding one after one thermocouple. The results are for burner two. As in the temperature distribution plot number eight can be seen as an outlier, see fig 3.8.

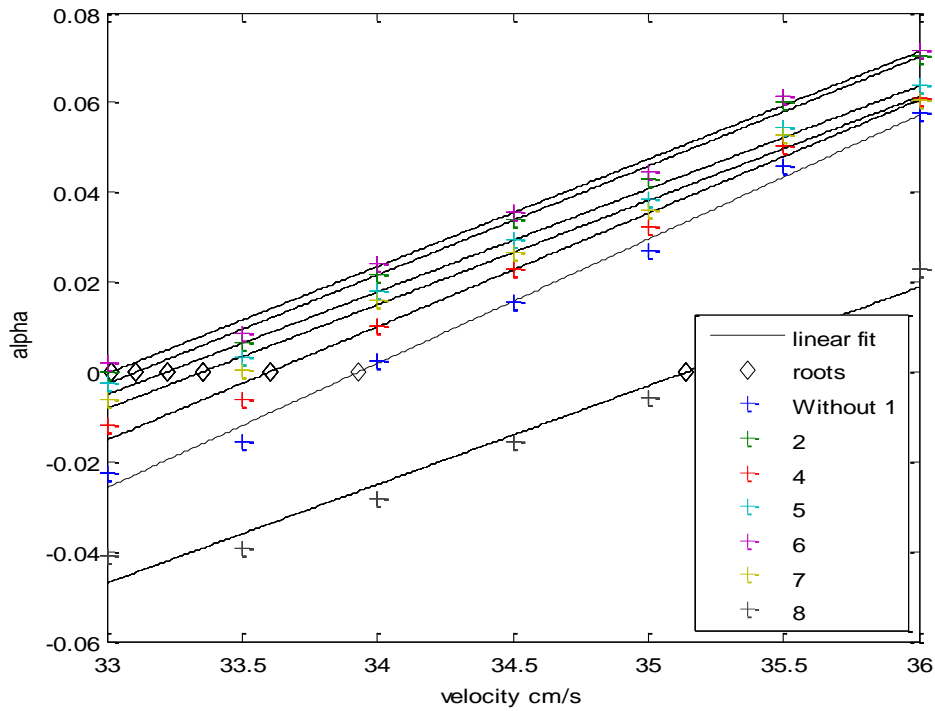


Fig 3.8. The alpha value dependent on the velocity for the thermocouples excluded one by one and the corresponding adiabatic burning velocity for methanol at an initial gas mixture temperature 298 K and $\phi = 0.9$ for burner number 2, thermocouple 3 excluded due to no contact.

The adiabatic burning velocities for the different excluded thermocouples in relationship to the different equivalence ratio show the same results, see fig 3.9. From fig 3.9 it can be seen that when thermocouple 8 is excluded the results are significantly higher than for all other cases. Thermocouple eight is an outlier and it is the thermocouple closest to the edge. It is therefore considered to be wrong and is excluded, same conclusions has been reached by J.P.J van Liepzig [13].

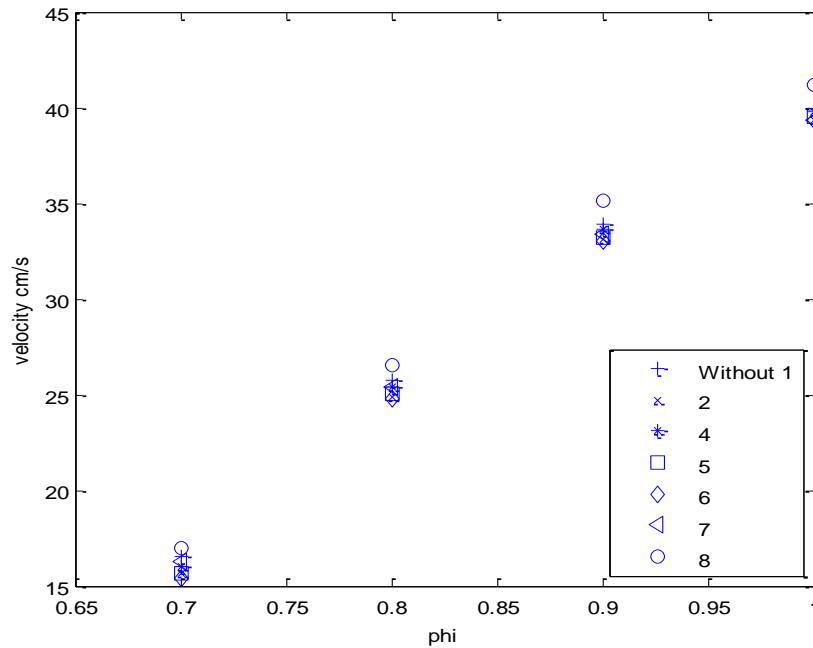


Fig 3.9. The velocity distribution when one after one thermocouple is being excluded as a relationship to phi for methanol at an initial gas mixture temperature 298 K for burner number 2, thermocouple 3 excluded due to no contact.

When from the beginning excluding thermocouple eight and then one after one excluding the others the outliers becomes thermocouple six and seven, see fig 3.10. Excluding thermocouple 1, 2, 4 and 5 does not significantly alter the results. When compared to previously measured values from burner 1 the experimental data is most accurate to the velocities found when both thermocouple seven and eight are excluded. When the same exclusion is done on acetone and compared to previously measured values the same conclusion is found, see fig 3.11.

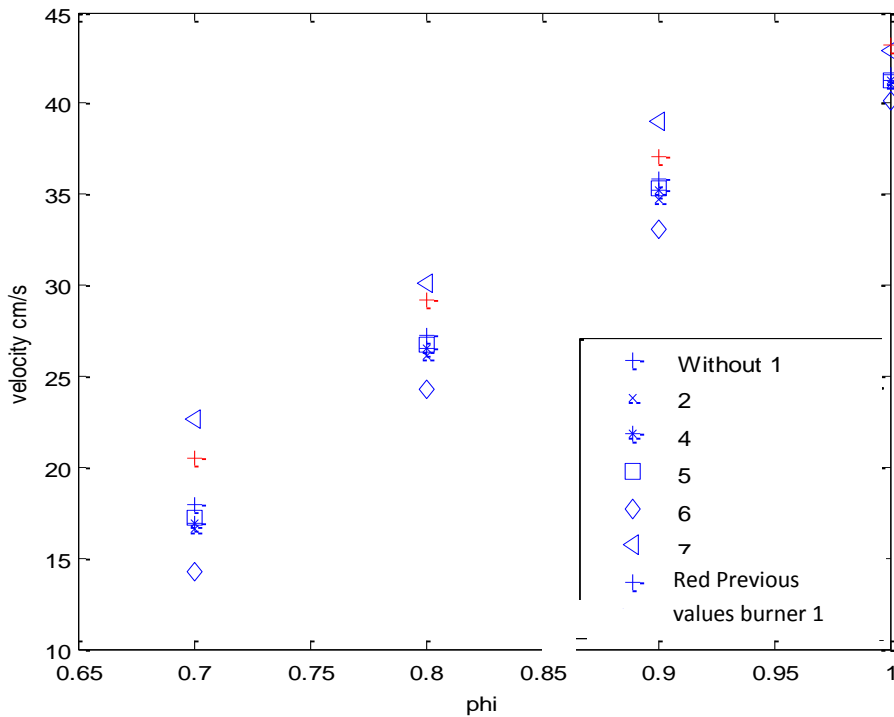


Fig 3.10. The velocity distribution without thermocouple eight when one after one thermocouple is being excluded as a relationship to phi and previous results as a comparison for methanol at an initial gas mixture temperature 298 K for burner number 2; thermocouple 3 is excluded due to no contact.

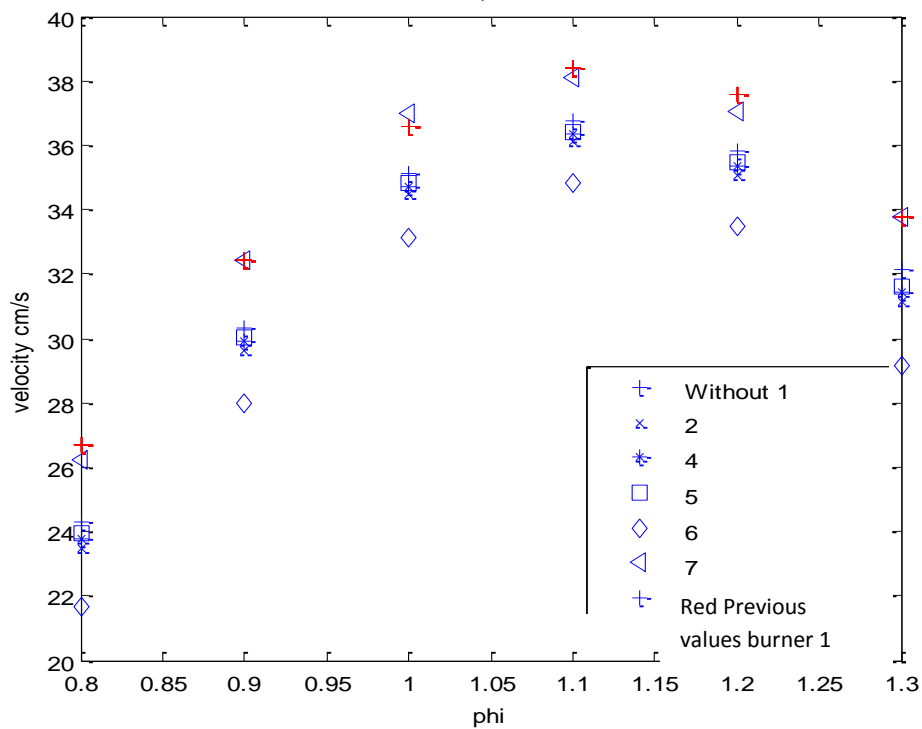


Fig 3.11. The velocity distribution without thermocouple eight when one after one thermocouple is being excluded as a relationship to phi and previous results as a comparison for acetone at an initial gas mixture temperature 298 K for burner number 2; thermocouple 3 is excluded due to no contact.

By reaching the conclusion that the results most consistent with previous results when thermocouple seven and eight are excluded the results from other measurements can be calibrated after this and results in agreement with results from burner 1 can be found. When excluding thermocouples a wider spread of velocities can be found, see fig 3.10 and 3.11, this increases the margins of errors so ideally all thermocouples wants to be used therefore as few thermocouples as possible should be excluded.

The resulting values from the exclusion of thermocouple seven and eight are shown in table 1 and 2.

Table 1. The adiabatic burning velocities for acetone

Experiment	0.7	0.8	0.9	1	1.1	1.2	1.3
Acetone 298K	-	26.23	32.46	36.99	38.12	37.02	33.77
Acetone 318K	-	-	-	40.04	41.46	-	-
Acetone 338K	24.73	32.15	39.70	44.56	45.26	44.63	
Acetone 358K	34.79	42.63	47.57	-	47.70	-	-

Table 2. The adiabatic burning velocities for methanol

	0.7	0.8	0.9	1.0
Methanol 298K	22.63	30.13	39.05	42.87
Methanol 318K	-	31.75	43.23	47.02

The acetone values fit well with previous results and the trend is consistent with the theory, see fig 3.12.

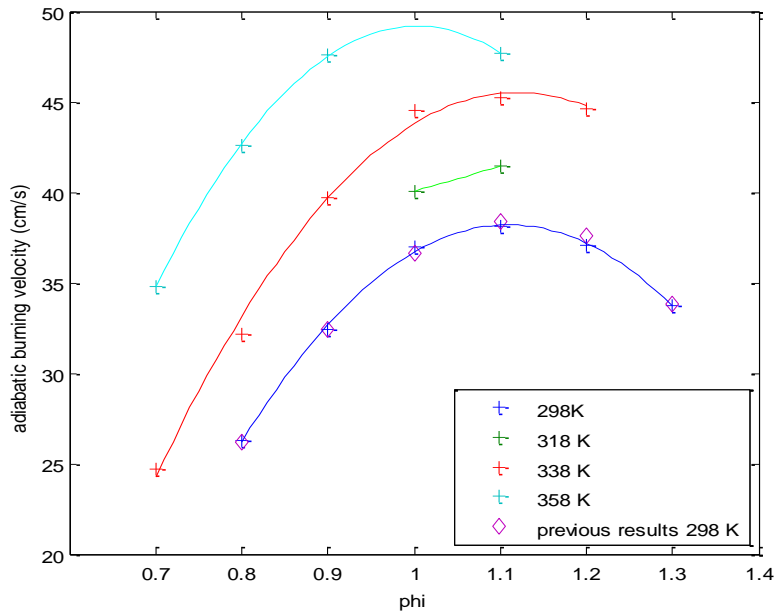


Fig 3.12. The adiabatic burning velocity when thermocouple 7 and 8 are being excluded as a function of phi for different temperatures on acetone, thermocouple 3 being excluded due to no contact.

3.3 Methanol formaldehyde

3.3.1 Preparation of solution

To dissolve the formaldehyde in the methanol they were mixed and then stirred and heated for several hours. The solution was then filtered to give a completely homogeneous fuel. Weight measurements were done between every step to insure the concentration of formaldehyde was correct. The density was then calculated by weighting three (10 ± 0.025) ml measuring flasks with the fuel. A simple Matlab program was written to make the calculations more efficient.

3.3.2 Density determination

When adding water to a solution the chemical properties change. If the experimental result for burning velocities differ from the model one of the reasons can be that the solution has some content of water. Methanol is a polar molecule and when exposed to air it attracts the water molecule, which also is polar. To investigate this the density was measured and calculated on some samples of methanol that had been exposed to air for different time periods and some samples that had been mixed with water directly. The purpose was to see if small differences in density could be seen in the solutions we used for fuel and it could be concluded that they actually contained some water and a different model should be applied to the results.

The density is the mass divided by volume

$$\rho = \frac{m}{V} \quad (8)$$

Since volume is a property that in general is not additive between different substances in a solution, neither is the density. The relationship was therefore investigated

3.3.3 Results and discussions

From the burner investigation the different adiabatic burning velocities could be determined, see table 3.

Table 3. The adiabatic burning velocities for formaldehyde methanol mixtures for burner 2.

	0.6	0.7	0.8	0.9	1.0	1.1
9.15% 298K	-	24.46	31.24	36.64	42.59	47.39
9.15% 298 K (OBS br 1)	-	21.06	29.57	36.58	-	-
10.75% 298K	18.23	26.06	30.62	36.11	-	-
10.75% 318K	-	24.19	32.96	45.36	-	-
23.75% 298K	-	-	-	20.53	-	-
23.75% 318K	-	17.83	25.76	-	-	-

Table 4. Previous results for the adiabatic burning velocities for formaldehyde methanol mixtures for burner 1.

	0.7	0.8	0.9	1.0
4.9% 298K	21.44	30.28	38.28	44.30
4.9% 318K	23.74	33.56	42.11	48.33
7.7% 298K	21.54	30.06	38.54	44.62
7.7% 318K	-	-	42.08	49.14

Some results from the previous experiment are also added to give a clearer relationship, see table 4. These results are consistent with the previous experiments but not with the theoretical predictions, see fig 3.13 and 3.14. The outcome of this reproduced experiment could have been either disproving the previous result but consistent with the model or results that still differed from the model. The results related in table 3 are still not in accordance with the model. However, this can still be the outcome of experimental errors and contaminated fuels

or the model has to be investigated and maybe modified. Since this is the second experiment disproving the model, further investigations have to be done.

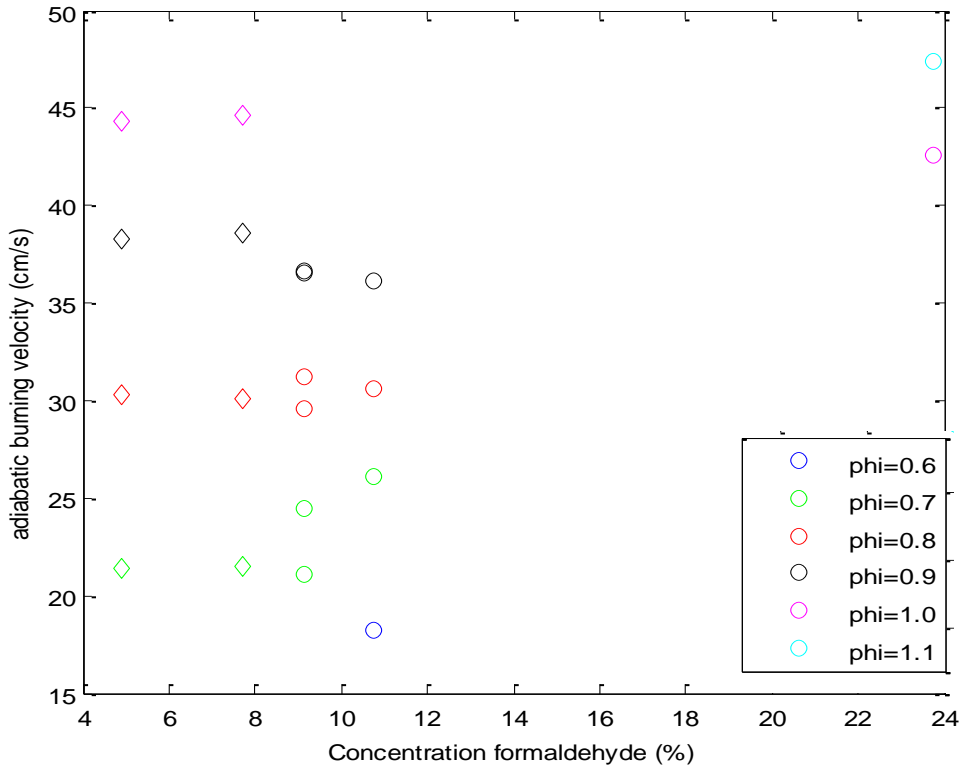


Fig 3.13. The relationship between the adiabatic burning velocity and the concentration of formaldehyde at different ϕ values and 298K; diamonds for previous results and circles for new.

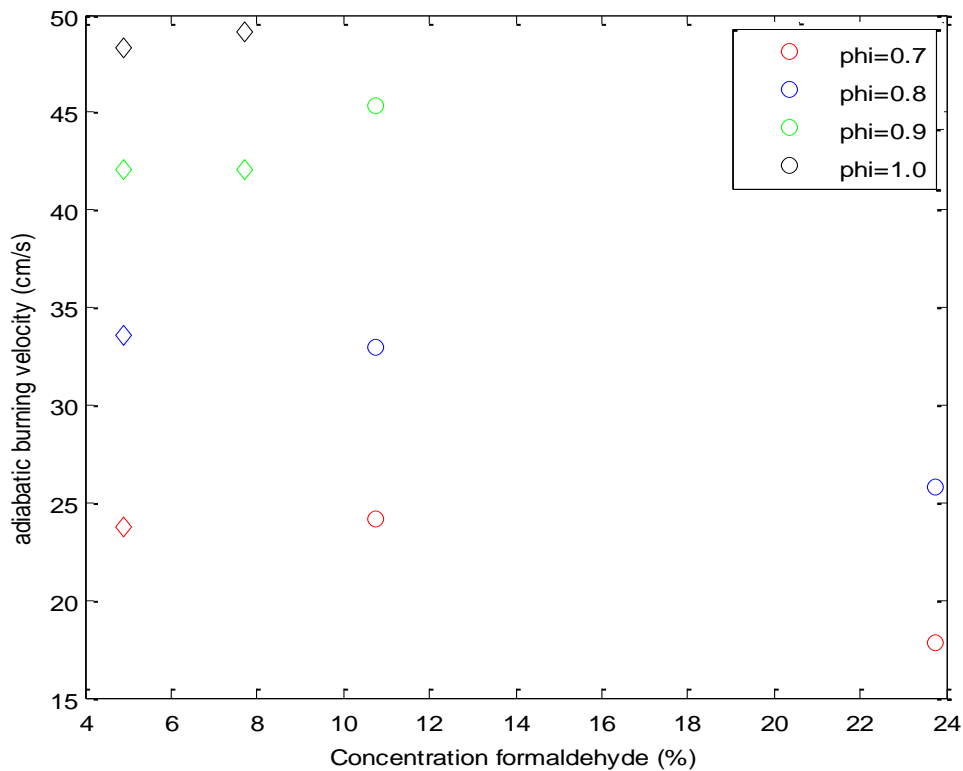


Fig 3.14. The relationship between the adiabatic burning velocity and the concentration of formaldehyde at different phi values and at the initial gas mixture temperature 318K; diamonds for previous results and circles for new.

Experiments where formaldehyde methanol mixtures are being burned this way are difficult to perform. In many cases it is hard to keep the flame stable, especially for high equivalence ratios and high formaldehyde concentrations. For this reason there are several values missing for a continuous graph. There have also been problems with condensation at low temperature and high equivalence ratios. There are some outliers, see table 3 and 4. If following previous trends, the results from this experiment has been lower than previous results, the outliers in fig 3.13 show no consistency to this.

The results of the water and methanol density relationship turn out to be linear between the different concentrations of water in methanol, see fig 3.15. As expected the relationship is not the same as if the both densities are added. The new density can be calculated with $\rho = 0.2816 \cdot x + 0.7912$ where x is the amount of water in the methanol in the $0 < x < 0.2$ interval.

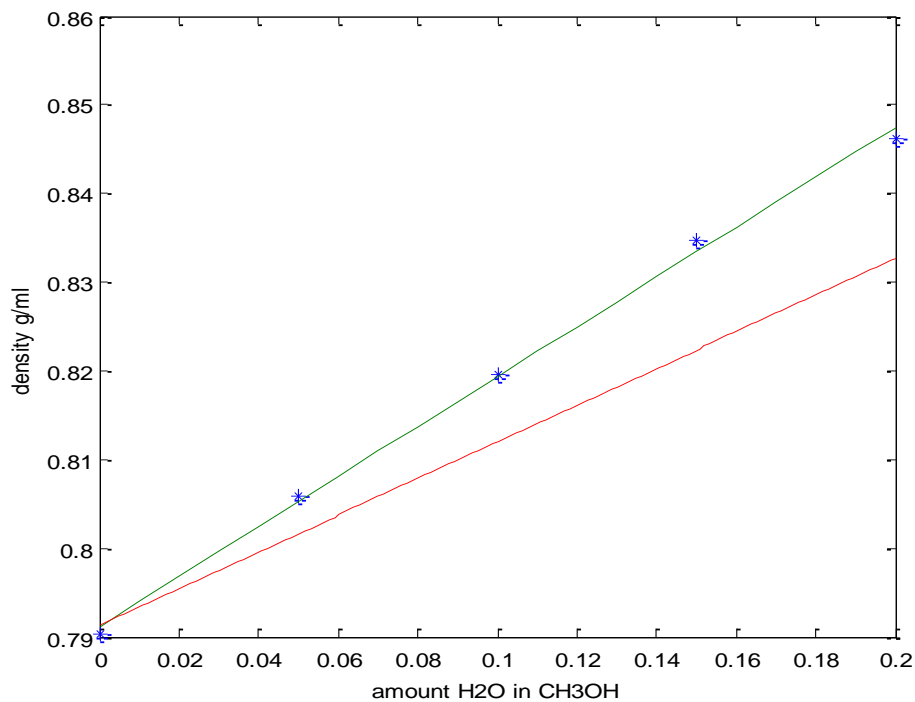


Fig 3.15. The density as a function of the amount of water from experiment, green, as a comparison to additive results, red.

When the density is measured on the methanol sample being exposed to air no relationship is seen and the differences in density between the samples lies within the error margin, see fig 3.16. It has to be noted, that in these tests methanol was exposed to air, without other influence. When preparing methanol + formaldehyde solutions, the mixture is exposed to both heating and stirring, and this might result in water uptake. The possibility that water has entered the fuel from the formaldehyde being contaminated is still a possibility.

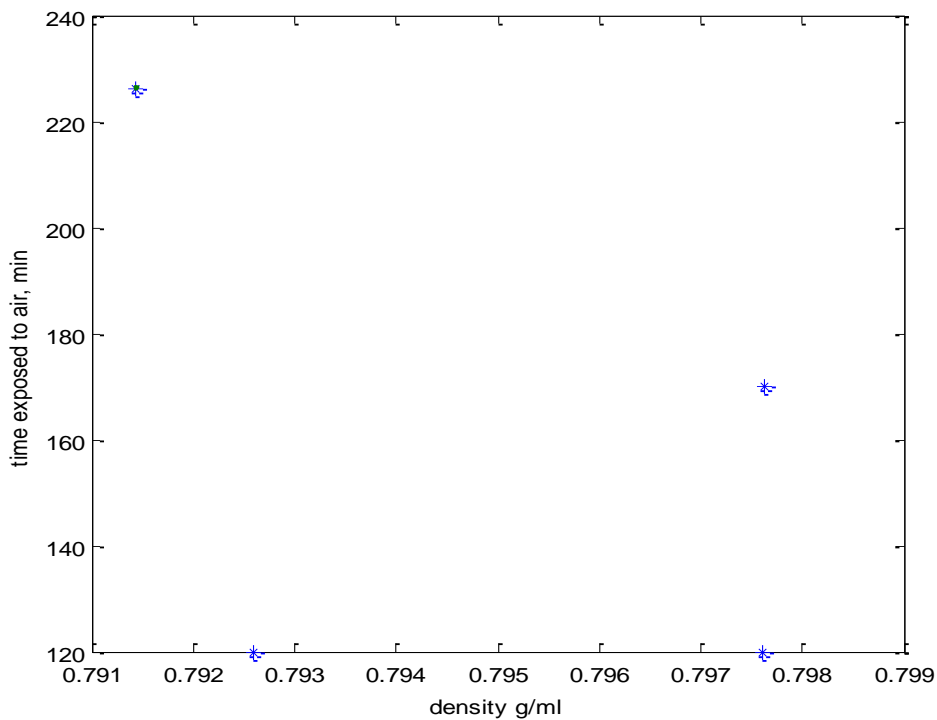


Fig 3.16. The density as a relationship to time methanol has been exposed to air

The density determination for the methanol formaldehyde mixtures turned out, as expected, to give a linear relation between concentration formaldehyde and density, see fig 3.17. In the figure an outlier can be seen at the concentration 11 %; the density determination was repeated three times for this fuel mixture and the outlier is the first measurement. The increasing density with time can be evidence of the fuel mixture getting contaminated by water when it is left for a time period. It should be noted that even though the fuel mixture was left for a time it was wrapped in air tight plastic.

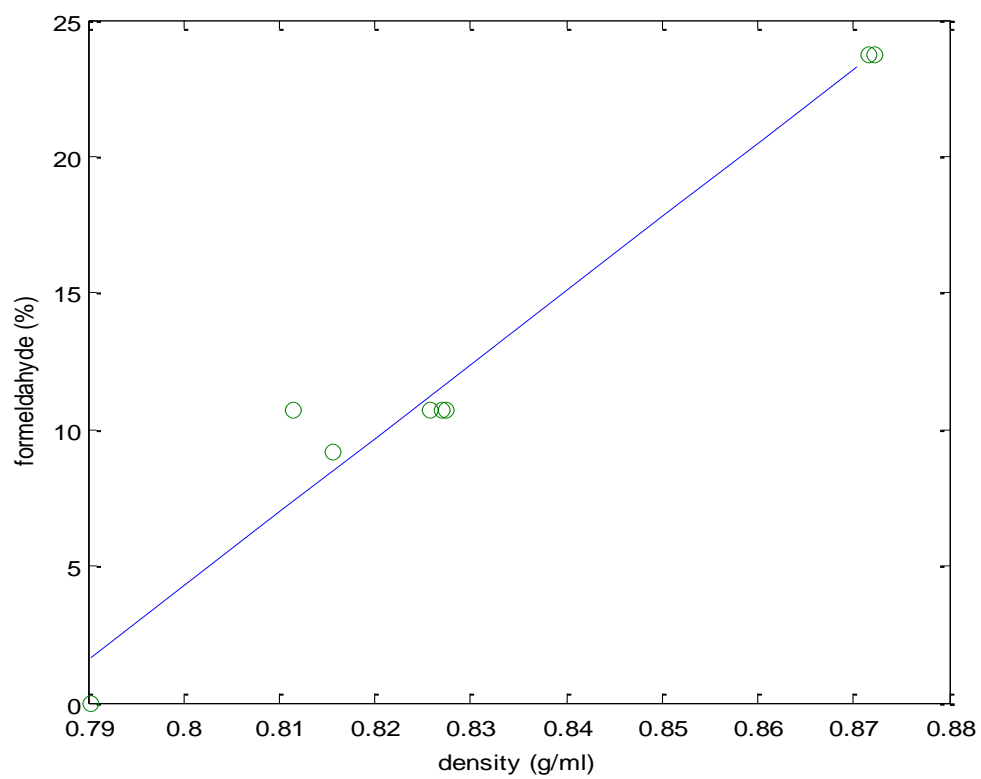


Fig 3.17. The density density as a function of concentration formaldehyde for formaldehyde methanol mixtures.

4 Summary and conclusions

A recreation of previous measurements was conducted either to support the theoretical model or the previous data which differed from the model. To investigate the results a statistical analysis was conducted concerning the results from different burner heads.

The thermocouples in the burners showed inconsistent temperature distribution; this is likely due to problems in the thermocouples. The temperature distribution can be observed in fig 3.4 – 3.11, when studying burner number 2 the conclusion that if thermocouple number 7 and 8, the two most outer ones, are being excluded, the results get consistent with previous results from burner 1. Burner 1 has given same results as other burners at other universities and is therefore considered to be trust worthy. The conclusion to exclude thermocouple number 8 is also reached by J.P.J van Liepzig [13], which is the outermost one; the effect is that thermocouple number 7 and 8 for burner 2 are considered to be incorrect and better to be left out. These conclusions were applied to the new data on formaldehyde methanol mixtures.

The formaldehyde methanol results showed similar trends to data from previous measurements. This can be observed in table 3 and 4 and fig 3.13 and 3.14. The results are still not consistent with the model which says that when the concentration formaldehyde is increased the adiabatic burning velocity should increase slightly. Instead the results show a decrease in adiabatic burning velocity when the concentration formaldehyde is increased. The effects are distinct at higher concentrations. Further experiments are necessary to understand the combustion characteristics of methanol.

The density determination showed indications of contamination of water on the methanol formaldehyde mixture of concentration 10.75%. It was also concluded that this contamination did not come from the methanol but likely from the formaldehyde. To try this theory further a small amount of water could be added in the model.

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Appendix

Program code

```
clear all
a=0.7;% lowest equivalence ratio
b=0.7;% highest equivalence ratio
K=[a:0.1:b]; %the equivalence ratios
f=1; %total number of files in each set
BB='Pure methanol 298 K, without 3';%titel plot
Markmap = ['+' 'x' '*' 's' 'd' '<' 'o'];%markmap plot
for i=1:f;
    Aarray=[];%creating a vector for the alphas
    L = ['eq' num2str(K(i)) '.txt'];%read in and store the various files
without the text in the beginning
    A=importdata( L, '\t', 21+1); %import the data without text
    s=size(A.data(:,1)); %retrive the number of rows and cols in the data
file
    v_index=0;%creating a start value at zero for v_index
    for N=1:8:s%Picking out 8 rows with temperatures at a time
        v_index = v_index+1;% adding one to v_index in each loop
        n =N:(N+7);%colects the data from the first 8 rows
        t=A.data((n),3); %Collets the temp numbers in column 3 for n
        v=A.data((1:8:s(1)),5); %Collects the vel numbers in column 5

        r=[ 0
            2.1
            4.2
            6.3
            8.4
            10.5
            12.6
            14.7];

        for j=1: numel(t) %sets all temperatures ower or under 200 C to
be 0 and radious to be 1
            if abs(t(j))>200
                t(j)=0;
                r(j)=1;
            end
        end
        t(8) = 1;%takes away thermocouple 8
        t(8) = 0;%takes away thermocouple 8
        t = t(t~=0); %discard t=0
        r = r(r~=1); %discard r where r=1

        for d=1:length(t) % takes away one measuring point at a time
            rloop=r;
            tloop=t;
            rloop(d)=1; %defines the one we want to take away as 1
            tloop(d)=1; %defines the one we want to take away as 1
            rloop = rloop(rloop~=1); %discard r where r(m) = 1
            tloop = tloop(tloop~=1); %discard n where r(m) = 1
        end
    end
end
```



```

D1(1) = 0;%sets start values
D2(1) = 0;
A1(1) = 0;
T1(1) = 0;
b=length(tloop);

    for c = 2:b+1%statistical calculation of parameters in
alpha
        D1(c) = rloop(c-1)^4 + D1(c-1);
        D2(c) = rloop(c-1)^2 + D2(c-1);
        A1(c) = rloop(c-1)^2*tloop(c-1)+A1(c-1);
        T1(c) = tloop(c-1) + T1(c-1);
    end

        D(d)=D1(b+1)*b - D2(b+1)^2;
        Aa(d) = A1(b+1)*b/D(d) - T1(b+1)*D2(b+1)/D(d); % calculates
the alpha values by using a statistical method

    end

        Aaarray=[Aaarray;Aa]; %creates a matrix consisting of the
different alphas

    end
        AA=[]; %creates a vector consisting of the adiabatic burning velocity
(velocities where alpha=0)
        for M=1:length(rloop)%creates a lin reg calculating the adiabatic
burning velocity (velocities where alpha=0)
            P=polyfit(v,Aaarray(:,M),1);
            A=roots(P);
            C=min(v):0.01:max(v);
            a1=P(1)*C+P(2);
        hold on
        AA=[AA A];% adds the different adiabatic burning velocities to AA

    end
end

```