HIGHER MARITIME SCHOOL ANTWERP

FACULTY OF MARINE ENGINEERING

Influence of hydrogen on the composition of exhaust gases

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of the degree of
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Foreword

After four years of studying at the Hogere Zeevaartschool, a thesis is the excellence way to close it. I can use the knowledge I have built up over the years turn it into research. Of course, this did not always run smoothly and have you need the support and experience of others to make this a success, for which I thank you.

This thesis will be an investigation of the effects on emissions when will add hydrogen in a combustion chamber. The main components in the test setup included a Javac diesel generator and an OH generator, from this configuration, our measurements are the result.

First of all I would like to thank my promoter, Raf Maes, who guided me from the beginning to the ending has supported and helped when I needed it. My parents who support and motivate me every day, and all the other people who love me helped nearby.

Resume

The thesis includes the effects of emissions when adding hydrogen in a diesel generator with RME. Expectations were very positive, hydrogen would be the emissions should be reduced significantly. During the measurements, the focus was on NO (nitrogen monoxide), NO2 (nitrogen dioxide) and PM (particulate matter). Sadly found after a t-test, a reliability test, we found no significant difference. At the conducting other similar studies, came out quite remarkable results above, this is how the rise in NO, the main cause of the NO increase is the increase in combustion temperature as a result of the flame speed of hydrogen. Because by adding hydrogen we increase the amount of HO2 in the cylinder, H2 will influence the conversion of NO to NO2 , resulting in a higher value of NO2 . Provided optimizations can these NOx 's be further reduced? Particulate matter of the pollutant Particles that are going to be emitted will also rise with the addition of hydrogen. This is are due to the oxidizing effect of hydrogen in the cylinder causing, this particles then enter the atmosphere through the exhaust. We made further also the comparison of the effects on emissions when one goes hydrogen add to other types of fuels.

Abstract

In this study, the effect of hydrogen enrichment on emissions of a diesel generator were examined. Our expectations were that hydrogen enrichment would reduce the emissions quite a lot. During our measurements, our focus led on the emissions of NO,NO2 and PMs. Unfortunately our results were not significant, but from other similar studies we found remarkable results. We found an increase of NO, this effect is duet of the high combustion temperature, this is a result of the high flame speed of hydrogen. When we increased the amount of HO2 in the cylinder, H2 improved the conversion of NO to NO2, which also led to an increase of NO2. With the right optimization methods, we could achieve better results so less emissions. PMs also increase proportionally with the increase of hydrogen enrichment. This as a result of the oxidizing effect of hydrogen in the combustion chamber. To broaden our research, we made a comparison with the effects of hydrogen on emissions combined with different types of fuel.

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Glossary

H2	Hydrogen
Fuel cells Fuel cells	
HHO	Oxy-Hydrogen, mixture of hydrogen and oxygen
NOx	Collective name for the mono-nitrogen oxides
NO	Nitric oxide
NO2	Nitrogen dioxide
KOH	Potassium hydroxide (electrolyte)
P.M	*Particulate matter,* unit to express concentrations. Particles with a diameter of less than 10 micrometres.
CO	Carbon
CO2	Carbon dioxide
HC	Hydrocarbons
VOCs	*Volatile organic compounds,* the collective name for all hydrocarbons that evaporate easily.

0 Introduction

In this research we will study the emissions when one uses oxy- hydrogen will add to an internal combustion engine. This is because pollution is high on the agenda state and alternative fuels are receiving more and more attention. We were convinced in advance that the addition of hydrogen for a decrease would cause emissions. However, during the investigation, we expectations need to be updated.

This work covers the basic concepts of electrolysis, emissions and alternative fuels clarified on the basis of the research that has been carried out. Hydrogen, as an alternative fuel, is arousing interest on several levels on. Despite the fact that several projects are already in operation, one continues still actively looking for solutions regarding more efficient use, storage and production. The materials and equipment used during the research trial are described in detail.

Subsequently, the comparison is drawn up of the various emissions that are emitted at a variable amount of oxy-hydrogen and load on the engine. Depending on our results, we will have to optimize our engine at the use of hydrogen.

Finally, we compare the different types of fuels. These are diesel, RME (Rapeesed Oil Methyl Esters), biogas and methane. How do they react fuels with the addition of hydrogen?

1 Hydrogen

1.1 What is hydrogen?

We call hydrogen as H2, which means that it is a hydrogen molecule made up of two hydrogen atoms. Forms under atmospheric conditions this substance is a diatomic molecule with oxygen. Hydrogen comes in big quantities for throughout the universe, found on the sun, in some stars, and the planet Jupiter is mostly hydrogen. becomes on Earth hydrogen usually produced by electrolysis.

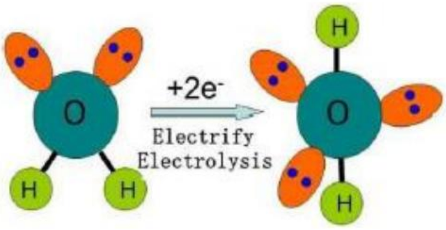

Figure 1 Electrolysis reaction

Source: Research gate

1.2 The properties of hydrogen

The flame speed of hydrogen has a very wide range compared to others fuels. This makes it possible to work with hydrogen in both rich and poor conditions, so hydrogen is almost easy to handle.

The amount of energy required to ignite hydrogen is remarkably low. This has its advantages and disadvantages, one danger here can be that hydrogen will easily ignite when it comes into contact with *hot spots,* points, places that subject to extremely high temperatures, or gases with high temperatures.
In contrast, one liter of hydrogen contains 3100 times less energy than one liter of diesel, this makes hydrogen very unfavorable to use as a fuel. Therefore, hydrogen used more in *fuel cells,* because hydrogen is more efficient in terms of storage and production.

Fuel cells use energy, such as hydrogen, to produce electricity produce. A fuel cell consists of two electrodes: a positive side (anode) and a negative side (cathode), with an electrolyte in between. Hydrogen goes to fed to the anode and oxygen to the cathode, after which the catalyst will produce hydrogen split into electrons and protons. These each take a different path to the cathode. Electrons have an external path through which there is a flow of electricity is resurrected. The protons go through electrolytes to the cathode, it follows that oxygen and electrons react with each other. This reaction results in heat and water.

When hydrogen is compressed, the temperature will rise. This is possible become dangerous because hydrogen has an *auto ignition temperature ,* ie that hydrogen itself will ignite at a certain temperature. In this case, the thermal efficiency limited.

Hydrogen has a high *flame speed,* this is the speed at which a flame is created after a burn. This value has been determined for all types of fuels and is mainly used by scientists.

The combination of hydrogen and air *(fuel-air ratio)* is very good, hydrogen has as a property of good miscibility. This property ensures homogeneity mixture of hydrogen and air. A major drawback to this is that leaking this substance, the hydrogen will easily disperse into the atmosphere.

The low density of hydrogen limits its possible uses usually large volumes are needed if one wants to add them during combustion a motorcycle. The low density will therefore entail a lower power.

1.3 The production of hydrogen

Today there are several methods to produce hydrogen, electrolysis, is a method in which pure water is split into by an electrical voltage hydrogen and oxygen.

Electricity that comes from a sustainable energy source, solar, water or wind energy, is developed using a sustainable production process. Unfortunately, we still generate electricity using nuclear power plants, which are none sustainable energy. It can also be made from fossil fuels, including hydrocarbons called, produce hydrogen. Hydrocarbons contain compounds with carbon and hydrogen particles. The newer cars already use this principle by refueling with natural gas. The natural gas passes through a hydrogen converter to produce. A disadvantage is that the composition of the exhaust gases is in addition to water also contain other components.

In addition, hydrogen can also be obtained from biomass. This is a process in which different micro-organisms convert biomass into hydrogen. Find this process for example, back in swamps and in the stomach of a cow.

That 'produced' hydrogen is then used by other micro organisms as a nutrient in which methane is formed.

Finally, hydrogen can also be produced through photosynthesis, a project of Japanese scientists.

Because hydrogen has a low density, hydrogen can only be stored as a gas on a large scale and with gigantic high pressures (700 atm. bar). When one would like to make hydrogen liquid again, 40% of its energy is used lost, which is immense. The storage of hydrogen as a liquid is equally difficult handling, one needs extremely low temperatures (-253°C). Both aggregation forms are not an optimal form to store hydrogen.

1.4 Hydrogen and shipping

Alternative fuels are a must for many individuals, shipowners or industries solution for the high bunker prices and the mandatory emission zones. *LowSupher Fuel Oils*,* including hydrogen, are therefore used by many people in many places investigated.

Although there are a few pilot projects in operation, including the FSC Alsterwasser and one container ship Zero, are achieving good results.
On the other hand, the storage of hydrogen remains very risky, so it will application will not work for every ship. For example ships that are longer cover distances.

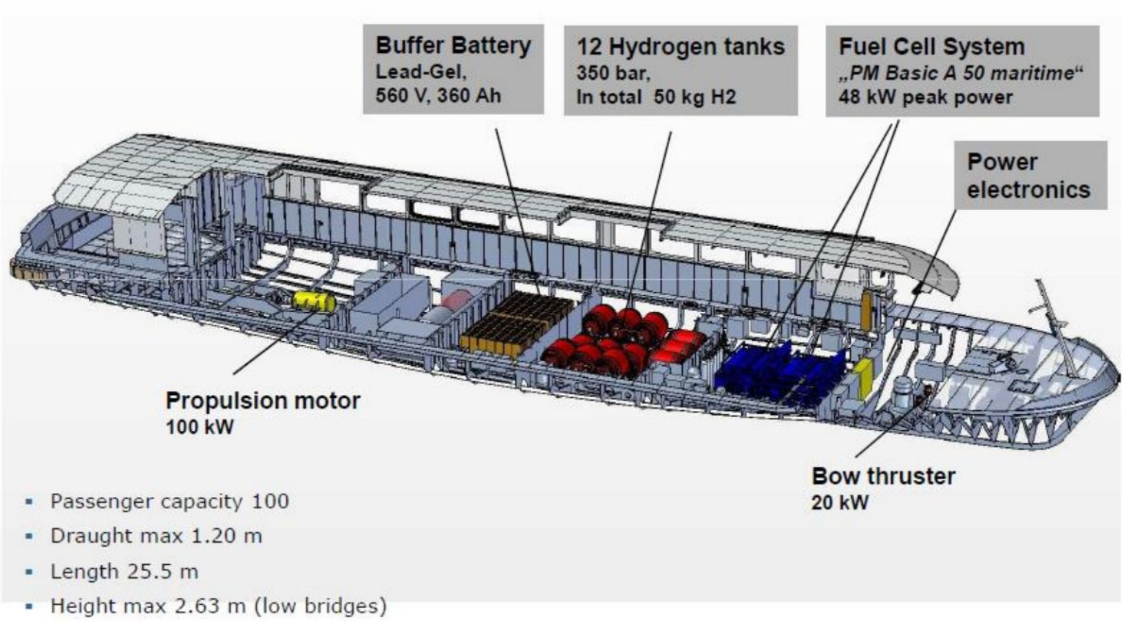

Figure 2 FSC Alster washer

Source: https://www.h2fc-fair.com/hm10/images/pdf/proton-motor06.pdf

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* LSFO is a fuel that may have a maximum sulfur content of 1.0%. This kind fuel must be used in SECAs (Sulphur Emission Control Areas) established by the MEPC (Marine Environment Protection Committee). applies to the North Sea and the Baltic Sea ECA zone, LSFO must also be burned here. Compared to a standard fuel it has a sulfur content of 3.5%.

If you are considering sailing on hydrogen, you should still do some here make notes. Hydrogen is a very small molecule that can possibly escape. When this substance ends up in the atmosphere, the chance of high risk of explosion. A second factor to take into account is the reaction between hydrogen and metal. Metal becomes very brittle in contact with hydrogen, so the storage tanks will have to be made from a different material become.

1.5 The effects of hydrogen in an internal combustion engine

A combustion engine will mix fuel and oxygen in advance, so that a mixture is drawn into the cylinder. By means of a spark it will 'explode' and generate energy. When one puts hydrogen into a combustion engine use, one encounters some problems, such as reduction of power, engine knock, back-fire, pre-ignition, and super-of megaknock'. (IT Yimaz, M. Gumus, A. Demir, 2016). A pre-ignition usually caused by reducing the size of the engine or by the use of turbochargers.
As a result, the temperature and pressure will rise faster than normal which can cause 'super or mega knock' and damage to the engine to take. It can be concluded that the use of hydrogen is not recommended for blast engines. The use in combustion engines, on the other hand, is one achievable cart.

1.6 The effects of hydrogen on internal combustion engines

Hydrogen can be introduced into the combustion engine in various ways, as fuel via the injectors or as a gas/air mixture via the inlet collector. Influences such as temperature, pressure, possible ignition delays and a change in combustion time were investigated. The combustion analysis from Yasin Karagoz, et al. (2016) developed very favorable results, the combination of fuel and hydrogen will therefore stimulate combustion. When hydrogen in the cylinder, the pressure and temperature increased considerably. The combustion cycle is about the same duration, but starts later by the addition of hydrogen. This may be due to the inflammation delay.

2 Research question

What concerns us is the reaction of HHO in combination with a combustion engine. This reaction can be examined by means of the composition of the exhaust gases.
Because hydrogen is one of the largest energy carriers, compared to others chemicals, these can more easily become organic and inorganic pollutants substances oxidize at a high rate despite the energy conservation being short expensive.

When this HHO enters the engine, it will have a catalytic combustion cause. This stimulates the CH chain, the combustion of flammable gases are improved and unburned HC, CO and PM are oxidized.

We hope to obtain favorable results during our research adding hydrogen will measure lower emissions. These emissions include NO, NO2 and PMs are measured at different loads. From this we hope to learn what changes take place in the engine itself.

2.1 Method

The HHO generator is coupled to the diesel generator inlet (Javac Nanomag), HHO is therefore sucked into the combustion chamber of the generator. We will investigate the composition of the exhaust gases at the based on the values of NO, NO2 and PM's with the following detection instruments; the Crowncon Gas-Pro and the Dusttrack DRX aerosol monitor 8533. The generator we charged with ventilators. As fuel there is RME (Rapeesed Oil Methyl Esters) used, a type of biodiesel that falls under the alternative fuels.

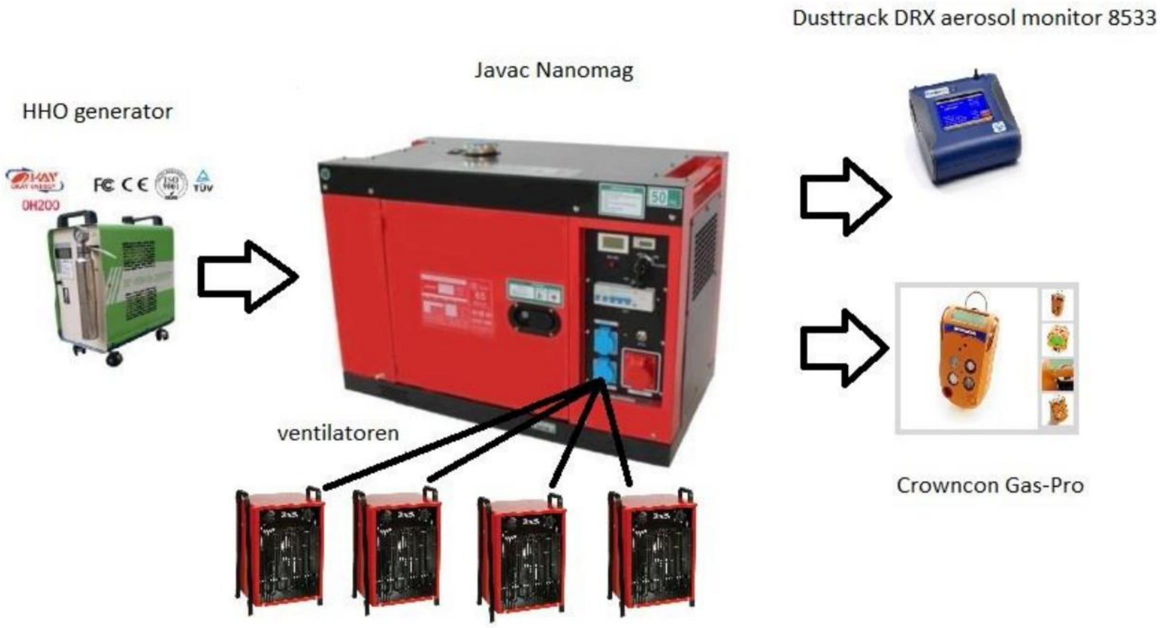


Figure 3 Research setup

Source: Own work

The NO and NO2 values are specified below.

• NOXes

Are described as the collective name of all mono-nitrogen oxides, these include NO, NO2 and NO3.

• NO

Nitric oxide is an inorganic compound that is produced by combustion processes. It is a colorless and odorless substance that causes air pollution causes.

• NO2

Nitrogen dioxide is an inorganic compound of oxygen and nitrogen also contributes to air pollution, acid rains and smog. NO2 is very dangerous for our respiratory system. When one becomes for a short period of time exposed, it leads to asthma or other breathing problems.

Longer exposure leads to the development of asthma and can lead to infections developing respiratory system. The fabric is of red-brown color and has like property that it dissolves easily in water. NO2, in addition to other NOX' and contributes to the reaction with other chemicals that form PM's and ozone.

• PM

PM stands for *particulate matter* or *particulate pollution,* it is the term for the mix of solid particles and liquid droplets present in the atmosphere. These particles usually consist of dust, dirt, soot and smoke. Some are with the naked eye observable others are too small and are only visible with a detection device designed for this purpose. The size of these particles is expressed by PM25 and PM10. PMs are usually the result of complex reactions from chemicals such as SO2 or NO. These emissions are often emitted by power plants, industries or motorized vehicles. When one will inhale PMs this can lead to serious health problems, especially when smaller than 10 micrometers, because these can go deep into the lungs and some even enter the bloodstream.

2.2 Materials

2.2.1 Detection instruments

• Crowncon Gas Pro:

Figure 4 Crowncon Gas-Pro

Source: https:// www.crowcon.com/ uk/ products/ portables/ gas-pro.html

A detection device that can measure up to five different types of gas, specially designed for workers who need to enter restricted areas.

Measurement Limits:

GAS	RANGE	ALARM	RESOLUTION
NOx	0-100 PPM	25 PPM	1 PPM
NO	0-20 PPM	1 PPM	0.5ppm

Table 1 Measuring Limits Crowncon Gas-Pro

Source: https://www.crowcon.com/uk/products/portables/gas-pro.html

• Dusttrack DRX aerosol monitor 8533

Figure 5 Dusttrack DRX aerosol monitor 8533

Source: http:// www.tsi.com/ DUSTTRAK-DRX-Aerosol-Monitor-8533/

This device allows us to measure the PM. PM has an air pollutant property that can be detrimental to our health when present in low levels concentrations in the atmosphere.

2.2.2 Oxygen hydrogen generator

Figure 6 Oxy-hydrogen generator

Source: http:// www.okayenergy.com/ d/ files/ download/ okay-catalogue-2016_1.pdf

The HHO generator (type OH200) will split water by electrolysis into hydrogen and oxygen, specifically in two hydrogen molecules and one oxygen molecule. The electrolysis of HHO is different from classical electrolysis in every way.

One is going to get a reaction between water and an electrolyte, namely KOH, the reaction produced by applying a voltage to the electrodes. At the cathode, the water molecules attract electrons to make OH ions and H2 molecules.

OH ions travel through the electrolyte to the anode where they fuse together and giving up electrons to make water, electrons and O2 .

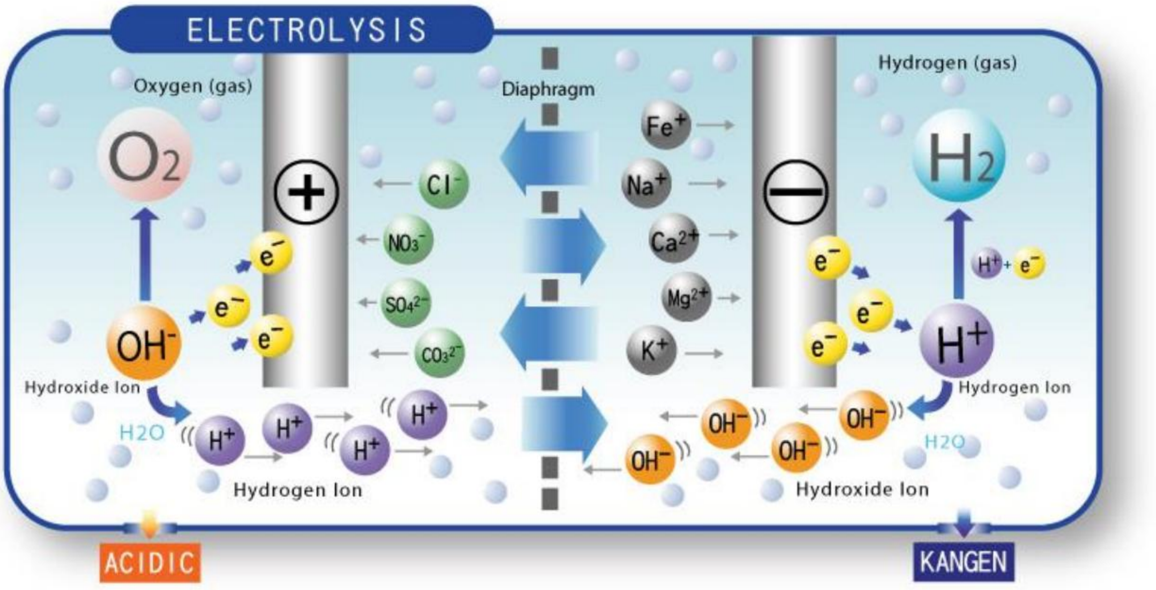


Figure 7 HHO electrolysis

Source: http:// hydrogencar.eu5.org/?p=124

The generator can be used for multiple applications, namely welding, cutting, polishing, ... but mainly by the jewelery industry.

The HHO generator has two vertical cylindrical tanks where the electrolysis will take place take place with the help of electrodes. Production will be highest when the alternating polarity + + + is. The supply of water and of the electrolyte is used to accelerate the production of electrolysis by it conductivity can be found in the horizontally placed buffer vessel. Bee in the following tests KOH (potassium hydroxide) is used, one has to be careful because this substance is very corrosive and can also release chlorine gas during electrolysis. Electrolysis is controlled with PWM† which also controls production is becoming. The flow rate can be regulated manually by means of a potentiometer and be read on the display. The supplied pressure can be found on the barometer. Below are some parameters of the OH200:

† PWM: pulse width modulation or pulse width modulation is a form of electrical supply or a means of digital data transfer. It is a square wave electrical signal with a fixed frequency. One has a signal 1 (full voltage) or 0 (voltage is turned off). Bee PWM one adjusts the duty cycle of the signal with the aid of time.

AC Voltage Requirement (V)	220/110 50/60Hz
Phase	single
DC Voltage &Current (A)	5V 60A
Power Consumption (kw/h)	0.7
Max Gas Output	200L/h
Max. Working Pressure (kg/cm^2)	2
Max. Water Consumption (L/h)	0.11
Water Feed	manual
Max. Flame Modifier Consumption (L/h)	0.1
Flame Modifier Feed	manual
Dimensions - L*W*H (mm)	450*250*510mm
Gross Weight (kg)	20
Power Supply Protection Grade	IP21S
Ventilation Space Requirement (mm)	200 in each direction

Table 2 OH200 generator parameters

Source: http:// www.okayenergy.com/ d/ files/ download/ okay-catalogue-2016_1.pdf

2.2.3 Javac Nanomag

The generator that our test setup contained was a Javac Nanomag. The Nanomag generators generate electricity through a permanent magnetic field by means of magnets made of aluminum, nickel and carbon. This magnets are mounted on the rotor. The generator is an air-cooled version from which a power of 6kW can be obtained. This is equipped with a 400V output, for very heavy applications to be fed at a speed of 3000 rpm a minute.

Figure 8 Javac Nanomag

Source: https:// javac.eu/ product/ nanomag-3000-tpm-generators/

2.3 Trial

2.3.1 Preparation

In the first test setup, the maximum delivery pressure and flow was attempted to test. This by keeping the tap (output) closed to a pressure of 1.8MPa, then the flow rate and pressure will drop. We return the crane at 1.6MPa open to allow the flow to stabilize,
after which we close the tap again. We obtain the ideal situation at a pressure of 1.6MPa with a peak flow rate of 80l/h and with a constant of 72l/h (when this regulation is not yet optimal, the pressure can drop to 1.3MPa). It is important to keep the output closed during start-up so that the pressure can spread build up.

2.3.2 Setup

First, a mixture of KOH and water was made
horizontally placed vessel was poured. The diesel generator was started. When it had a certain exhaust temperature, we were able to carry out the tests without it adding hydrogen. After these tests were completed successfully,
we were able to start up the HHO generator and run the tests with the addition of hydrogen. First we used this with a flow rate of 100 l/h, then with 150 l/ h. The generator was also loaded using fans.

Figure 9 Setup OH generator

Source: Own work

Figure 10 Generator setup

Source: Own work

2.3.3 Trial test results

The research was extended to the measurement of various parameters viz the composition and temperature of the exhaust gases. These parameters were measured at different loads (namely 0kW, 1.4kW, 2.8kW, 3.5kW and 4.9kW) with or without the addition of HHO.

NO	
Load RME 100lH2 150lH2	0.00 0.00
	0.83 0.00 1.67 1.50 3.33
0	7.67 7.67 6.00 11.83 9.83
1.4	8.50 21.33 13.50
2.8	
3.5 4.9	

NO2			
	3.30	3.23	3.53
0	4.58	5.43	6.05
1.4	4.28	5.10	5.30
2.8	3.52	3.97	4.53
3.5 4.9	1.10	1.50	1.62

P.M	
0	1.99 2.36 3.61 2.75 4.87
1.4	5.24 4.35 7.93 7.72 4.72
2.8	8.67 8.00 7.00 16.35 14.75
3.5	
4.9	

Table 3 General test results

Source: Own work

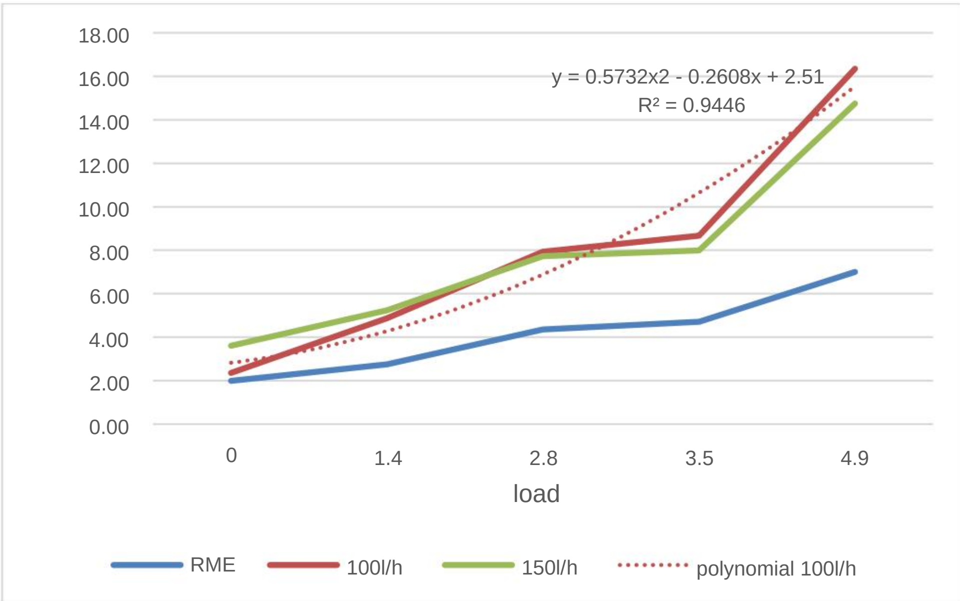
2.3.3.1 Test trial: NO

Subsequent test results indicate the values of NO with or without addition of hydrogen and at the different loads.

NORME 0 0.00	**100lH2**	**150lH2**
1.4 0.00 **2.8**	0.00	0.83
3.33 **3.5** 6.00 **4.9**	1.67	1.50
8.50	7.67	7.67
	11.83	9.83
	21.33	13.50

Table 4 Test Results NO

Source: Own work



graph 1 Test results NO

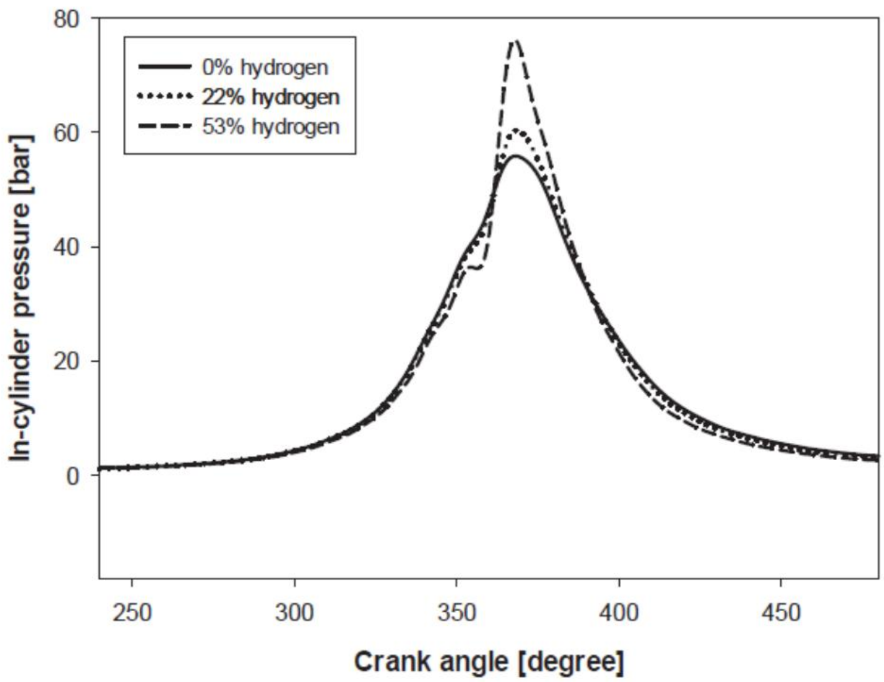
Source: Own work

From these results we find an increase in NO. The graph gets steeper depending on whether the load is more than 1.4kW. This will give the engine more fuel inject and draw in more air. When we introduce HHO into the cylinder, it will these burn faster, resulting in higher pressures and temperatures in the cylinder will be present. This results in an increase in NO emissions.

graph 2: Averages NO

Source: Own work

Graph 2 shows the averages of the measured NO values at a different phase, namely with RME or with the addition of hydrogen (100l/h – 150l/h). From the trend line, we clearly see that NO rises when RME is increased by a simulate addition of hydrogen. This finding is confirmed on the graphs 1 & 2.

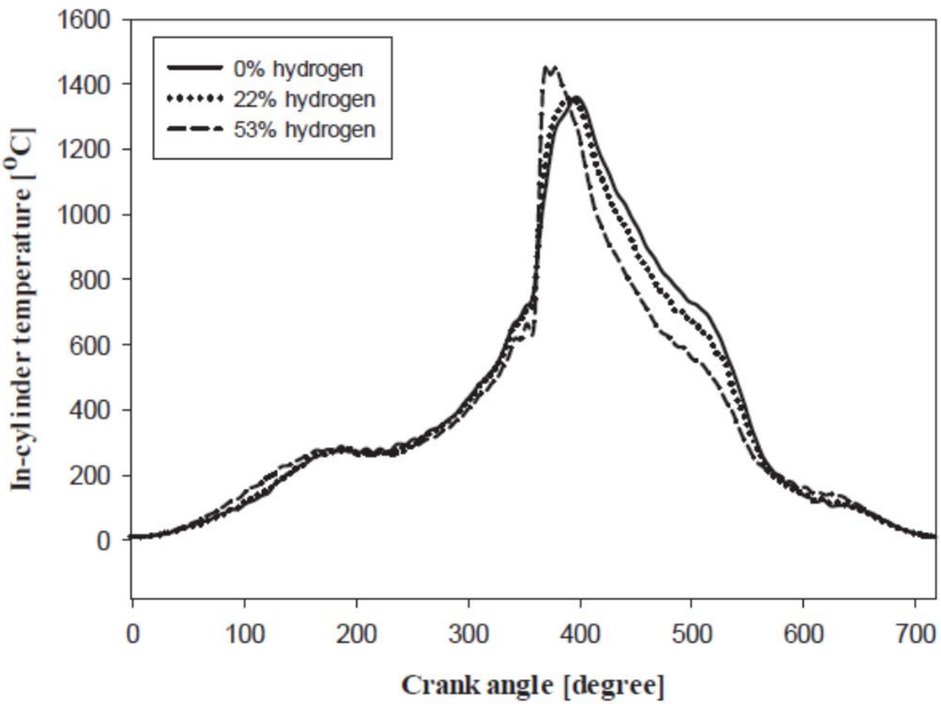


graph 3: Effect of different percentages of hydrogen enrichement on in-cylinder gas pressure related to the crank angle at 1100 rpm engine speed & fuel engine load

Source: https:// www.sciencedirect.com/ science/ article/ pii/ S0360319915301750

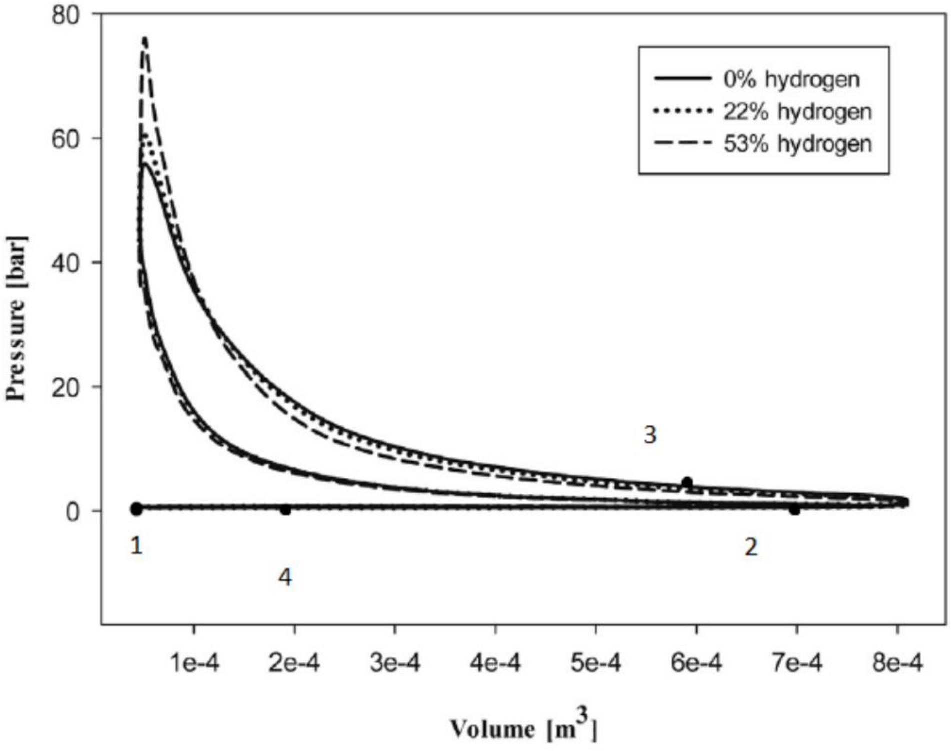
The higher pressures in the cylinder are due to the high flame speed of hydrogen, hydrogen will therefore entail a faster combustion. In graph 3 shows the effect of hydrogen on the pressures in the cylinder at a constant speed and a constant load on the motor. These values are from a study by Yasin Karagoz, Ilker Gûler, Tarkan Sandalcÿ, Levent Yûksek and Ahmet Selim Dalkÿlÿc (2015). With an addition of 53% hydrogen, the pressure will have increased by about 20 bar at a crank angle of 370°, compared to the pressure with the conventional fuel. Graph 4 shows the effect of hydrogen on the temperature in the cylinder, which rises by 100°C with an addition of hydrogen (53%) compared to the conventional fuel, both at a crank angle of 400°.

From another source (IT Yilmaz, A. Demir and M. Gumus, 2016) one can also state that the peak pressures in the cylinder fall earlier due to the ignition delay that occurs. According to them, this is due to the chemical reaction that hydrogen has on the classic fuel during the combustion.



graph 4: : Effect of different percentages of hydrogen enrichement on in-cylinder gas temperature related to the crank angle at 1100 rpm engine speed & fuel engine load

Source: https:// www.sciencedirect.com/ science/ article/ pii/ S0360319915301750



graph 5: Effect of different percentage of hydrogen enrichment on cylinder gas pressure related to cylinder volume at 1100 rpm engine speed and full engine load

Source: https:// www.sciencedirect.com/ science/ article/ pii/ S0360319915301750

Chart 5 (Yasin Karagoz, Ilker Gûler, Tarkan Sandalcÿ, Levent Yûksek and Ahmet Selim Dalkÿlÿc ,2015), represents a PV diagram. A PV diagram shows the combustion cycle of an engine, in our case the diesel or combustion engine. At n°1 in the graph, the motor starts sucking in air, op atmospheric pressure, here we measure a constant pressure with a changing volume, this is called an isobar in thermodynamics. From n°2 in the graph, they are going to be compressed, the pressure rises considerably. After the combustion has been able to take place, one will expand to n°3. Last will one gets rid of the exhaust fumes to n°4. The total work done by the system can be determined on the basis of the surface of the 'banana'. Of this information in mind and the measured values, one can conclude that with the addition of hydrogen the combustion improves. You also get higher peak pressures and achieves a more homogeneous combustion, due to the high flame speed of hydrogen.

In an investigation it is important to check the reliability of the measured values testing, this can be done using a t-test.

We use a t-test to test the reliability of a mean against a known average and this on a confidence factor of 5% confidence interval, also called testing the hypotheses. It is a way to compare hypotheses. Through the difference of it sample mean and calculate a reference value from that mean.

The values found are then compared with the acceptance area in the t-table (see Appendix). For example, one can calculate whether that a measured value is significant or not.

NO	**RME**	**100 lH2**	**1501H2**			
	μ_0		μ_2			
GEM	3.57	μ_1	6.67			
THE V	3.73	8.50 8.59	5.44			
						5% t-distribution
t-key 100l/h	1.28356405				<=>	2.13
t-key 150l/h	1.27385309					
H0:	$\mu_0 < \mu_1$ $\mu_0 < \mu_2$		=	WHERE		
H1:	H0		=	FALSE		

Table 5 T-key NO

Source: Own work

From this calculation we can conclude that the values are not significant. The null hypothesis is rejected. So no improvement is observed due to the addition of H2.

2.3.3.2 Test trial NO2

Subsequent test results show the values of NO2 with or without the addition of hydrogen and at different loads.

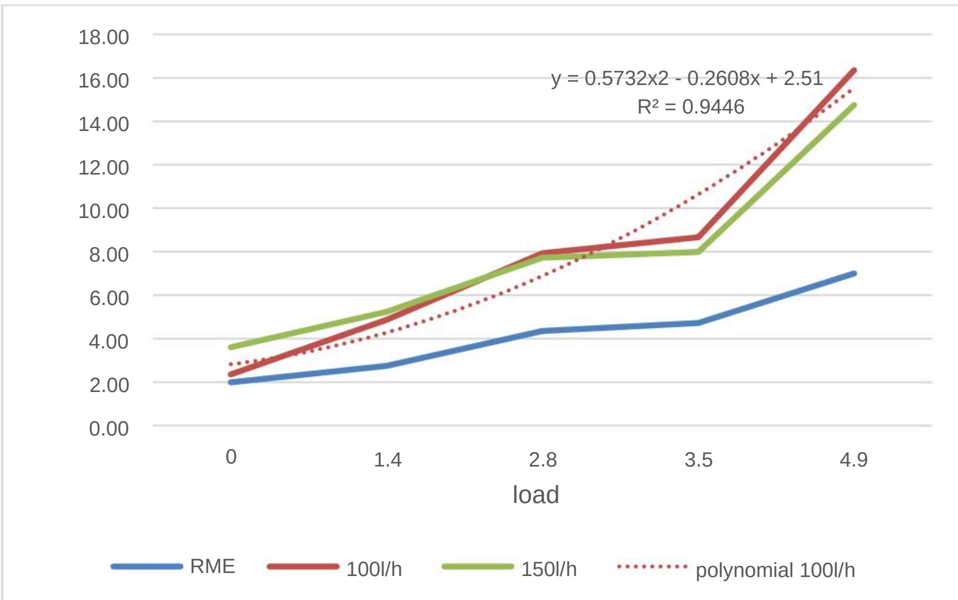
NO2	**RME 100lH2 150lH2** 3.53	
	3.30 3.23 4.58	6.05
0	5.43 4.28 5.10	5.30
1.4	3.52 3.97 1.10 1.50	4.53
2.8		1.62
3.5 4.9		

Table 6 Test results NO2

Source: Own work

NO2 strongly depends on the reaction time of the combustion, the temperature in the cylinder and the amount of oxygen. Because hydrogen involves higher temperatures will entail, one can therefore expect higher emission values.

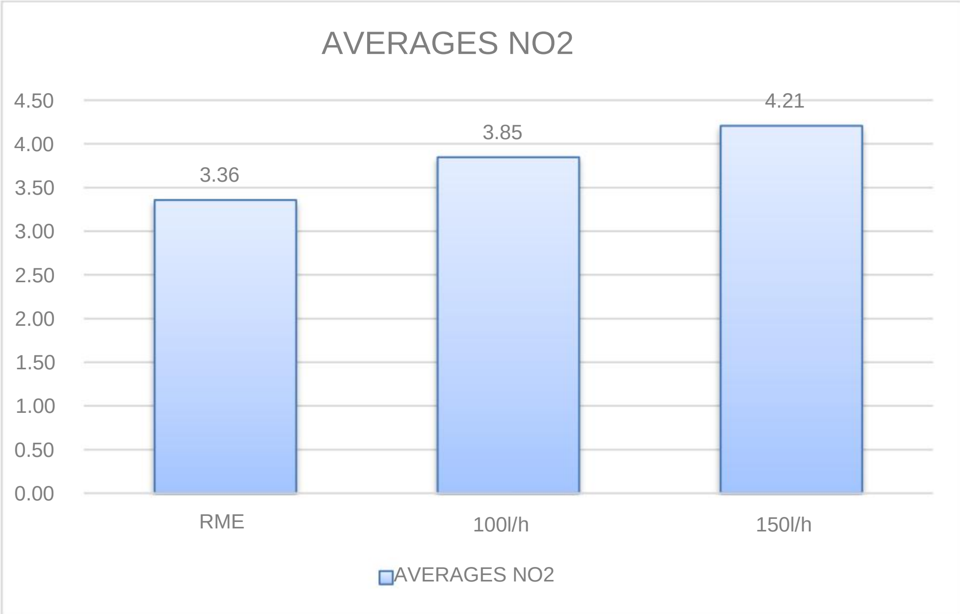
Because we use HHO in the study, the amount of oxygen present is also higher. This will also translate into the results.



graph 6 Test results NO2

Source: Own work

In graph 6, all measured values are compared depending on the load with the NO2 emissions. From a load of 1.4kW, all values drop significantly both with or without adding hydrogen. The peak at 1.4kW may be a consequence of the unburned particles H2, depending on the load on the engine.



graph 7: NO2 averages

Source: Own work

From graph 7 it can be said that NO_2 will rise when hydrogen is added add. The cause of this is the hydrogen itself, when hydrogen is added to the cylinder, the amount of HO_2 will also increase. We see that from chemistry HO_2 will influence the conversion of NO and NO_2 . That's why we're seeing a decrease in NO but also an increase in NO_2.

$$NO + HO = NO_2 + OH$$

NO2	**RME 100lH2 150lH2** μ2 4.21 1.72					
	μ0	μ1				
GEM	3.36	3.85				
THE V	1.37	1.58				
						5% t-distribution
t-key 100l/h	0.69345795				<=>	2.13
t-key 150l/h	1.10373581					
H0:	μ0< μ1 μ0< μ2		=	WHERE		
H1:	H0		=	FALSE		

Table 7 T-test NO2

Source: Own work

From this calculation we can conclude that the values of NO2 are not significant are. The null hypothesis is rejected. So no improvement is observed due to the addition of H2.

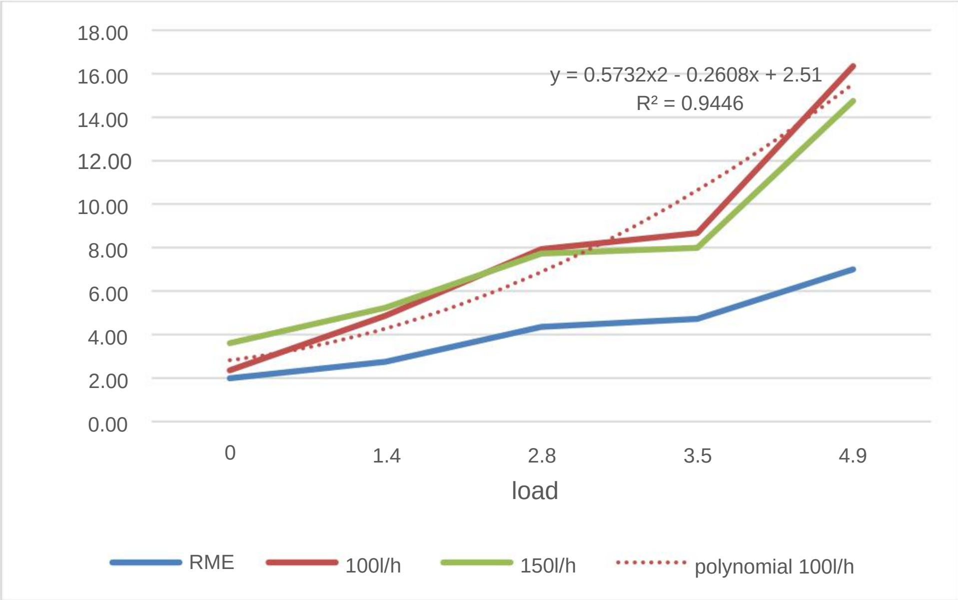
2.3.3.3 Test trial PM

Subsequent test results show the values of PM with or without the addition of hydrogen and at different loads.

PM RME 100lH2 150lH2 2.36 3.61 4.87		
	1.99	5.24 7.93 7.72
0	2.75	8.67 8.00 16.35
1.4	4.35	14.75
2.8	4.72	
3.5 4.9	7.00	

Table 8 PM test results

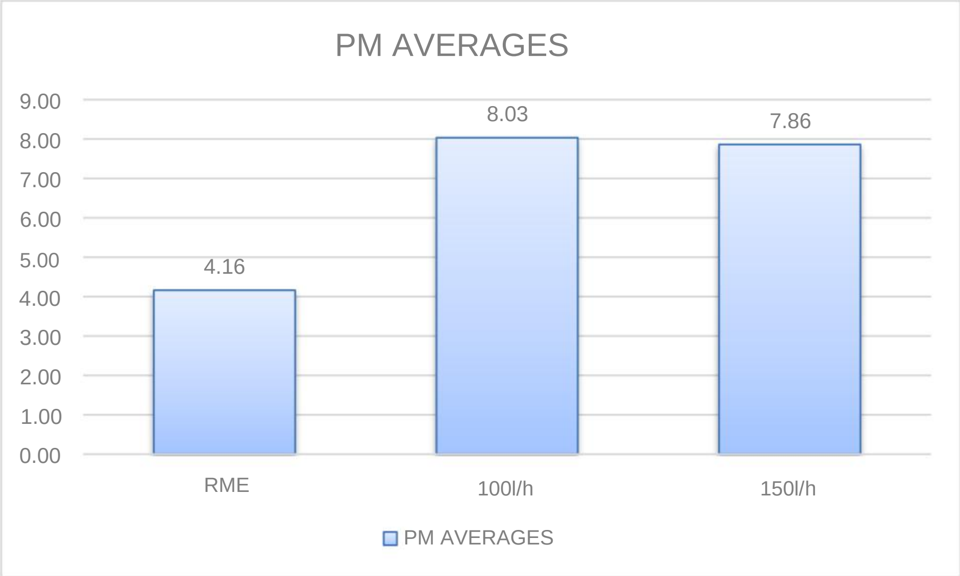
Source: Own work



graph 8 Test results PM

Source: Own work

From the graph one can say that when the motor is running with no load the influence of HHO has little or no effect. When a motor has no load running, the fuel supply will be low, which means fewer PMs anyway generate compared to full load. We see clearly at a higher load the effect of HHO. The oxidizing effect on any polluting deposits in the engine can affect this. PMs can also be a result of a poor combustion, but since hydrogen has the property to encouragement, one can refute this hypothesis.



graph 9: PM averages

Source: Own work

P.M		**RME 100lH2 150lH2**				
		µ0	µ1	µ2		
GEM		4.16	8.03	7.86		
THE V		1.94	5.29	4.26		
						5% t-distribution
t-key 100l/h	1.63747771				<=>	2.13
t-key 150l/h	1.94326056					
H0:	µ0< µ1 µ0< µ2		=	WHERE		
H1:	H0		=	FALSE		

Table 9 T-test PM

Source: Own work

From this calculation we can conclude that the values are significant. The null hypothesis is rejected. So no improvement is observed due to the addition of H2.

2.4 Decision

The measured values of NO and NO2 have not been found to be significant, we can therefore do not base a decision on these measurements. The reliability of these tests are not satisfactorily due to outliers or the small number of measurement results.
The study by (S. Liu, RN Li, Y. Zhao, XX Li, Z. Wang, 2015) shows what the consequences of NO and NO2 when hydrogen is added.

According to them, adding hydrogen to a diesel engine is the solution air pollution. Hydrogen has the property to catalyze and accelerate combustion optimize. Emissions have been measured at various speeds and taxes. At a low load, the effects of HHO are small. When the load will increase, larger values of NO and PM will be measured because the chemical reaction of HHO and diesel are not yet optimal. At 100% load all types of emissions will decrease significantly as a result of the better mixing of diesel and HHO. The decrease in NO will translate into an increase in NO2 the chemical reaction in the combustion chamber. Because hydrogen after combustion does not contain HC, CO, SO2, smoke, ozone, ..., these can be eliminated when measuring. In the test trial of PM, we can conclude from the values that due to the addition of hydrogen the polluting components in the engine will oxidize and that they are expelled with the exhaust gases. Hydrogen thus has a decarbonizing effect in the engine. Several manufacturers have installations have therefore already been designed that will clean the engine with the help of hydrogen.

The effect of the RME fuel is also of great importance here. RME is a biodiesel and will therefore react differently than the classic diesel. The fuel composition has therefore deviating properties that will influence the air-fuel ratio. Further they also affect the atomization or injection in the engine. This results in a poor combustion and high emissions causing engine efficiency to deteriorate go.

3 Floor

Based on some other research on hydrogen, I can make a

draw up a comparison of the effects on the emissions when hydrogen is used

added to diesel, methane and biogas compared to the effect without the addition

of hydrogen.

3.1 Comparing emissions from various fuels

3.1.4 Diesel RME H2

Emissions DIESEL RME				RME	RME- H2
NO				>	ÿ
NOx	<	10- 30%	ÿ	<	ÿ
CO	>	70%	ÿ	>	ÿ
CO2	>	5%	ÿ	>	ÿ
P.M	>	60%	ÿ	>	ÿ
HC	>	50%	ÿ	>	ÿ

Table 10 Comparison of emissions

Source:

https:// www.researchgate.net/ publication277604993_Performance_and_specific_emissions_contours_throug wood_the_operating_range_of_hydrogen fueled_compression_ignition_engine_with_diesel_and_RME_pilot_fuels

RME will of course emit less compared to the classic diesel, see anyway we at the emissions of NOX 'and a maximum of 30% at the RME. As before states, this is due to the amount of oxygen atoms there are in biodiesels present. The same applies to RME and RME in combination with hydrogen.

RME will significantly increase the temperature in the cylinder and the extend the ignition period, depending on the amount of fuel one will use inject. These will have a negative effect on emissions. If we use the engine, we can achieve better results.

Some examples of optimizations are more precise injection control or working with an EGR *(exhaust gas recirculation).*

3.1.5 Biogas- H2

Emissions	Biogas	
	Biogas- H2 (dual)	Biogas (single)
HC	>	
NOx	<	low-load
NOx	>	Medium/High load

Table 11 Comparison of emissions

Source: https:// doi.org/ 10.1016/ j.energy.2017.02.070

The effects of biogas-H2 on the engine are higher temperatures due to a greater presence of CO2 in the mixture. The presence of CO2 is too thanks to the biogas production process. Longer ignition periods and a higher NOX value is also a result of the presence of CO2 . The increases in CO, HC and PM are an effect on the reduction of thermal oxidation.

The hydrocarbons will decrease at higher temperatures, so when the engine more heavily loaded, the fuel oxidizes more easily. The most important reason of the presence of the NOX and is that one has to deal with high temperatures has in the cylinders and a large number of oxygen atoms. (IT Yilmaz, M. Gumus, Midhat Talibi, Paul Hellier, & Nicos Ladommatos, 2016).

3.1.6 Methane- H2

Methane is a fuel with four hydrogen atoms and one carbon atom and it exists mainly from natural gas.

Burning methane gives the following results from a chemistry point of view.

$$_4 +202 => \quad _2 + 2 \quad _2$$

If there is not enough oxygen present, CO will develop.

$$2 \quad _4 + 302 => 2 + 4 \quad _2$$

Methane in combination with hydrogen will make the engine beat. Beating the engine is the premature or uncontrolled self-ignition of the fuel. By means of this advanced pressure development will tend to push the piston into the crankshaft to rotate in the opposite direction. Another adverse effect is backfire, this is when the combustion or explosion in the inlet or outlet collector occurs in instead of in the combustion chamber. The following effects are due to a poor fuel-air ratio. Some other effects are that the periods of inflammation are shorter and temperatures will rise. The value of NOx will vary depending of the injection periods. When one injects, one goes to higher temperatures generate which will influence the NOx's. (Midhat Talibi, Ramanarayanan Balachandran, & Nicos Ladommatos, 2016)

3.2 Optimizing the use of hydrogen

From the previous chapter it can be concluded that hydrogen generally has an increase of the engine's efficiency. When we would the engine it is optimizing for the use of fuel in combination with hydrogen it goes without saying that we would also get better results with an attempt to reducing emissions.

Since we are dealing with higher temperatures, it is important to have visibility to get on this change in the engine. This can be done using sensors. Some are convinced that the rise in temperature is one consequence of the pressure increase in the cylinder. Thus, pressure sensors are designated in one or each cylinder of the engine, these must be connected to the fuel pumps so that you can control the combustion. When we can configuration like this optimization, it is theoretically possible to emit *zero* emissions.

3.3 Other methods of eliminating emissions

Other methods are still being researched to this day improve emissions after combustion. There are two different methods: the *in-cylinder improvements* and the *exhaust gas treatments.* Among the *in-cylinder improvements* we have added the LTC *(low temperature combustion).* This will lower the combustion temperature so that also soot and NOx 's are reduced. But also by a *low pressure injection system,* 34

we can control the fuel-air ratio for each cylinder separately, thus increasing the power output will also rise. The downside to this system is that when using gas from a low density works, in combination with small motors that reach high speeds, the injectors have to transport high volumes in a short time. The durability of the injectors will drop with major consequences such as leaks. Using *timed injection* can this risk of *backfire* be reduced? By using an EGR valve *(exhaust gas recirculation valve)* or by optimizing the injection, one goes for it ensure that all fuel is present before starting to ignite.
Temperature and NOx 's fall, but HC and CO rise. become LTC modifications therefore often used as *after treatment* in combination with NOx traps, DOC *(diesel oxidation catalysts)* and DPF *(diesel performance filter).* NOx traps go the NO and Reduce NO2 emissions by absorbing them during lean periods or low taxes. The NOx traps are an improvement on the EGR and SCR. The EGR has limited efficiency and the SCR requires a continuous supply of exhaust gases has. The diesel oxidation catalyst is an installation on the exhaust that removes the CO and HC will reduce emissions by oxidizing them. The chemical reaction has like result only the emission of CO2 and water. The diesel performance filter will cause soot and Remove PMs from the exhaust gases.

Another method for reducing emissions can also be achieved by only add hydrogen in the exhaust collector. The hydrogen only needs to be in small quantities concentrations are present before any effect will occur. The temperature and the NOx and will drop significantly. According to another study, this can also be achieved by adjusting the geometric shape of the cylinder.

4 Conclusion

First of all, one would like to emphasize that the use of alternative fuels is mainly is due to the stricter rules on emissions. Though sometimes its production not so environmentally friendly, which then leads to contradictions.

According to our research, the various fuels can be used in combination with compare hydrogen. When comparing emissions we come across remarkable ones results against.

RME, an alternative fuel, will emit 30% more NOx than diesel. When hydrogen is added to the RME, this number will only increase, this is due to the large number of oxygen atoms present in the mixture and the chemical reaction of HO2, which affects the conversion of NO to NO2 . At 100% capacity, it can be said that the emissions (NO, CO, HC, PM) will decrease by the optimal consumption. From this study, it can therefore also be argued that alternative fuels have completely different effects on the engine than the classic ones fuels. We measure higher temperatures in the cylinders and the ignition periods differ according to the type of fuel.

The load is used to measure biogas in combination with hydrogen diverse values. A low load is associated with low values. But at a high load, very high values are measured. This can be explained by the presence of CO2 in the biogas. When using higher temperatures, one finds low values of HC but high values of NOx 's.

Methane has some bad properties when combined with hydrogen. The engine will not run efficiently and experience some problems. Ignition periods are getting shorter, temperatures higher and a higher value on NOx 's can be measured.

It is difficult to indicate the best fuel since one still has the possibility has to optimize the engine with the different fuels.

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Appendix

T table

$1-\alpha$	0.90	0.95	0.975	0.99	0.995	0.9975	0.999	0.9995
n=1	3.08	6.31	12.71	31.82	63.66	127.32	318.33	636.67
n=2	1.89	2.92	4.30	6.96	9.92	14.09	22.33	31.60
n=3	1.64	2.35	3.18	4.54	5.84	7.45	10.21	12.92
n=4	1.53	2.13	2.78	3.75	4.60	5.60	7.17	8.61
n=5	1.48	2.02	2.57	3.37	4.03	4.77	5.89	6.87
n=6	1.44	1.94	2.45	3.14	3.71	4.32	5.21	5.96
n=7	1.41	1.89	2.36	3.00	3.50	4.03	4.79	5.41
n=8	1.40	1.86	2.31	2.90	3.36	3.83	4.50	5.04
n=9	1.38	1.83	2.26	2.82	3.25	3.69	4.30	4.78
n=10	1.37	1.81	2.23	2.76	3.17	3.58	4.14	4.59
n=11	1.36	1.80	2.20	2.72	3.11	3.50	4.02	4.44
n=12	1.36	1.78	2.18	2.68	3.05	3.43	3.93	4.32
n=13	1.35	1.77	2.16	2.65	3.01	3.37	3.85	4.22
n=14	1.35	1.76	2.14	2.62	2.98	3.33	3.79	4.14
n=15	1.34	1.75	2.13	2.60	2.95	3.29	3.73	4.07
n=16	1.34	1.75	2.12	2.58	2.92	3.25	3.69	4.02
n=17	1.33	1.74	2.11	2.57	2.90	3.22	3.65	3.97
n=18	1.33	1.73	2.10	2.55	2.88	3.20	3.61	3.92
n=19	1.33	1.73	2.09	2.54	2.86	3.17	3.58	3.88
n=20	1.33	1.72	2.09	2.53	2.85	3.15	3.55	3.85
n=21	1.32	1.72	2.08	2.52	2.83	3.14	3.53	3.82
n=22	1.32	1.72	2.07	2.51	2.82	3.12	3.51	3.79
n=23	1.32	1.71	2.07	2.50	2.81	3.10	3.48	3.77
n=24	1.32	1.71	2.06	2.49	2.80	3.09	3.47	3.75
n=25	1.32	1.71	2.06	2.49	2.79	3.08	3.45	3.73
n=26	1.31	1.71	2.06	2.48	2.78	3.07	3.44	3.71
n=27	1.31	1.70	2.05	2.47	2.77	3.06	3.42	3.69
n=28	1.31	1.70	2.05	2.47	2.76	3.05	3.41	3.67
n=29	1.31	1.70	2.05	2.46	2.76	3.04	3.40	3.66
n=30	1.31	1.70	2.04	2.46	2.75	3.03	3.39	3.65
n=40	1.30	1.68	2.02	2.42	2.70	2.97	3.31	3.55
n=50	1.30	1.68	2.01	2.40	2.68	2.94	3.26	3.50
n=100	1.29	1.66	1.98	2.36	2.63	2.87	3.17	3.39
n=200	1.29	1.65	1.97	2.35	2.60	2.84	3.13	3.34
$n=\infty$	1.28	1.64	1.96	2.33	2.58	2.81	3.09	3.29