Preface

First I would like to thank all the pioneers in water ingestion in engines,

The HHO people, the ultrasonic generated fog people, the Reacteur Pantone people, a lot of people mixing water and fuel and an angry young man with a SAAB with steam injection and even maybe more, who all placed video's on YouTube.

Recommended videos:

http://www.dailymotion.com/video/xslcg_moteur-pantone_news?start=18
(Watch the white handkerchief.)

http://www.youtube.com/watch?v=dAkRLjx8FeU
(Watch the disappearing of the exhaust plume due to no more soot condensation nuclei and the increase of torque.)

http://www.youtube.com/watch?v=y4mUzdbZTmw
(Look for all the certified fuel saving papers)

Without them I would never have had the idea that water ingestion would benefit the combustion process. Following their lead I came up with the solution why ingestion of water is beneficiary to the combustion process. And though the production of hydrogen gas is not true, they did a far better job than the car manufacturers and the oil companies who had still a heuristic approach to a process that existed for more than a century. The car manufacturers made more soot with their GDI engines where the water injection people made less soot.
The interesting thing in water injection is that the power and torque of the engine are amplified by the same amount that you save, and I have to thank a lot of people confirming this by sharing their experience of driving through the morning fog while their car outperformed itself.

Next I would like to thank my wife, for relieving me of bathroom cleaning duties for ten weeks and giving me hugs, kisses and a lot of cigars.

Furthermore I would like to thank Prof. dr. Lauth, university of Aachen, who helped me with the entropy of large molecules.

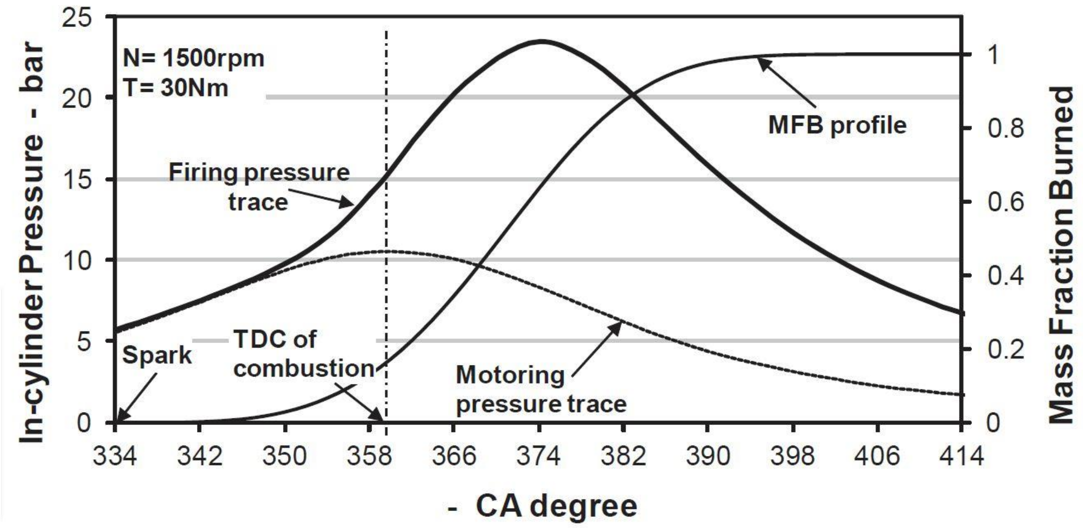
Last I would thank Prof. Fabrizio Bonatesta, Oxford Brookes University, for his graph on INTECH.

Lots of fun reading,

Peter Rotgans

Why do we burn gasoline still so foolishly?

When we burn gasoline in a 4 stroke engine we really want that just 14 degrees after TDC (piston then has only travelled 1,5% of the stroke) pressure is present which we can expand in the power stroke. This requires that at TDC we must have an ongoing combustion reaction. The combustion was initiated by a spark. And now we have to have some knowledge chemistry - combustion reactions in a confined space proceed **exponentially** (bomb) - and the combustion reaction is dependent on the mixture proportions. With the proper air fuel ratio (lambda = 1), the reaction is fastest and with less ideal mixture (lambda = 1.1 or lambda = 0.9) 10% slower. The figure below is from a INTECH document and represents a cylinder pressure measurement. The beauty of this measurement is that all interesting phenomena occur around TDC and thus are not disturbed by piston moves.



26 degrees before TDC (top dead center), there is a spark and slowly the reaction gets going, enhanced by the pressure changes caused by the piston. This is where the compression ratio becomes a factor. What is also striking in the pressure diagram is that the exponential behavior suddenly stops and around 14-15 bar is transformed into a linear curve . This is the anti-knock mechanism, which is realized by making the fuel in the cylinder **condense** on to the coldest part, which will be the cylinder head. When the fuel is condensed the mixture will **gradually deviate from ideal** and **the reaction speed will decrease**. As the speed formula for the exponential behavior is something like A*exp(B) and both A and B which are mixture dependent.

The gain in this control loop is only 1 so its step response is deviating linear. When you reach the first condensing pressure the piston should stay still or otherwise you will get a quadratic curve. Steeper (up) when the piston was going up – or shallower (down) when the piston goes down

Some history:

Around 1890 many inventions have been made, such as the invention of the automobile and carburetor by Karl Benz and what many petrol heads do not know: On the chemical side by Jacobus van't Hoff, Dutch Nobel laureate, whose suspicions about gas mixtures of mutually soluble substances were picked up by the French chemist Raoult which led to the laws of Raoult in 1883. The laws of Raoult in turn led to a better understanding of distillation processes. The first automobile by Karl Benz was powered with kerosene, because this was used for lamp oil. The refining process of crude oil in the 1880s was designed to make lamp oil and the higher fractions were discarded. However, kerosene has a boiling point between 150 and 300 degrees, and will therefore have condensing characteristics even when the cylinder head is kept at 100 Celcius (The early automobiles were cooled by boiling off water and it was not till 1900 that Daimler invented the honeycomb radiator).
Due to the improved distillation techniques, petroleum distillation got better and petroleum distillers were no longer dependent on what was present in the crude oil, they could mix afterwards. After the discovery of the first anti-knock agent isooctane by Graham Edgar in 1926 a RON test with a variable compression motor was developed so that some useful information was available in the direction of the user. The cooling of this engine is set at 100C.

The RON test examined

This test is also enlightening because it was done with only two components. Raoult's law states that the vapour pressure of a mixture of two ideally soluble components is the mole weighted average of the two. Well the vapour pressures at 100 degrees Celcius are about 1 bar for heptane and 1 bar for isooctane. The RON number is stated as a volume mix so first we have to figure out how many moles there are in a litre:6,8 moles for pentane and 6 moles for isooctane. At RON =90 there are 0,68 moles of pentane and 5,4 moles of isooctane so the combined vapour pressure at 100 degrees Celcius is (1*0,68 +1*5,4)/6,08=1 bar. The molar fraction of the fuel is about 2 %of the mixture. As partial pressures are mole weighted the partial pressure is also 2% of the mixture. Thus at around 50 bars the mixture will start to condensate. This is not what we are looking for. So something else must be happening. Gasoline itself does not alter when compressed, thus the only alternative is a reaction of gasoline with air molecules (N2 or O2).

However when you convert isooctane into octane you get a surplus of energy and that can be used to create a bond of 2 Isooctane+ N2= $C_{16}H_{36}N_2$ [*1] .

The formed molecule has a boiling point of over 300 degrees Celcius and a higher auto ignition temperature. The formation would halve the moles of the isooctane part and would, at 200 degrees Celcius under its boiling point, make the vapour pressure almost zero. Now the combined vapour pressure, at 100% formation, would read (1*0,68+0*2,7)/3,38=0,2 bar, by halving the moles the partial pressure would be now about1% and would lead to a start of condensation at 20 bar. This is for RON 90 so at RON 95 this would be about 12 Bar.

This is also a strong indication what anti-knock agents do: They are molecules that have the ability to react using N2 and/or O2 under influence of pressure and temperature so they catch several of the smaller CH molecules to make one heavy molecule.

This is an elegant solution because at first the molecules a free and easy to light with a spark and then, at higher pressures and temperatures, combined to gooey giants, which are also less likely to self-ignite in a non-ideal mixture, to control the reaction.

Every method has a downside, which is in this method of knocking control: Fuel (and most of it gooey) is condensed onto to the cylinder head. Now the (gooey) fuel has to be burnt off with air with little oxygen. This leads to soot and unburned hydrocarbons, which is bad for the environment.

Let me try to explain some well-known issues using condensation control

General

The reaction that you are trying to control is **exponential** and when it reaches the critical speed for a given pressure the condensation directly in front of the flame front starts to lag a bit due to the fact that with the reaction pressure you have to compress all of the mixture (over the speed of sound) and the molecules have to move to the cylinder head and fat molecules don't move so fast. When this lagging occurs the reaction gets out of control at first quadratic and then exponential. In a fraction of a millisecond the flame front reaches near sound speed velocities.

Knocking

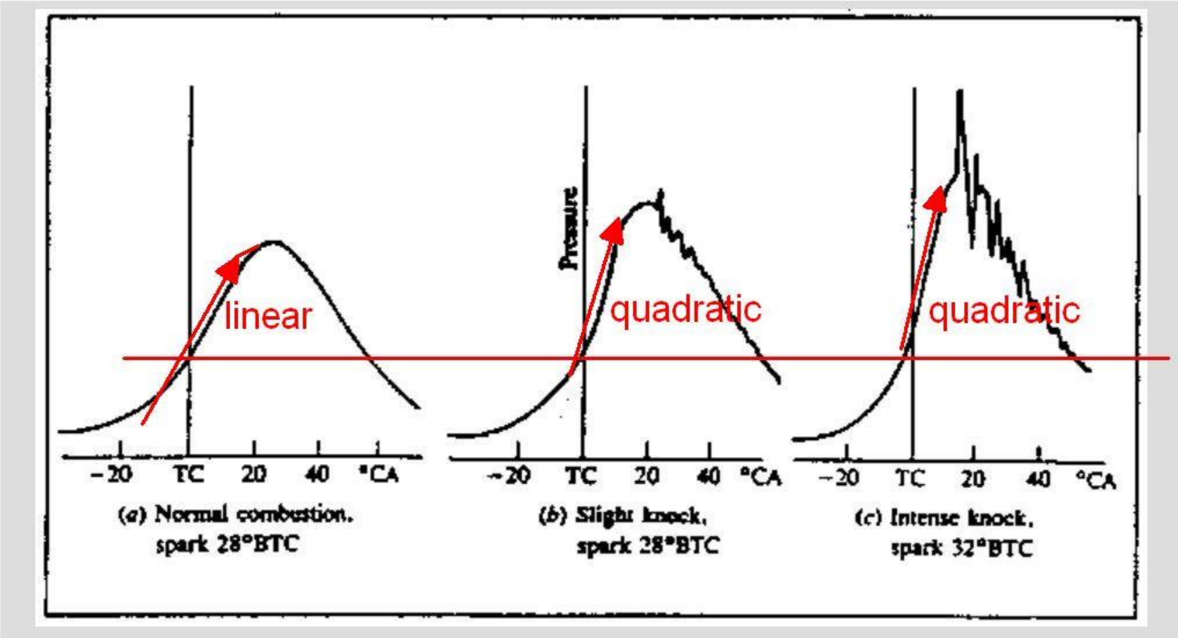
With knocking I get a picture of a man under the path of a supersonic jet: he will hear a boom because the sound waves of a trajectory add up. Something similar happens in the mixture when the flame front accelerates towards the speed of sound: There is an area where a trajectory of pressure waves adds up. This means the mixture in this area is depleted and the flame front has to eat its way through it, thus slowing down. The rest of the unburnt mixture only sees a shock wave and veers back almost to its original state, the reaction gains speed ….and so on.

Let us look at some more specific problems

Running Pour
If you run poor the condensation will be late.
The control mechanism is only linear so when you are late the pressure increase will be linear but much steeper and the flame front will reach critical speed. Knocking

Ignition is to early

The piston is still moving up at the start of condensation. There is tiny fraction of extra pressure at this point. However the curve will become quadratic and reaches high pressures earlier.



Acceleration pump

Once you step on the throttle the thermostat is ignorant of this event and the cylinder head will temporarily become hotter - condensation is too late at too high a pressure --knocking
Old solution: Add more fuel using an acceleration pump to deal this higher temperature which will result in condensation at - or below-the right control pressure. (Too bad that no one has had the idea that bypassing the thermostat with a valve kept closed by spring and opened through a leaky air pump with the throttle movement would do the same (it would have saved some fuel)

Heavy load situation

Heavy load (you drive up a mountain with your caravan in tow) is now solved with a richer mixture. What happens is that there is a temperature gradient in the cylinder head wall which leads to a higher temperature of the inside (condenser).
Old solution: add fuel. (One could have solved that with a cam connected to the throttle setting the thermostat at a lower temperature)

Remedies

The temperature issues are easily resolved by letting the ECU take control of the cooling.

By now you have gathered that we are going to look at ways to make less fuel condense and use less fuel before TDC. There I get a picture that you should sneak up on TDC with low pressure and a wide flame front (when you want to burn a lot of fuel fast you'd better have large enough flame to start with).

Two spark plugs provide a fuel saving of 10% and more torque. (Ducati Multistrada). (it moves the parameter of the fireball twice the original size down to once the original size as you can see in the 3D part)

Another idea may be using the same spark plug say every 2 - 5 cam degrees to create multiple balls of fire during the first 10 degrees after the initial ignition. With that I see multiple little fiery balloons with taking off. The first one has already grown and the last one still tiny.
My late uncle built something like that for his Volvo Amazon in about 1970 when low cost thyristors became available and claimed some fuel efficiency.

This section is for the more creative

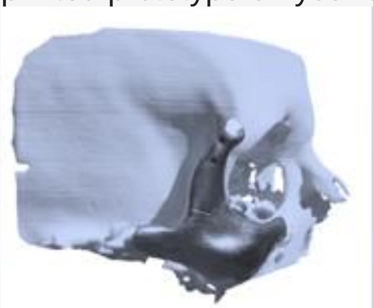
Maybe you could even use LED's and glass fibers to create a lot of sparks.

Even rings of tungsten embedded in ceramics in the cylinder head heated with a short pulse of several thousands of Volts.

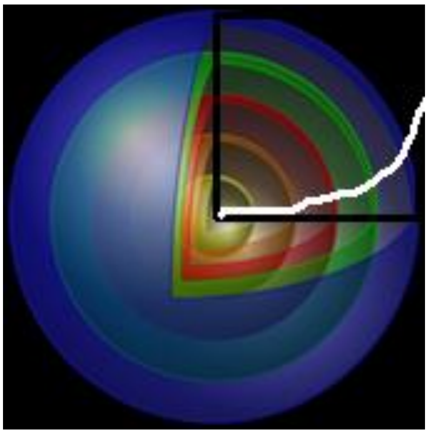
A laser pulse that causes blooming?

Or just inject on a sizzling hot surface isolated from the piston with aerogel and refractory kiln materials (e.g. saint gobain, http://www.lo-mass.com/).

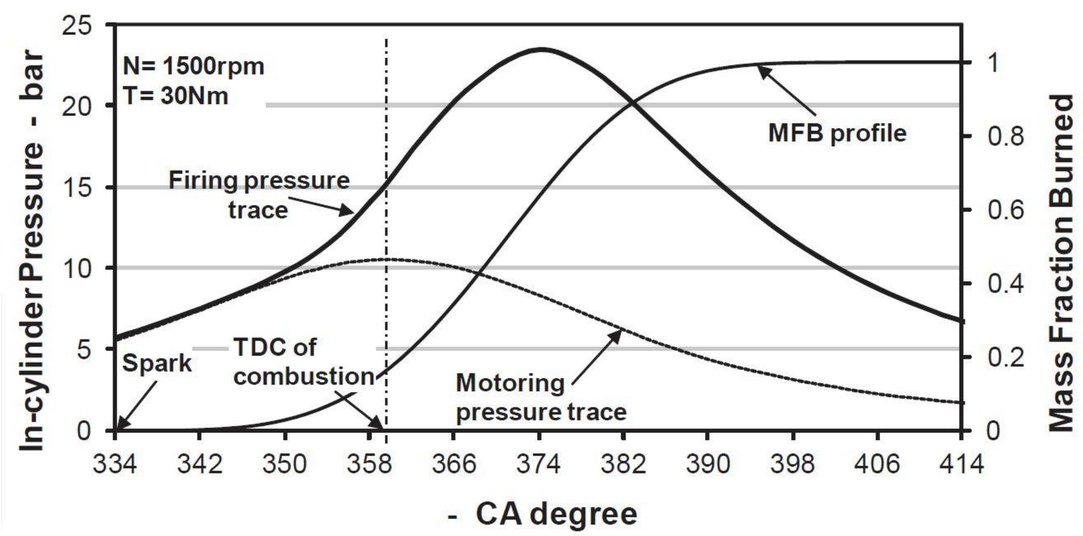
In this day and age you can make almost anything you think of and even have a 3D printed prototype on your desk within days.

With the photos of 3d titanium prints above I get the idea of making pistons or pushrods This illustrates that in this day and age your imagination is the only holding you down.



The burning of a mixture is a 3D process. Imagine all the available mixture represented by a sphere . The mixture is consumed from the middle outwards(it starts with a spark in the middle). All the points at a certain radius are linked together over pressure with the parameters of a gasoline bomb (exponential). It is easy to see that when you do something at the start that would change parameters of the orange to look like the parameters of the small yellow then the blue would get the parameters of the green. When condensation starts all the linking parameters are changed from that point on.(it is no longer a bomb).



When we look back at this picture. At TDC we consumed 18% of the fuel so at TDC we are at 55% of the radius (about the red globe) so at TDC we also start condensation in the green and blue shell.

We used 18% to light the fuel until TDC (While it was pressing the piston in reverse. At the other side of TDC you get the power back but it still does not add to the result because -18+18=0)

I think the Mass fuel burnt curve (MFB) is a little optimistic at the end because the last of the burning off occurs in the exhaust stroke.

We are now going to look at the condensation stages and how they affect the burnt mixture we take this a stage for stage because lowering the pressure would restore the mixture.

The condensation starts at 14 bars and first we get a linear curve which stops at 20 bars at 14 bar no fuel was condensated and at 20 bars the amount of fuel remaining in the mixture is 14/20. So 6/20 of all the fuel remaining has condensed. At 20 bars the fraction burned has gone up to 30% Simple Integration for the fuel burned from 18% to 30% MFB leads to a total of 0,5*0,3= 0,15 *12% =1,8%.

After the linear part we get a downward quadratic part up to 23 bar and back to 22 bar where fuel is condensed out and vapourized back into the mixture the MFB @ 22 bar is 80% leads to a total of 0,50 +0.3 = 15%. The than still remaining 20 % have also condensed but with a **total** of 0,3= 6 %

We lost 23% in condensation and 18% in ignition so we burned at a 59-41 effective to ineffective ratio.
This means that is you burn only 6% of fuel more effective you would get a mileage (or power) improvement of 10 %.

Adding water (protect your cold parts with steam)

This could be used in both new and existing engines
(This is the part for chip tuners, aftermarket developers and automobile manufacturers)

Although having plain water on board is a pain in the neck when it freezes and maybe you would have to do some filtering like reversed osmosis to prevent calcium build ups in the steam converter/nozzles, but the fuel saving could run up to 15-20 % and the exhaust gasses would be cleaner so you would not need for a soot/fine particles filter. (some people even drive electric cars for the environment)

The steam would have to condensate at a given pressure at the end of the exponential stage of the burn, **before the fuel condensates**. In our pressure chart this would be 12-15 bar. This would lower the pressure build up by also condensing the water produced in the reaction and would make the burn off easier because the condensed fuel does nor land directly on the cylinder head but on the water.(less unburnt less soot/fine particles).
There might be some reservations on the issue of condensation of water, but with the given reaction the condensation of water would occur anyway when half the fuel was burned and this would have landed on **top** of the gooey stuff (making the burn off even harder) and now you can hope the water condensed from the reaction creeps under it and propels the unburnt fuel back into the flame when the water evaporates.
To avoid having the thermal loss from the evaporation heat of the extra water ingested you could make steam with residual heat of the exhaust pipe.
The best way is to inject the steam directly into the cylinder at the end of the intake stroke. A spark plug with a steam channel(with a check valve). The steam would come from a valve controlled by the ECU. For aftermarket developers that don't want replace the ECU it would be easier to introduce it in the intake part. If you make a steam converter that would deliver the right amount of water at a winters day at full throttle, chances are that on a moist summers day at idle the steam would be so hot it would interfere with the air intake. Therefore: cool it back to the temperature you need. If you introduce it just after the air filter you need about 105 degrees Celcius. If You have a turbo and you know its maximum pressure you should introduce the steam after the intercooler and you would have to consult a steam table for the steam temperature at this pressure. Or regulate it from the ECU.
Introduction of steam before an intercooler does not look good to me because you might condense water which would find its way to a cylinder when you take a corner making you find out the hard way that water is somewhat incompressible.
Power freaks could also choose to switch from steam to sprayed water at high loads . This would be less economical but the air would cool and the air would become denser through the evaporation of the water and would give more POWER.

All you need is :

the air quantity taken in (the ECU already knows this in grams/s)
a (kg water) / (kg air) sensor (the best place is near the air temperature sensor and maybe the two could share the same A/D converter in time sharing using a spare output discrete to govern the time sharing)

a dosage pump (you would need a spare analog output of the ECU to steer it, or if you only have a spare discrete you could send a code with it)

some tubing and a water tank (and last of all :some water)

And if there are more spare inputs and outputs on the ECU you could come up with a plan to take over temperature control. (and map out unnecessary enrichments)

Note: If you don’t take over the temperature control you should also ”enrich” the added steam because it will also condense later.

This section is for tinkerers only

Buy an old laptop and make it work on 12 V. ($40)
Buy an OBD(II) interface to go with it(USB RS232).($40)
Download an OBD(II) program at Sourceforge for Windows (free)
Download the free Microsoft Visual C++ compiler environment (free)
or the GNU C++ compiler (also free)
Compile the program and run it as an OBD program as a test (you could do the maximum air intake test)

Tinker with the program and Laptop to get a steady flow of air intake messages.(a lot of work but free, however you could invite a programmer friend which will set you back two cases of beer)
Download Microsoft DirectX and find a sample program (MSDN) for sound output (free)Or find a Sourceforge program that can output sound.(also free)
Combine the two programs so you can output a 1000Hz block wave at a given level The 1000 Hz is chosen because the pump motor has to run at very low speeds When you regulate DC motors using just DC levels they are harder to regulate then when you give a chopped signal. You might even try to steer by varying the width of the block wave but keep the positive and negative waveforms equal because audio circuits tend to be AC coupled and not DC

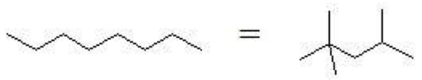
Here we get into how much water you want to ingest. To test this you connect your PC to the ODB, display the air taken in and get a passenger beside you to read the maximum value when you really put your foot down at high revs. The next reading you take is that of idling with a heated up engine and no air conditioner you will need that later.
The maximum reading will give you the maximum in grams/second. Multiply this with 0.06 and you will have the kg/min. (pump specs are in l/min)
For example: you read a max of 83 grams/second you will get 5kg/min.
Your cylinder head inside will be approx. 100C. The steam table value for 100C is one bar (surprised?) . You want condensation at 12 bars (so you have room for experiments). Thus the partial water vapour pressure at 12 bars cylinder pressure should be 1 Bar. The amount of moles of water /(moles of water +moles of air) = condensation pressure/cylinder pressure=1/12. A mole of “standard” air has a weight of 29 grams so in 5kg there are 217 moles. Rewriting the partial pressure equation gives: (12-1) moles of water =217. You need 127/11=19,7 moles of water. A mole of water has a weight of 18 grams so you need 160 grams of water/min. as a maximum.
A nice way of dosage is a miniature cogwheel pump used with miniature airplanes as a fuel pump. ($30)
You can burn 5 kg of air with 5/12=0,4 litres of gasoline 0,4/0,16=1 litre of water for 2,5 litres of fuel this will give an idea of the water reservoir needed .But if during your experiments you find out that the cylinder head temperature is 80Celcius and you look in the steam table the condensation pressure is only 0,5 of a bar so you need only 1 litre of water for 5 litres of fuel. And if you find out you only have water condense at 14 bars instead of 12: 1 water on 6 fuel.
Now we have to amplify the headphone output of the laptop, you could use an old car radio with an auxiliary input or buy a booster.
E.g. you buy a cheap stereo car audio amplifier (booster)$20-40 best with an adjustable input or use variable resistor as volume control car radio booster .

Connect it to the earplug output of the Laptop and rectify the output of the booster with a diode $0,3 or bridge rectifier $2 and use it to power the pump. Be careful not to burn the pump because some boosters put out a lot of Volts so regulate it back with the variable resistor and beware that in a lot of boosters **neither** of the speaker outputs is ground (it will save some fuses and /or end stages).
First you regulate the maximum output with the level control of the booster to be at the maximum you calculated when the PC puts out the maximum square wave level.
Measure the amount water you pump from a bucket into a measuring cup in 1 minute.
Next thing is you put the square wave level at minimum and look if there still is a steady flow (if the pump starts the stalling –or stops totally)and if the smallest flow is small enough to feed water at idling speeds. If it stops find out at which level it starts running again and measure the amount of water there and calculate how little you need at 15 bars condensing and a 80degrees cylinder head temperature at idle speed. If the water coming out is way too much you could try to regulate pump by switching from amplitude to duty cycle from e.g. four times the starting speed level downwards and see if this remedies the stalling pump.
When this is finished you can make a table of which water output goes with what level When it is linear you need a few points when it's not you have to take extra measurements
Make the laptop calculate how much water is needed with grams of air going in to the engine and produce the 1000Hz tone needed.
Attach a piece of pipe to the exhaust using hose clamps (this is your steam generator)
Attach a temperature sensor like the old thermostat of a coffee machine/ water boiling kettle to the pipe and attach it to the coil of an automotive relay, having a stationary contact. Attach the other contact of the thermostat to ground and the other end of the relay coil to wire that is live when contact is on (preferably with a fuse).
Use the stationary contact in the pump circuit (the thermostat goes in off state when you want the pump to go on)
Attach your newly built dosage pump to one end of the pipe with a hose
Attach the other end of the pipe to the intake tract of the engine with a hose.
Attach the dosage pump to the water tank
Fill the tank with water
For the purists that really want to save water: Look on the hygrometer and thermometer on the front porch.
Calculate the grams of water in the air with a steam table (or have a table in the Laptop) give this as an input to the computer so it can compensate for this.

And You're off Lots of fun

Appendix 1

*1 When you look at the following reaction



By formula: $C_8H_{18} = C_8H_{18}$

Quantity	Value	Units	Method	Reference	Comment
$\Delta_r H°$	-9.4 ± 1.0	kJ/mol	Ciso	Prosen and Rossini, 1945	liquid phase; Calculated from ΔHc

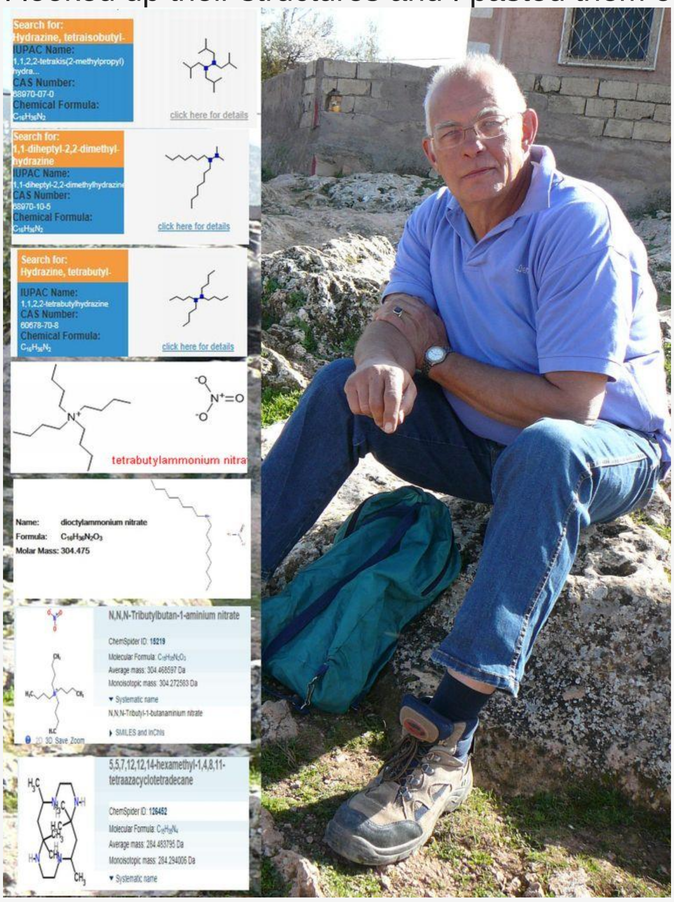
It is easy to see that you get energy when you straighten the isooctane molecule.

So I looked up the candidates for C16H36NxOx

And here are the results:

1.Hydrazine, tetraisobutyl- (C16H36N2)
2.Hydrazine, 1,1-diheptyl 2,2-dimethyl- (C16H36N2)
3.Hydrazine, tetrabutyl- (C16H36N2)
4.tetrabutylammonium nitrate (C16H36N2O3)
5.dioctylammonium nitrate (C16H36N2O3)
6.Ammonium nitrate, tetra-(n-butyl)- (C16H36N2O3)
7.cis-(5,12)-7,7,14,14-Hexamethyl-1,4,8,11-tetraazacyclotetradecane (C16H36N4)

I looked up their structures and I pasted them on a holiday picture of me

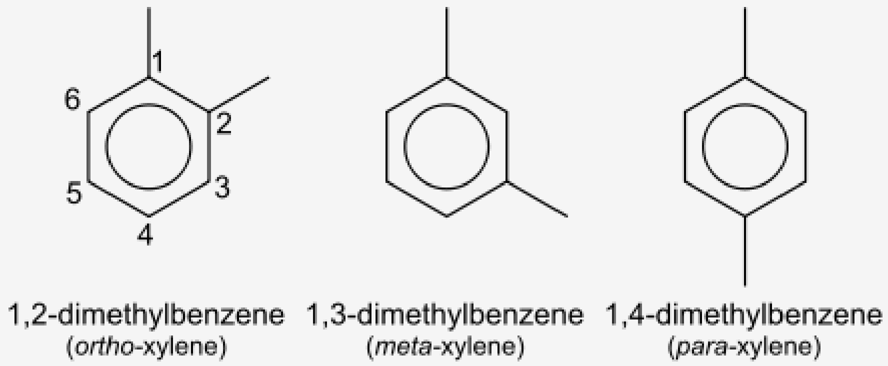


The structures together with the knowledge something straight has to come out narrows it down to 2 and 5.

However the formation enthalpy's of these large molecules have never been measured. In a discussion with Prof. dr. Lauth, university of Aachen I went for a known molecule palmitic acid $C_{16}H_{32}O_2$ which led to an energy surplus of 784 kJ/mol Which leads to the following guestimate: deduct the formation of 1 CO2 and 2 H2O and add the formation of ½ of CH4 which leads to
785-775+36=46 which is considerably more than the 2x 9,4 kJ/mol from the straightening so I think larger molecules have a tendency to have a lower formation enthalpy's than the sum of the parts.

As you might have noticed, the calculated condensation pressures are lower than the measured values. I think this is due to instability of the hydrazine and that with temperature the hydrazine disintegrates easier and on the other hand the formation gets easier so that there will be an equilibrium at 90-95% formation.

Xylene is a well-known anti knock agent



And just looking at it makes you wonder if it could snatch up 2 linear alkanes helped by N2 and/or O2 .

For diesel engines I have done some postings on the dieselnet forum.

The condensation is much easier to prove due to the high boiling point (180C- 220C) of diesel.

http://dieselnet.com/forum/viewforum.php?f=3

injecting steam just after intake stroke

by **peterr** on Tue Jul 15, 2014 1:50 pm

Maybe most of you never thought of a cylinder head as a condenser however at top dead center (where most of the burning is done) piston and cylinder head are only millimeters away from each other. That is why the mixture is in close contact with the cylinder head. E.G. a diesel running at lambda=3 with a cylinder head temperature of 90 C. Diesel fuel is a mixture with a mean of C10H22. From Raoults law we know all these different components will give one common vapour pressure. Let take C10H22 as the mean. At lambda =1 it would represent 1.7% of the moles in the mixture wich is also the partial pressure . At lambda =3 it is 0.5%. The vapour pressure at 80C below its boiling point will be 3% of a bar. This means that at 6 bars total pressure it starts condensing. I think a nice way to improve on the mileage is to add steam to process in such a way that the condensed fuel would land on top of the water. As most diesel inject at greater pressures the water would not have to condense at 6 bars but only when enough diesel is injected in. This would A. lower the pressure by condensating the H20 formed by the reaction before TDC (less NOx) because after TDC the piston will slow down the reaction by reducing the pressure and B. facilitate burning off from the cylinder head (giving better mileage and less soot) . Has anyone tried this approach? I mean trying to focus on the cylinder head instead of focussing on the fuel (Wartsilla)?
peterr

Posts: 6
Joined: Tue Jul 15, 2014 1:31 pm
Top

Re: injecting steam just after intake stroke

by **peterr** on Thu Jul 17, 2014 6:04 am

I have given the wrong example (I only started to look at diesel engines this week AT lambda is 25 (partial pressure=0.068%) the pressure where the fuel would start to condensate would be 44 bar. And I have found out that there are many types of diesel fuels (look in the fuel specification what the boiling point is). And of course the given temperature applies to the inside of the cylinder head so you must also correct for temperature gradients
peterr

Posts: 6
Joined: Tue Jul 15, 2014 1:31 pm
Top

Re: injecting steam just after intake stroke

by **peterr** on Mon Jul 28, 2014 3:48 am

I had some trouble finding the exact vapour pressure curves the larger carbon hydrates. All I found is this rather old (like me) graph of vapour pressures in torr. And as a guestimate, when you know the boiling point and have the temperature of the inside of the cylinder head then you also know the temperature difference. With this difference you look up the pressure from the boiling point down. by the way octane has a boiling point of 125 Celcius.
Attachments

Phase_Change_Diagram_for_Liquid_Alkanes.jpg (120.17 KiB) Viewed 780 times