FUEL FEEDING SYSTEM FOR A PRE-VAPORIZED ETHANOL ENGINE

Francisco José Alves, laranjatomate@yahoo.com.br
Sandro Guimarães Souza, sandro@sc.usp.br
Josmar Dawilson Pagliuso, josmar@sc.usp.br
São Paulo University, São Carlos Engineering School, Mechanical Engineering Dept.; Av. Trabalhador Sãocarlense, 400, 13566-590, São Carlos-SP, Brazil

Abstract. *Pre-vaporized ethanol engine (PVEE) has the potential to be more efficient and less polluting than conventional ethanol-powered engines. In it, the fuel is vaporized with the heat rejected by the engine through the heat from cooling water or lubricating oil and intook in gaseous form, taking advantage of this kind of fuel but without some of its inconveniences. The PVEE project, developed at São Carlos Engineering School since the 80's, was polished looking for economical and technical liability for future use in automotive vehicles. New gaseous fuel injection technologies recently available in Brazil have contributed to this goal, together the development of a sustainable and self-adjustable ethanol vapor generating system which uses water from the engine's cooling system.*

Keywords: *Gaseous fuels, renewable energy, fuel injection*

1. INTRODUCTION

Recently the use of ethanol as fuel in Otto internal combustion engines has recovered its prestige and importance it once had in the past. Since the release of IPCC's (Intergovernamental Panel on Climate Change) reports in February and April 2007 (IPCC, 2007a,b), which confirm the hypothesis that climate changes are caused mainly by human activities, environmental questions have gained space in the media all over the world. One of its consequences is the demand for renewable energy sources for transportation media like ethanol and biodiesel. Brazil plays an important role in the production of these fuels and have gained the attention of other countries, which are looking for trade and technology transference agreements to use them alone or blended with fossil fuels to reduce their emission of greenhouse gases.

Due to the huge energy demanded for moving automotive vehicles around the world, it is necessary to stress that renewable fuels and internal combustion engines must be used in a responsible way. Although being renewable they may cause enviromental and social impacts, mainly those due to land use for their production, according to appointments of Ruz(2007) and Ludd(2002).

Brazil is not only a good supplier of this raw *commodity*, but also a developer of related higher built-in technology goods, like ethanol-powered engines. Earlier projects held at São Carlos Engineering School-São Paulo University (EESC-USP) since the 1980's (Celere, 1981; Feitosa, 1998; D'Ávila, 2003) have developed this technology, highlighting the use of vaporized ethanol. The advantages of ethanol use are synthesized and further explained in Pagliuso's project (1999).

As ethanol is a pure substance, differently from gasoline which is formed by dozens of hydrocarbons with different boiling points; there is the possibility of evaporating and intaking it on the engine in gaseous form, since blends of distinct fuels will not be made in the same tank, as in *flex fuel* vehicles. Gaseous fuels have some advantages and disadvantages in relation to liquid fuels. Some of them can be mitigated with the use of vaporized ethanol instead of standard gaseous fuels.

1.1 Advantages of liquid and gaseous fuels

The main stimuli for developing an engine powered by a gaseous fuel are homogeneity of air-fuel mixture and greater tolerance for lean mixtures. Homogeneous mixtures burn in faster and complete way, offering potential to less fuel waste. Kazakov et al. (2003) realized experiments with ethanol droplets of several diameters in microgravity environment and related computational simulations for the comparison of results. They observated smallest droplets burn in less time, as the larger ones need more time to heat fuel, diffuse it into air adequately before flame front arriving. There is also condensation of water vapor of air, which supplies latent heat to the droplet but takes the final of this process more difficult.

Strahle (1993) and Kanury (1992) showed homogeneous flammable mixtures can burn in a wider range of air-fuel ratio, even in rich or lean direction. The use of lean mixtures is advantageous when one aims to for obtain the same torque in some internal combustion engine with a greater opening of throttle valve. Less choking of air flow leads to less head losses and better yield.

Souza (2004) claims to the fact an internal combustion engine operating exclusively with gaseous fuel can have a combustion chamber format optimized for more efficient burn, without worry of create too high turbulence levels on intake air needed for misture homogenization, which has the side effect of leading to undesirable heat exchange with combustion chamber walls.

One of the main inconveniences in using Compressed Natural Gas (CNG) in automovtive vehicles is the need for installing heavy tanks to store it at pressures near 20 MPa, which increases vehicle weight, alters the behavior of vehicle's suspension system and take too much space. In the PVEE case a smaller boiler evaporates fuel in a *just-in-time/on demand* way, according to the engine's needs. In the present study manometric presures of ethanol under boiling did not reach 80 kPa, and the steam generator has dimensions compatible with the space available under the hood.

On the other hand, there are also advantages in using liquid fuels which disappear when switching to gaseous fuels. In the case of ethanol the main one is the cooling effect due to the fuel evaporation inside the cylinder. Where the latent vaporization heat of ethanol is nearly 3 times gasoline's, and ethanol-powered engines consume nearly 1,6 times the mass of fuel due to its lower heat release; in each cycle ethanol present in the cylinder is capable to absorb 4,8 times latent heat absorbed by gasoline during aspiration and compression strokes. This leads to lower temperatures and pressures during compression stroke and less compression work realized on the fluid, increasing the liquid work of each cycle.

Beyond the gain in the liquid work per cycle, the stronger cooling effect leads to lower maximum flame temperatures, with response in fewer nitrogen oxides (NO$_x$) emissions and fewer predisposition to knocking.

Table 1. Physical properties for ethanol.

Property	Value	Property	value
Latent heat of vaporization (J/g)	1020	Density at 99°C	717
Superior Combustion Heat (J/g)	27710	Research Octane Number	110
Inferior Combustion Heat (j/g)	26839	Viscosity (Pa.s) at 20°C	1,20
Density (Kg/m^3) at 15,6°C	794	c$_p$/c$_v$ for air-ethanol stoich. mixture	1,34

Source: Rose and Cooper (1977)

2. MATERIALS, EQUIPMENT AND METHODS

To produce ethanol vapor, the heat rejected by the engine can be used through exhaust gases, lubricating oil or water from the cooling system. The last option was chosen as it is safer than dealing with surfaces at near exhaust manifold temperatures, which could produce great quantities of vapor instantaneously when in contact with fuel, and the capacity to offer greater heat capacity than oil, because there is more water than oil circulating through the engine and water has higher specific heat. The disadvantage relies on a narrower temperature difference between cooling water (which must not be higher than 100°C by safety reasons, having a minimum value of 94°C) and boiling fuel (which floats in the range of 86°C – 93°C).

As there are not many studies of ethanol ebulition (in this field, studies of commonly boiled fluids like water, ammonia, oxygen and refrigeration fluids predominate) it was ncesssary to take conservative estimates. It is well-known that surface treatment, wall superheating (difference between wall heat and saturation temperature for a fluid under a given pressure) and fluid's surface tension behavior have influence on the heat tranfer ratio with phase change. A study by Thome (1990) shows that ethanol boiling on a smooth metallic surface, the boiling starts witk a 6K superheat, suddenly raising to the level of 100kW/m^2 before 10K of superheating.

A 48-tube copper beam was built, having 235mm of length and 4,7625mm(3/16") of diameter each, totalizing 0,3375m^2 (0,2250 m^2 on the internal side) of heat transfer area. The external surface, which is in contact with boiling ethanol, was sandblasted aiming to create microchannels which improve the heat transfer rates in a simple and cheap way. Water outgoing engine's cylinder head is transported to the boiler through an insulated hose, next flowing to the cooler.

Experiments previously realized in the same engine (D'Ávila, 2003) had showned a maximum fuel consumption of 5,2g/s. From the room temperature of 25°C up to ebulition temperature of 97°C, and adding latent heat needed to boil fuel, the required power is

$$\dot{q}_{vaporization}\left[c_p(T_{ebulition} - T_{inlet}) + h_{lv}\right] \cong 5700W \tag{1}$$

Admiting cooling water flows in an order of 1kg/s, only 1/3 of the fuel burning energy is converted into work and another 1/3 is wasted through cooling system. There is a temperature fall of nearly 10°C through the cooler:

$$\dot{q} = \frac{Q_{comb} \times PCI}{3} = 45690W \tag{2}$$

$$Q_{agua} \cong \frac{\dot{q}}{c_p\,\Delta T_{radiador}} = 970g/s \tag{3}$$

For the internal side, where water from the cooling system supplies heat for ethanol boiling, the heat exchange without phase change has the following procedure to calculate the heat transfer coefficient:

$$v = \frac{Q}{A\rho} = \frac{0,97}{3,8.10^{-4} \times 0,9615} = 2,65 m/s \tag{4}$$

$$Re = \frac{\rho v D}{\mu} = \frac{961,5 \times 2,65 \times 3,175.10^{-3}}{2,89; 10^{-4}} = 27992 \tag{5}$$

$$Nu = \frac{hD}{k} = 0,023 Re^{0,8} Pr^{0,3} = 0,023 \times 27992^{0,8} \times 1,80^{0,3} = 99,07 \tag{6}$$

$$h = \frac{Nu.k}{D} = \frac{99,07 \times 0,679}{3,1785.10^{-3}} = 21185 W/m^2K \tag{7}$$

Thermal resistance of tubes values:

$$\Omega_{Cu} = \frac{ln(r_2/r_1)}{2\pi k_{Cu} L} = \frac{ln(0,0047625/0,0031785)}{6,2832 \times 397 \times 0,235} = 6,917.10^{-4} m^2K/W \tag{8}$$

Remaining calculations about external side heat transfer coefficient, which is not directly proportional to temperature difference.

$$U = \frac{1}{\frac{D_i}{D_e}\frac{1}{h_int} + \Omega_{Cu} + \frac{1}{h_{ext}}} \tag{9}$$

With an estimated temperature difference of 14K, and a heat flux evaluated as 16800W, the minimum heat transfer coefficient should be:

$$U_{min} = \frac{\dot{q}}{\Delta T} = 1206 \frac{W}{m^2K} \tag{10}$$

Since the heat flux avilable for a temperatura difference of 14K is evaluated as nearly 50kW/m^2 for the heat transfer surface used, according to Thome's (1990) evaluations.

$$h_{ext,min} = \frac{1206}{0,944779} = 1276,5 \frac{W}{m^2K} \tag{11}$$

Due to the proximity between values of minimum heat transfer coefficient on the external side and the minimum heat transfer coefficient required, it ispossible to observethat the thermal resistences of copper tubes and convection on the internal side are less important. Having minimum coefficient required on external surface, temperature difference between it and fuel (wall superheat) values:

$$\frac{q''}{h_{ext}} = \frac{16886 W/m^2}{1276,5 W/m^2K} = 13,07K \tag{12}$$

Which is enough to promote boiling, according to ethanol-boiling relationships presented by Thome (1990).

Another important concern in projecting the boiler is the PVEE operation in transient regimes. It is not a good idea to have huge amounts of vapor accumulated for use in high demand moments, but produce it as safer as possible according to engine's consumption. The new technologies introduced on aftermarket CNG conversion kits sold in Brazil allow controlling a gate valve between the pressure reducer and the intake throat, instead of having a gas carburetion with fixed-opening valve regulated only once, according to the technician's experience. The introduction of this kind of CNG kit was important to reduce the consumption and polltuant emissions of CNG vehicles, which were raising in some Brazilian cities due to the popularity CNG has achieved.

In PVEE's case when the fuel demand increases and the gate valve opens, there is a pressure drop inside the boiler as in that moment the consumption is larger than the production, subtracting a net quantity of vapor from it. Lower pressure leads to lower saturation temperature, which leads to larger wall superheat and vapor production. In the long run *flash vapor* created by pressure drop can meet new engine's demand. On the other hand, when the consumption decreases and the gate valve closes some steps, the vapor acculumation leads to a pressure raise. Therefore the saturation temperature becomes higher and closer to the wall temperature, allowing for a smaller producion of vapor.

The CNG kit used has also a *joystick* to do *on the fly* corrections of fuel consumption, controlling the step motor which moves gate valve. Its inconvenience relies on the fact that it is not possible to change its position quickly enough to evaluate the transient regimes.

The ethanol level inside the boiler is controlled by a needle valve (used in carburettors) and a float on its fuel inlet. The thrust made by the weight of the fluid displaced neutralizes the float's weight and makes force enough to neutralize the force caused by fuel pressure multiplied needle's valve's orifice. An adjustable pressure reducer was set up to feed the boiler with a pressure always 0,35kgf/cm^2 higher than those found inside the boiler, because of head loss in the needle valve. Greater pressure difference puts the ethanol level higher, because a higher float thrust is needed to closea the valve. The opposite occurs adjusting the pressure reducer to feed the boiler with lower pressure differences.

A programmable ECU (Electronic Control Unit, the main controller of an electronic fuel injection system) was also used to control the liquid fuel injection during some tests made with liquid ethanol por comparison purposes, and during warm-up when the boiler was unable to produce ethanol vapor. This equipment also allows controlling ignition timing *on the fly*, and finding better ignition advance, for each regime. Switching to gasesous fuel feeding CNG kit turns on the fuel injector simulator, which sends an injector-like signal to the ECU (either the original or the programmable one is in use) when they are off.

The engine used is Volkswagen AT 1000, year of manufacture 2001, water-cooled, with 4 in-line cylinders, one intake and one exhaust valve per cylinder, 999cm^3 of displacement (bore=67,0mm, stroke=70,6mm), originally ethanol-powered, and compression ratio 14,1:1. In all tests performed the engine ran with neither air filter nor catalytic converter.

2.1 Adaptations to gaseous ethanol

The suction throat (also known as Venturi) supplied to the CNG kit is unable to deal with gaseous ethanol. Another throat was built, using ethanol-compatible materials (corrosion is the main concern), tangential fuel admission and toroidal chamber to symetrically distribute fuel in the suction region. Its angles are smoother (8°and 9°) to cause fewer head losses. This new Venturi is also unmountable and has non-passing holes supplied with water from the cooling system to keep it warm and avoid ethanol condensation.

Once the original pressure reducer from CNG kit was not used (pressure ranges are different), the gate valve was subject to higher pressures of fuel from the boiler. The pressure reduction was made at the gate valve, through a narrower channel made on a brass plug. PTFE and Polyamide (Nylon®) poles were used to insulate the electronic devices of this valve, like step motor from high temperatures of its shield due to contact with vaporized ethanol. There is a jacketed tube to transport ethanol vapor between the boiler and the throat. The vapor is transported along the inside tube and protected from condensation by water from the coling system flowing along the outside tube. A 20mm long transparent hose allows ensuring that there is no liquid fuel entering the Venturi.

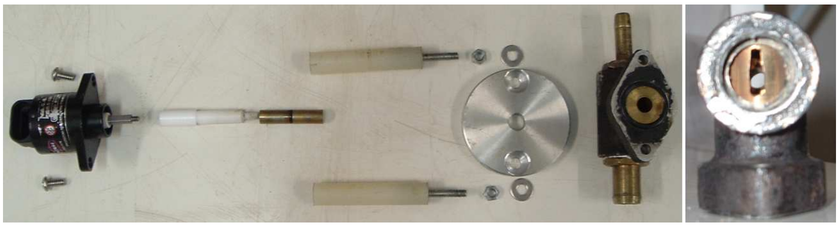

Figure 1. Adaptations in gate valve and step motor for gaseous ethanol.

As there is no pressure regulation at the boiler exit, the pressure on it must be kept constant. The thermostatic switch was substituted by an electronic control of cooler's fan speed, because oscillations in water temperature influence the in boiler pressure, gaseous fuel production and consequently air-fuel ratio. A pressure regulator adapted to gaseous ethanol and to fuel flow required by an internal combustion engine would allow eliminating this manual control (there is no control system, fan speed was controlled manually) and using a gate valve similar to that originally used in the CNG kit. Plenty of hability was required to keep the water at boiler inlet varying in a narrow range, considering it passes through the boiler, cooler, returns to the engine (receiving heat) to go back to the boiler. In any kind of feeding, fuel consumption was measured using a weighing scale and optical sensors. After the pointer had passed through the optical sensor, a 100g weight was put on the secondary tank which supplies fuel directly to fuel pump. Time interval between the two passages indicates the time for consumion of 100g of fuel. In each case five measurements were taken, with exceptions of four or three in some of them when the engine was not working stably. The aritmethic mean was taken as fuel consumption.

2.2 Strategies for PVEE operation

When running in vaporized ethanol, similar conditions of torque and speed were pursued, in relation to the original fuel injection system. Efficiency (work done by fuel consumption ratio) and emissions were compared, in some cases dealing with specific emissions in g/kWh. Some attention was paid to slightly less efficient regimes which promoted an abrupt fall in emissions.

Speeds of 2000, 3000, 4000 rpm in throttle positions of 25%, 50% and WOT (Wide Open Throttle) were run with original fuel injection system for the comparison of results. When on gaseous ethanol, tests had begun from the same

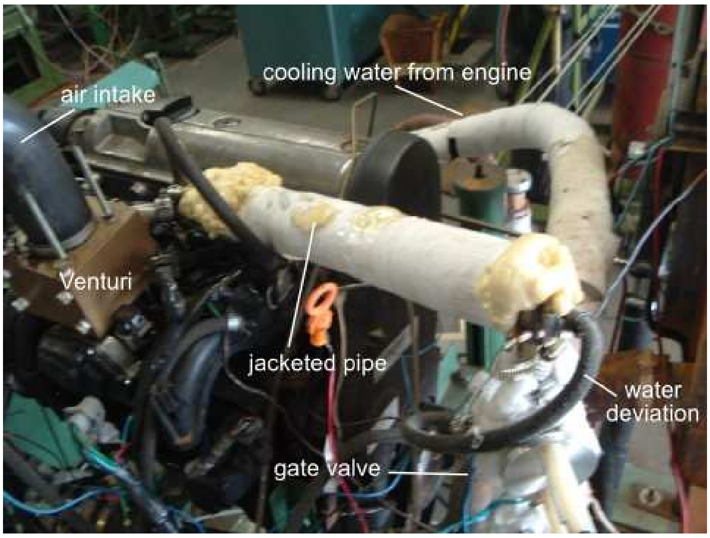

Figure 2. Ethanol vapor transport equipment from boiler to throat.

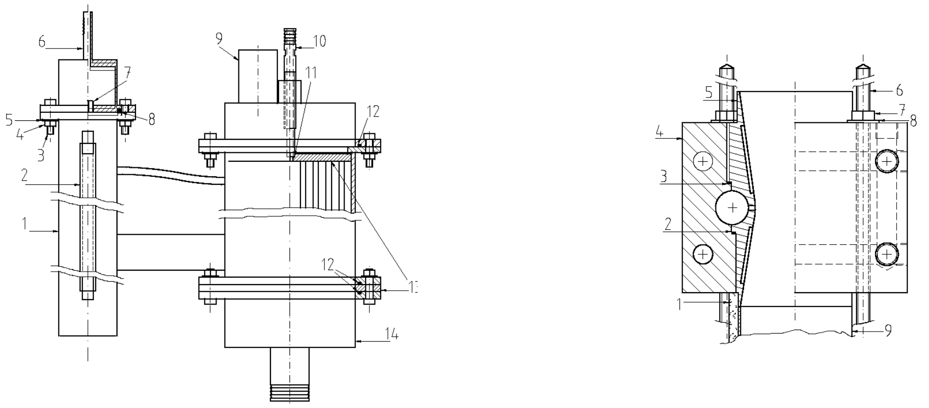

Figure 3. Boiler and throat.

throttle position and stoichiometric mixture, opening it and taking the mixture leaner, without change gate valve position. Some of them had lead to very different torques compared to the original regimes, requiring new tests with original ECU in throttle positions which give the same torque and speed read on equivalent vaporized regimes. Therefore, a fair comparison of consumption and emissions could be made.

3. RESULTS

Vapor production ceased when wall superheat fall to less than 6K. This was done in some tests when the cooler fan was turned on in its maximum speed to lower cooling water temperature. This result complies with that presented by Thome (1990).

It was not possible to stablish stable regimes neither for idle condition nor at 4000rpm WOT. In both extreme conditions the water temperature in the boiler's inlet was oscillating in an irregular way, blocking regular fuel supply. In the second case the engine got very sensible to detonation, being impossible to find an ignition timing which combines satisfatory torque and absence of knocking. It was not possible to run the engine in the case of excess of air lower than 50% because the boiler was unable to supply more than 3,0g/s of ethanol vapor. The head loss in the boiler's exit is the main cause for it. Under these limit condition the boiler pressure did not fall, which indicates it was still able to feed the engine. The window made on the plug put on gate valve shell has an area similar to the pipes where ethanol vapor is transported, beig not a problem when it is wide open. Also, the spark positioned on one side of the combustion chamber instead be on its center, raises time needed to burn the misture completely, bringing to the knock phenomenon in high power reimges. It is also important to remember there is no in-cylinder cooling effect, because the intaking gaseous fuel has no latent heat to cool the flammable mixture.

In general, intermediate regimes operated with gaseous ethanol got better efficience using the strategy of keeping fuel consumption and raising air consumption with wider throttle openings. Lesser head loss improved efficiency, helped by more homogeneous mixture, which allowed a more efficient burn. Some stoichiometric regimes registered better efficiency compared to those run with original fuel injection system. Even with the same position of gate valve, larger air consumptions lead to fuel consumptions a bit higher, because suction effect is higher at throat, which is conic and suctions fuel at its minimum diameter just to take its machining easier, not to provide gas carburetion effects.

Carbon Monoxide (CO) emissions were the easiest to control, staying lower than 0,11% with just 5% of air excess. The NO_x emissions were on 2000ppm level in both liquid and gas fuel feeding, having inprovement in specific emissions when there was an increase in efficiency. These emissions fall surely just with $\phi > 1,35$, where ϕ is the air-fuel ratio divided by its stoichiometric value (8,33 for hydrous ethanol). Some isolated cases gave lesser NO_x emissions with ϕ in the 1,12–1,20 range; but without a defined pattern. It is difficult to combine high efficiency and low NO_x emissions, either controlling air-fuel-ratio or ignition timing, because both attitudes do opposite things with these emissions seting up them in opposite directions. Few regimes combined these two goals.

Total Hydrocarbons (THC) emissions reduce with increase of air-fuel ratio until a certain inflexion point, after which it raises again because irregularities in flame porpagating inside cylinder. Running on vaporized ethanol this inflexion ponit occoured with different values of ϕ in each regime, in the 1,10–1,40 range. Curiously there are regimes with higher efficiency and higher THC emissions, compared in the same speed-torque combination, which means a better burn can lead to even better efficiences. There is a suspecton on flame extinction on some places of combustion chamber, because THC emissions are higher in some cases and CO ones are small. It can be supposed that where flame passes it burns well leaving few CO partially burnt, but where flame doesn't reach all the combustion chamber there will have unburnt hydrocarbons. Exhaust gases analyser used was designed to use by gasoline-powered engines, so it reads propane molecules in its THC reader. It doesn't read aldehydes too, an important emission of ethanol-powered engines. Propane molecules are greater than of THC's emitted by an ethanol-powered engine. So, it can just offer a comparative measure between distinct kinds of supplying fuel in the same engine.

It was possible run the PVEE with more than 70% of air excess ($\phi > 1,70$), but with low efficiency and unfavorable THC emisson levels. At least by now it is not possible to operate PVEE without throttle valve and just dosing fuel flow, like in Diesel engines. A *brake by wire* algorythm for control throttle opening looking for offering more efficient regimes is the more proper way.

Combustion was slower in almost all regimes run with gaseous ethanol, compared to their equivalents in liquid ethanol. Despite the mixture is more homogeneous and flame front reaching all fuel vaporized, fuel dilution (lean mixtures) compensates this effect and decreases flame speed. This requires bigger combustion times and ignition advancing.

Once ECUs are programmed to take air-fuel ratio richer in maximum acceleration regimes, some tests with vaporized fuel/rich mixture and liquid fuel/stoichiometric mixture were performed, to offer a fair comparison between these different fuel injection systems. Tests at 2000rpm and 3000rpm have shown torque loss is lower with vapor/stoichiometric in relation to the liquid case. Slightly rich mixtures can lead the PVEE to greater torques when needed, with lesser efficiency fall and not too high emissions of CO and THC.

Table 2 shows data about some experiments made. Each working regime is characterized by four parameters: speed, throttle position, air-fuel ratio read by linear lambda sensor and ignition timing. Figures 4 through 6 show test results for (2000rpm/24,50% throttle)-like regimes for several air-fuel ratios.

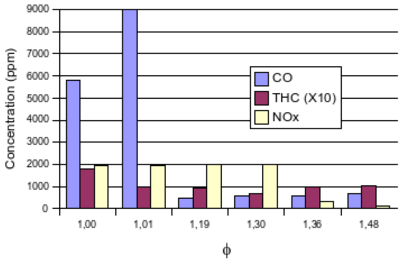

Figure 4. Emissions.

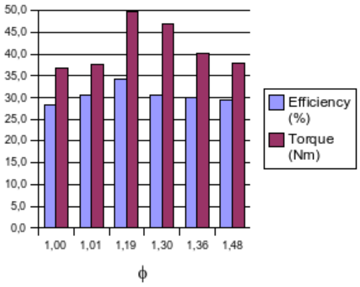

Figure 5. Torque and efficiency.

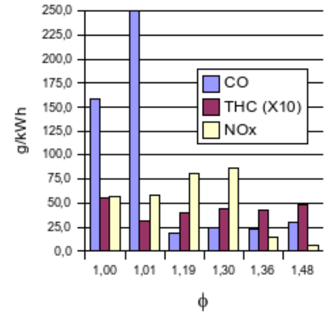

Figure 6. Specific emissions.

3.1 Transient heating

In a PVEE it is important to evaluate warm-up time needed to start vapor production properly. Measurements of water temperature before and after the boiler, lubricating oil and boiler pressure were performed. Two conditions were evaluated: with and without thermostat, which limits water circulation inside engine, allowing circulation to cooler when it reaches a determined temperature). Both runs were performed starting with the whole engine at room temperature, starting from liquid fuel but with the boiler open to the fuel feeding. The switch from liquid to gaseous fuel was gradual,

Table 2. Collected and calculated data for some working regimes.

ω (rpm)	$\lvert\phi\rvert$ (%)	ϕ λ sensor	Ignition °BTDC	CO (%)	THC (ppm)	NO_x (ppm)	τ (Nm)	η (%)	$\dot{m}_{air}$ (g/s)	$\dot{m}_{fuel}$ (g/s)	λ calculated	Feeding type
2000	24,50	1,01	18,7	0,32	1,09	1933	37,70	28,0	9,11	1,13	0,97	O
2000	41,25	1,19	17,4	0,05	92	1977	49,86	34,3	12,31	1,22	1,21	G
2000	34,60	0,97	17,6	0,27	1435	1977	50,04	27,1	12,42	1,55	0,96	O
2000	100,00	0,92	15,8	3,121	724	997	58,60	27,9	13,49	1,77	0,92	O
2000	100,00	0,99	25,8	0,16	997	1989	55,60	30,9	13,45	1,51	1,07	L
2000	100,00	1,01	13,4	0,45	212	1968	57,93	30,9	12,75	1,57	0,97	G
3000	52,50	1,02	14,2	0,30	387	1956	60,80	31,7	20,86	2,42	1,04	O
3000	53,00	1,01	15,6	0,27	176	2004	60,80	32,8	20,49	2,34	1,05	G
3000	100,00	1,22	14,5	0,09	115	85	49,68	30,3	21,45	2,07	1,24	G
3000	100,00	1,24	20,0	0,07	196	1970	52,19	32,9	31,60	2,00	1,29	G
3000	100,00	1,41	17,1	0,08	154	26	39,63	27,8	20,89	1,80	1,39	G
3000	55,75	1,31	23,0	0,08	286	1973	49,68	31,3	21,65	2,00	1,30	G
3000	100,00	0,91	14,0	3,36	568	758	64,40	28,2	21,76	2,87	0,91	O
3000	100,00	1,00	17,8	0,57	95	1946	65,46	32,3	21,53	2,56	1,01	L
3000	100,00	0,95	15,8	2,05	198	1960	62,05	31,7	20,71	2,47	1,01	G
3000	100,00	1,02	14,9	0,21	175	2017	60,98	33,1	20,80	2,33	1,07	G
3000	100,00	1,22	14,5	0,09	115	85	49,68	30,3	21,45	2,07	1,24	G
3000	100,00	1,41	17,1	0,08	154	26	39,63	27,8	20,89	1,80	1,39	G
4000	24,25	1,01	22,1	0,45	431	1203	10,80	14,4	10,8	1,26	1,03	O
4000	29,25	1,14	22,2	0,16	142	750	13,09	18,6	12,12	1,18	1,13	G
4000	32,25	1,22	19,2	0,11	563	70	12,55	14,5	14,43	1,46	1,19	G
4000	25,60	0,99	21,0	0,44	899	1201	12,55	15,9	11,64	1,33	1,05	O

$\lvert\phi\rvert$: Throttle valve opening. BTDC: Before Top Dead Center
Kind of fuel feeding: O=Original ECU, L=Liquid with programmable ECU, V=Ethanol vapor.

cutting liquid fuel injection in small amounts (programmable ECU allows that) when vapor production rises. Figure **??** shows the evolution of boiler inlet and outlet temperatures of water, and oil temperature, for both tests. Figure 9 shows the pressure evolution in both cases. One can note that without thermostat installed water warm-up is faster. In the same way boiler pressure reaches 0,5kgf/cm^2, needed to feed the engine properly, in a shorter time interval when this device is ausent.

4. CONCLUSIONS

PVEE has potential to be more efficient and less pollutant than liquid ethanol-powered engines. It is also possible operating it in some cases with a sligtly lower efficiency and very lower emissions. In these situations a catalytic converter which causes less head losses could be used to compensate efficiency loss.

Advances about earlier PVEE fuel feeding systems was made, remaining further development to put a PVEE-propelled vehicle into the tracks and sreeets. In example, it is possible to use miltipoint fuel injection and injectors suited for gaseous fuels and a *supercharger* for improving air intake, which is damaged by greater space occupied by gaseous fuel.

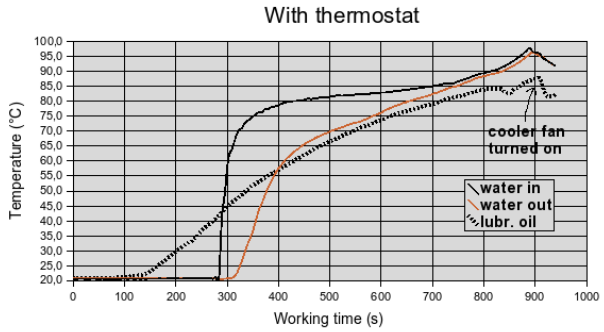

Figure 7. Temperature evolution, with thermostat.

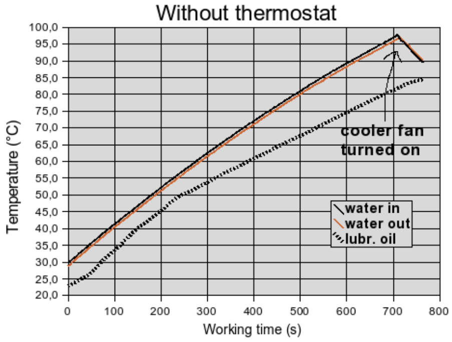

Figure 8. Engine fluids warm-up without thermostat.

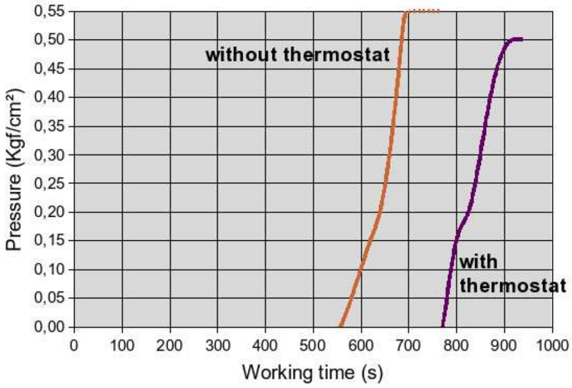

Figure 9. Pressure evolution through time.

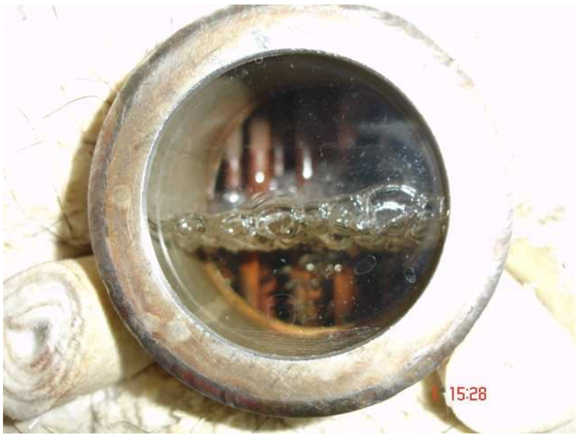

Figure 10. Ethanol ebulition.

Reaching good performance in a narrow range of regimes, it can still be used in hybrid vehicles, where internal combustion engine works near the more efficient conditions, transferring part of the instantaneous non-used energy to a battery which will supply the electric engine later. Stationary engines can use vaporized ethanol too, where natural gas (which is a cheaper *commodity* taking into account the energy content of it and current prices) is not available, PVEE may deliver more mechanical work using less fuel.

5. ACKNOWLEDGEMENTS

Tha authors thank to CAPES (Coordination for College Personnel Improvement), CNPq (National Research Council) and FAPESP (São Paulo State Research Support Foundation) for financial support; “Auto Modelo” Authorized Bosch repair garage and KGM/Netgás Natural Gas Kits for technical support; Virgolino Oliveira Group sugar and ethanol plants for fuel donated; Volkswagen of Brasil for the engine donated, and to the developers of the free softwares used throughout this work.

6. REFERENCES

Celere, S. W., 1981, “Desempenho de motores de ignição por centelha com álcool etílico pré-evaporado”, PhD. Thesis, São Carlos Engineering School, São Paulo University, São Carlos-SP, Brazil.

D’Ávila, M. T., 2003, “Estudo de um motor regenerativo, do ciclo Otto, movido a etanol pré-vaporizado”, PhD. Thesis, São Carlos Engineering School, São Paulo University, São Carlos-SP, Brazil.

Feitosa, M. V., 1998 “Estudo da partida a frio em motores movidos a etanol”, M.Sc. Thesis, São Carlos Engineering School, São Paulo University, São Carlos-SP, Brazil.

Intergovernamental Panel on Climate Change, 2007, “Climate Change 2007: The physical science basis”, Geneva, Switzerland. http://www.ipcc.ch/SPM2feb07.pdf

Intergovernamental Panel on Climate Change, 2007, “Climate Change 2007: Impacts, adapatation and vulnerability”, Geneva, Switzerland. http://www.ipcc.ch

Kanury, A. M., 1992, “Introduction to Combustion Phenomena: For fire, , incineration, pollution and energy applications”, Ed. Gordon and Breach Science, Yverdom, Switzerland.

Kazakov, A. et al., “Detailed modeling of an isolated, ethanol droplet combustion under microgravity conditions”, Combustion and Flame, No. 134. pp. 301–314, 2003.

Ludd, N.(Org.), 2002, “Apocalipse Motorizado: A tirania do automóvel em um planeta poluído”, Ed. Conrad, São Paulo, Brazil.

Pagliuso, J. D., 1999, “Redução de emissões de poluentes nos motores de combustão interna através do uso de álcool pré-vaporizado, injeção direta múltipla e combustão com excesso de ar”, FAPESP Project 99 1964-1. http://www.fapesp.br

Rose, J. W. and Cooper, J. R., 1977, “Technical Data on Fuel”, The British National Comittee, London.

Ruz, F. A. C., 2007, “The internationalization of Genocide”, Granma International, No. 2760, La Habana, Cuba. http://www.granma.cu/INGLES/2007/abril/mier4/14refexf.html

Souza, S. G., 2004, “Um estudo sobre a evolução das câmaras de combustão dos motores do ciclo Otto a gasolina e sua aplicação ao etanol hidratado como combustível alternativo”, M. Sc. Thesis, São Carlos Engineering School, São Paulo University, São Carlos-SP, Brazil.

Strahle, W. C., 1993, “An Introduction to Combustion”, Ed. Gordon and Breach Science Publishers, Longhorn-PA, USA.

Thome, J. R., 1990, “Enhanced Boiling Heat Transfer”, Ed. Hemisphere Publishing Corp., New York, USA.