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Novel high performance steam engines - a better solution than FC and ICE?

2.17.05 *Peter Platell, LOWTE AB*

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During the 60's a growing concern about air pollution from cars ends up with an interest in steam engines for cars due to the inherent advantageous qualities to offer low exhaust gas emissions. The external and low temperature combustion gives favourable combustion conditions and very low exhaust gas emissions. However, the modern steam engine system has many other inherent qualities that make it attractive for stationary as well as mobile applications. During the 70's several steam engine projects for automotive applications were carried out. A JPL report concluded (among others) that steam engine systems would likely not be competitive in automotive applications. However, it is easy to understand why these conclusions came up. There was a low understanding of the particular issues that have to be addressed when realizing a modern steam engine for the future.

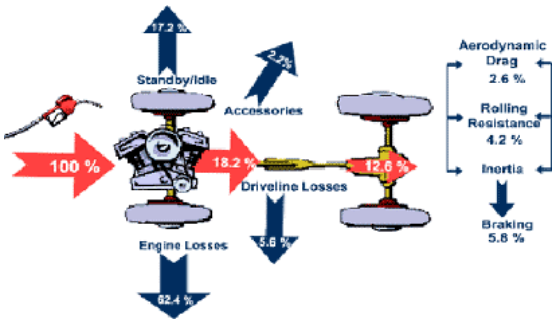


Figure 1 Energy efficient for a typical ICE

Figure 1 (www.fueleconomy.gov/feg/atv.shtml) shows that an internal combustion engine (ICE) only has an average efficiency of 12 % despite that the maximum efficiency for a gasoline engine is 35 %. The main reason to that is that a 200 kW ICE operates at very low loads (10-20 %) almost all it's live where efficiency is about 10 % instead of 35 %. A steam engine has the opposite efficiency characteristic, that is, maximum efficiency at part load (10-20 % load) and lower efficiency at full load. Complete simulation indicate 32 % efficiency at part load for a steam engine, that is 3 times lower fuel consumption for a 200-300 kW engine operating during normal conditions. Figure 1 shows also that consumption at standby/idling corresponds to 17 %. The steam engine system doesn't consume energy when standing still.

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Driveline losses are also lower due to the torque characteristic of a steam engine which involves a very simple gear box.

If considering all desired qualities in an automotive application it seems very well founded to make a deeper look on the novel high performance steam engine system.

The modern steam engine system has a great potential to offer the best qualities form the conventional internal combustion engine system and electric propulsion system without the negative qualities as:

- High specific power (kW/kg, kW/litre, kW/$)
- Low fuel consumption (high part load efficiency, no idling consumption)
- Attractive torque direct at the wheel without any complex gear-box
- Fuel flexibilities (Even solar energy for additional mileage)
- Zero emission driving for a limit range
- Extremely low exhaust gas emissions (In the same order of magnitude as FC)
- Powerful regenerative engine braking (reduced also fuel consumption)
- Low maintain cost
- Low investment cost (two heat exchangers and a reciprocating piston engine)
- High performance but still energy efficient due to high part load efficiency

What does it takes to implement at modern high performance steam engine?

Steam power is associated with large and bulky system producing electricity in centralized large power plants. However steam power embodied as high revving steam engine employing high pressure will offer very high specific power (> 2 kW/kg), which makes it interesting even for aeroplane applications.

Burner will be different depending on fuel but in general all types of fuel can be used. The burner with a large air inlet area compared to internal combustion engine and the continuous combustions process makes it possible to oxidize large amount of fuel and hence the steam engine system is considerably less sensitive to the decreased air density at higher altitudes for instance, which makes it possible to high rate of climbing and altitude in aerospace applications.

Steam Generator (boiler) has to be implemented by multiplies parallel capillary tubes employing laminar flow offering a size of a shoebox instead of a large room as when adopting conventional boiler technology. Besides low weight, small occupied space, high temperature efficiency. Such a prototypes have been built and tested.

A so-called steam buffer is high temperature sensible heat storage for working fluids involving two phases of working fluids. The steam buffer offers a peak shaving function but also short terms energy storage with an energy density of approximately 100 Wh/kg and a very high power density of 10 kW/kg for solar energy stored as sensible heat. The steam buffer also makes it possible to make use of braking energy during vehicle speed retardation in the same ways as electric powertrains. Opposed to electric battery the steam buffer can absorb the high power that occurs during engine braking. Such a regenerative engine braking function could save substantial energy in automotive applications with many starts and stops as for instance city vehicles as buses. A proof of the concept of the steam buffer has passed.

The reciprocated piston engine has to operate without oil lubrications, at least not for the piston rings. Further more, it should be implemented as a high-speed oil-free multi cylinder axial piston engine. The design takes advantages of the favourable inherent torque characteristic which means a vibrations free and low irregular torque (smooth) operating characteristic within the whole shaft speed range. Such design unfolds the use of a simply and cheap gear box or even in some applications (city buses etc.) only the differential. A 300 KW steam engine will measure approximately 280 mm x 400 mm (height x diameter) and has a displacement volume of only 0,25 liters.

High pressure implies high-speed nature, which together in turn gives very high specific power for the steam engine proper. The Steam engine also offers almost the same reversed power output and offers a very powerful engine braking function that also is regenerative together with the steam buffer.

A condenser buffer offer high rate of condensing, of paramount importance for air-cooled applications with heavy fluctuating power demand. Even if the air-cooled condenser is efficient it is difficult to condense the high rate of steam that can occur during acceleration in automotive applications without the Condenser Buffer.

The air-cooled condenser is a crucial component for realising high performance air-cooled steam power system. Such an air-cooled heat exchangers is very important when realising an automotive steam power system because almost all waste heat has to be rejected to the

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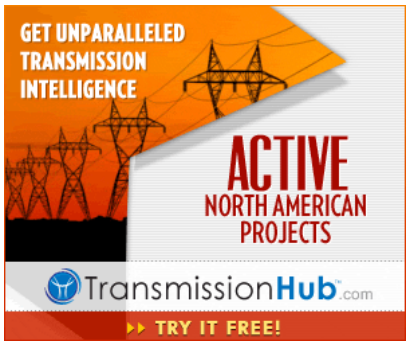
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ambient air (as also for the fuel cell) contrary to internal combustion engine where a large part of the waste heat is also rejected in the exhaust gas pipe and thus don't call for such a high thermal performance as in the steam power case. The air-cooled condenser has to offer high compactness but still offer low-pressure drops. It must offers large heat transfer areas behind a small inlet area but still involving low pressure drop and thus reduced fan power or RAM-pressure. Such air-colled condenser has been built and tested where the corresponding fan power is only in the order of 1 % of the exchanged heat in the heat exchanger.

The steam engine system can also harness solar energy, adding further mileages without burning any fossil fuel. The solar energy evaporates the water which, is used either for propelling the vehicle directly or stored as sensible heat in the Steam Buffer for use the next coming hours. The modern steam engine system will realise a propulsion system that can use liquid fuel (the most favourable energy storage form) but can also make use of the intermittent, unpredictable, environmental-friendly solar energy when it is possible.

The modern steam power system for automotive applications will involve some stumble-blocks before a commercial complete system is realised but compared to the alternative it seems well founded to develop some prototypes. The most crucial part for successful implementing is probably the high-speed oil-free reciprocating piston engine. However, new material indicates promising ways to realise the oil-free high performance steam engine. When also considering that the modern steam power system can act as a bottoming cycle to ICE and other power cycles and realising combi-cycles or hybrids with very high efficiency and that each component also are interesting for conventional ICE and fuel cells it seems even more sensible to study the novel steam power technology further.

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Readers Comments

Date	Comment
George Fleming *2.23.05*	It is good to think about the steam engine. How long would it take to get up a head of steam, and what about freezing weather? Would the condenser be under a vacuum? Seals would be a special problem then. When will a prototype engine be ready? Please provide more information on the condenser, such as details of construction, size, pressure drop on air and steam sides. Would a fluid other than water work better?
Roger Arnold *2.26.05*	In the late '60s, I read articles about steam engines for cars. I was a big fan of the concept. It seemed to have a lot going for it. But then in the '70s, Bill Lear tried to take the concept and run with it. He failed. Now, Bill Lear was a brilliant engineer, and very successful inventor and businessman. (He's best known for the Lear Jet.) He had made a comfortable fortune, and then sank a good bit of it into development of automotive steam engines. So the fact that he failed can't be dismissed out of hand. What happened? As I recall, he was unable to overcome the relatively poor thermal efficiency of steam engines relative to ICEs. His best efforts yield prototypes that were very clean and quiet, with great acceleration, but that got lower fuel mileage than comparable ICE vehicles and were a lot more expensive. End of story. Unless somebody has found some new tricks to improve efficiency, I have to very skeptical of steam's future potential.
George Fleming *2.27.05*	Mr. Arnold, thanks for the history. The condenser is usually recognized as the most difficult part of the design. I would like to know whether Dr. Platell has overcome this problem. If a better condenser has been found, the technology might be useful in another application: heating the combustion air for an experimental internal combustion engine: http://83.219.63.174/liChannelID/8/Articles/290029/Taking+the+spark+out+of+ignition.htm
Marshall Loring Jr. *2.27.05*	I am glad to see that the steam car concept is still being revisited. The driving characteristics of a direct coupled steam engine are well suited to automobile propulsion. If the efficiency and weight limitations can be overcome they deserve attention. And modern materials plus computer modeling for design should make this possible.

In 1950 while I was an undergraduate EE student at UC Berkeley, I had the pleasure of knowind and assisting the owner of a 1929 Doble steam roadster This was a 6000 pound car with a 4 cylinder double expansion engine directly coupled [via a differential] to the rear axle. It used a honeycomb air cooled condenser. Fuel consumption was about 5 mpg [not too far out of line for its weight and vintage] of #2 oil; water consumption was about 7 mpg. Acceleration was phenomenal – the car would out run a new Dodge Hemi V8 from 25 mph. The car used a flash boiler about 2' in diameter and <2' high. I remember getting under way in 25 seconds on a cold start The car warmed up to good performance after about 3 minutes on the road.

I believe this car is still running and last I knew it was owned by a man in Burlingame, CA – a few miles from where I live.

Marshall Loring

Peter Platell *3.2.05*

George , sorry for the long respons time. yes you are right, the air cooled condenser is cruical component for an air cooled steam engine. Start time will be different depending on different design strategy and will be in the range of 1 sec to several minutes . These figures depends on the choice to solve the freezing issue. The best choice is probably to heat insulate the complete system and let a pilot flame keep the system at temperature levels well above freezing point. Other solution involves design where water is drain into a design that account for expanding water. A third solution is the mixture ammonia into the water (some kind of Kalina cycle light). We share both the problem to reject large amount of heat to the ambient air and the freezing problem with the fuel cell people , but we see viable ways to solve these problems . The air cooled condenser has a pressure drop of about 100 Pa during normal driving speed on high way 60 mph. The size of the heat exchanger core is not big. However, it is at least equal important to make sure that inlet and outlet of the cooling air is not restricted by the car body or devices. I am not sure what you mean with the idea to heat the intake air in an ICE?. That will results in higher NOx and lower specific power .

Arnold , my father met Bill Lear when he was working at SAAB and know a lot about his project. There were different companies working on different steam engine system. Lear was going to use a Screw expander (Instead of a reciprocating engine turbine etc) Screw expanders is not an approriate choice as expander. We can talk a lot of expanders choice but for us iit is only the reciprocating piston engine that is able to provide the qualities we need in a vehicle that can compete with the internal combustione engine. Lear also faced the problem with rejecting heat to the ambient air. Fan power to force the cooling air through the condenser package was about half of the generated work from the expander. Lear used conventional radiator technology and that is not possible to use if we are going to get a competetive efficiency and high power output. Marshall I am glad that you are glad that someone is working on steam engine . We are convinced that it is possible to obtain high effiency and high specific power output with a proper thermodynamic approach and further, new material will also makes it possible to obtain the necessary life time. Actually, inherent physcial qualties implies higher specific power than all other competitors claims.

We have made some cost estimation together with the Swedish automotibe industry and specific cost (kW/kg) is very competitve to ICE and not to mentioned fuel cells. Peter Platell

George Fleming *3.2.05*

Peter, according to the article I referenced, the proposed homogeneous charge compression ignition engine (HCCI), also called controlled auto-ignition, preheats the air. Or maybe the air/fuel mixture. It is not clear to me whether the fuel is injected towards the end of the compression, or mixed with the air before it enters the combustion chamber. The intended fuel is hydrogen, which would reduce the problem of premature ignition, compared to gasoline at least.

Somehow they get the mixture to burn at the right time, at several locations in the mixture. Ignition is by compression, no spark is used. They claim that this reduces the maximum temperature of combustion, thus reducing NOX. To maintain power, the heated air is not inducted, but compressed to an intermediate level so that it can be injected. This also reduces throttling losses, according to the article.

This engine requires a heat exchanger, to transfer heat from the exhaust gas to the air. If you have developed an improved heat exchanger for your steam engine, it might be useful for the HCCI engine also.

Peter Platell *3.5.05*

George, thanks now I understand little better I think , I will talk with some HCCI people ,

Len Gould *3.7.05*

George: Dr. AleiFeris appears to be using charge pre-heating in order to achieve the high compression temperatures required for ignition of the lean mixtures used in HCCI without having to mechanically increase the compression ratio. Targeting adaptation of standard diesel engines? No go, the extreme pressures (think running a gasoline engine in the "knocking" condition continuously x 3) make either costs or weight got out of range. That's why the EERE group is using the linear generator piston engine. However, that introduces the problems of requireing to run 2 stroke cycle which is particularly a problem at these conditions. Also reduces peak specific power in half.

Both the HCCI groups and Peter Platell should talk to Dr. Wolfgang Seeman. He's invented a new concept in piston engine, the "Aero Diesel", which essentially replaces the crankshaft with a swash plate as in hydraulic motors. Every piston is matched with an opposing cylinder in the opposite direction so compression power isn't passed through bearings. The engine is composed of multiple pairs of opposed cylinders arranged in a circle around a single shaft carrying a single swash plate. A German Formula 1 engine company has offered to build him prototypes if he could come up with some money.

http://www.aero-diesel.net/html/english.html

I have an animated GIF image illustrating the concept which I could send if you asked at lengould@sympatico.ca

Cheers.

http://www.aero-diesel.net/html/english.html

George Fleming *3.8.05*

Mr. Gould, your first paragraph seems to go something like this: "1. Preheating avoids the necessity for high compression ratio. 2. The pressure would be too high for standard diesels." Aren't these statements contradictory? Also, a two stroke cyle engine has (theoretically) twice the specific power of a four stroke cycle engine. What is a linear generator piston engine, and why is it different in that regard?

Thanks for the aero-diesel link. I couldn't find any illustrations there, so will email you for the image.

Len Gould *3.9.05*

George: What I was saying is that for ignition to happen in an HCCI engine, the fuel air charge must be heated to the very high ignition temperature of the lean fuel mixture at whatever mixture ratio being used. There would be two ways to do this, either a cold charge and very high compression ratios eg. 33+:1, as in the EERE tests, or by a preheated charge and eg. 17:1 typical of engines built to run diesel cycle, which I presume Dr. Aleiferis is testing.

The reference to high pressures is not to compression presures but to combustion pressures, which become extremely high in an HCCI engine due to the simultaneous combustion of the entire homogenous charge once compression temperatures reach ignition temperature, unlike diesels which heat the air above ignition temperature first, then introduce droplets of fuel as a spray which doesn't all burn at the same instant. HCCI puts a real pounding onto bearings, and especially piston rings, in a crank-based engine.

My statement "Also reduces peak specific power in half" is confusing in that context i agree. What I meant was that whereas the EERE's linear generator engine design (must) run two cycle (and that introduces complications), Dr. Aleferis' adaptation of a diesel engine would likely run 4 cycle, therefore only 1/2 specific power.

Les Shepard *2.11.07*

The USA government is so wrapped up in oil and ethanol, etc., it hasn't had time to address other forms of alternatives such as closed system steam vehicles such as the Lear attempt. Can you send copies of your article to congress's attention or can you give me permission to do so? As an old (87) WWII veteran, I can vividly remember riding in British double decker buses fueled by charcoal. Back in Chicago in the late 40's I knew a school science teacher who converted his old auto to do the same. Oil will not last forever and ultimately its loss will adversely affect the planet earth. Thanks for listening, Les Shepard

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