REVIEW OF CRYOGENIC TECHNIQUE FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

Cryogens are efficient thermal storage media which, when used for Automotive purposes, offer significant advantages over Electrochemical battery sciences, both in performance and economy. An Automotive propulsion concept is presented which use liquid N_2 as the Working fluid for an open Rankine cycle. The principle of performance is like that of a steam engine, except there is no heating involved. Liquid N_2 (nitrogen) is Pressurized and then evaporate in a heat exchanger by the atm. (atmospheric) temperature of the surrounding air. The resulting high - pressure nitrogen gas is fed to the engine changing pressure into mechanical power. The only exhaust is nitrogen. The usage of cryogenic fuels has sustainable benefit over other fuel. Also, factors such as production and storage of nitrogen and pollutants in the Exhaust give advantage for the cryogenic fuels.

Keywords -Difficulties in implementation, Efficiency, Performance of Cryocar, Rankine Cycle.

I. INTRODUCTION

As the world progresses through the 21st century, it causes increasing fuel prices, tougher emissions regulations, and a switch on renewable energy sources. These consequences are evident in the increased accessibility of extreme low emissions gas vehicles and gas-electric hybrids. The main disadvantage of both of these advancements is that they are yet dependent on fossil fuel and that they produce harmful emissions, even though in smaller amounts. So alternative fuel research has been increased, focusing on H_2 and fuel-cell technology. [1]
Liquid N_2 is one of best possible alternative energy carrier, as it can be cheaply produced, is non-flammable, produces only the emission of N_2 back into the environment, and is renewable. Heat exchangers convert liquidN_2 into gas up to ambient temperature, and also provide the needed pressure to power for actuation system. This heating is done by the atmosphere without any additional heat sources, resulting in an easy, authentic, and potentially effective propulsion system.When the only heat input to the engine is supplied by atm. heat exchangers, an automobile can easily be propelled while satisfying stringent tailpipe emission standards. N_2 propulsive systems can provide automotive ranges of nearly 400 km in the zero emission modes, with decreases operating costs than those of the electric cars currently being considered for mass production. In geographical regions that allow ultra low exhaust vehicles, the range and performance of the liquid N_2automobile can be fundamentally extended by the accession of a small efficient burner. Some of the advantages of a transportation

infrastructure based on liquid N_2 are that recharging the energy storage system only requires minutes and there are minimal environmental hazards associated with the manufacture and use of the cryogenic "fuel". The basic idea of N_2 propulsion system is to utilize the atmosphere as the heat source.

II. FACTORS EFFECTING CRYOCARS EFFICIENCY

2.1 Cost Of Production

Liquid N_2 production is an energy-intensive process. Currently practical refrigeration plants producing a few tons/day of liquid N_2 operate at about 50% of Carnot efficiency.

2.2 Energy Density Of Liquid N_2

Any process that relies on a state change of a substance will have much lower energy densities than processes involving a chemical reaction in a substance, turns have lessenergy density than nuclear reactions. The energy density derived from N_2's isobaric heat of evaporation and Cp (specific heat) in gaseous state that can be realized from liquid N_2 at atm. pressure and 0°C ambient temperature is about 97 W-hr/kg. This compares with about 3,000 W-hr/kg for a gasoline combustion engine running at 28 percentthermalefficiency& 30 times the density of liquid N_2 used at the Carnot efficiency.

For an constant heat expansion engine to have a range comparable to an I.C. (internal combustion) engine, a 350-litre (92 US gal) isolated onboard storage vessel is required. A practical volume, but a noticeable increase over the typical 50-litre (13 US gal) gasoline tank.

2.3 Frost Formation

Unlike I.C.engines, using a cryogenic working fluid requires heat exchangers to heat and cool the working fluid. In a humid atmosphere, ice formation will block heat flow and thus represents an engineering challenge. To prevent ice build up, multiple working fluids can be used. This adds topping cycles to ensure the heat exchanger doesnot come below 0^0C. Additional heat exchangers, weight, complexity, efficiency loss, and expense, would be required to enable ice free operation.

2.4 SAFETY

However efficient the insulation on the N_2 fuel tank, there will be fatal losses by evaporation to the environment. If a vehicle is stored in a poorly ventilated space, there is some risk that leaking N_2 could reduce the O2 concentration in the air and cause asphyxiation. Since N_2 is a colourless and odourless gas that already makes up 78 % of air,such a change would be difficult to detect. Cryogenic liquids are hazardous if spilled. Liquid N_2 can cause frostbite and can make some materials extremely brittle. As liquid N_2 is colder than 90.2K, O_2 from the atmosphere can condense. Liquid O_2 can spontaneously and violently react with organic chemicals, including fossil fuel products like asphaltsince the liquid to gas expansion ratio of this substance is **1:694**, a enormous amount of force can be generated if liquid N_2 is rapidly vaporized. In an accident in 2006 at TexasA&M University, the pressure-relief valve of a tank of liquid N_2 were sealed with brassPlugs. As a result, the tank failed catastrophically, and blasted.This cause difficulty in implementation.

2.5 Tank

The tanks must be designed to safety standards befitting for a pressure vessel, such asISO 11439.The storage vessel may be made of:Steel,Al,Carbon fibre,Kevlar,other materials or combinations of the above.The fibres materials has considerably low density than metals but generallymore costly.Metal tanks are corrosive but it can withstand more number of pressure cycles.

2.6 Material For Air Motor / Double Rod Piston Cylinder

As LN_2 is at cryogenic temperature it is difficult to use normal material in expander / motor as it get brittle it & produces stresses. So material used for it should be properly selected as per their properties to withstand such low temperature.

Table 1: Liquefaction temperatures for some systems [2]

System	CH_4	O_2	Ar	CO_2	N_2	Ne	H_2	He
Liquefaction temperature(K)	111.7	90.1	87.4	81.1	77.3	27.2	20.4	4.2

For cryogenics applications, materials must be carefully selected because of the forcefully changes in the properties of materials at low temperature. Materials which are normally ductile at atm. temperature may become extremely brittle subjected to cryogenic temperature, while some improves ductility. Once the materials are selected, the method of Joining them must carefully consider to insure that the desired performance is conserve by using the proper bonding, brazing, or welding techniques and materials although at low Temp. strength and stiffness of most materials increase, they tend to reduce in size and become rather brittle. Heating solid body from absolute zero requires energy. In a free body, this energy apparent itself in two ways: an increase in temperature and a change in volume. Both of these are directly related to the additional vibration energy of the individual Atoms. [2]

III. WORKING

It works on simple thermodynamic RankineCycle:

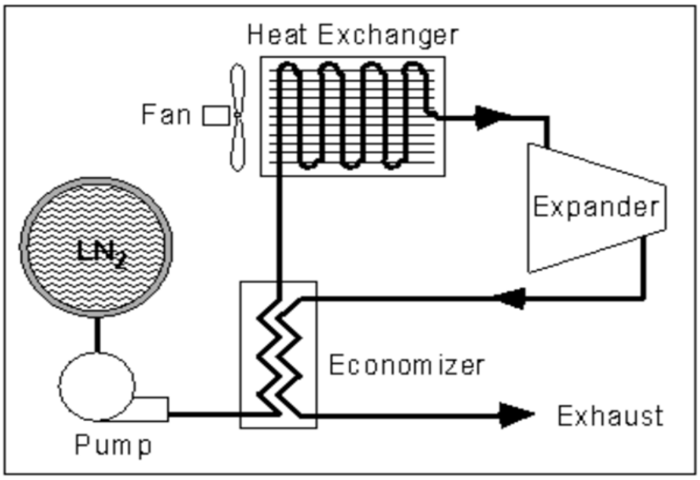

Fig1: LN_2 liquid N_2 propulsion cycle. [3]

3.1 Parts of a Liquid N_2 Propulsion Cycle

The main parts and their functions are discussed in detail as follows:

3.1.1 Cryogen Storage Vessel

The primary design constraints for automobile cryogen storage vessels areresistance to deceleration forces in the horizontal plane in the event of trafficaccident, low boil-off rate, small size and mass and reasonable prize. Crash- worthy cryogen vessels are being developed for hydrogen-fuelled vehicles that willavoid loss of insulating vacuum at closing speeds of over 120 km/h.Moderately high vacuum (10-4 torr) with critical insulation can provide boil-off rates as low as 1.5% per day in 200 litre (53 gal) containers. Using appropriatetitanium or Al alloys for the inner and outer vessels, a structurallyreinforcedDewar could readily have a seven-day holding period. The cost of amass produced 200 litre automotive tanks for liquid hydrogen containment hasbeen estimated to be between $200 and $500 (in 1990 dollars). Thus the expenseof a 400 litre LN2tank (or two 200 litre tanks) is expected to be reasonable. [3]

3.1.2 Pump

The pump is used to pump the liquid N_2 into the engine. The pumps used for this purpose have an operating pressure ranging between 480 –580 Psi. As the pump, sucks liquid instead of gas, it is noticed that the efficiencyis high. [5]

3.1.3 Economizer

A preheater, called an economizer, uses leftover heat in the engines exhaust to preheat the liquid N_2 before it enters the heat exchanger. Henceit acts as a heat exchanger between the incoming liquid $N_2$and the expel gas which is left out. This is similar to the preheating process which is done in compressors. As the use of the economizer, the efficiency isimproved considerably. The design of this heat exchanger is such as to avoid frostformation on its outer surfaces. It will also increase performance of car.

3.1.4 Expander

The maximum work output of the LN_2engine results from an isothermalexpansion stroke. Vehicle power and torque demands would be satisfied by both choking themass flow of LN_2 and by controlling the cut-off point of N_2injection, which issimilar to how traditional reciprocating steam engines are regulated. The maximumpower output of the propulsion engine is limited by the highest rate at whichheat can be absorbed from the environment. The required control system to accommodate the desired vehicle performance can be effectively implementedwith either manual controls or an on-board computer. The transient responses of LN_2power plant and corresponding operating procedures are topics to beinvestigated. [3]

3.1.5 Heat Exchanger [1]

The primary heat exchanger is a critical component of a LN_2car.For an constant heat expansion engine having an injection pressure of 5.MPa, the heat absorbed from the environment can, inprinciple, is converted to useful mechanical power with about 45% efficiency. Thus the heat exchanger system shouldbe providentially designed to absorb at least 76 kW from theenvironment when its temperature is about 0°C. To estimate the volume and mass of the primary heat exchanger, it wasmodelled as an array of individually fed tube elements that pass the LN_2 at its extreme discharge without excessive pressure drop. Each element is a 10 m long section ofAl tubing having an outside diameter of 10 mm and a wall thickness of1 mm.

The exterior heat transfer coefficient is based on that for cylinder incross flow and the internal heat transfer is for fully developed agitated flow. Thebulk temperature of air is assumed to decrease across each tube row asdetermined from energy conservation and the pressure drop is determined forwhole tube bank. The heat transfer calculations accounts for N_2pressure dropand variations in its thermal properties in the tube elements. Some of the significant phenomena not considered at this stage of analysis were the effects ofthe transient LN_2 flow rates, start up, ice accumulation, tube fins, and axial thermalconduction.

The formation of prime ice is so highly probable. The atm. moisturewill be removed relatively quickly as the ambient air is chilled over the first few tube rows, leaving enormously dry air to warm up the colder parts at the rear of theheat exchanger where the LN_2enters. Surface coatings such as Teflon can be usedto unwanted ice build-upand active measures for vibrating the tube elements mayalso is applied. However, these approaches may not be necessary since high LN_2flow rates are also want during times of peak power necessity and the heatexchanger elements are much longer than essential to elevate the LN_2temperature to near atmospheric at the lower flow rates required for cruise. Thus, the frosted tuberows may have ample opportunity to de-frost once the vehicle comes up to speed.

Even though inclement weather will certainly demean the performance of the cryomobile, it will not forbid effective operation. If the propulsion systemoperating circumstances were such that the LN_2 could only be heated to 270 K prior to injection, the flow rates of $LN_2$for the adiabatic and isothermal cycles to generate 35 kW would be 120 gm/sec and 187 gm/sec, respectively. The antecedent described heat exchanger configuration can theoretically heat the higher LN_2 flow rate to 260 K with 25 radiator elements when the vehicle is travelling at 25 km/sec (18 mi/h) and the ambient air temperature is only 0°C. The LN_2 pressure drop would be about 0.055 MPa, which is easily compensated for with the cryogenic pump. The electric fan would requirearound 1.5 kW to accelerate the airand overcome the 400 Pascal pressure drop through the heat exchanger if the vehiclewere standing still. Since each element is 0.80 kg, the total tubing mass would be19 kg. If the same mass was added by the duct and manifolds then the total mass ofthe heat exchanger would be less than 40 kg. When operating on a typicalCalifornia day, it is expected that this over-designed cryogen vaporizer will readilyheat the LN_2up to ambient temperature without any appreciable icing.

IV. POWER CYCLE

There are many thermodynamic cycles available for utilizing the thermal potential of liquid N_2. This system uses an open Rankine cycle. The temperature verses entropy diagram for the open Rankine cycle is described below.

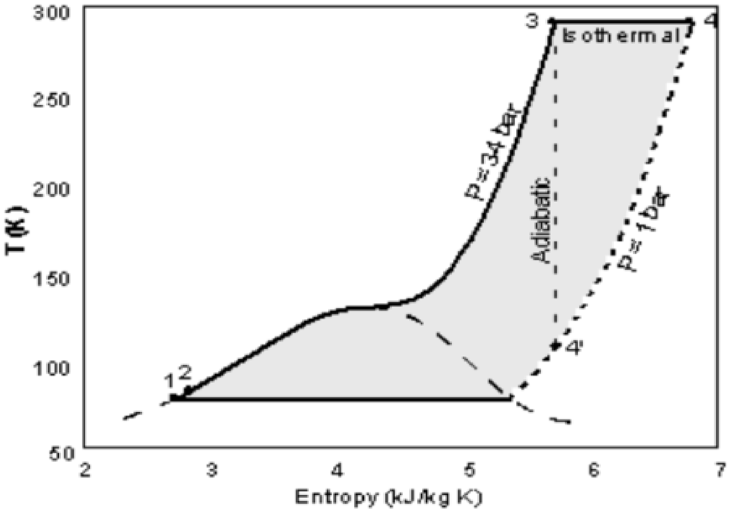

Fig2: Temperature - entropy diagram for the open Rankine cycle. [3]

State 1 is the cryogenic liquid in storage at 0.10 MPa and 77 K. The liquid is pumped up to system pressure of 5 MPa (supercritical) at state 2 and then enters the economizer. State 3 indicates N2 properties after it is being preheated by the exhaust gas. Further heat exchange with atmospheric air brings the N2 to 290 K at state 4, ready for expansion. Isothermal expansion to 0.2 MPa at state 5 would result in the N_2 exhaust having sufficient enthalpy to heat the LN_2 to above its critical temperature in the economizer, whereas adiabatic expansion to state 6 would not leave enough enthalpy to justify its use. The specific work output would be 300 and 200 kJ/kg-LN_2 for these isothermal and adiabatic cycles, respectively, without considering pump work. While these power cycles do not make the best use of the thermal potential of the LN_2, they do provide specific energies competitive with those of batteries.

4.1 Performance of the open Rankine cycle

The thermodynamic and economic performances of the isothermal and adiabatic modes of the open Rankine cycle are shown in Table 1. These figures are based on the specifications of a modified Honda CRX for which performance data were available. The cost of 3 ¢ per kg-LN_2 was derived assuming only the energy cost of production.

Table 2: Performance of the open Rankine cycle [1]

Process	Adiabatic	Isothermal
Pump work	6 KJ/Kg-LN_2	6 KJ/Kg-LN_2
Net output	194 KJ/Kg-LN_2	314 KJ/Kg-LN_2
Heat input	419 KJ/Kg-LN_2	750 KJ/Kg-LN_2
Energy density	54 W-h/Kg-LN_2	87 W-h/Kg-LN_2
LN_2 flow rate	1.5 Kg/Km	0.93 Kg/Km
Operating cost	3.9 Rs/km	2.4 Rs/Km

V. ADVANTAGES

- Studies indicate that liquid N_2 automobiles will have significant performance and environmental advantages over electric vehicles.[1]
- A liquid N_2 car with a 60 gallon volume tank will have a potential range of up to 200 miles, or twice than that of a typical electric car. Furthermore, a liquid N_2 car will be much lighter and refilling its tank will take only 10-20 minutes, rather than the several hours required by most electrical car concepts.
- Motorists will fuel up at filling stations likely to today's gasoline stations. When liquid N_2 is manufactured in large quantities, the operating cost per mile of a liquid N_2car will not only be less than that of an electric car but will actually be competitive with that of a gasoline car.
- Economical: LO_X& LH_2 costs less than gasoline.[5]

VI. DISADVANTAGES

- The principledrawback is the inefficient use of primary energy. Energy is used toliquidify N_2; turn provides the energy to run the motor. Any conversion ofenergy between forms results in loss. For liquid N_2 cars, energy lost whenelectrical energy is converted to liquid N_2.
- Liquid N2 is not yet available in public refuelling stations.
- Leakage.[6]
- Boil off rate.[5]

VII. FUTURE SCOPE

- Range Extension and Power Boosting :

Range extension and performance enhancement can be complete by heating the liquid nitrogen to above ambient temperatures with the combustion of a relatively low contamination fuel such as ethanol or natural gas. By increasing the gaseous nitrogen temperature to 500 K, the specific work at 5 MPa for the adiabatic engine is increased by 60.75% to make it nearly the same as the work from anconstant heat expansion engine operating at 300 K. In this particular propulsive cycle an extra heat addition of up to 200°C results in only a 30% increase in limited power. Thus the advantage of operating above atm. temperature depends, in part, on how constant heat the expansion process can be made to be. There is also the provocative possibility of storing energy for boosting power or wider range by applying a medium that undergoes a state change to the final super heater section of the heat exchanger system. Ideally the state change material would be slowly “recharged” as it imbibes heat from the environment while the vehicle is parked and during cruise when peaking power is not required. Fast recharging with electric heaters may also be considered. We recognize that this added ramification must compete in mass and concentrated with the secondary of just carrying more LN_2.

VIII. CONCLUSION

The advantage for utilizing the available energy of liquid N_2 for automotive propulsion looks much guaranteed. Time to refuel, infrastructure investment, and economical are among the issues to consider, in added the range and performance, when comparing the relative merits of different zero emission vehicle technologies. The convenience of pumping a fluid into the storage vessel is very attractive when compared with the typical recharge times colligate with lead-acid batteries. Manufacturing $LN_2$from atm. air inherently removes small quantities of atm. pollutants and the installation of largescale liquefaction device at existing fossil-fuel power stations could make flue gas condensation processes economical and even discard the exhaust of CO_2.

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