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# **Production and Uses of Cryogenics**

G.Raj Kumar<sup>1</sup>, J.Rabinson Anburaj<sup>1</sup>, P.Pravinkumar<sup>2</sup>, C.Ravindran<sup>2</sup>

Dept. of Mechanical Engineering, Sasurie College of Engineering, Tirupur, Tamilnadu, India<sup>1</sup>

Assistant Professor, Dept. of Mechanical Engineering, Sasurie College of Engineering, Tirupur, Tamilnadu, India<sup>2</sup>

**ABSTRACT:** In this materialistic world we try to improve our standard right from our standard of living. The conventional energy we use today is obtained from the fossil like coal, petroleum products. These sources are depleting day by day. And may cause lead us to starve for power. Though we use conventional energy source and the power we obtained from them are very low and takes time to be put in action and implementation such energies require fast area which cannot be managed by the over whelming population. Thus we finally step into the field of cryogenics.

Cryogenics is one of the fascinating and monstrous growing fields, when used for automotives purposes, offer significant advantages over current technology, both in performance and economy. The main concept of development of this alternative energy source has main necessities.

1. Depletion of energy resources 2. Pollution cased by the present day fuels

In this paper the need for the development of the cryocar and its functioning as a zero emission vehicles are clearly briefed.

The principle of operation is like that of a steam engine, except there is no combustion involved. Instead, liquid nitrogen at  $-320^{\circ}\text{F}$  ( $-196^{\circ}\text{C}$ ) is pressurized and then vaporized in a heat exchanger by the ambient temperature of the surrounding air. This heat exchanger is like the radiator of a car but instead of using air to cool water, it uses air to heat and boil liquid nitrogen. The resulting high-pressure nitrogen gas is fed to an engine that operates like a reciprocating steam engine, converting pressure to mechanical power. The only exhaust is nitrogen, which is the major constituent of our atmosphere.

## **I. INTRODUCTION**

### **CRYOGEN USED:**

“Nitrogen is probably the most common cryogen handled. Liquid nitrogen is commonly produced by "distilling" it from liquid air. . Once at its destination it can be used as a cryogenic liquid but most often it is vaporized and used as a gas. The use of Nitrogen can be justified because it is inert and water-free.

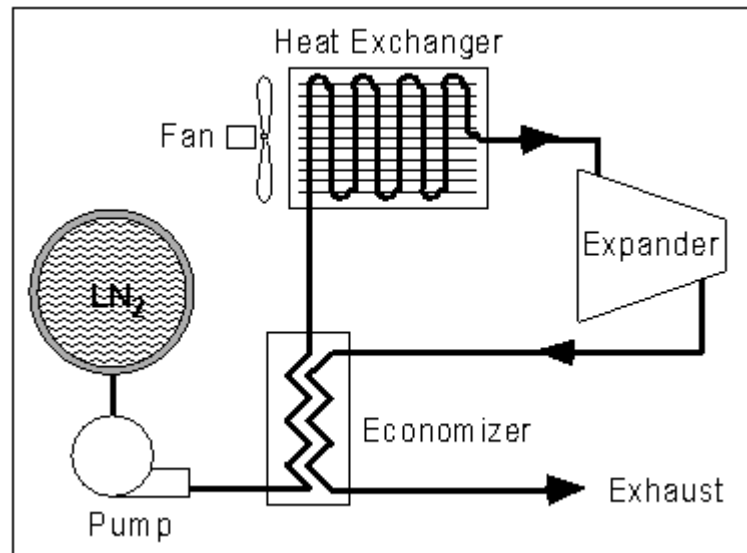
### **LN2 PROPULSION USING ONLY AMBIENT AIR:**

A schematic of a Rankine cycle propulsion system using only ambient air to heat the cryogenic working fluid is shown in Figure. An insulated "fuel" tank contains LN2 at atmospheric pressure and a temperature of 77 K. A cryogenic pump draws LN2 from the bottom of the tank and compresses it to the operating pressure of the system.

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Pressurized LN<sub>2</sub> then passes through the heat exchanger, which is optimized as a LN<sub>2</sub> vaporizer and N<sub>2</sub> superheater, to raise the gas temperature to just below ambient conditions. The gaseous N<sub>2</sub> is then injected into the cylinder as the piston approaches top dead center. It is possible for multiple expansion strokes and reheats to be utilized, at the expense of mechanical complexity, to approach quasi-isothermal performance. If the exhaust gas has sufficient enthalpy it passes through an economizer before being vented to atmosphere. The nitrogen condensation phase closing the Rankine cycle occurs at stationary air liquefaction plants. It has low operating costs, ample propulsive power, and reasonable round trip energy efficiency. It is referred to as cryomobile. It uses atmospheric heat as source.

## II.THERMAL STORAGE EFFECTIVENESS

Because the design and expense of the cryomobile are driven primarily by the cryogen heat sink, it is useful to characterize performance by a "sink efficiency",  $\eta = W/Q_L$ , i.e. the inverse of the coefficient of performance for a refrigerator. The "reversible work" for LN<sub>2</sub> is  $W_r = 769 \text{ kJ/kg-N}_2$  and the corresponding sink efficiency is  $\eta = 1.78$ . Thus, only a small fraction of the reversible work needs to be recovered to provide the cryomobile with a driving range commensurate with that of battery-powered vehicles of comparable weight.

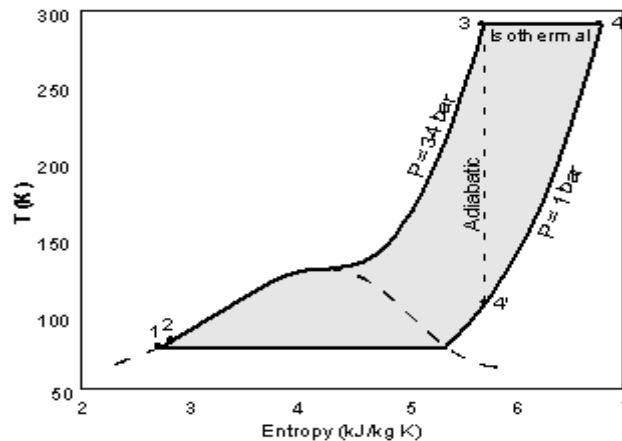
### POWER CYCLE:

The Rankine cycle is among the most attractive choices for approximating Carnot performance, when using a fixed temperature heat source and sink. We have focused on directly using the nitrogen itself as the working fluid, wherein the liquid is compressed with a cryogen pump, heated and vaporized by heat exchange with the atmosphere, and then expanded in a piston-cylinder engine.

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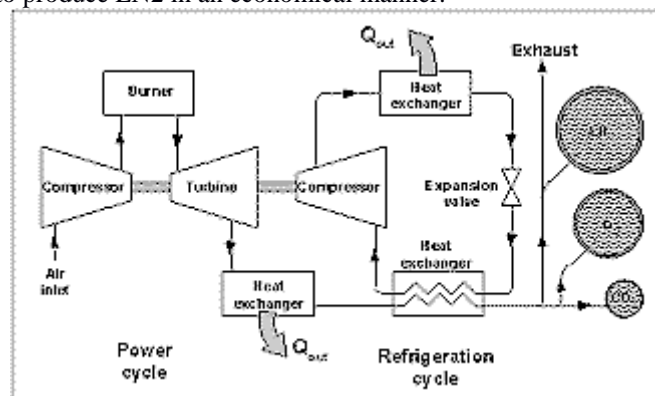
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The temperature-entropy diagram for a representative case is illustrated in Fig. 2. State 1 is the cryogenic liquid in storage at 0.1 MPa and 77 K. The liquid is pumped up to system pressure of 4 MPa (supercritical) at state 2 and then enters the economizer. State 3 indicates N<sub>2</sub> properties after its been preheated by the exhaust gas. Further heat exchange with ambient air brings the N<sub>2</sub> to 300 K at state 4, ready for expansion. Isothermal expansion to 0.11 MPa at state 5 would result in the N<sub>2</sub> exhaust having enough enthalpy to heat the LN<sub>2</sub> to above its critical temperature in the economizer, whereas adiabatic expansion to state 6 would not leave sufficient enthalpy to justify its use. The specific work output would be 320 and 200 kJ/kg-LN<sub>2</sub> for these isothermal and adiabatic cycles, respectively, without considering pump work. While these power cycles do not make best use of the thermodynamic potential of the LN<sub>2</sub>, they do provide specific energies competitive with those of lead-acid batteries.

### LIQUID NITROGEN MANUFACTURE:

The cost of the LN<sub>2</sub> "fuel" is expected to be reasonable. The primary expense for producing LN<sub>2</sub> is the energy cost for compression of air. Cryogenic separation of nitrogen from other condensable in air typically requires only a very small fraction of the total energy. So the ideal work to manufacture LN<sub>2</sub> from air is very nearly that for using nitrogen as a feedstock. This work is exactly the reversible work obtainable from an ideal cryo-engine, 769 kJ/kg. The actual work required in a modern LN<sub>2</sub> plant is 2.0-2.5 times the minimum, or 1540-1920 kJ/kg.<sup>11</sup> Assuming an industrial electric rate for interruptible power of 5¢/kW-h, the energy cost would amount to 2.6¢/kg-LN<sub>2</sub>, in accord with delivery prices of LN<sub>2</sub> in large quantities. Marketing the other commercially important components of air will help offset the LN<sub>2</sub> production costs. Since the equipment needed for air liquefaction can be powered solely by electricity, it is conceivable to decentralize the "fuel" manufacturing process and to place small scale production facilities at the LN<sub>2</sub> dispensing sites. A cost-benefit analysis is needed to determine the smallest air liquefaction machinery that can be used to produce LN<sub>2</sub> in an economical manner.



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### APPLICATION TO AUTOMOTIVE PROPULSION:

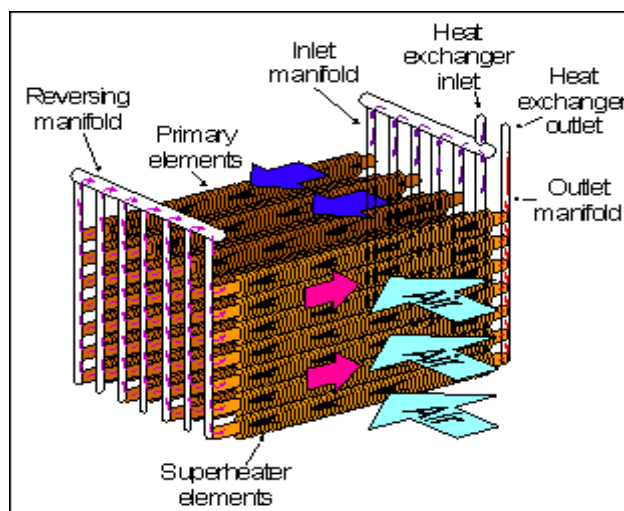
The LN2 pump is assumed to compress the cryogenic liquid to operating pressure with 80% efficiency. An ideal expander is assumed and the LN2 injection cut-off point has been adjusted so that the final pressure after expansion is always 0.11 MPa. For the range of pressures, the work of the isothermal cycle increases monotonically with increasing pressure, whereas the adiabatic LN2 engine is only weakly dependent on peak cycle pressure above 4 MPa. Since this is a reasonable operating pressure for both piston and turbine expanders, it will be used to illustrate the performance potential of the LN2 energy storage system. Estimates of the mass and volume of the LN2 required for a given range are 7.8 kW at 97 km/h (60 mi/h). The "fuel" operating costs are based on the economics of supplying LN2 from a plant opted for its production (2.6¢ per kg-LN2). For the specified cruise conditions, the propulsion system having an isothermal expansion process will consume LN2 at a rate of 25 gm/sec and have an operating cost of approximately 2.4¢ per kilometer.

### COMPONENT DESCRIPTION:

**EXPANDER:** The maximum work output of the LN2 engine results from an isothermal expansion stroke. Achieving it will be a challenge, because the amount of heat addition required during the expansion process is nearly that required to superheat the pressurized LN2 prior to injection. Thus, engines having expansion chambers with high surface-to-volume ratios are favored for this application. Rotary expanders such as the Wankel may also be well suited. A secondary fluid could be circulated through the engine block to help keep the cylinder walls as warm as possible. Multiple expansions and reheats can also be used although they require more complicated machinery. Vehicle power and torque demands would be satisfied by both throttling the mass flow of LN2 and by controlling the cut-off point of N2 injection, which is similar to how classical reciprocating steam engines are regulated. The maximum power output of the propulsion engine is limited by the maximum rate at which heat can be absorbed from the atmosphere

### HEAT EXCHANGER:

The primary heat exchanger is a critical component of a LN2 automobile. To insure cryomobile operation over a wide range of weather conditions, Thus the heat exchanger system should be prudently designed to absorb at least 75 kW from the atmosphere when its temperature is only 0°C. The heat exchanger configuration heat the higher LN2 flow rate to 250 K with 25 radiator elements when the vehicle is traveling at 25 km/sec (16 mi/h) and the ambient air temperature is only 0°C. The LN2 viscous pressure drop would be about 0.05 MPa, which is easily compensated for with the the cryogen pump.



The electric fan would require approximately 1.5 kW to accelerate the air and overcome the 400 Pa pressure drop through the heat exchanger if the vehicle were standing still. Since each element is 0.76 kg, the total tubing mass would

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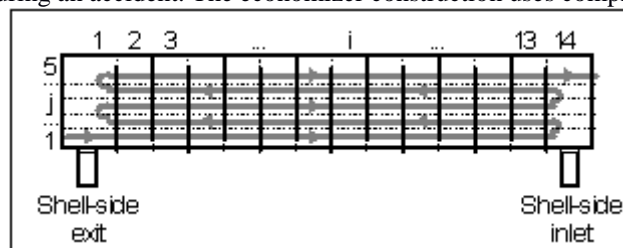
be 19 kg. If the same mass was added by the manifolds and duct then the net mass of the heat exchanger would be under 40 kg

### CRYOGEN STORAGE VESSEL:

The primary design constraints for automobile cryogen storage vessels are resistance to deceleration forces in the horizontal plane in the event of a traffic accident, low boil-off rate, minimum size and mass and reasonable cost. Crash-worthy cryogen vessels will prevent loss of insulating vacuum at closing speeds of over 100 km/h. Moderately high vacuum (10<sup>-4</sup> torr) with super insulation can provide boil-off rates as low as 1% per day in 200 liter (53 gal) containers. Using appropriate titanium or aluminum alloys for the inner and outer vessels, a structurally reinforced dewar could readily have a seven-day holding period. The cost of a mass produced, 200 liter automotive tank for liquid hydrogen containment has been estimated to be between \$200 and \$400 (in 1970 dollars). Thus the expense of a 400 liter LN<sub>2</sub> tank (or two 200 liter tanks) is expected to be reasonable. It can be stored at atmospheric pressure without any refrigeration.

### ECONOMIZER:

The economizer is required to vaporize and, if possible, superheat liquid nitrogen at mass flow rates of up to 300 g/s. It must not produce excessive pressure drop on either the tube- or shell-side fluids. The economizer must also be safe in both normal operations and during an accident. The economizer construction uses compression fitting.



### TECHNICAL ISSUES:

#### Range Extension and Power Boosting:

Range extension and performance enhancement can be realized by heating the LN<sub>2</sub> to above ambient temperatures with the combustion of a relatively low pollution fuel such as ethanol or natural gas. The augmentation of power output is most apparent for the adiabatic expansion engine. By increasing the gaseous N<sub>2</sub> temperature to 500 K, the specific work at 4 MPa for the adiabatic engine is increased by 60% to make it nearly the same as the work from an isothermal expansion engine operating at 300 K. There is also the intriguing possibility of storing energy for boosting power or extending range by applying a medium that undergoes a phase change to the final superheater segment of the heat exchanger system.

**Liquid Nitrogen Infrastructure Considerations:** There are many advantages that might be anticipated pending successful development of a transportation system based on liquid nitrogen. Large scale demand for LN<sub>2</sub> would result in some inevitable cleansing of the atmosphere due to the air liquefaction process.

Atmospheric contaminants such as sulphur and nitrogen compounds, chlorinated fluorocarbons, and other greenhouse gases, are necessarily removed during the air liquefaction process and can be readily disposed of in an environmentally friendly manner. Promoting new technologies that can enhance the efficiency of operations natural to a big city, involving everything from air-conditioning and food processing. The per-kilometer operating costs are much lower for the LN<sub>2</sub> car because there are no major component replacements. Refilling operations for the cryomobiles will only take minutes and can be very safe

The round trip energy efficiency of a practical LN<sub>2</sub> thermal storage system is less than that of batteries, approximately 17% for the isothermal example discussed here as compared to 60% for a typical EV. Adapting this technology to LN<sub>2</sub> distribution will not pose any significant technical challenges. Delivering road emergency quantities of LN<sub>2</sub> may also be much easier and more cost effective.

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## **III. CONCLUSION**

Applying LN<sub>2</sub> as a portable thermal storage medium to propel both commuter and fleet vehicles appears to be an attractive means to meeting the ZEV regulations soon to be implemented. Pressurizing the working fluid while it is at cryogenic temperatures, heating it up with ambient air, and expanding it in reciprocating engines is a straightforward approach for powering pollution free vehicles. Ambient heat exchangers that will not suffer extreme icing will have to be developed to enable wide utility of this propulsion system. Since the expansion engine operates at subambient temperatures, the potential for attaining quasi-isothermal operation appears promising. To date no fundamental technological hurdles have yet been discovered that might stand in the way of fully realizing the potential offered by this revolutionary propulsion concept.

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