Cryogenic Liquid Nitrogen Vehicles

Sharvin Ghodekar

Department of Mechanical engineering, Dr D Y Patil School of engineering, Pune

sharvinag@yahoo.co.in

Abstract- On account of rising air pollution throughout the world and the automobile emissions being the largest contributor to the same, there is an immediate need to provide some alternative means of transport to the current conventional gasoline vehicles. Liquefied nitrogen cooled up to cryogenic temperatures and used as a propellant in cryogenic heat engine can be one of the future trends. Heat from atmosphere vaporizes liquid nitrogen under pressure and produces compressed nitrogen gas. This gas draws a pneumatic motor with nitrogen gas as exhaust. To use liquid nitrogen as a non-polluting fuel, a multiple reheat open Rankin and a closed Brayton cycle are used. A zero emission vehicle utilizing such a propulsion system would have an energy storage reservoir that can be refilled in a matter of minutes and a range comparable to that of a conventional automobile.

Keywords- cryogenic temperature, Brayton cycle,

I. INTRODUCTION

Mitigating increases in urban air pollution and greenhouse gases that come from vehicle tailpipe emissions is the primary motivation behind developing alternative transportation technologies that do not rely on combustion of fossil fuels. Consumer acceptance of a replacement transportation technology, however, is highly dependent on the new vehicle sticker price, operating expenses, reliability, and convenience of use. Thus it is advantageous for the energy storage system of a zero emission vehicle (ZEV) to have low initial cost, quickly and economically recharge, and to provide driving performance comparable to that of conventional automobiles. In addition, the most desirable technological solutions will eliminate the release of automotive combustion products in areas of poor air quality, while also reducing the net amount of pollutants released to the environment as a consequence of their implementation.

Careful consideration of the overall environmental impact of a particular ZEV technology and the corresponding costs of necessary infrastructure development is necessary to evaluate the ability of any new transportation system to meet the goals of society. Currently, the battery-powered electric vehicle is the only commercially available technology that can meet ZEV standards; however, these vehicles have not sold well. This is primarily due to their limited range, slow recharge, and high initial cost. All of these issues can be traced directly to the limitations of electrochemical energy storage, particularly lead-acid and Ni-Cd batteries. These heavy metal energy storage systems remain the dominant technology in the electric vehicle market, but exhibit specific energies in the range of only 30-40 W-hr/kg and energy densities of 60-90 W-hr/l.1. This compares with about 3,000 W-hr/kg for gasoline combusted in an engine running at 28% thermal efficiency. Lead-acid batteries can take hours to recharge and must be replaced every 2-3 years. Recycling of metals from batteries does significantly reduce the amounts released to the environment; however, these processes are currently not 100% effective. Hence, in addition to significantly increasing operating cost per kilometer driven, the need for several battery replacements over the lifetime of the vehicle raises the specter of increased heavy metal pollution, were lead-acid and Ni-Cd battery-powered electric fleets ever to become widespread.

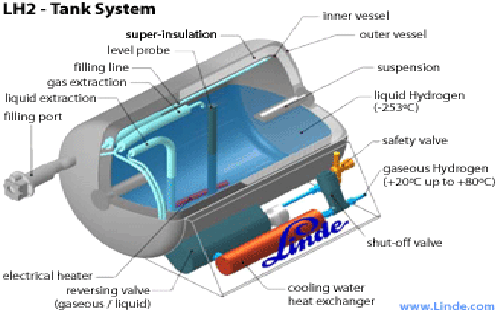
With the approach of deadlines in California and several other states for the production of vehicles that emit no pollutants, nearly everyone’s attention has focused largely on electric cars. Now, developments suggest that vehicles fueled by liquid nitrogen may offer an attractive alternative to battery power. Working independently, two groups of researchers have updated the steam engine, using liquid nitrogen instead of water. Ambient air warms and vaporizes liquid nitrogen, generating compressed gas that drives a motor. Carlos A. Ordonez and his colleagues at the University of North Texas in Denton demonstrated the concept in a prototype vehicle they named CooLN2Car Fig.(2). Abraham Hertzberg, Carl Knowlen, and their co workers at the University of Washington in Seattle converted an old mail truck into a prototype dubbed LN2000 Fig.(1).

II. Liquid nitrogen

Physical properties

- Molecular Weight: 28.01
- Boiling Point @ 1 atm: -320.5°F (-195.8°C, 77°K)
- Freezing Point @ 1 atm: -346.0°F (-210.0°C, 63°K)
- Critical Temperature: -232.5°F (-146.9°C)
- Critical Pressure: 492.3 psia (33.5 atm)
- Density, Liquid @ BP, 1 atm: 50.45 lb/scf
- Density, Gas @ 68°F (20°C), 1 atm: 0.0725 lb/scf
- Specific Gravity, Gas (air=1) @ 68°F (20°C), 1 atm: 0.967
- Specific Gravity, Liquid (water=1) @ 68°F (20°C), 1 atm: 0.808
- Specific Volume @ 68°F (20°C), 1 atm: 13.80 scf/lb
- Latent Heat of Vaporization: 2399 BTU/lb mole
- Expansion Ratio, Liquid to Gas, BP to 68°F (20°C): 1 to 694

Liquid Nitrogen is the cheapest, widely produced and most common cryogenic liquid. It is mass produced in air liquefaction plants. The liquefaction process is very simple in it normal, atmospheric air is passed through a dust precipitator and pre-cooled using conventional refrigeration techniques. It is then compressed inside large turbo pumps to about 100 atmospheres. Once the air has reached 100 atmospheres and has been cooled to room temperature it is allowed to expand rapidly through a nozzle into an insulted chamber. By running several cycles the temperate of the chamber reaches low enough temperatures the air entering it starts to liquefy. Liquid nitrogen is removed from the chamber by fractional distillation and is stored inside well-insulated Dewar flasks. The process to manufacture liquid nitrogen in large quantities can be environmentally very friendly, even if fossil fuels are used to generate the electric power required. The exhaust gases produced by burning fossil fuels in a power plant contain not only carbon dioxide and gaseous pollutants, but also all the nitrogen from the air used in the combustion. By feeding these exhaust gases to the nitrogen liquefaction plant, the carbon dioxide and other undesirable products of combustion can be condensed and separated in the process of chilling the nitrogen, and thus no pollutants need be released to the atmosphere by the power plant. The sequestered carbon dioxide and pollutants could be injected into depleted gas and oil wells, deep mine shafts, deep ocean subduction zones, and other repositories from which they will not diffuse back into the atmosphere, or they could be chemically processed into useful or inert substances. Consequently, the implementation of a large fleet of liquid nitrogen vehicles could have much greater environmental benefits than just reducing urban air pollution as desired by current zero-emission vehicle mandates.



Fig(1)Liquid nitrogen storage tank

III. Working

A schematic of the proposed LN2 propulsion system is shown in Fig. (5).The cryogen "fuel" is stored in a vacuum jacketed vessel which would have appropriate relief features to safely accommodate boil off. A cryo-pump would pressurize the fluid to the supercritical operating pressure of the system and a carefully designed heat exchanger will enable the working fluid to be warmed to near ambient temperature without suffering a detrimental build-up of frost. The gaseous N2 fills a receiver which minimizes pressure surges in the system due to changing power demands. Variable timed valves provide controllable cut-off to release N2 gas into the expander as needed. A warmant fluid is circulated through the expander walls to maintain them at near ambient temperature (Fig 5). The warmant must be pumped through another heat exchanger system (a conventional radiator would suffice) to efficiently conduct ambient heat into the engine. A quasi-isothermal reciprocating expander is proposed for this embodiment and its work output is transmitted to the wheels by means of a conventional transmission. Since the exhaust N2 is near ambient temperature it is prudent to use it to preheat the pressurized LN2 in an economizer to minimize contact of cold cryogen lines with ambient air.

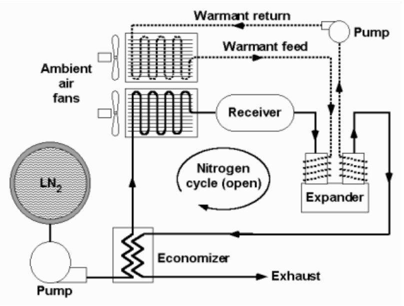


Fig (2) Schematic of liquid nitrogen conversion system

Open Rankine Cycle Process

The processes considered are the expansion of nitrogen gas at 300K and 3.3 MPA to near atmospheric pressure. The first process considered is isothermal expansion from 3.3 MPA to 120KPA and the work can be easily computed as

$$W_{isothermal} = rT \ln (P_2/P_1)$$

r = 0.2968 (KJ/KgK) for nitrogen gas and T = 300K.

The result for Nitrogen is 291.59 KJ/Kg. Another limiting process is the simple adiabatic expansion of the gas in which no heat is admitted during. The expansion. The work is calculated as

$$W_{adiabatic} = KrT\ [1-(P_2 / P_1)^{K-1/K}] (k-1)$$

Where T = 300K and K = 1.4, the ratio of specific heats for nitrogen.

The resulting W adiabatic is 180KJ/Kg of Nitrogen exhausted at 150KPA.

Closed Brayton Cycle Processes

Operation of liquid-nitrogen fueled, regenerative, closed Brayton cycle cryogenic heat engine is illustrated. Considering adiabatic expander and compressor, the specific energy provided by the system is given by

$$W = e_g \mu\ (e_e w_e - w_c/e_c) \quad \ldots\ldots(1)$$

Here,

$$\mu = A\varepsilon L/Rt_{cold}(p^{\varepsilon}-1)] \quad \ldots\ldots(2)$$

is the ratio of the working fluid mass flow rate to the liquid nitrogen vaporization rate.

T_{cold} is the temperature of the heat single.

P is the ratio of the absolute pressures on the high and low pressure sides.

L = liquid nitrogen's latent heat of vaporization.

R = 8314 J/mol-K universal gas constant

$\varepsilon = 1-1/r$

r = working fluid's ratio of specific heat capacities at constant pressure and constant volume.

The ideal specific energy provided by an adiabatic expander is

$$We = RT_{hot}\ (1-p^{-\varepsilon})/[A.\varepsilon] \quad \ldots\ldots\ldots\ldots(3)$$

That = temperature of heat source

The ideal work done by an adiabatic compressor per unit mass of gas is

$$Wc = RT_{cold}\ (P^{\varepsilon}-1)(A.\varepsilon) \quad \ldots\ldots(4)$$

By combining equations we get

$$W = e_g L\ [e_e p^{-\varepsilon} (T_{hot} / T_{cold}) - (1/e_c)] \quad \ldots\ldots\ldots(5)$$

The equation (5) considers the energy available from using liquid nitrogen as a heat sink. The cold nitrogen gas that is produced by vaporizing liquid nitrogen can be used a heat sink as well.

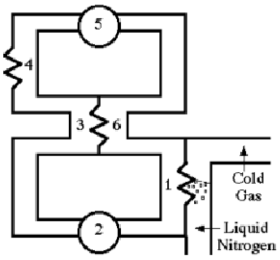


Fig (3) Closed Brayton cycle

IV. Case study

CooLN2

The CooLN2 Car is a converted 1973 Volkswagen. Fig(2). A single-cylinder reciprocating expander that runs on compressed nitrogen gas with the exhaust gas released into the atmosphere was considered. When compressed gas flowed into the expander cylinder, isobaric work was done on the moving piston by the gas. The net isobaric expansion work done during a single cycle is gauge pressure of the gas multiplied by the volume of the gas that flows into the cylinder.

The isobaric specific energy is $W_i = (P_h - P_i)V = P_h(1-P^{-1})V$

$P_h - P_i$ is the difference in absolute pressure between inlet and exhaust gas.

If P_i is atmospheric pressure, P_h-P_i is the gauge pressure of compressed gas.

V is the volume occupied by the compressed gas per unit mass of gas.

$P = P_h / P_i$ is inlet to exhaust pressure ratio.

The isobaric specific energy is $W_i = RT_h (1-P^{-1}) /A$.

Here T_h refers to the temperature of the high pressure inlet gas.

Fig (4) CooLN2

LN2000

The UW vehicle-dubbed LN2000 Fig(1) works like a steam engine, except it is powered by vaporizing very cold liquid nitrogen instead of steam from boiling water. The nitrogen vapor turns an air motor to propel the car and then exits the tailpipe. Since the atmosphere already is 78 percent nitrogen, the environmental effect of driving LN2000 vehicles-even millions of them-would be virtually undetectable.

The LN2000's heat exchanger pulls liquid nitrogen from an insulated fuel tank through a series of aluminum tubing coils and specially designed pipes. Engine exhaust and outside air are circulated around the coils and pipes to gradually warm up the nitrogen from a minus 320 F liquid to an ambient-temperature gas.

The heat exchanger is like the radiator of a car, but it acts in the opposite way. Instead of using air to cool water, it uses air to boil liquid nitrogen into nitrogen gas.

Fig. (5) LN2000

The conversion from liquid to gas expands the volume of the nitrogen 700 times, building sufficient pressure to turn an air motor much like pressure from burning gasoline drives an internal combustion engine.

With a $360,000 U.S. department of energy grant, UW researchers and students have built a LN2000 prototype from a converted Grumman Kubvan mail truck. Aside from the Husky decals, the vehicle looks much like any other postal truck on the outside. But open up the back and one finds insulated tanks, piping, hoses and gauges more befitting a research laboratory than an automobile. Under the hood is a 15 horsepower air motor originally designed to power a winch for raising ship anchor. And instead of generating plumes of foul exhaust, the LN2000 emits cold nitrogen gas which freezes water vapor in the air to form small clouds behind the vehicle.

While the reliance of internal combustion engines on non-renewable fuels has prompted automotive engineers to make car motors more efficient over the years, air motors have had the luxury of remaining fabulously inefficient. As a result, the motor used in the LN2000 prototype gives gas guzzling new meaning by consuming about five gallons of nitrogen fuel per mile. Plus it musters a top speed of only 22 M.P.H. and chugs laboriously up hills.

V. Area of application

- Transport vehicles as both private and public transport means.
- Goods transport.
- Ecology pure and fireproof cars for city, plants, warehouses and airports.
- Invisible in infra-red radiation region vehicle for counter terrorism operation

VI. Advantages

Liquid nitrogen vehicles are comparable in many ways to electric vehicles, but use liquid nitrogen to store the energy instead of batteries. Their potential advantages over other vehicles include:

- Much like electrical vehicles, liquid nitrogen vehicles would ultimately be powered through the electrical grid, which makes it easier to focus on reducing pollution from one source, as opposed to the millions of vehicles on the road.
- Transportation of the fuel would not be required due to drawing power off the electrical grid. This

presents significant cost benefits. Pollution created during fuel transportation would be eliminated.

- Lower maintenance costs
- Liquid nitrogen tanks can be disposed of or recycled with less pollution than batteries.
- Liquid nitrogen vehicles are unconstrained by the degradation problems associated with current battery systems.
- The tank may be able to be refilled more often and in less time than batteries can be recharged, with re-fueling rates comparable to liquid fuels.

VII. Disadvantages

- The principal disadvantage is the inefficient use of primary energy. Energy is used to liquefy nitrogen, which in turn provides the energy to run the motor. Any conversion of energy has losses. For liquid nitrogen cars, electrical energy is lost during the liquefaction process of nitrogen.
- Liquid nitrogen is not available in public refuelling stations nor is there a distribution system in place.

VIII. Future scope

There is research going on to design a more efficient motor that could achieve top speeds of 60 m.p.h. and two to three miles per gallon in an optimally designed vehicle. This would enable the LN2000, using a 100-gallon tank, to match the average range for gas-powered vehicles of 250 miles between fill-ups. As large as the 100-gallon tank sounds, it would still weigh less and take up less space than the batteries used in electric cars.

The liquid nitrogen vehicle also has the potential to be more economical to operate than electric vehicles, according to the UW researchers. Assuming a 10-cent-per-gallon price for mass-produced liquid nitrogen, they predict the LN2000 would cost about 4 cents per mile to drive compared with an estimated 7 cents-per-mile cost of driving electric cars (including the cost of battery replacement every two to three years).

Another advantage for liquid nitrogen cars is that they don't require a new infrastructure for mass utilization. Today's filling stations can easily be converted to dispense liquid nitrogen instead of gasoline. And users will be able to fill up in minutes rather than the 4-6 hours required to fully recharge an electric car battery.

IX. Conclusion

In the present scenario, the more such vehicles are used, the cleaner the air will become. And an added advantage would be if the liquefaction process is driven by non-polluting energy sources such as solar energy, wind energy, tidal energy. Even if the liquid nitrogen manufacturing plant is powered by fossil fuels, the exhaust from these plants would be trapped for use as the feedstock for the liquid nitrogen, so no pollutants would be released into the atmosphere. In addition to the environmental impact of these vehicles, refuelling using current technology can take only a few minutes, which is very similar to current gas refueling times.

X. References

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