LIQUID NITROGEN AS A NON- POLLUTING FUEL

A SEMINAR REPORT

Submitted by

SHUBHAM RAGHUVANSHI

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BONAFIDE CERTIFICATE

This is to certify that the Technical Seminar report entitled '**LIQUID NITROGEN AS A NON-POLLUTING FUEL'** being submitted by SHUBHAM RAGHUVANSHI, in fulfillment of the requirement for the award of degree of Bachelor of Technology in Discipline of MECHANICAL ENGINEERING, has been carried out under my supervision and guidance. The matter embodied in this thesis has not been submitted, in part or in full, to any other university or institute for the award of any degree, diploma or certificate.

Mr. Grandhi Suresh Kumar
(Project Supervisor)
Department of Mechanical
Sir Padampat Singhania University,
Udaipur

Prof. Naveen Kumar
(Head of Department)
Department of Mechanical
Sir Padampat Singhania University,
Udaipur

Dr. Achintya Choudhary
Dean, School of Engineering
Sir Padampat Singhania University,Udaipur

DECLARATION

I, **SHUBHAM RAGHUVANSHI**, student of Bachelor of Technology (Mechanical Engineering) hereby declare that the project titled LIQUID NITROGEN AS A NON-POLLUTING FUEL which is submitted by me to Department of Mechanical Engineering, School of Engineering, Sir Padampat Singhania University, Udaipur, in partial fulfillment of requirement for the award of the degree of Bachelor of Technology in Mechanical Engineering, has not been previously formed the basis for the award of my degree, diploma or other similar title or recognition.

SHUBHAM RAGHUVANSHI,
Enrollment Number: **10ME001118**
Department of Mechanical Engineering
B.Tech, 4^{th} Year
Sir Padampat Singhania University,
Udaipur.

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I am particularly indebted to my parents for inspiring and motivating me to accomplish this seminar report of my Bachelor of Technology degree.

List of Figures

List of Symbols, Abbreviations and Nomenclature

K	Kelvin
°C	Celsius
°F	Fahrenheit
Atm	Atmospheric pressure
T	Temperature
P	Pressure
W_i	Isobaric specific energy
MPA	Mega Pascal
k	Ratio of specific heat of nitrogen
μ	Ratio of the working fluid mass flow rate
ε	Ratio of specific heat capacities
L	Latent heat of vaporization.

ABSTRACT

This report examines the capability of several energy conversion process to provide sufficient energy in a world where the non-renewable resources are getting depleted. Moreover pollution caused by them is increasing at a rapid rate. One such efficient and non-polluting means of running the vehicles is the use of liquid nitrogen. To use liquid nitrogen as a non-polluting fuel, a multiple reheat open Rankine and a closed Brayton cycle are used.

These are concentrated to cryogenic heat engines. an automobile was converted to run on liquid nitrogen, In 1997 as a proof of the principle of using liquid nitrogen as a fuel. Earlier work has shown that the energy available by operating various thermodynamic cycles between atmospheric temperature and liquid nitrogen temperatures (77 K) can provide more energy per unit mass than is available from current lead-acid batteries and some project and implimentationed battery technologies.

1. INTRODUCTION

In 1997, the University of North Texas (UNT) and University of Washington (UW) independently developed liquid nitrogen powered vehicles in which the propulsion systems in these vehicles are cryogenic heat engines in which a cryogenic substance is used as a heat sink for heat engine. A Liquid Nitrogen Car

There are approximately 247 million vehicles in the U.S. today and approximately 97% of those vehicles are gasoline or diesel powered The current average fuel efficiency of automobiles in the U.S. is 20.2 miles per gallon nearly 50% lower than on road fuel economy in other industrialized nations .This presents a twofold challenge . First, fossil fuel supplies are limited. Some estimates indicate that the world could see a peak in its total oil production mandated by resource availability and economic and political factors as soon as 2012.After such a peak, fossil fuel production will decrease. Second, gasoline powered vehicles are extremely dirty. Burning one gallon of gasoline emits 19.4 pounds of carbon dioxide along with a host of other pollutants In response to this obvious need for a shift away from fossil fuel powered vehicles, we propose to explore the use of liquid nitrogen as a combustion-free clean alternative vehicle fuel. The use of liquid nitrogen as such a fuel for automobiles has many possibly far-reaching benefits. Several analysis have shown that the specific energy achievable with cryogenic heat engines using liquid nitrogen as the working fluid are comparable to current battery technologies. 1,2 Since the source of liquid nitrogen is air (78% of air is nitrogen), liquid nitrogen is readily available at a low cost. In a liquid nitrogen cryogenic heat engine, ambient heat from the atmosphere is used as a heat source to cause liquid nitrogen to phase change from a liquid to a gas. Subsequent heating of the gas by heat from the atmosphere provides rapid expansion to run an expander. The exhaust gas, nitrogen gas, is released into the atmosphere. It should be noted that air is composed of 78% nitrogen, and so the exhaust gas of a liquid nitrogen engine is simply a component of air. A cryogenic heat engine running on liquid nitrogen is an environmentally clean, combustion-free engine, which could be used for zero emission vehicles

2. CRYOGENIC AND ITS DEVELOPMENT

2.1Cryogenics

The branches of physics that deals with the study of very low temperatures, how to produce them, and how materials behave at those temperatures.

2.2Cryogenic Engineering

It is mainly concerned with temperatures found in range of –150^{o}C to absolute zero (-273.15^{o}C).

Cryogenic temperatures are achieved either by the rapid evaporation of volatile liquids or by the expansion of gases confined initially at pressures of 150 to 200 atmospheres. The expansion may be simple, that is, through a valve to a region of lower pressure, or it may occur in the cylinder of a reciprocating engine, with the gas driving the piston of the engine. The second method is more efficient but is also more difficult to apply. Pioneering work in low-temperature physics by the British chemists Sir Humphrey Davy and Michael Faraday, between 1823 and 1845, prepared the way for the development of cryogenics. Davy and Faraday generated gases by heating an appropriate mixture at one end of a sealed tube shaped like an inverted V. The other end was chilled in a salt-ice mixture.. The combination of reduced temperature and increased pressure caused the evolved gas to liquefy. When the tube was opened, the liquid evaporated rapidly and cooled to its normal boiling point. By evaporating solid carbon dioxide mixed with other, at low pressure, Faraday finally succeeded in reaching a temperature of about 163 K (about -110°C/-166°F).If a gas initially at a moderate temperature is expanded through a valve, its temperature increases. But if its initial temperature is below the inversion temperature, the expansion will cause a temperature reduction as the result of what is called the Joule-Thomson effect. The inversion temperatures of hydrogen and helium, two primary cryogenic gases, are extremely low, and to achieve a temperature reduction through expansion, these gases must first be pre-cooled below their inversion temperatures.

2.3 Various Cryogenic Fluids

- Liquid Nitrogen
- Liquid Helium

3. LIQUID NITROGEN

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 temperature 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 flask.

3.1 Properties of Liquid Nitrogen

Liquid nitrogen is inert, colorless, odorless, non-corrosive, nonflammable, and extremely cold. Nitrogen makes up the major portion of the atmosphere (78.03% by volume, 75.5% by weight). Nitrogen is inert and will not support combustion; however, it is not life supporting. Nitrogen is inert except when heated to very high temperatures where it combines with some of the more active metals, such as lithium and magnesium, to form nitrides. It will also combine with oxygen to form oxides of nitrogen and, when combined with hydrogen in the presence of catalysts, will form ammonia.

3.2 Physical Properties

- Molecular Weight: 28.01
- Boiling Point @ 1 atm: -320.5°F (-195.8°C, 77^{o}K)
- Freezing Point @ 1 atm: -346.0°F (-210.0°C, 63^{o}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

3.3PRODUCTION OF LIQUID NITROGEN

3.3.1 STIRLING PROCESS

This is the most famous process by which liquid nitrogen was generated. Here air is sucked in and compressed through compressor so that water is rejected out, and then through pressure swing adsorption the excess amount of oxygen and its wastes are removed and the remaining nitrogen is sent into cryogenerator and it is compressed as liquid nitrogen and stored in tanks.

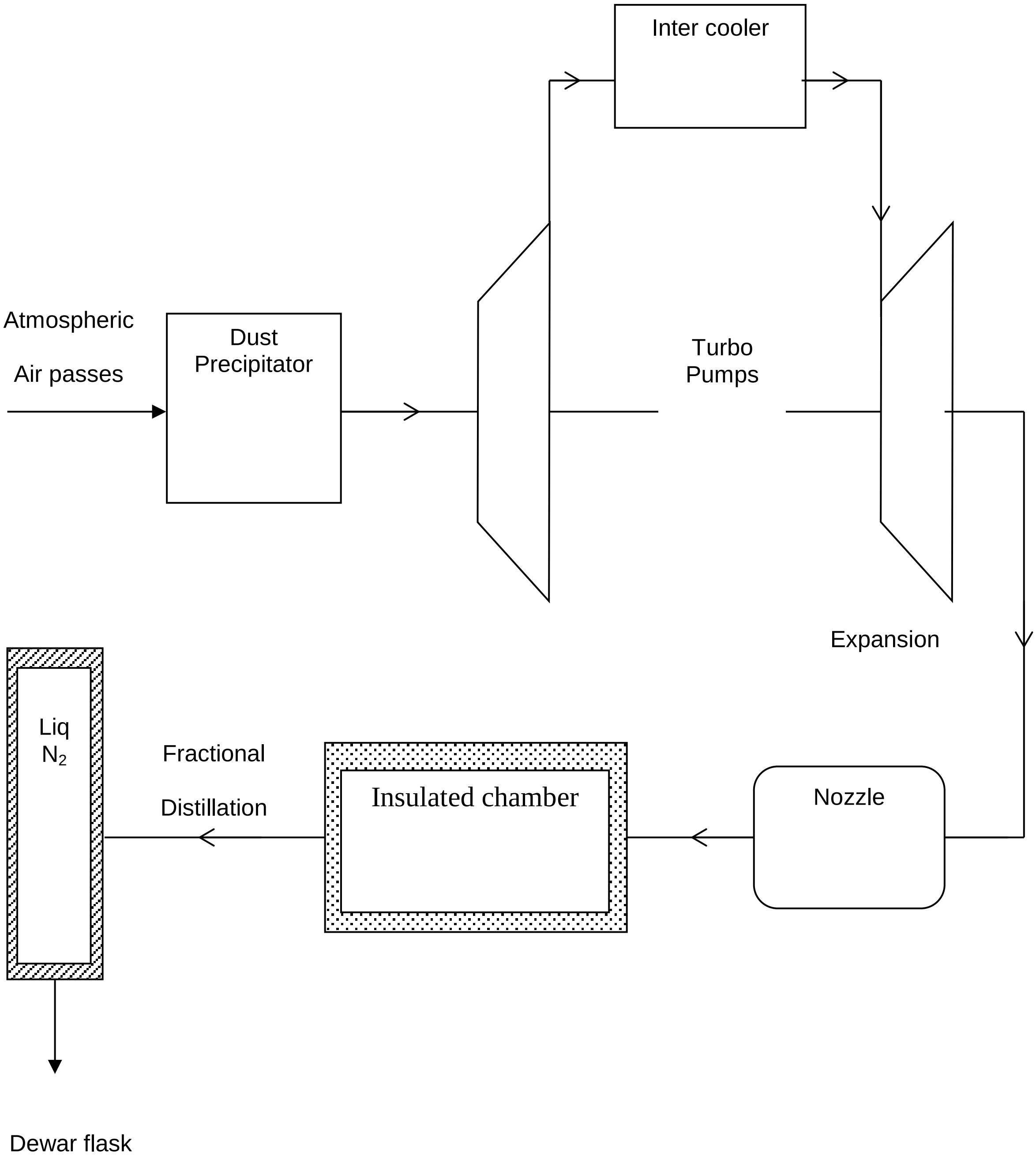
A practical Stirling liquid nitrogen compressor which compresses the nitrogen at cryogenic temperature. The sketch and its specifications are given below

Storage of Nitrogen

The nitrogen is stored in Dewar flask which is a vacuum flask

Dewar flask

A glass vessel used for keeping liquids at temperatures differing from that of the surrounding air. This is done by reducing to a minimum the transfer of heat between the liquid and the air. A Dewar flask consists of a double-walled flask, with the space between the two walls exhausted to a very high vacuum, to minimize transfer of heat by convection and conduction. The inner surfaces of the walls are silvered to reduce transfer of heat by radiation; areas of contact between the two walls are kept at a minimum to keep down conduction of heat.



Nitrogen cycle showing the production of liquid nitrogen

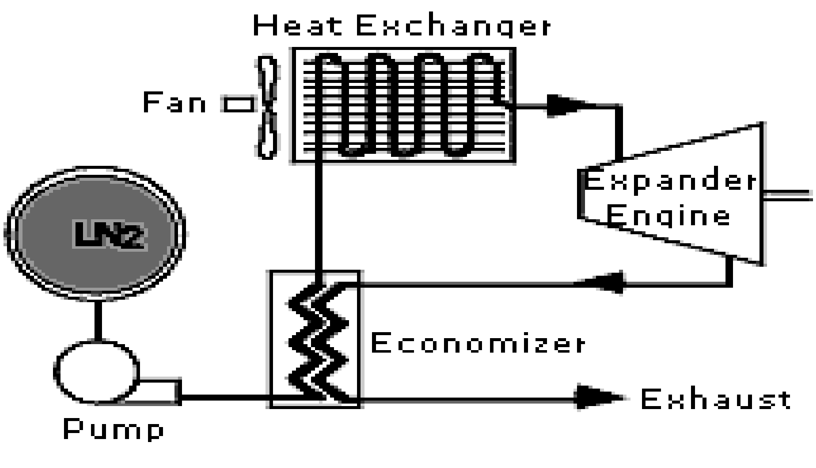
4. CRYOGENIC HEAT ENGINE

4.1 Definition

It is a engine which uses very cold substances to produce useful energy. A unique feature of an cryogenic heat engine is that it operates in an environment at the peak temperature of the power cycle, thus, there is always some heat input to the working fluid during the expansion process.

4.2 Main Components of the Engine:

- A pressurized tank to store liquid nitrogen
- A pump that moves the liquid nitrogen to the economizer, Pressurant bottles of N_2 gas substitute for a pump.
- A primary heat exchanger that heats (using atmospheric heat) liquid nitrogen to form nitrogen gas, then heats gas under pressure to near atmospheric temperature.
- An Expander to provide work to the drive shaft of the vehicle
- An economizer or a secondary heat exchanger, which preheats the liquid N_2 coming out from the pressurized tank taking heat from the exhaust.



Liquid nitrogen energy conversion system

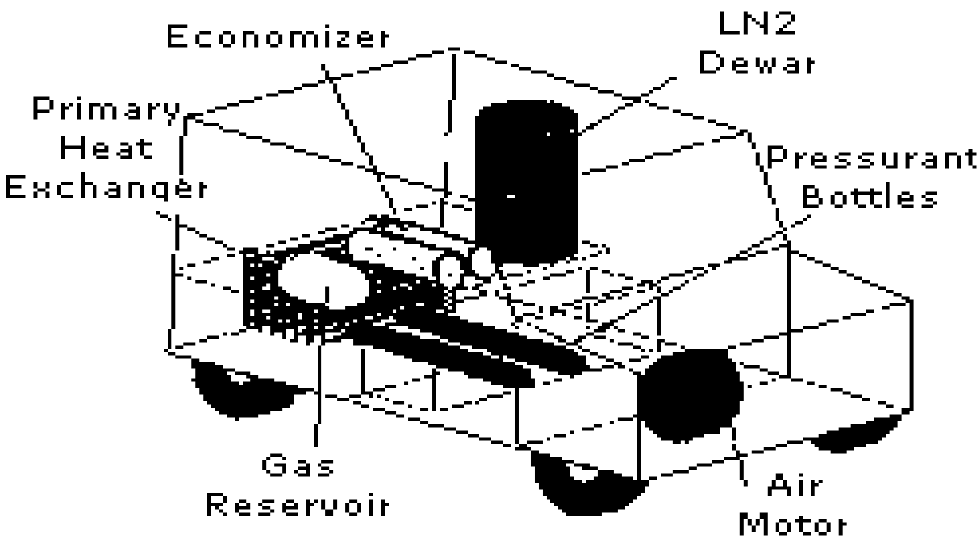
4.3 LN2000

Another version of an air-powered car is being developed by researchers at the University of Washington using the concept of a steam engine, except there is no combustion. The Washington researchers use liquid nitrogen as the propellant for their LN2000 prototype air car. The researchers decided to use nitrogen because of its abundance in the atmosphere -- nitrogen makes up about 78 percent of the Earth's atmosphere -- and the availability of liquid nitrogen.

4.3.1 Working

The liquid nitrogen, stored at -320 degrees Fahrenheit (-196 degrees Celsius), is vaporized by the heat exchanger. The heat exchanger is the heart of the LN2000's cryogenic engine, which gets its name from the extremely cold temperature at which the liquid nitrogen is stored. Air moving around the vehicle is used to heat the liquid nitrogen to a boil. Once the liquid nitrogen boils, it turns to gas in the same way that heated water forms steam in a steam engine

Nitrogen gas formed in the heat exchanger expands to about 700 times the volume of its liquid form. This highly pressurized gas is then fed to the expander, where the force of the nitrogen gas is converted into mechanical power by pushing on the engine's pistons. The only exhaust is nitrogen, and since nitrogen is a major part of the atmosphere, the car gives off little pollution. However, the cars may not reduce pollution as much as you think. While no pollution exits the car, the pollution may be shifted to another location. As with the evolution car, the LN2000 requires electricity to compress the air. That use of electricity means there is some amount of pollution produced somewhere else. Some of the leftover heat in the engine's exhaust is cycled back through the engine to the economizer, which preheats the nitrogen before it enters the heat exchanger, increasing efficiency. Two fans at the rear of the vehicle draw in air through the heat exchanger to enhance the transfer of heat to the liquid nitrogen.



Setup position of various components of nitrogen powered car

4.4 How does the Nitrogen Powered car work?

Heat from the atmosphere vaporizes liquid nitrogen under pressure and produces compressed nitrogen gas. This compressed gas runs a pneumatic (compressed gas drive) motor with nitrogen gas as the exhaust.

5. PRINCIPLE OF OPERATION

The University of Washington discovered a car that runs with liquid nitrogen as a fuel. Researchers at the University of Washington are developing a new zero-emission automobile propulsion concept that uses liquid nitrogen as the fuel. The principle of operation is like that of a steam engine, except there is no combustion involved. Instead, liquid nitrogen at –320° F (–196° 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.

5.1 LN2000 MODEL AND SPECIFICATION

The LN2000 is an operating proof-of-concept test vehicle, a converted 1984 Grumman-Olson Kuban mail delivery van. The engine, a radial five-cylinder 15-hp air motor, drives the front wheels through a five-speed manual Volkswagen transmission. The liquid nitrogen is stored in a thermos-like stainless steel tank, or Dewar, that holds 24 gallons and is so well insulated that the nitrogen will stay liquid for weeks. At present the tank is pressurized with gaseous nitrogen to develop system pressure but a cryogenic liquid pump will be used for this purpose in the future. A preheated, called an economizer, uses leftover heat in the engine's exhaust to preheat the liquid nitrogen before it enters the heat exchanger. Two fans at the rear of the van draw air through the heat exchanger to enhance the transfer of ambient heat to the liquid nitrogen. The design of this heat exchanger is such as to prevent frost formation on its outer surfaces. As with all alternative energy storage media, the energy density (W-hr/kg) of liquid nitrogen is relatively low when compared to gasoline but better than that of readily available battery systems. Studies indicate that liquid nitrogen automobiles will have significant performance and environmental advantages over electric vehicles. A liquid nitrogen car with a 60-gallon tank will have a potential range of up to 200 miles, or more than twice that of a typical electric car. Furthermore, a liquid nitrogen car will be much lighter and refilling its tank will take only 10-15 minutes, rather than the several hours required by most electric car concepts. Motorists will fuel up at filling stations very similar to today's gasoline stations. When liquid nitrogen is manufactured in large quantities, the operating cost per mile of a liquid nitrogen car will not only be less than that of an electric car but will actually be competitive with that of a gasoline car.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.

5.2 Analysis of CooLN2 Car Performance:

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 expanders 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.

The COOLN2 Car which a converted 1973 Volkswagen and runs on liquid nitrogen is an illustrative to the use of isobaric expansion equation.

6. POWER TRAIN OF NITROGEN POWERED CAR

6.1 NITROGENS ECONOMY

Nitrogen is more economic and in mass production for producing 1gallon of n2 (4litres) it costs Rs4/-. And moreover for electric vehicles 1000 pounds of lead are used and it costs more than this . Currently, most road vehicles are powered by internal combustion engines burning fossil fuel. If transportation is to be sustainable over the long term, the fuel must be replaced by something else produced by renewable energy. The replacement should not be thought of as an energy source; it is a means of transferring and concentrating energy, a "currency" Liquid nitrogen is generated by cryogenic or Stirling engine coolers that liquefy the main component of air, nitrogen (N_2). The cooler can be powered by renewable generated electricity or through direct mechanical work from a hydro or wind turbines. Liquid nitrogen is distributed and stored in insulated. The insulation reduces heat flow into the stored nitrogen. Heat from the surrounding environment boils the liquid. Reducing inflowing heat reduces the loss of liquid nitrogen in storage. The requirements of storage prevent the use of pipelines as a means of transport. Since long-distance pipelines would be costly due to the insulation requirements, it would be costly to use distant energy sources for production of liquid nitrogen. Petroleum reserves are typically a vast distance from consumption but can be transferred at ambient temperatures. Liquid nitrogen consumption is in essence production in reverse. The Stirling engine or cryogenic heat engine offers a way to power vehicles and a means to generate electricity. Liquid nitrogen can also serve as a direct coolant for refrigerators, electrical equipment and air conditioning units. The consumption of liquid nitrogen is in effect boiling and returning the nitrogen to the atmosphere.

6.2 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

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

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 Wadiabatic is 180KJ/Kg of Nitrogen exhausted at 150KPA.

6.3 Closed Brayton Cycle Processes:

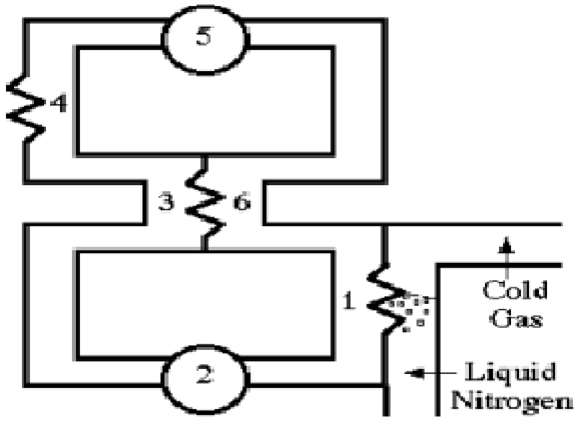


Figure 1 Closed Brayton-cycle cryogenic heat engine

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

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

Here,

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

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

That = temperature of heat source

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

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

By combining equations we get

$W = e_g L\,[e_e p^{-\varepsilon}(T_{hot}/T_{cold}) - (1/e_c)]$ ……..(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.

7. ADVANTAGES,DRAWBACKS

7.1 ADVANTAGES

- ✓ The energy density of liquid nitrogen is relatively low and better than readily available battery systems.
- ✓ They have significant performance and environmental advantages over electric vehicles.
- ✓ A liquid nitrogen car is much lighter and refilling its tank will only 10-15 minutes.
- ✓ The exhaust produced by the car is environmental friendly.

7.2 DRAWBACKS

- The N_2 passing through the tubes of the heat exchanger is so cold that the moisture in the surrounding air would condense on the outside of the tubes, obstructing the air flow.
- Then there's the safety issue. Should a nitrogen car be kept in a poorly ventilated space and, if the Nitrogen leaks off, it could prove fatal.
- Turning N_2 gas into a liquid requires a lot of energy. So while cryogenic cars have zero emissions, they rely on energy produced at emission generating power plants.

7.3 Probable solutions:

- A tube within a tube design.
- N_2 passes back and forth inside a set of three nested tubes.
- By the time it reaches the outermost tubes, the N_2 is warm enough that the exterior wall of the tube remains above the freezing point of water.
- Route the exhaust from the fossil fuel power plants through cryogenic plants, so that the pollutants and the greenhouse gases could be condensed for later disposal

7.4 Efficiency:

A liquid nitrogen car with a 60-gallon tank will have a potential range of up to 200 miles, or more than twice that of a typical electric car

Why not commercialized?

Even though the technology is 10 to 12 years old, still it has not come to the market for two reasons.

- Safety issues have not been sorted out as yet.
- Lack of funds for research.

<u>8. THREATS FOR OTHERS</u>

8.1 FOR ELECTRIC CARS

The cost of production of 1 gallon of liquid nitrogen costs approx about Rs. 2/- (4 cents) whereas an electric car requires 7 cents. Refilling of the tank requires just 10-15 min, while an electric car requires an considerable amount. Extremely non pollutant whereas, lead-acid batteries used in electric cars pose threats in increasing metal pollution.

8.2 FOR HYDROGEN CAR

More over nitrogen is safer than hydrogen since this is less combustible than hydrogen and the liquefaction process is simple rather than hydrogen. The engine design is simple and the availability is more

9. CONCLUSION

SO due to the nitrogen abundance and its property of inertness and zero emissions we would see the world filled with car that would be propelled by nitrogen everlasting.

The scope of cryogenics has expanded widely from basic military and space applications to various civil applications. Already Infrared sensors are being increasingly used for fire detection alarm systems, energy conservation thermo graphic analysis, astronomical observations, and medical thermo graphic analysis for early Cancer detection.

The future developments are expected to lead towards disposable miniature 80 K cryogenics. Ever since the introduction of cryogenic nitrogen, it has found applicability in practically all fields because of its higher efficiency as compared to cryogenics based on other refrigerating cycles Cryogenics offer immense scope for the researchers and scientists for challenging ideas for new developments. Thus we conclude that the cryogenic nitrogen are playing a very important role in the researches and applications of its liquefaction, preservation and super cooling processes In a real sense, the more such vehicles are used, the cleaner the air will become if the liquefaction process is driven by non-polluting energy sources. In addition to the environmental impact of these vehicles, refueling using current technology can take only a few minutes, which is very similar to current gas refueling times.

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