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ENGINEERING DESIGN OF A CRYOGENIC POWER PLANT

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ABSTRACT

Liquid nitrogen warms up at room temperature (27°C) because of its low liquefaction temperature of - 196°C. In this stage, it undergoes first a phase change (from liquid to gas), which results in an expansion of 174.6 times the original volume of liquid. The resulting nitrogen gas is than warmed by room temperature expanding an extra 3.7 times. Hence, the net expansion for liquid nitrogen is 645.3 (i.e., 174.6 × 3.7) times the original volume when heated to room temperature. Due to the non-ideal gas behavior of N_2 at such extreme pressures, the theoretical pressure of the container would be over 30000 PSI. Due to this dramatic expansion the liquid nitrogen vaporize to create high-pressure in the presence of a Heat Exchange Pressurize Tank (HEPT) very quickly. In the present paper, the engineering and technical details of the HEPT discussed, which is capable to deliver very high-pressurized gas jet via an adjustable nuzzle and rotate a turbine with very high speed, hence produces electricity with a generator efficiencies of 0.85 at 40 psi. This portable LN_2 based electric power generator can provide vital information to built an alternative electric power plant for industries.

I. INTRODUCTION

Nitrogen is the main component of air, comprising 78 to 79% by volume. Again, liquid nitrogen (LN_2) is primarily used as refrigerant agent. The boiling point of LN_2 is −195.8 °C. So at normal temperature and atmospheric pressure (27°C and 1atm.), large volumes of nitrogen gas are evolved from small volumes of liquid nitrogen i.e. 1 liter of LN_2 gives around 0.7 m^3 of vapour [1-3]. Expansion ratio of liquid to gas at 27°C is nearly 1:700. Hence even at room temperature vapour expands 700 times more then the volume of the liquid. The critical pressure of LN_2 is 3400Kpa or 33.54 atm. So the vapour produces a very high pressure at the exit of the container. This pressure-volume work associated with the expansion of gases is discussed in most introductory physics book. The above high-pressurized vapour thrust cane produce electricity by introducing a turbine coupled with generator. Similar arrangement is also required in case of liquid nitrogen fueled (LNF) engine [4, 5]. In the present paper, an attempted has taken to produce electricity using high-pressurized thrust of LN_2 generated using a Heat Exchange Pressurize Tank (HEPT). The engineering and technical details of the HEPT discussed, which is capable to deliver very high-pressurized gas jet via an adjustable nuzzle and rotatea turbine with very high speed, hence produces electricity.

To begin the process of creating a pure form of liquid nitrogen, regular air must be used as a starting point. Before the air is actually separated into its different constituents, all of, or at least most of, the air must be cooled until it is liquefied. Specifically, air begins to liquefy at a temperature of negative 140.7 degrees Celsius, negative 221.3 degrees Fahrenheit, and at a pressure of 37.7 bars. This is called the critical point of air[6].Not all of the gases, which include argon, nitrogen, oxygen, carbon dioxide and small amount of other gases, have the same critical point. The only one that is of concern is nitrogen, which has a critical point of negative 146.9 degrees Celsius (-232.42 degrees Fahrenheit) and a pressure of 33.5 bars.

The next step in the process of liquefying nitrogen is called separation by rectification. In this step a double column rectification system is used and a diagram of the system. .In the double column rectification system, there are two columns, an upper and lower, and a re-boiler or condenser in the middle. The lower column is where the process of creating the liquid nitrogen begins. To begin, the liquefied air that we obtained in the first step is brought to the lower column, which is kept at around 5.6 bars to the top's 1.5 bars. The higher pressure

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in this case allows the liquid air to heat up, and since liquid nitrogen has a lower boiling point than the other gasses.

II. METHODOLOGY

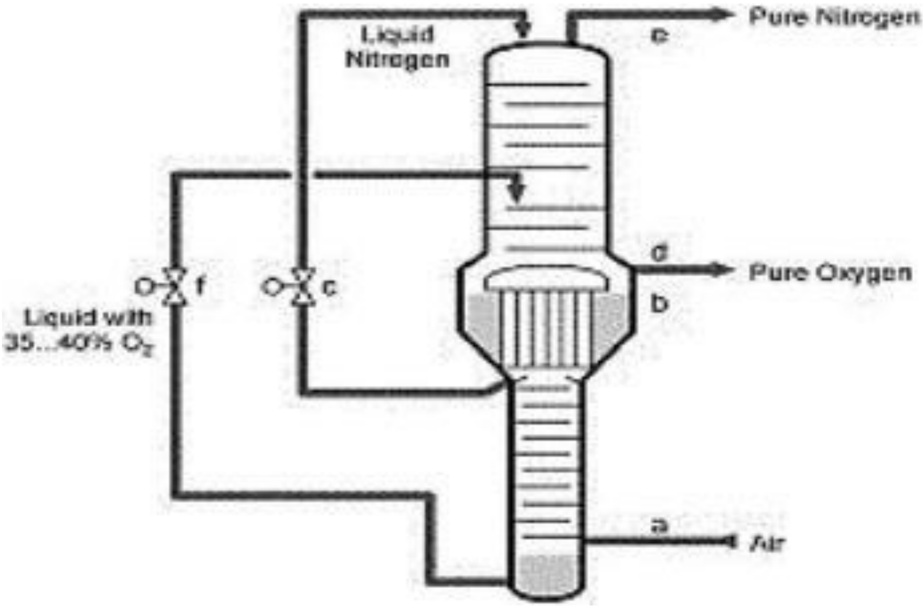

Figure.1 A Double column liquid rectification system process (top column)

Before both the nitrogen and the liquefied air are transferred to the top column, the liquid nitrogen is extracted from the bottom column and taken to a condenser where it is liquefied and returned to the top column. At this point in the process, both the liquid air and the liquid nitrogen are in the top column that is at a lower pressure. In the top of the top column the liquid nitrogen is allowed to evaporate, creating a pure form of nitrogen gas. In the bottom of the top column the re-boiler takes its role in the process. The main purpose of the re-boiler or condensers "to generate a flux of vapor to feed to a distillation tower; the vapor rises up the tower contacting a downwards-flowing liquid stream". This allows vapors to be created, which then drives the process of further distillation separation. The output of this process is the creation of pure oxygen. At the end of this procedure, the two products that are left are pure nitrogen and oxygen. At this point the nitrogen can be condensed and cooled so that it can reach a liquefied state. This ~~is~~ process is one of many that can be used to make liquid nitrogen.

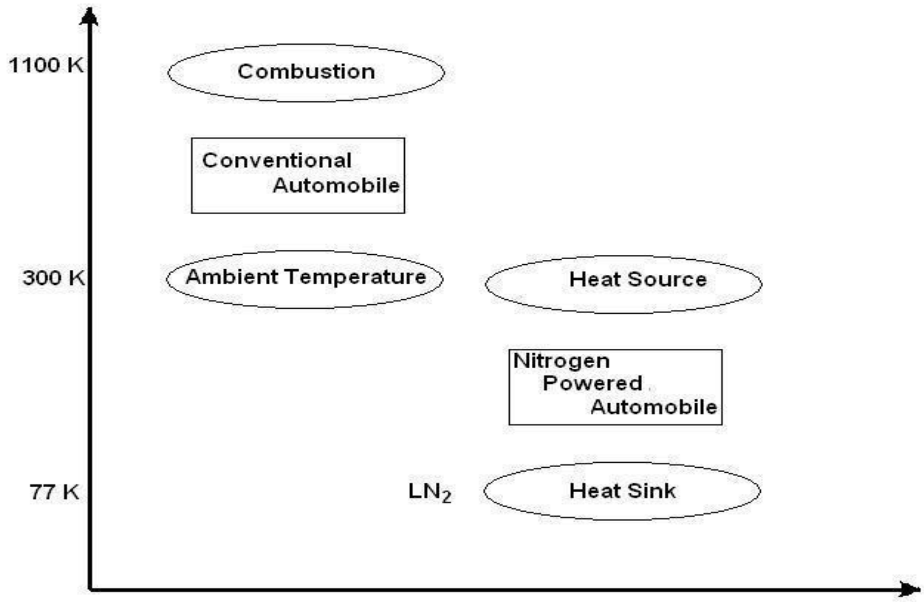

Figure.2

Liquid nitrogen warms up at room temperature (27°C) because of its low liquefaction temperature of - 196°C. Another important and curious properties of LN_2 is its density. Density of liquid (normal boiling point of -195.8°C, 1 atm.) is 807 kg/m³, gas is 1.25 kg/m3 and at STP is 4.62 kg/m³. In boiling stage, it undergoes first a phase change (from liquid to gas), which results in an expansion of (807/1.25), 174.6 times theoriginal volume of liquid. The resulting nitrogen gas is than warmed by room temperature (27°C) expanding an extra (4.62/1.25), 3.7 times. Hence, the net expansion for liquid nitrogen is 645.3 (i.e., 174.6 × 3.7) times the original volume when heated to room temperature. Critical density (314 kg/m³) value are those values below with a gas will not form into a liquid [3]. This makes it very useful as a means of producing high pressure. Many different ways are available to utilize and use the energy stored in a cryogenic medium. There are some standard thermodynamics cycles which are used to produce power like Brayton cycle and Rankine cycle.

1. Liquid Nitrogen storage tank

The Dewar (a vacuum insulated vessel to store cryogen) whose capacity is 1 liter of liquid Nitrogen at bar. The boil off (evaporation) rate is about 3% per day. The primary protection against over-pressure is a relief valve connected to the internal vessel. The valve serves as the bleed for the evaporated Nitrogen

2. Pressurization system

It consists of high pressure Nitrogen bottles (each weighs around 2 kg) stored under the rear deck of the vehicle.The pressurized tanks are initially filled to a starting pressure of about few psi. This regulated down to the system pressure of 20 psi before being injected to Dewar

3. Economizer:

It is actually a pair of shell and tube type heat exchanges. Each of the tube make 5 passes through the interior of the shell. Internal baffles direct the shell side gas across the tubes in a cross flow pattern.

4. Ambient Air Heat exchanges:

Heat exchanges is made up of ¼ in cu-tube elements which are manifolded together to make a staggered array of tubes in cross-flow with the incoming air. The air is propelled through the heat exchanges by the conduction of heat from the surrounding.

5. Ex-pander:

The expander installed vane type air motor. The motor is attached to the turbine. The output drive shaft drives amotor to produce power.

Liquid nitrogen cryogenic engines operate similarly to gasoline combustion engines, where a working fluid is rapidly expanded to drive pistons, thus applying work to the system. In this system, liquid nitrogen is quickly brought from cryogenic temperatures (< 150 K) to ambient temperature, which is the temperature of the surroundings. The result is an increase in volume within the piston chamber, comparable to gasoline combustion. The exhaust, nitrogen gas (N_2), is then harmlessly released into the atmosphere at ambient temperature [8].

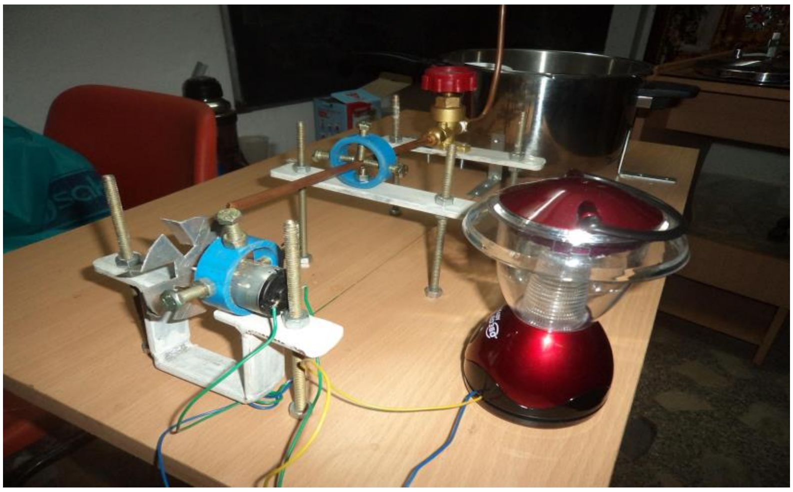

Figure.3 Working model of Cryogenic power plant.

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III. CONCLUSION

In conclusion, this prototype cryogenic device gives an idea to design a power plant which producespower without emitting any pollutants. The major points are as follows:

(a) The HEPT was maintained at 118 psi at a maximum tank shear stress 1115 psi (for the safety purpose)

(b) Spring Loaded Relief Valve was set at 142psi.

(c) A small power generator of 8W capacity was designed and aligned in the in path of the Nozzle.

(d) We obtained around 7 W with an efficiency about 0.85 at a pressure 40 psi.

(e) This project can be implemented for large scale power production for Industry.

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