Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 14	No. 2	pp.427-430	2015

Original Research Paper

Carbon Dioxide Capture Via Liquid Nitrogen in Compression Ignition Engine

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 10-9-2014
Accepted: 13-10-2014

Key Words:
Diesel engine
Emission
CO_2 Capture
Liquid nitrogen

ABSTRACT

The current study presents a new process for post combustion carbon dioxide (CO_2) capture in diesel engine. Cryogenic technique is used to achieve CO_2 separation from engine exhaust gas. The proposed process converted the CO_2 in the form of dry ice using a cooled liquid absorbent (liquid nitrogen) at low pressure (close to atmospheric) and cryogenic temperature. The liquid nitrogen has a temperature of -196°C provided the cooling power to freeze out the CO_2 in the form of dry ice. Experiments are performed in single cylinder four stroke diesel engine with an eddy current dynamometer and AVL444 Di-Gas analyser. The engine exhaust gas is allowed to pass over liquid nitrogen CO_2 capture system. The result shows that liquid nitrogen is able to convert 90% of CO_2 in the form of dry ice at full load condition.

INTRODUCTION

In recent years the greenhouse effect of CO_2 has arrested concentration as a factor contributing to the global warming. Counteracting this effect is right away needed throughout the world to defend the global environment. The sources of CO_2 are ubiquitous in every area of human activities that involve combustion of fossil fuels and the tendency is towards stricter emission control than before. In view of these factors many studies are under way in the recovery of CO_2 from combustion exhaust gases, especially from those emitted by internal combustion engines and on the storage of the recovered CO_2 without releasing it to the atmosphere.

Carbon capture and storage (CCS) technology is a productive research area for the past two decades. The carbon capture technology is broadly classified into two types: post combustion and pre combustion systems. Relative merits of each type of carbon capture have been discussed by Rubin (2004) and McGlashan (2007). The current study discusses a new cryogenic process for post combustion carbon capture.

CRYOGENIC SEPARATION

At cryogenic temperature, mass transfer can be attained by a process of condensation. As per Hise et al. (1983) statement, the cryogenic process for carbon capture, operated by passing the flue gas through a cooling stage, can sufficiently reduce the vapour pressure of CO_2 to enable its condensation. Cryogenic technology has been ignored in most parts of studies due to its perceived low efficiency and practical difficulties when compared with other technologies, but this is principally due to two physical properties of CO_2, namely, (a) high temperature of its triple point : -56°C. (b) high vapour pressure at its triple point: 5.1 bar.

If CO_2 is condensed from the flue gas at near to ambient pressure, it will make dry ice, whatever the temperature. If a liquid condensate is desired, the flue gas needs to be compressed to 5.1 bar (Hise et al. 2004). Cryogenic cycles have been proposed by McGlashan et al. (2008) and observed that condensation of CO_2 occurs below the triple point temperature and near to atmospheric pressure.

CO_2 ABSORBENT

To select suitable absorbent different constraints are applied in this case since the absorbent needs to perform heat transfer and convert the CO_2 in the form of dry ice. Examining the following properties, liquid nitrogen comes into view as fine chemical agent to capture CO_2 in the form of dry ice.

a. Freezing point: Liquid nitrogen freezing point at 1 atmosphere is -210°C. The Smithsonian table indicated that the freezing point of CO_2 on liquid nitrogen is -78°C.
b. Molecular weight: Liquid nitrogen's molecular weight is 28.01 kg/kmol which is similar to CO_2's molecular weight of 44.1 kg/kmol. As a result, the account of circulating absorbent should be convenient.
c. Volatility: Liquid nitrogen's volatility is high at the temperature likely to occur in the process. In effect, liquid nitrogen is possible to boil-off. Hence, precooling system is used in this study to resolve the problem.

d. Corrosiveness: According to Fontana (1986), the corrosion rates are generally lower in cryogenic temperature and the low level of water vapour present at these temperatures should also reduce corrosion rates.

e. Viscosity: Yaws (1999), graphically represent the variation of dynamic viscosity with respect to temperature and shows liquid nitrogen and CO_2 have very low dynamic viscosity.

EXPERIMENTAL SETUP AND PROCEDURE

Selection of materials for low temperature services have been examined by Ramesh Singh (2009) based on American Society of Mechanical Engineers (ASME) specifications. The present experimental setup consists of a precooling system (spiral coiled coils), heat exchanger and liquid nitrogen coils. The precooling system is made up of stainless steel (SS-304), which has an inner diameter 32mm and outer diameter of 38mm. The heat exchanger is made up of mild steel which has 300mm diameter and 500mm length, closed by a lid of 5mm thick and 320mm diameter. The chamber leakage is arrested by silicon gasket. A hollow liquid nitrogen coil of capacity of 2 litres having 17.4mm inner diameter, 19mm outer diameter, 280mm outer to outer diameter and span height of 330mm is welded on the lid surface. The lid also consists of a pressure gauge and a relief valve for letting out the gases from the heat exchanger. The pressure gauge is calibrated up to 100bar and relief valve automatically releases the gas when it attains desired pressure. The entry of exhaust gases into the chamber is controlled by non-return valve (to prevent back flow) and flow control valve (to control the amount of flow). Fig. 1 shows the line diagram of liquid nitrogen CO_2 capture system.

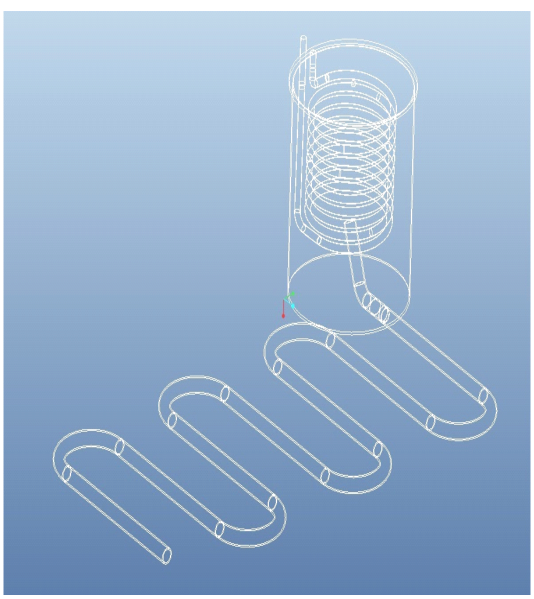

Fig.1: Line diagram of liquid nitrogen CO_2 capture system.

Table 1: Properties of liquid nitrogen.

Molecular weight	28.01 kg/kmol
Boiling point @ 1 atm	-195.8°C
Freezing point @ 1 atm	-210°C
Critical temperature	-146.9°C
Critical pressure	33.5 atm
Density @ BP, 1 atm	50.45 lb/scf
Latent heat of vaporization	2399 Btu/lb mole

Table 2: Engine specification.

Brake Power	4.4 kW
Speed	1500 rpm
Compression ratio	17.5:1
Bore	80 mm
Stroke	110 mm
Ignition	Compression ignition
Cooling	Water cooled
Loading system	Eddy current dyanamometer

Table 3: Analyser specification.

Particulars	Range
NO_X	0-5000 ppm
HC	0-20000 ppm
CO	0-10 vol %
CO_2	0-20 vol %

The present study was carried out in a constant speed direct injection diesel engine coupled with an eddy current dynamometer and AVL444 Di-Gas analyser. Tables 2 and 3 show the specifications of the engine and gas analyser respectively. Fig. 2 (a) and Fig. 2 (b) show the photographic view of total experimental setup.

The brief analysis above has indicated that low temperature is essential if adequate carbon dioxide capture is to be achieved when using liquid nitrogen as an absorbent. Precooling system needs to reduce the temperature of the exhaust gas to room temperature where the liquid nitrogen absorbent can function properly without all being evaporated. The liquid nitrogen is continuously poured into the liquid nitrogen coils. The exhaust gas from precooling system is allowed to pass over liquid nitrogen CO_2 capture system at varying pressure rates, say continuous flow of exhaust gas, 1.5 bar and 2 bar pressure in the system. The above study is conducted for varying load conditions at constant speed.

RESULTS AND DISCUSSION

Enhancement of CO_2 reduction by the liquid nitrogen capture system is compared with normal engine CO_2 exhaust. The following three conditions are used in liquid nitrogen

Fig.2(a): Photographic view of the experimental setup.

Fig.2 (b). Photographic view of experimental setup.

CO_2 capture system; (i) continuous flow of exhaust gas in liquid nitrogen CO_2 capture system, (ii) maintain 1.5 bar pressure in liquid nitrogen CO_2 capture system, (iii) maintain 2 bar pressure in liquid nitrogen CO_2 capture system. The exhaust gas from the liquid nitrogen CO_2 capture system allowed in to the gas analyser and concentration of CO_2 is measured. The variation in CO_2 concentration with brake load for normal engine CO_2 exhaust and liquid nitrogen CO_2 capture system is shown in Fig. 3.

At the normal engine exhaust, CO_2 concentration is 9.2% at full load condition. The continuous flow of gas in the liquid nitrogen capture system shows 26% reduction of CO_2 at the exit. When the exhaust gas pressure is increased to 1.5 bar inside the liquid nitrogen capture system, concentration of CO_2 reduced by 65%. Owing to the additional pressure rise of 2 bar inside the system, the magnitude of CO_2 emission reduced to 90% compared to that of the normal

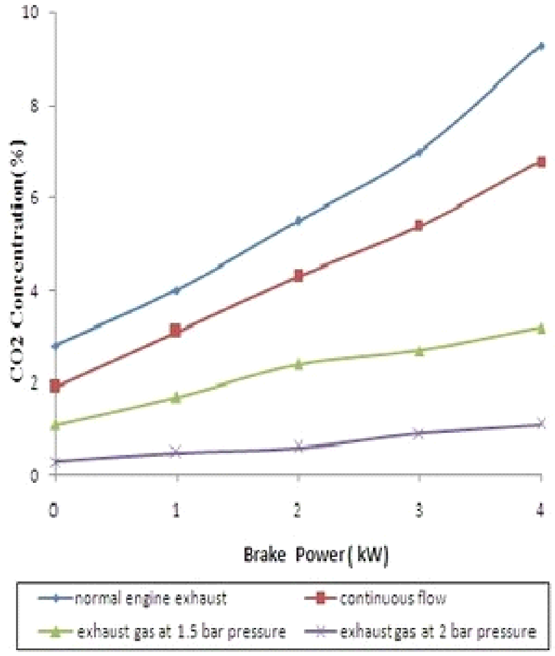

Fig. 3: Variation of CO_2 concentration with respect to brake power.

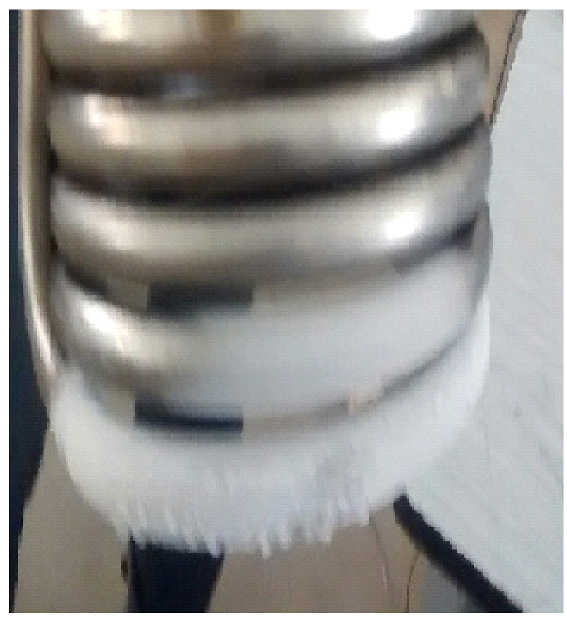

Fig. 4: Dry ice form of CO_2 over liquid nitrogen coils.

engine exhaust. Fig. 4 shows the dry ice form of CO_2 over liquid nitrogen coils.

CONCLUSION

The current study has proposed the use of liquid nitrogen as the primary absorbent of CO_2 in the carbon capture process. An analysis of engine exhaust gas from the cryogenic heat exchanger system is conducted that illustrate liquid nitrogen as an excellent absorbent and captured 90% of CO_2 in the form of dry ice at maximum load condition.

This study goes on to propose an extension of the process by recirculation of liquid nitrogen. By this means, the vapour state of nitrogen at the exit of liquid nitrogen coils will be able to convert into liquid nitrogen.

ACKNOWLEDGEMENT

The authors acknowledge the Management and Dr. R. Joseph Xavier, Principal, Sri Ramakrishna Institute of Technology, Coimbatore for providing facilities and support to execute the research work. The authors declare that they have no competing financial interests.

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