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SURFACE VEHICLE INFORMATION REPORT

J2699 JUL2011

Issued 2011-07

Liquefied Natural Gas (LNG) Vehicle Fuel

RATIONALE

Liquefied Natural Gas (LNG) is a cryogenic hydrocarbon liquid used as a transportation fuel and by its very nature as a cryogen changes in composition as it is transferred from the LNG production facility to fueling station and then to the vehicles fuel storage system. At present there are no guidelines that can help the industry manage the change in composition of LNG so that the end user receives a fuel that meets the specifications required for proper operation of the vehicle. The time sensitive nature of LNG is unique in the transportation industry and SAE J1616 is needed to provide a methodology to determine LNG useable lifetime.

The only agency in North America that provides a minimum composition level of natural gas vehicles is CARB. This regulation is a Compressed Natural Gas standard and the reference to water, CO2, sulfur, and lubricates which do not apply to LNG, the hydrocarbon components of natural gas do apply. The minimum level of methane and max levels of ethane, propane, butane, and nitrogen, provide important references for engine manufactures. These minimum and maximum levels of constituents in the fuel composition are crucial in the engine design.

When using LNG as a vehicle fuel, it is stored at some combination of cryogenic temperature and relatively low pressure. It is not uncommon for the fuel to go through several transfers as it is moved from production site storage, to a transport tank, transport tank to a local refueling station tank and then into the vehicle tank. During each transfer, and during periods of storage, heat transfers into the fuel, which if left to evaporate its composition will change.

In order to provide fuel to the engine that meets the minimum hydrocarbons requirement of CARB, the LNG vaporization must be controlled and LNG inventories must be managed. Therefore, this document includes the information required to calculate a "dispense by" date for LNG. With a fixed set of assumptions on evaporation rates, a known initial fuel composition, the future fuel composition can be calculated. While this document is based on CARB requirements, the same methodology can be used for different fuel composition targets were required.

The purpose of this document is to provide the fixed assumption and calculation so that LNG producers can provide the require product information data which fuel composition and it's "dispense by" dates can be calculated. The "dispense by" date provides users the date when the fuel no longer meets the minimum hydrocarbon requirement of CARB, which may compromise the engine emission performance, warranty or reliability. The "dispense by" date provides users the time/date when the fuel meets the minimum hydrocarbon requirement of CARB. Beyond this date/time the fuel composition may compromise engine emission performance, warranty or reliability.

FOREWORD

Liquefied natural gas (LNG) is a practical automotive fuel with advantages and disadvantages when compared to conventional liquid fuels. Large quantities of natural gas are produced in North America. It has a higher “octane” rating, provides lower exhaust emissions of criteria (and many other) pollutants, and can cost less on an equivalent energy basis than other fuels.

LNG is a cryogenic liquid, which is produced by removing heat from natural gas. As heat is removed, the vapor cools and condenses, resulting in a liquid product with a boiling point of about –162 °C (–260 °F) at atmospheric pressure. Liquefaction increases the energy density of natural gas, thereby reducing its on-board vehicle storage volume for a given range and payload.

Typical pipeline natural gas and compressed natural gas is chiefly methane (generally 88 to 96 mole percent) with the balance being a decreasing proportion of higher hydrocarbons such as ethane, propane, and butane. It can also contain nitrogen, water, carbon dioxide, oxygen, sulfur compounds and trace amounts of lubricating oil.

The composition of LNG is different from that of pipeline natural gas as a result of the liquefaction process. Most of the hydrocarbon constituents remain soluble in LNG. However, other components, such as water, carbon dioxide, sulfur compounds and trace amounts of lubricating oil are be removed during the liquefaction process.

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When using LNG as a vehicle fuel, it is stored at some combination of cryogenic temperature and relatively low pressure. It is not uncommon for the fuel to go through several transfers as it is moved from production site storage, to a transport tank, transport tank to a local refueling station tank and then into the vehicle tank. During each transfer, and during periods of storage, heat transfers into the fuel, which if left to evaporate its composition will change.

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1. SCOPE

This SAE Information Report applies to liquefied natural gas used as vehicle fuel and requires LNG producers to provide the required information on the fuel composition and its "dispense by" date.

1.1 Purpose

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2. REFERENCES

2.1 Applicable Document

The following publication forms a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 State of California Publication

Available from website http://ccr.oal.ca.gov/.

Specifications for Compressed Natural Gas, California Air Resources Board, Title 13, Division 3, Chapter 5, Article 3, Section 2292.5 of the California Code of Regulations

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J2343 Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles

2.2.2 NFPA Publications

Available from the National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 800-344-3555, www.nfpa.org.

NFPA 52 2006 Vehicular Fuel System Code

NFPA 59A 2006 Standard for the Production, Storage, and Handling of Liquefied Natural Gas

3. DEFINITIONS

3.1 CRYOGENIC LIQUIDS

Fluids with a normal boiling point below –153 °C (–243 °F).

3.2 FUEL MOLE PERCENT

The number of moles of the constituent in one mole of the gas mixture, multiplied by 100. The mole percentage is equal to the volume percentage.

3.3 LIQUEFIED NATURAL GAS (LNG)

A cryogenic liquid, produced by reducing the temperature of natural gas to about –162 °C (–260 °F) at atmospheric pressure.

3.4 METHANE NUMBER

A measure of the knock resistance of natural gas used in an internal combustion engine. A methane number of 100 represents the knock resistance of pure methane, and is approximately equal to a motor octane number of 140. Presence of higher hydrocarbons in the fuel tends to reduce the methane number and thereby its knock resistance.

3.5 STANDARD GAS VOLUME PERCENTAGE

The volume fraction of a gas constituent at standard conditions, multiplied by 100. Commonly used by the gas industry.

3.6 DISPENSE BY DATE

The last date at which a given composition of fuel meets California Air Resources Board specification.

3.7 WEATHERING

A change in the constituent composition of the cryogenic fluid mixture remaining in the tank, as ambient heat transfers into the tank and gas vapor of different composition is released to control the tank pressure.

4. ENGINE MANUFACTURERS' NATURAL GAS COMPOSITION REQUIREMENTS

Major engine manufacturers that currently sell engines that operate on Natural Gas have designed those engines to operate on wide range of fuel compositions. However, in North America the only jurisdiction that has a related Natural Gas composition requirement is California Air Resources Board (Section 5). While this requirement is for CNG, the combustion and emission characteristics of LNG and CNG are the same.

4.1 Engine Tolerance

Older natural gas engines are much more sensitive to changes in fuel composition than newer engines, which use knock, exhaust gas composition and other sensors to modify spark timing, air-fuel ratio and other engine parameters in closed-loop fashion. Because the older "open loop" engines had no means to compensate for significant changes in fuel composition, such changes would likely affect engine power, emissions, durability, and fuel economy. Most importantly, fuels with increased proportions of "higher hydrocarbons" (such as ethane, propane and butane) have a lower methane number (or octane number) than high-methane fuels. Open loop engines designed to run on high methane number fuel can suffer detonation (engine knock) on a lower methane number fuel. Just as in high-compression gasoline engines forced to run on a lower octane fuel, such engines can suffer severe physical damage. Closed-loop operation and knock sensors allow engines to adapt to a much wider range of fuel without damage and without significantly affecting performance or emissions. Therefore users of older or open-loop engine designs need to be sure their engines are fueled with natural gas of the proper composition, or alternatively, the engine's controls are properly calibrated for the fuel being used.

5. CARB (CALIFORNIA AIR RESOURCES BOARD) COMMERCIAL CNG REQUIREMENTS

The only U.S. regulatory requirements for vehicular natural gas sold commercially are the Specifications for Compressed Natural Gas set forth by the California Air Resources Board in Title 13, Division 3, Chapter 5, Article 3, Section 2292.5 of the California Code of Regulations (See §2). These are requirements for Compressed (not Liquefied) Natural Gas. Since natural gas engines are normally designed to be fueled by either CNG or LNG, these specifications for vehicular natural gas may be of interest. Natural gas inducted into the engine, whether stored on board as CNG or LNG, should be acceptable to all engine manufacturers if it meets or exceeds the CARB specifications.

Please note that, while the composition of CNG will stay essentially the same from its delivery to the fueling station, through the dispenser, into the vehicle and into the engine (although water and foreign particles may be taken out before, during or after the compression process), LNG composition can be expected to change, as described in Section 6 and other sections of this Information Report. This means that, although LNG, as delivered to the fueling station or dispensed to the vehicle, may meet or exceed CARB's commercial CNG specifications, it may not be of acceptable composition when it enters the engine. For example, weathering (see §6.3) could allow a higher than acceptable ethane content or a lower than acceptable methane content at various times during the fueling cycle.

TABLE 1 - CARB COMMERCIAL CNG REQUIREMENTS (1/1/1993)

Specification	Value	Test Method
Hydrocarbons (expressed as mole percent)		
Methane	88.0% (min.)	ASTM D 1945-81
Ethane	6.0% (max.)	ASTM D 1945-81
C_3 and higher HC	3.0% (max.)	ASTM D 1945-81
C_6 and higher HC	0.2% (max.)	ASTM D 1945-81
Other Species (expressed as mole percent unless otherwise indicated)		
Hydrogen	0.1% (max.)	ASTM D 2650-88
Carbon Monoxide	0.1% (max.)	ASTM D 2650-88
Oxygen	1.0% (max.)	ASTM D 1945-81
Inert gases(1)	4.5% (max.)	ASTM D 1945-81
Water(2) – The dew point at vehicle fuel storage container pressure shall be at least 10° below the 99.0% winter design temperature listed in Chapter 24, Table 1, Climatic Conditions for the United States, in the American Society of Heating, Refrigerating and Air Conditioning Engineer's (ASHRAE) Handbook, 1989 fundamentals volume. Testing for water vapor shall be in accordance with ASTM D 1142-90, utilizing the Bureau of Mines apparatus.		
Particulate Matter – The compressed natural gas shall not contain dust, sand, dirt, gums, oils, or other substances in an amount sufficient to be injurious to the fueling station equipment or the vehicle being fueled.		
Odorant(2) – The natural gas at ambient conditions must have a distinctive odor potent enough for its presence to be detected down to a concentration in air of not over 1/5 (one-fifth) of the lower limit of flammability.		
Sulfur	0.001% (max.)	Title 17 CCR §94112

1. LNG typically contains much less Nitrogen than CNG. Issues that deal with issues of Nitrogen concentrations in LNG are addressed in Section 9.
2. Not applicable to LNG. Both, water and odorants are removed during the liquefaction process.

6. LNG PROPERTIES

6.1 Fuel Density as it Relates to Storage

The density of LNG will change with temperature or saturation pressure. Thus, a tank being filled with fuel at atmospheric pressure will hold more kilograms (pounds) of fuel than a tank being filled with fuel saturated at 10 atmospheres. Fuel tanks are rated for a maximum storage pressure; they can, however, be filled with fuel at any lower saturation pressure.

Different engine manufacturers require fuel to be delivered to their engine at different pressures. As a result, maximum density storage is not normally possible.

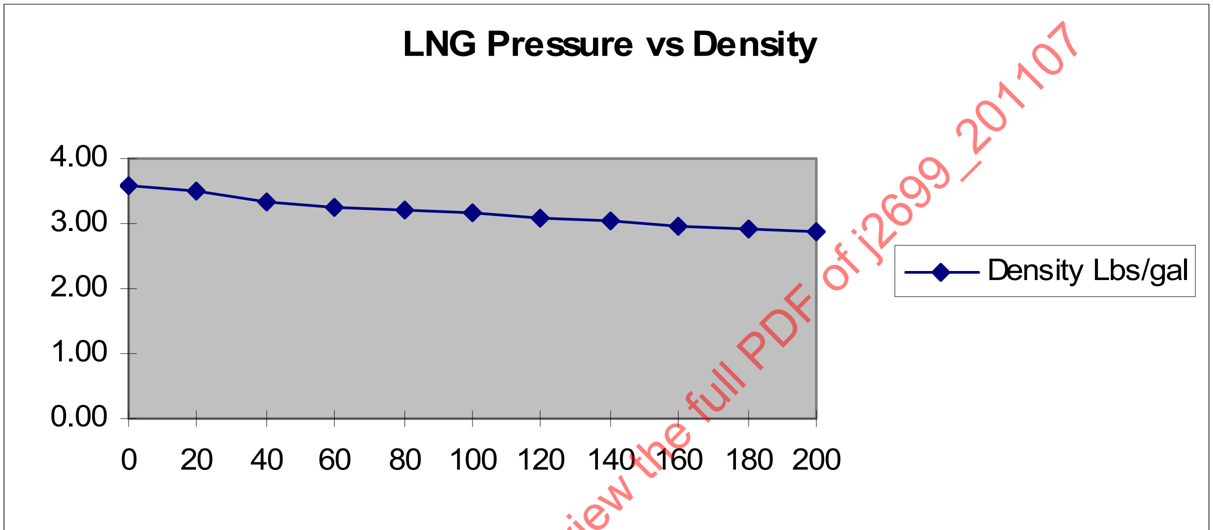

FIGURE 1 - LNG PRESSURE VERSUS DENSITY

6.2 Saturation Pressure as it Relates to Temperature

The point at which temperature and pressure of a liquid-vapor system are in equilibrium or the pressure at which the liquid will automatically boil. Raise the temperature, and the pressure will raise, lower the pressure and the temperature will fall. As a commonplace example, water will boil at 100 °C (212 °F) at sea level, but will boil at roughly 94 °C (202 °F) in Denver, where there is less air pressure. If a liquid is artificially pressurized, as in a pressure cooker, it will boil at a higher temperature than when in an open pot. Accurate control of the saturation pressure of dispensed LNG in the fuel tank may be important because some LNG vehicle systems rely on this pressure to drive fuel to the engine.

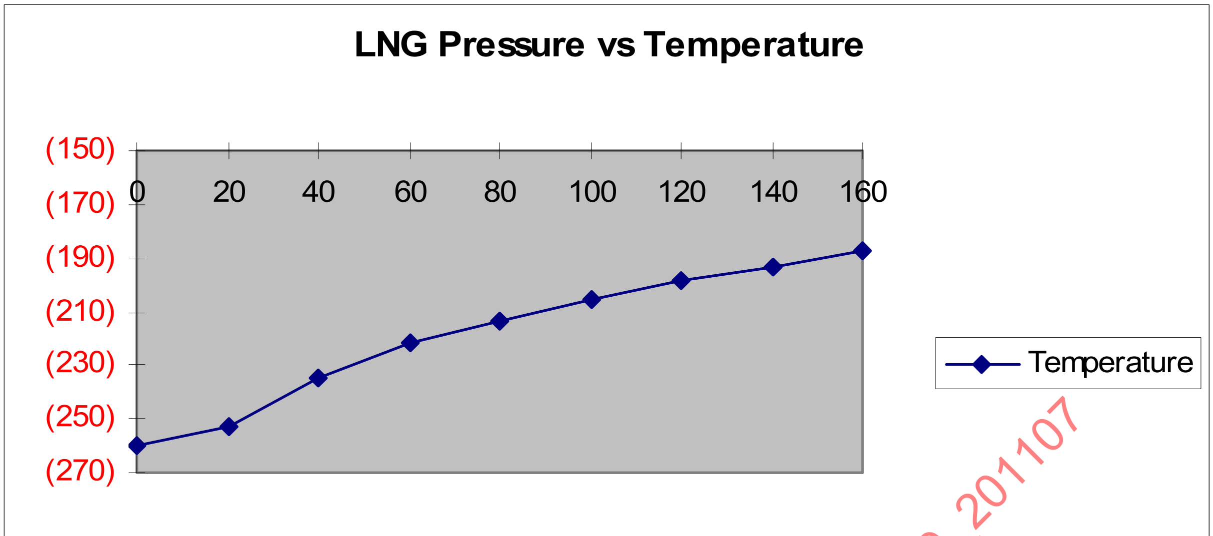

FIGURE 2 - LNG PRESSURE VERSUS TEMPERATURE

6.3 Weathering

The LNG weathering (selective vaporization) process in storage tanks refers to the change in the constituent composition of the fluid remaining in the tank as ambient heat transfers into the tank and gas vapor of different composition is released to control the tank pressure. Gas constituents with the lowest boiling points, such as nitrogen and methane, preferentially escape from the liquid phase into the vapor, and are released first in the weathering process. This phenomenon increases the content of the higher boiling point components in the liquid remaining in the tank, (i.e., ethane, propane, and other higher hydrocarbons), which affects the composition of the fuel. Specifically, nitrogen entrained in LNG can boil off first, allowing fuel initially taken from the gas above the liquid in the tank, to be too "lean" for proper engine combustion (nitrogen enrichment). Weathering can also allow methane to boil off, increasing methane content if gas is initially taken from the top of the tank and therefore reducing the methane content of the remaining liquid. Changes in LNG composition may affect vehicle and fueling station operations. Composition changes can trigger fuel maintenance procedures (see 8.1) that must be instituted to maintain the consistency of the gas delivered to the vehicle engine. Weathering is influenced by the heat transfer rate of the LNG storage tanks, method of saturation practices, and rate and amount of vehicle fuel use. Vehicles and LNG fuel stations that are actively used should not experience substantial LNG weathering.

7. LNG BULK TRANSPORTERS AND LNG PRODUCTION FACILITY REQUIREMENTS

The LNG production facility is required to provide a detailed LNG Product Specification Sheet (LPSS) which includes the fuels composition and "dispense by" date. The "dispense by" date is determined comparing the fuels methane, ethane, c3+ and c6+ to charts 7.2 or other similar method. The gas which has the shortest time before reaching its maximum or minimum allowable limit will determine that loads "dispense by" date. The product specification sheet must be made available to the LNG station operator upon delivery. Fuel composition percentage from the product sheet should be rounded down to the lowest half percent for methane and to the highest half percent for all other constituents.

The "dispense by" date charts 7.2 take into consideration normal product transfer from the LNG bulk transporter, to the LNG Station and to the LNG vehicle. If the product is transferred more than twice, then the LNG "dispense by" date must be reduced by one week for each additional transfer.

EXAMPLE: LNG Product Specification Sheet (LPSS)

TABLE 2 - SOURCE FUEL COMPOSITIONS

Components	Case 1	Case 2	Case 3	Case 4	Case 5
C1	89.40	92.00	95.00	96.32	98.51
C2	4.86	3.00	3.55	3.22	0.80
C3	0.90	1.10	0.50	0.27	0.30
i-C4	0.36	0.18	0.24	0.03	0.10
n-C4	0.24	0.12	0.16	0.02	0.06
i-C5	0.36	0.06	0.24	0.00	0.09
n-C5	0.24	0.04	0.16	0.00	0.06
C6	0.14	0.08	0.05	0.00	0.08
N2	3.50	3.42	0.10	0.14	0.00
	100.00	100.00	100.00	100.00	100.00

7.1 "Dispense by" Date Assumptions

7.1.1 Evaporation Rate

From the time the LNG is loaded into the tanker trailer at the production facility to the point it is burnt in the engine, the evaporation rate is 1% per day day once relief pressure is reached and venting has been initiated. Pressure rise time is not considered in charts 7.2.

Rationale: Evaporation rate from storage in various tanks (Transport trailer, Dispensing stations, and vehicle tanks). These tanks are all designed with a maximum evaporation rate of less than 1%. Bulk tanks may have significantly lower evaporation rate resulting in less venting.

7.1.2 Vehicle Usage

The amount of time LNG is in Vehicle storage tank till the time it is used is 1 week.

7.1.3 Normal Product Transfer

It is assumed that LNG is only transfer to another tank twice from the time is it initially loaded into a LNG Bulk transporter.

NOTE: Alternative calculation methods for "dispense by" date shall state assumptions on LPSS.

7.2 "Dispense by" Date Charts

7.2.1 Methane/Time Composition Chart

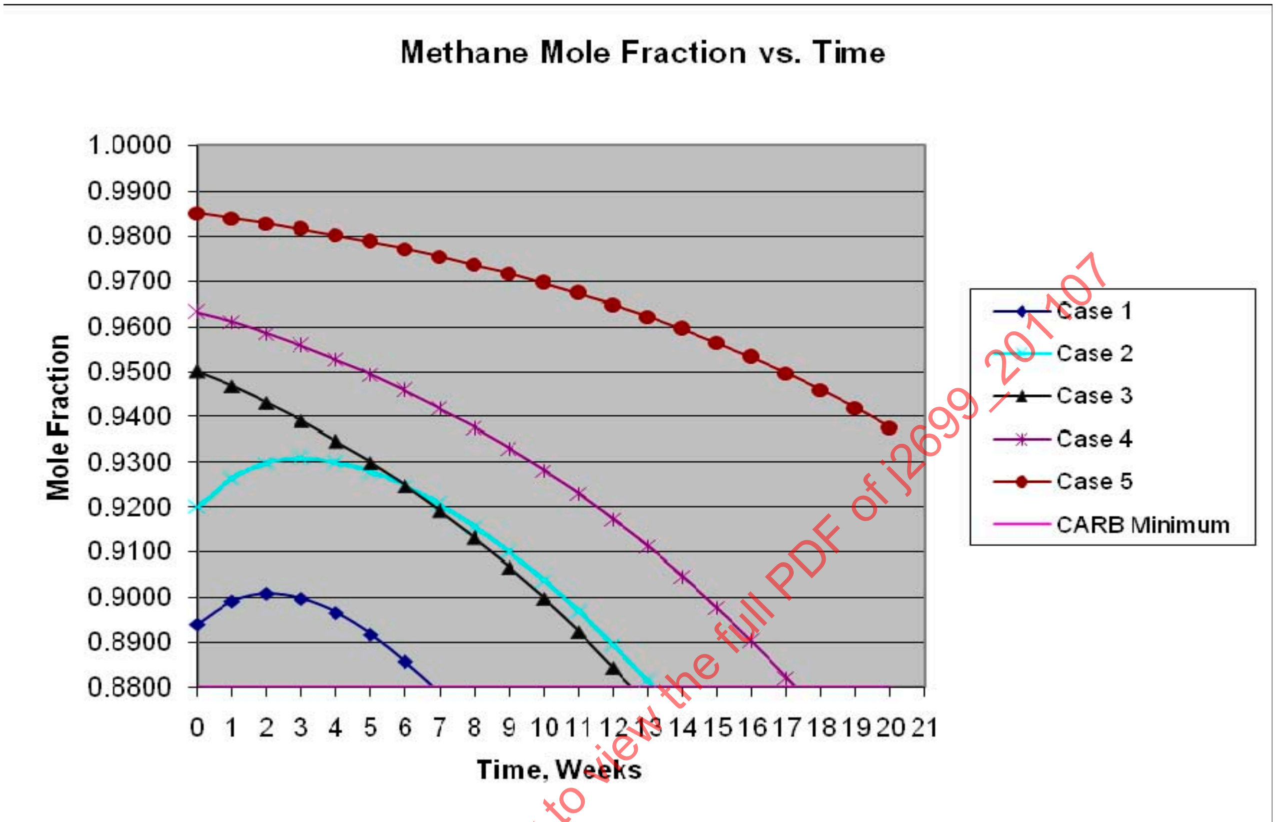

FIGURE 3 - METHANE MOLE FRACTION VERSUS TIME

7.2.2 Ethane/Time Composition Chart

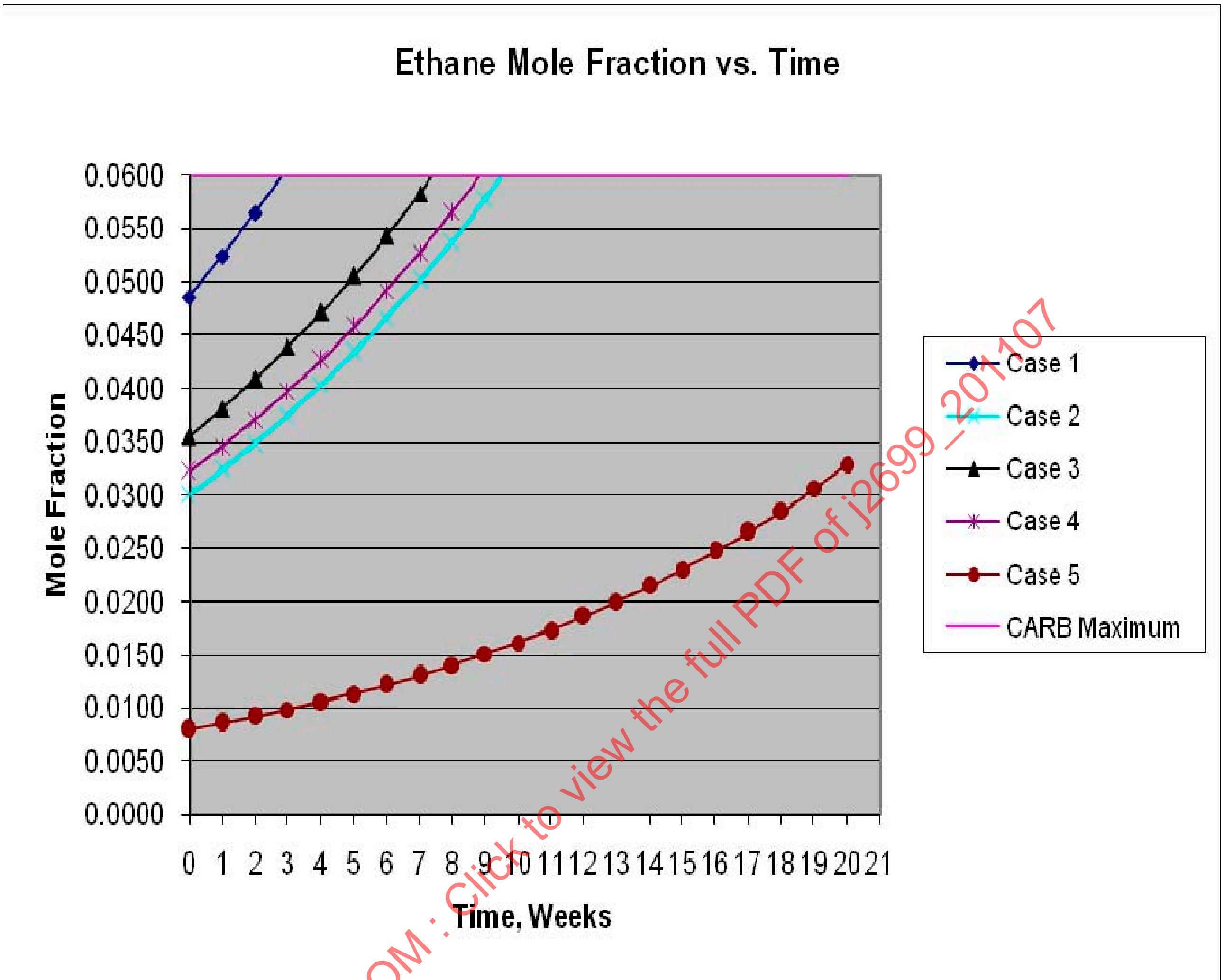

FIGURE 4 - ETHANE MOLE FRACTION VERSUS TIME