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Boosting Octane Number of Gasoline by Natural Gas Concentrated with Methane

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Highlights

- The gasoline produced by the fractionation of natural gas condensate has a low octane number;
- Natural gas concentrated with methane can be used for boosting the octane number;
- The method proposed to boost the octane number of gasoline is promising.

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Abstract

Gasoline obtained from the fractionation of indigenous natural gas condensate has a low octane number (78) and is therefore of limited use. Lead-based octane boosting and catalytic reforming are not the viable methods for many fractionation plants. This study was therefore aimed at developing an inexpensive conceptual alternative method for boosting the octane number of gasoline. Natural gas concentrated with methane having a high octane number (more than 100) was dissolved in gasoline to boost the octane number partially (86). Selective additives such as ethanol, tert-butyl alcohol, methylcyclopentane, toluene, iso-octane, and xylene were blended first with the gasoline to aid the dissolution of natural gas molecules. The loss of the absorbed gas molecules from the gasoline with the increase in temperature was also observed, and we found out that it is required to try for avoiding any increase in temperature in the finished gasoline. Moreover, the developed conceptual method is promising. Finally, the findings of this simulation study can be useful for further research into the development of an affordable alternative method for fractionation plants for boosting the octane number of the gasoline derived from natural gas condensate.

Keywords: Antiknock, Gas Condensate, Gasoline, Natural Gas, Octane Booster, Octane Number

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1. Introduction

Gasoline is produced from crude oil and other petroleum liquids and is used as an engine fuel in vehicles (Derek et al. 2016). Most of the gasoline produced in petroleum refineries is unfinished gasoline known as gasoline blendstock. Gasoline blendstocks require blending with other liquids to provide finished

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gasoline suitable for the use in spark ignition four strokes internal combustion engines (Çelikten et al. 2015; Duleep 2012; Eman 2008). Finished gasoline is available for use in various grades having different octane numbers. The octane number is the measure of antiknocking properties of the finished gasoline (Eric 2013; Kalghatgi et al. 2005). A higher octane number provides better antiknocking properties. The octane number of the finished gasoline depends on the ingredients, setup, and feedstock used in the production and blending processes (Mittal and Heywood 2008; Okamoto et al. 2003). Natural gas condensate is also used as a feedstock for gasoline production (James 2019).

Table 1

The production of natural gas condensate and fuels for financial years 2016–2017.

Sample	Component	Amount (barrels)
01	Condensate by state-owned companies	525,424
02	Condensate by international oil companies	3,819,550
03	Gasoline by state-owned companies	789,239
04	Diesel by state-owned companies	333,811
05	Kerosene by state-owned companies	78,698

Natural gas condensate is a low-density mixture of hydrocarbon liquids which are actually present as gaseous components in the raw natural gas produced from many natural gas fields (James 2019). Gas condensate condenses out of the raw natural gas if the temperature is reduced to below the hydrocarbon dew point temperature of the raw gas (James 2019). There are 25 natural gas fields in Bangladesh. A number of the gas fields located in the northeastern part contain a high fraction of condensate. Condensate production has been increased significantly through the installation of a liquid recovery unit in Bibiyana gas field. The production of condensate in Bangladesh for financial years 2016–2017 is listed in Table 1 (Bangladesh 2015, 2016, 2017). This condensate is used by the fractionation plants to produce solvents and fuels. The fuels, namely gasoline, diesel, and kerosene, produced by the fractionation plants located at different state-owned gas fields are also presented in Table 1 (Bangladesh 2015, 2016, 2017). There are also 13 condensate fractionation plants in the private sector for producing solvents and fuels, including gasoline.

The gasoline produced from natural gas condensate has the average octane number of 78 and is of very limited use. Lead-based octane boosters cannot be used in Bangladesh due to many constraints (William 2005). Also, catalytic reforming is not the method of choice for the enhancement of gasoline octane number due to the requirement of high capital investment (James 2011). This research was therefore aimed at developing an inexpensive conceptual alternative method. To this end, natural gas molecules were dissolved in the gasoline to increase the octane number. Organic additives were also employed to enhance the absorption of natural gas in the gasoline. The effect of temperature on the loss of the absorbed gas molecules was also analyzed.

2. Methodology

The collected natural gas condensate and gasoline samples were tested and analyzed according to the respective ASTM standards. The test results for the condensate and the gasoline are summarized in Tables 2 and 3 respectively.

Table 2

The average properties of the natural gas condensate in Bangladesh.

Sample	Test parameter	Test method	Result
01	Distillation	ASTM D 86	
	Initial boiling point (°C)		48–54
	5 vol % recovered (°C)		70–80
	10 vol % recovered (°C)		83–93
	20 vol % recovered (°C)		90–107
	30 vol % recovered (°C)		98–118
	40 vol % recovered (°C)		108–126
	50 vol % recovered (°C)		118–136
	60 vol % recovered (°C)		129–146
	70 vol % recovered (°C)		144–154
	80 vol % recovered (°C)		170–177
	90 vol % recovered (°C)		222–254
	95 vol % recovered (°C)		265–292
	Final boiling point (°C)		280–299
02	Density at 15 °C (gm/cm^3)	ASTM D 1298	0.780–0.790
03	Reid vapor pressure at 38 °C (psi)	ASTM D 323	2.56–4.55
04	Water content (wt %)	ASTM D 95	Nil
05	Sediment (wt %)	ASTM D 473	Nil

Table 3

The average properties of the gasoline in Bangladesh.

Sample	Test parameter	Test method	Result
01	Distillation:	ASTM D 86	
	Initial boiling point (°C)		40–57
	5 vol % recovered (°C)		51–72
	10 vol % recovered (°C)		58–80
	20 vol % recovered (°C)		66–89
	30 vol % recovered (°C)		74–95
	40 vol % recovered (°C)		80–100
	50 vol % recovered (°C)		88–105
	60 vol % recovered (°C)		94–110
	70 vol % recovered (°C)		101–117
	80 vol % recovered (°C)		111–126
	90 vol % recovered (°C)		127–146
	95 vol % recovered (°C)		136–178
	Final boiling point (°C)		160–190
	Residue (vol %)		0.00–1.00
02	Density at 15 °C (gm/cm^3)	ASTM D 1298	0.722–0.760
03	Reid vapor pressure at 38 °C (psi)	ASTM D 323	2.85–7.40
04	Copper strip corrosion (3 h at 50 °C)	ASTM D 130	Freshly polished–1a slight tarnish
05	Octane number, research method	ASTM D 2699	77–80.9
06	Oxidation stability (min)	ASTM D 525	> 300
07	Color	ASTM D 1500	ASTM 1 Visual: clear

Aspen HYSYS software v8.8 (Aspen Technology Inc., the USA) was used as the simulation tool. The accuracy and applicability of this simulation tool was validated in several articles (Santana 2010; Yadollah and Mohammad 2014; Yadollah et al. 2013). Peng–Robinson equation of state was chosen as the thermodynamic model in the simulation of the fluid properties (Aspen, 2019). Other selections required for the simulation were the best fit for hydrocarbon systems (Aspen, 2019). A gasoline stream was created by the oil manager with the input of the test results in Table 3. An additive stream was also created with the required chemicals and blended with the gasoline stream to yield a mixed stream. The purpose of the application of the additives to the gasoline was to enhance the absorption of natural gas molecules having a high octane number (Zeng et al. 2009). In addition to the ability to increase the absorption of natural gas molecules, the additives are required to be uniformly miscible with gasoline, thermally stable, noncorrosive, environmentally allowable up to a limit, nontoxic, and readily available in the desired quantities. Assessing the physical, thermal, and chemical properties and the commercial availability, toluene, xylene, iso-octane, ethanol, methylcyclopentane, and tert-butyl alcohol (TBA) were chosen and used as the potential additives. The mixed stream consisting of gasoline and the additive was passed through a cooler for temperature adjustment. Atmospheric pressure was the operating pressure of the cooler. The stream from the cooler was finally fed into a simulated absorption column of 10 equilibrium stages at the top in the name of gasoline feed. On the other hand, the natural gas was supplied into the same absorption column at the bottom. The composition of the natural gas was set as found in the chromatographic analysis (see Table 4).

Table 4

The average composition of the natural gas in Bangladesh.

Sample	Component	mol % or vol %
01	Methane	93.536–98.489
02	Ethane	0.802–3.790
03	Propane	0.006–1.324
04	iso-Butane	0.000–0.309
05	n-Butane	0.000–0.310
06	Higher components	0.002–0.603
07	Nitrogen	0.129–0.790
08	Carbon dioxide	0.08–0.842

Shimadzu gas chromatograph (GC–17A, GC–14B), capillary column (DB–1), and packed column (Porapak Q) were used for the analysis of the composition of the natural gas samples. The results of the chromatographic analysis were consistent with the composition of the natural gas reported by Bangladesh Oil, Gas, and Mineral Corporation (Bangladesh 2015, 2016, 2017). The absorption column was kept at atmospheric pressure. The reason for the selection of atmospheric pressure is that gasoline is mostly transported, stored, and used at atmospheric pressure. The liquid stream leaving from the bottom of the absorption column was the finished gasoline with a relatively higher octane number. The simulation and the conceptual principle of the proposed method are demonstrated in Figure 1.

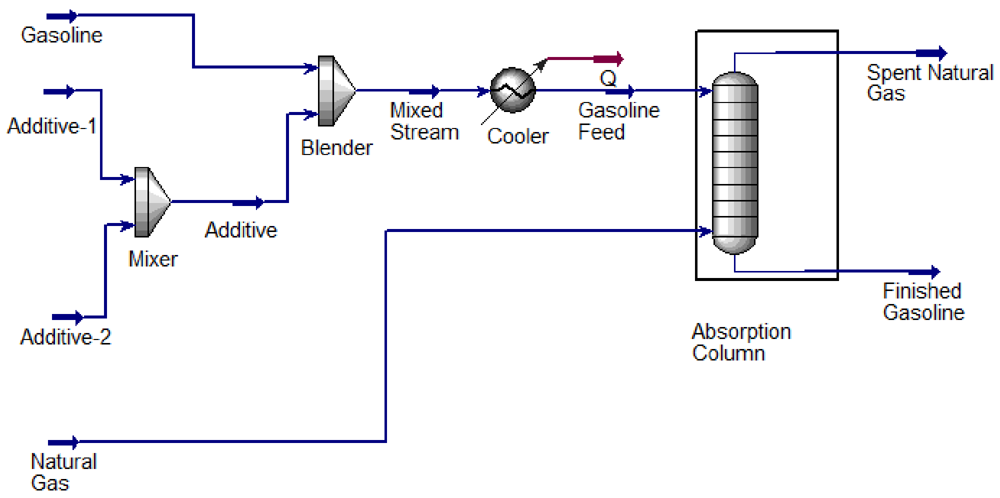

Figure 1

The developed conceptual alternative method for boosting the octane number of gasoline.

3. Results and discussion

The gasoline produced by the fractionation of natural gas condensate in Bangladesh possesses an octane number in the range of 77–81. The inclusion of methane having an octane number of 120 can increase the octane number of gasoline substantially. Methane can easily be made available for gasoline treatment in the form of natural gas. Ethane, propane, normal butane, and iso-butane present in the natural gas also have a high octane number of 108, 112, 94, and 102 respectively. It is therefore expected that the octane number of gasoline is enhanced if it can be given a dose of natural gas. However, the natural gas due to its higher volatility cannot be retained in the gasoline at the required amounts (Fahimeh and Ahad 2020; Mohammad et al. 2020). A number of additives as mentioned above with different proportions and combinations were consequently blended with gasoline to absorb natural gas molecules. The disengagement of the absorbed natural gas molecules from the gasoline was also analyzed with the increase in temperature.

Table 5

Boosting the octane number of gasoline by natural gas with the use of a single additive.

Sample	Individual additive: amount*	Gasoline	Mixed stream		Finished gasoline	
		Octane number	Octane number	Temperature (°C)	Octane number	Temperature (°C)
01	Toluene: 0.04	78	79.4	25.02	84.44	14.13
02	Toluene: 0.02	78	78.7	25.09	83.90	13.67
03	Xylene: 0.04	78	78.94	25.11	83.85	14.54
04	Xylene: 0.06	78	79.4	25.09	83.90	15.14
05	iso-Octane: 0.04	78	78.34	25.09	82.30	14.61
06	Ethanol: 0.064	78	78.8	23	84.50	13
07	Methylcyclopentane: 0.04	78	78.92	25.15	85.1	13.35
08	TBA: 0.04	78	79.7	25	86.40	16.5

*kgmol/h additive per kgmol/h gasoline.

3.1. Necessity and selection of additive

Toluene, xylene, iso-octane, ethanol, methylcyclopentane, and tert-butyl alcohol were selected carefully as mentioned in the Methodology Section and were tried as the additive. The additives were blended with the gasoline both individually and as a mixture. The basis of blending was kg mole of additive per kg mole of gasoline. The amounts of the additives used are listed in the second column of Tables 5 and 6. These amounts were optimized by Aspen HYSYS software v8.8 and gave the best absorption of natural gas molecules. These amounts are also expected to possess minimal hazards. Each additive itself was found to boost the octane number of gasoline to a small extent as can be inferred from the difference between the octane number of gasoline and that of the mixed stream in Table 5. The absorption column was simulated with 10 equilibrium stages to treat the mixed stream with natural gas. The enhancement of the octane number of the gasoline by the natural gas can be read from the difference between the octane number of the mixed stream and that of the finished gasoline in Table 5. All of the additives were individually found to be capable of aiding the absorption of the natural gas into the gasoline. The additives can be ranked as tert-butyl alcohol, methylcyclopentane, toluene, xylene, iso-octane, and ethanol in the order (high to low) of the ability to aid the absorption of the natural gas into the gasoline for increasing its octane number. The tert-butyl alcohol can therefore be preferred as a single additive. It should be noted that a sufficient flow rate of the natural gas is always required to be maintained in the column considering the flow rate of the gasoline. Further, the use of more equilibrium stages in the column would give better absorption and thus a higher increase in the octane number of gasoline. As presented in Table 6, similar consequences were observed when the additives were applied as a mixture. However, methylcyclopentane was found to give a better result as a mixture in combination with toluene, xylene and/or iso-octane.

Table 6

Boosting the octane number of gasoline by natural gas with the use of an additive mixture.

Sample	Additive mixture: amount*	Gasoline	Mixed Stream		Finished Gasoline	
		Octane number	Octane number	Temperature (°C)	Octane number	Temperature (°C)
01	Toluene: 0.03 Xylene: 0.01	78	79.3	25.05	84.28	14.23
02	Toluene: 0.035 Xylene: 0.005	78	79.35	25.04	84.38	14.18
03	iso-Octane: 0.02 Toluene: 0.02	78	78.26	25.05	83.33	14.4
04	iso-Octane: 0.01 Toluene: 0.03	78	78.82	25.04	83.9	14.27
05	Methylcyclopentane 0.015 iso-Octane: 0.005 Toluene: 0.02	78	78.6	25.08	85.63	13.92
06	Methylcyclopentane: 0.02 Toluene: 0.02	78	78.7	25.09	85.8	13.76
07	Methylcyclopentane: 0.01 Toluene: 0.02 Xylene: 0.006 iso-Octane: 0.004	78	78.75	25.07	85.8	14.06
08	Methylcyclopentane: 0.01 Xylene: 0.008 Toluene: 0.024	78	79	25.07	84.27	14.04
09	Methylcyclopentane: 0.02 Xylene: 0.02	78	78.6	25.13	85.42	13.92

*kgmol/h additive per kgmol/h gasoline.

3.2. Effect and control of temperature

The temperature of the absorption column is thermodynamically required to be kept as low as possible to promote the absorption of the natural gas molecules in the gasoline. The temperature of the finished gasoline obtained from the bottom of the absorption column may subsequently increase during transportation, storage, and use, which may cause a loss of the natural gas molecules from the finished gasoline. Therefore, the effect of the increase in temperature on the final octane number of gasoline was analyzed. The temperature of the finished gasoline was increased to 30 °C and finally to 40 °C. Gasoline is transported, stored, and used at ambient temperature which can vary slightly from location to location and is likely to have a value far lower than 40 °C in Bangladesh. However, Table 7 demonstrates that both for a mixture of the additives and a single additive, the octane number of the gasoline declines with an increase in the temperature of the finished gasoline, which is attributed to the loss of the natural gas molecules as confirmed by the simulation results. Hence, any rise in the temperature of the gasoline is required to be suppressed.

Table 7

The effect of the temperature on the octane number of the finished gasoline.

Additive blended with gasoline: amount*	**Finished gasoline**	
	Temperature (°C)	**Octane number**
Methylcyclopentane: 0.02 Xylene: 0.02	25	84.5
	30	83.5
	40	83.0
Methylcyclopentane: 0.01 Xylene: 0.008 Toluene: 0.022	25	85.0
	30	84.0
	40	83.2
Methylcyclopentane: 0.02 Toluene: 0.02	24	84.7
	30	83.7
	40	83.1
Methylcyclopentane: 0.01 Toluene: 0.02 Xylene: 0.006 iso-Octane-0.004	25	84.9
	30	84.0
	40	83.2
Toluene: 0.035 Xylene-0.005	25	83.5
	30	82.9
	40	82.2
TBA: 0.04	24.5	84.7
	30	84.0
	40	83.6
Ethanol: 0.062	23.5	83.9
	30	83.3
	40	82.8

*kgmol/h additive per kgmol/h gasoline.

4. Conclusions

Natural gas condensate has significantly been produced in a number of gas fields of Bangladesh. The condensate is being fractionated to yield solvents and fuels, including gasoline. The gasoline having an octane number of 77–81 is of limited use, and lead-based octane boosters are not allowed to be used in the gasoline. Also, the catalytic reforming process is not affordable for many fractionation plants. Therefore, the present study was aimed at developing an inexpensive conceptual alternative method for boosting the octane number of gasoline. To this end, the gasoline blended with the selective additives was treated by the natural gas in an absorption column. It was found that the natural gas concentrated with methane is able to boost the octane number of gasoline. The treated finished gasoline is required to be kept at ambient or moderate temperature so as to prevent the loss of the absorbed gas. This conceptual development can be useful for further research into boosting the octane number of the gasoline obtained from natural gas condensate.

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Nomenclature

ASTM	American Society for Testing and Materials
BUET	Bangladesh University of Engineering and Technology
GC	Gas chromatograph
TBA	Tert-butyl alcohol

References

Aspen HYSYS 8.8 Manual. https://www.scribd.com/document/362669425/Hysys-8-8-Manual, Last Accessed 0n 10th October, 2019.

Bangladesh Oil, Gas and Mineral Corporation Annual Reports, 2015, 2016, 2017.

Çelikten, İ., Karaaslan, E., Solmaz, H., Okur, M., and Polat, S., Experimental Investigation of the Effects of Gasoline Additives on Engine Performance and Exhaust Emissions, Journal of Thermal Science and Technology, Vol. 1, No. 35, 2015.

Derek, S., Alexander, P., and Robert, W. A., Historical Analysis of the Co-evolution of Gasoline Octane Number and Spark-ignition Engines, Frontiers in Mechanical Engineering, Vol. 1, No. 16, 2016.

Duleep, K., Review to Determine the Benefits of Increasing Octane Number on Gasoline Engine Efficiency: Analysis and Recommendations–Tasks 2–5, CRC Project No. CM-137-11-1b, Coordinating Research Council, Inc., 2012.

Eman, A. E. S., Improvement of Gasoline Octane Number by Blending Gasoline with Selective Components, Thesis for Master of Science in Chemical Engineering/Oil Refinery and Petrochemical Industry, Department of Chemical Engineering, University of Technology, Bagdad, 2008.

Eric, W. C., Exploring the Use of a Higher-Octane Gasoline for the US Light-duty Vehicle Fleet, Thesis for Master of Science in Mechanical Engineering, Department of Mechanical Engineering, Massachusetts Institute of Technology, 2013.

Fahimeh, M. and Ahad, G., Mass Transfer Modeling of CO_2 Absorption into Blended Aqueous MDEA–PZ Solution, Iranian Journal of Oil & Gas Science and Technology, Vol. 3, No. 9, 2020.

James, G. S., Gas Condensate (Chapter 9), https://doi.org/10.1016/B978-0-12-809570-6.000096, Natural Gas (Second Edition), A Basic Handbook, 2019.

Kalghatgi, G., Nakata, K., and Mogi, K., Octane Appetite Studies in Direct Injection Spark Ignition (DISI) Engines, Society of Automotive Engineers Technical Paper, Vol. 1, No. 0244, 2005.

Mittal, V. and Heywood, J. B., The Relevance of Fuel RON and MON to Knock Onset in Modern SI Engines, Society of Automotive Engineers Technical Paper, Vol. 1, No. 2414, 2008.

Mohammad, R., Mahmood, R. R., and Hajir, K., Investigating the Treatment of Oil and Gas Produced Water Using a Spray Dryer on a Bench Scale, Iranian Journal of Oil & Gas Science and Technology, Vol. 1, No. 9, 2020 .

Okamoto, K., Ichikawa, T., Saitoh, K., Oyama, K., Hiraya, K., and Urushihara, T., Study of Antiknock Performance under Various Octane Numbers and Compression Ratios in a DISI Engine, Society of Automotive Engineers Technical Paper, Vol. 1, No. 1804, 2003.

Santana, G.C.S., Martins, P.F., Lima D. S. N., Batistella, C.B., Maciel Filho, R., and Maciel W. M.R., Simulation and Cost Estimate for Biodiesel Production Using Castor Oil, Chemical Engineering Research and Design, Vol. 88, No. 5–6, 2010.

William, K., Ethyl-leaded Gasoline: How a Classic Occupational Disease Became an International Public Health Disaster, International Journal of Occupational and Environmental Health, Vol. 11, No. 4, 2005.

James, G. S., Refining Processes (Chapter 2), https://doi.org/10.1016/B978-0-8155-20412.10002-5, the Refinery of the Future, 2011.

Yadollah, T. and Mohammad, R. K. N., A Novel Distillation Design for Vapor Phase Dimethyl Ether Production Process, Asia-Pacific Journal of Chemical Engineering, Vol. No. 9, No. 3, 2014.

Yadollah, T., Seyyed, H. H., Mohammad, G., Mohammad, R. K. N., and Ahmad, S., from Laboratory Experiments to Simulation Studies of Methanol Dehydration to Produce Dimethyl Ether Part I: Reaction Kinetic Study, Chemical Engineering and Processing: Process Intensification, Vol. 73, No. 144, 2013, Zeng.

Z. Z., Na, G., Lei, C., and Xin, Q. S., Methane Absorption and Application of Mixed Organic Aggregate Prepared from Span80 and Alkaline Salt, Science in China Series E: Technological Sciences, Vol. 52, No. 8, 2009.