Ammonia as an alternate transport fuel: Emulsifiers for gasoline ammonia fuel blends and real time engine performance

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Introduction

- The combined future volumes of conventional petroleum, heavy oil, oil sands and oil shale total 29.9 trillion BOE
- Lasts only for 51 years as assessed in 2009 [1]
- Need of alternative for transportation

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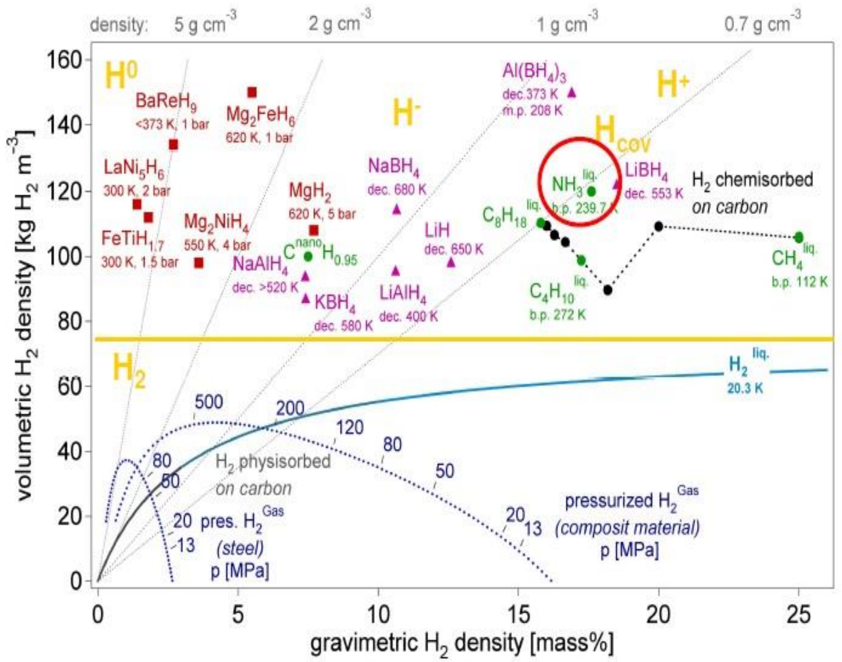
Introduction (Contd.)

* Production with renewable energy
* Entire supply chain is carbon free
* On site fuel production
* Sustainable
* New infrastructure not required



A. Züttel, "Materials for hydrogen storage", Materials Today, Septemper (2003), pp. 18-27

[2]

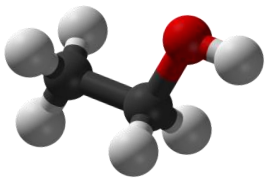
Introduction (Contd.)

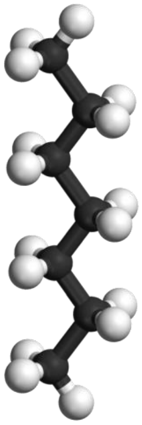
* Current situation
  * Ammonia-gasoline/diesel dual fuel systems
  * AmVeh from Korea Institute of Energy Research

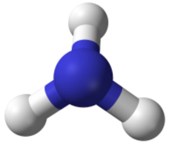
* Our Objective
  * Less infrastructure requirement
  * Less end user equipment (vehicle) modification

Solution

* Gasoline-ammonia composite fuel blends
* Similar to gasoline-ethanol fuel blends
* Molecular structure decreases the solubility
* Emulsifiers (surfactant) to increase the solubility
* Ethanol/Methanol







* Gasoline-ammonia fuel blends - minimum new infrastructure requirements and end user equipment modifications

Literature Review

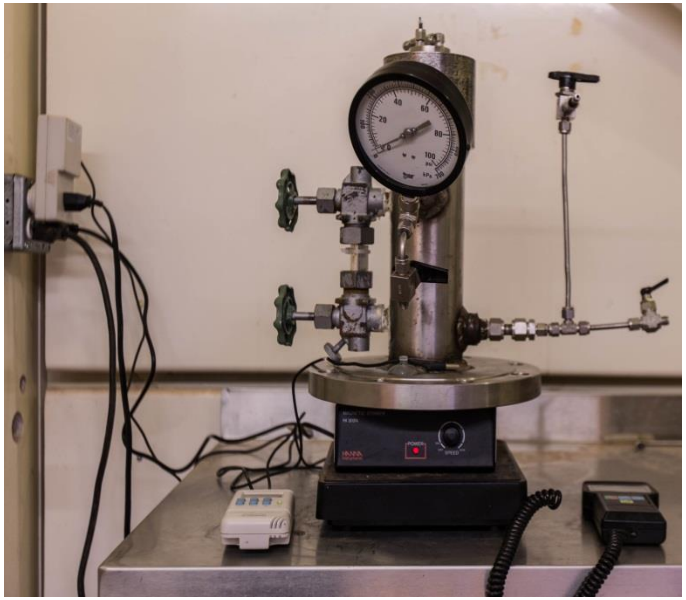
* Various use of ammonia as an energy
* Ammonia solubility in gasoline not studied in any kind of literature
* Nearest match is ammonia solubility in ethanol/methanol [10-11]
* Emulsifiers have not been identified for ammonia
* Actual engine performances and emissions of composite fuel blends have not been measured

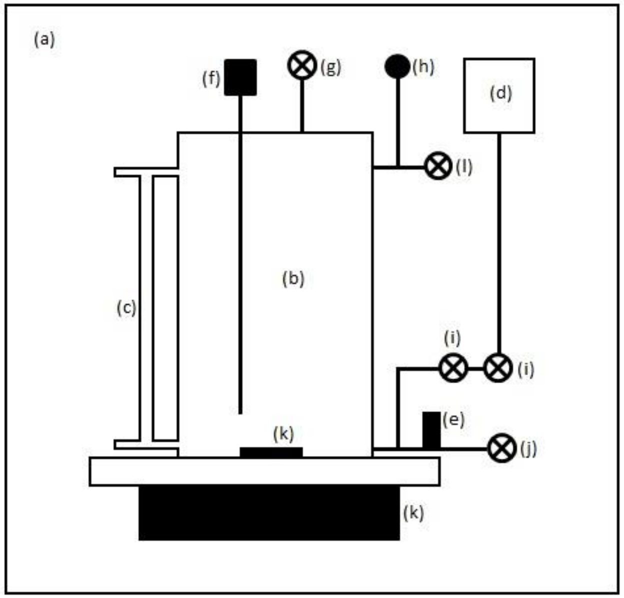
Experimental Methodology

* Static-analytic method used for gas solubility measurements in liquids [10-12]
* High pressure thermostated Vapor Liquid Equilibria (VLE) cells
* VLE cells used to measure the solubility of gaseous ammonia in liquid gasoline
* Ethanol/Methanol used as emulsifier

Experimental Methodology (Contd.)

* A small stainless steel VLE cell was constructed to identify suitable emulsifiers and measure solubility accurately





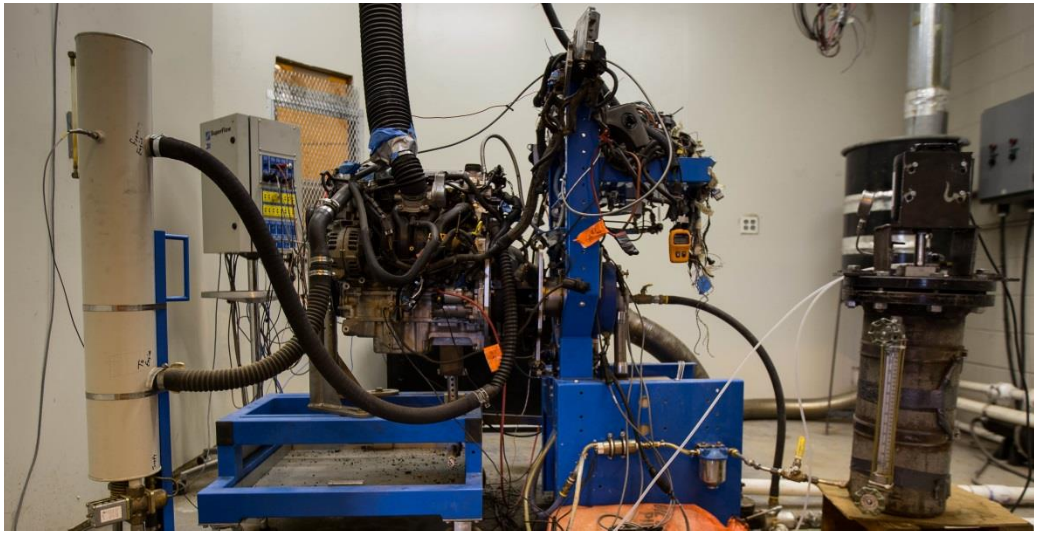
(a) thermostated chamber (b) VLE cell (c) borosilicate gage glass for liquid level measurements (d) ammonia charging tank (e) pressure transducer (f) K type thermocouple thermometer (g) relief valve (h) bourdon tube pressure gage (i) charging tank connection valves (j) liquid feed in valve (k) magnetically coupled mixer (l) auxiliary valve for gas chromatography (not used)

Experimental Methodology (Contd.)

* A larger thermostated VLE cell was used to produce proven blends in large quantities for the engine dynamometer tests

Experimental Methodology (Contd.)

* Dynamometer testing of developed fuel blends
  * Superflow 902 engine dynamometer
  * GM Ecotec 2.4L gasoline engine



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Solubility Results

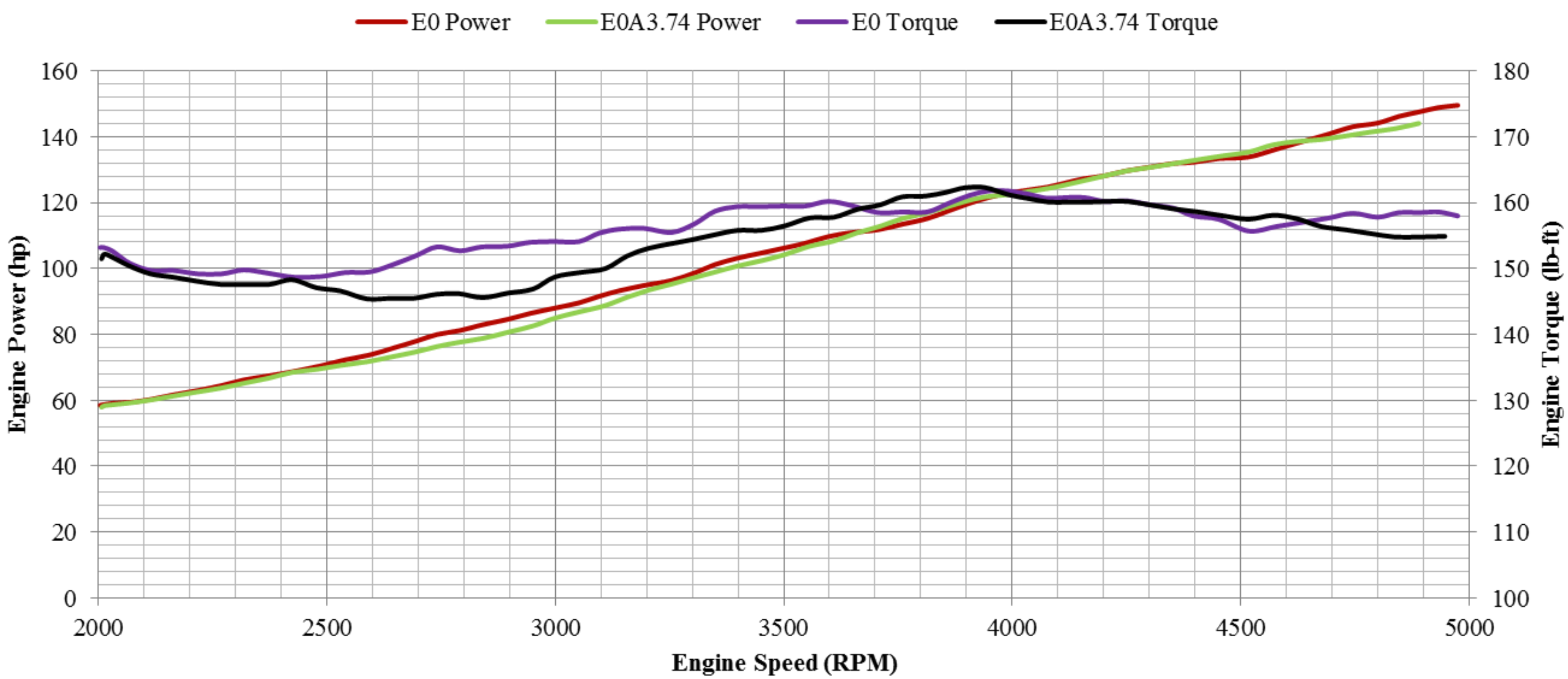
* Solubility of ammonia in gasoline
  * Baseline gasoline
  * With ethanol as an emulsifier
* Various percentages of ethanol were used
  * E0 – Baseline ethanol/methanol free gasoline
  * E10/M10 – Gasoline with 10% of ethanol/methanol
  * E20/M20 – Gasoline with 20% of ethanol/methanol
  * E30/M30 – Gasoline with 30% of ethanol/methanol
* Solubility (volume increase @ 50 Psi and 286.15 K) [13,14,17,18]
  * E0 – 4.51%
  * E10 – 11.03% M10 – 11.50%
  * E20 – 13.79% M20 – 23.00%
  * E30 – 17.76% M30 – 30.00%

Solubility Results - Ethanol

CHANGE OF SOLUBILITY, PERCENTAGE VOLUME INCREASE, AND MOLALITY OF AMMONIA IN GASOLINE WITH PRESSURE AT 286.15 K AND 50 Psi [13,14,17,18]

	Solubility (g/l)	Vol. Inc. (%)	Molality (mol/kg)
E0	23.04	4.51	1.77
E10	51.43	11.03	4.02
E20	81.21	13.79	6.50
E30	104.50	17.76	8.08
M10	68.14	11.50	5.26
M20	136.40	19.07	10.88
M30	189.45	30.00	15.11

Dynamometer Results – E0 [13,14,17,18]



POWER AND TORQUE CURVES OF E0 AND E0A3.74

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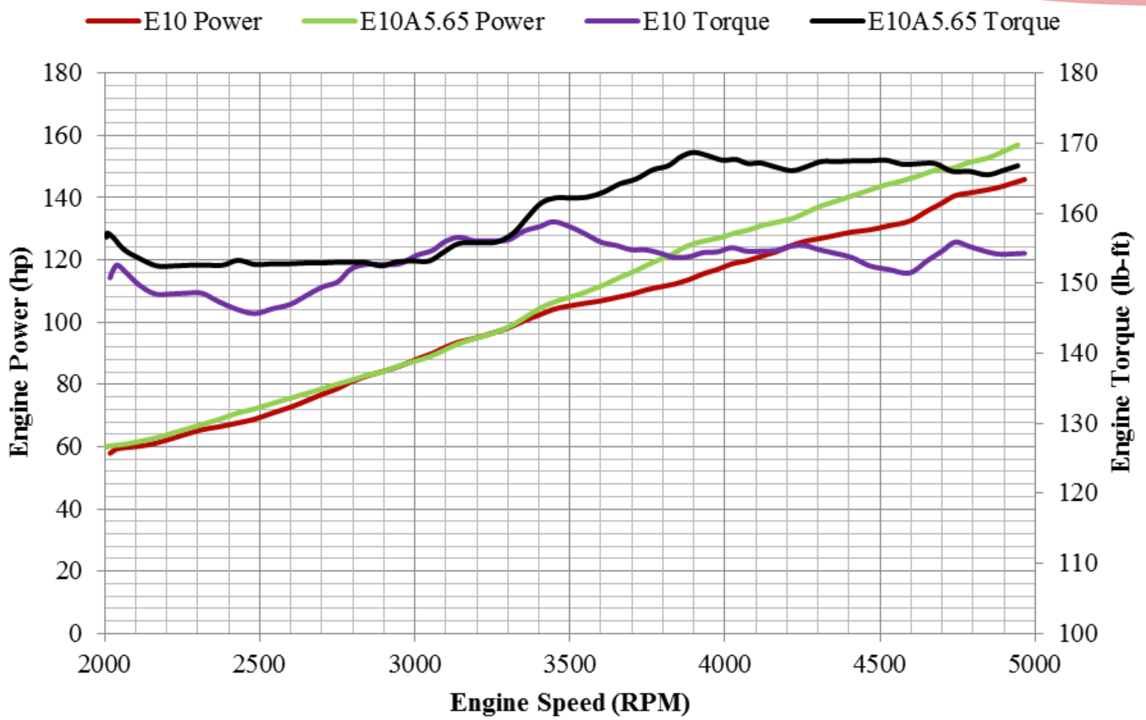
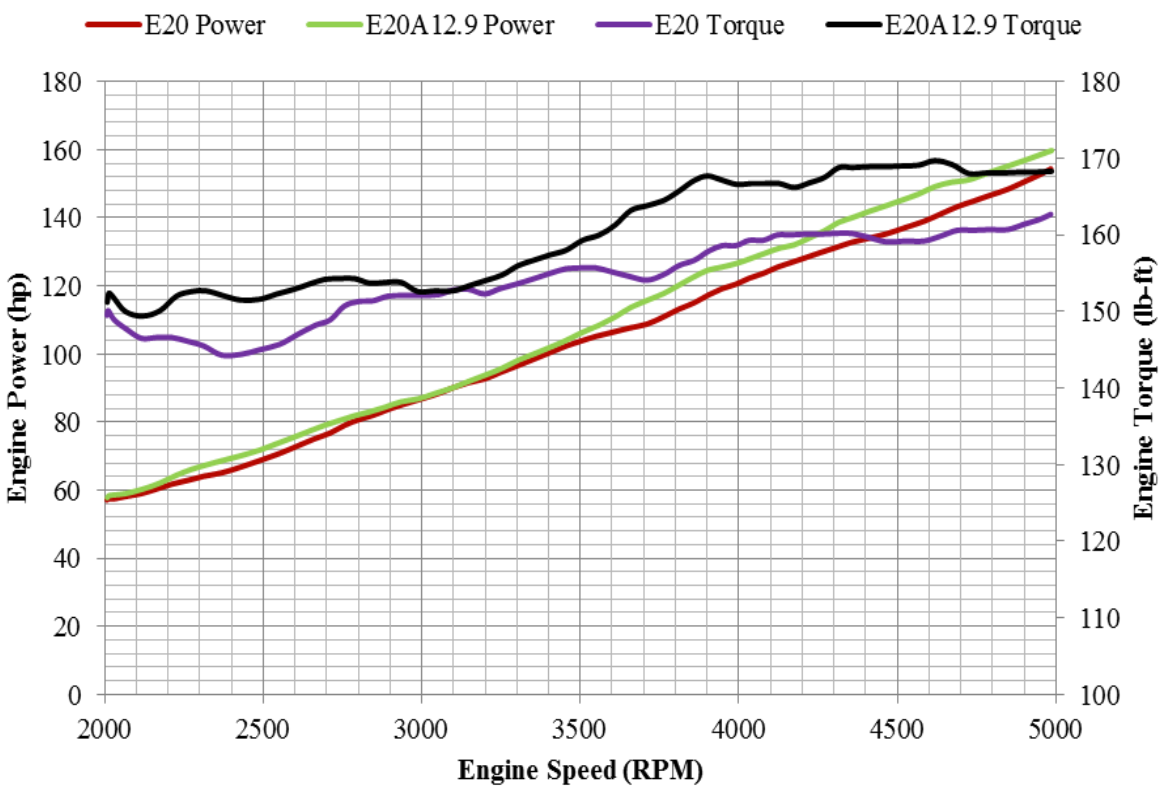
Dynamometer Results – E10



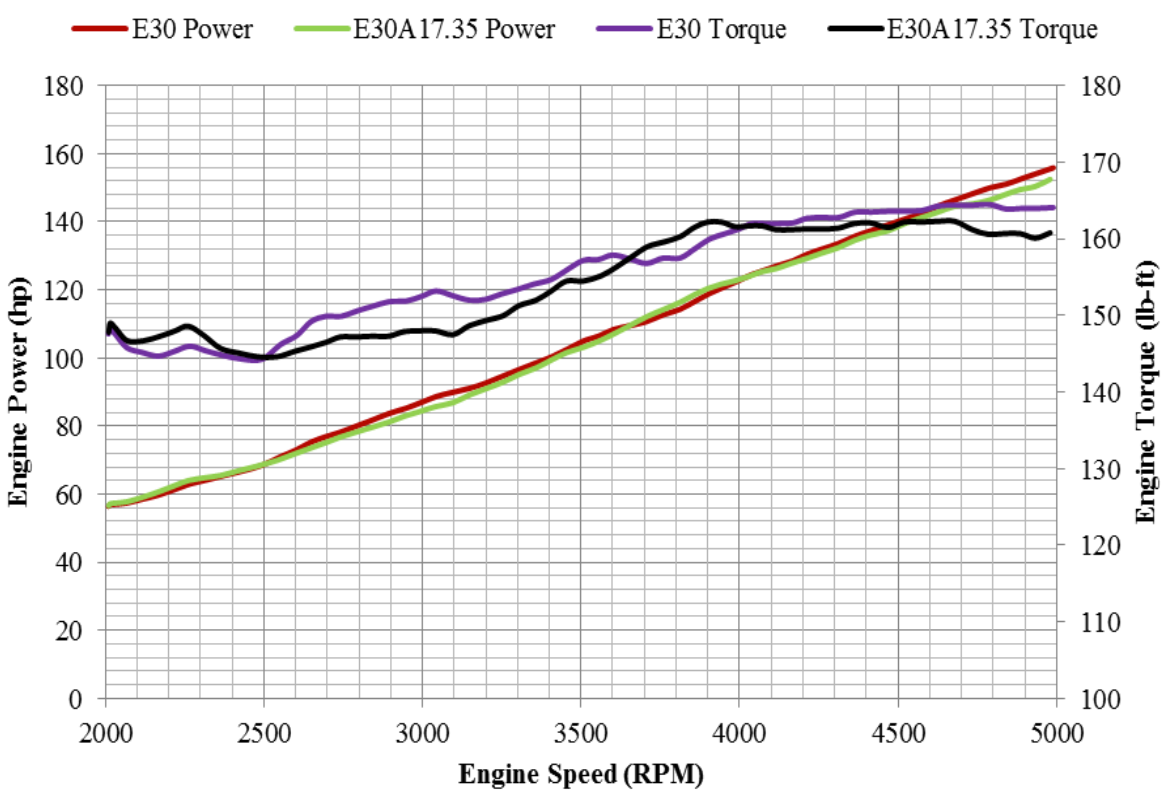
POWER AND TORQUE CURVES OF E10 AND E10A5.65

Dynamometer Results E20



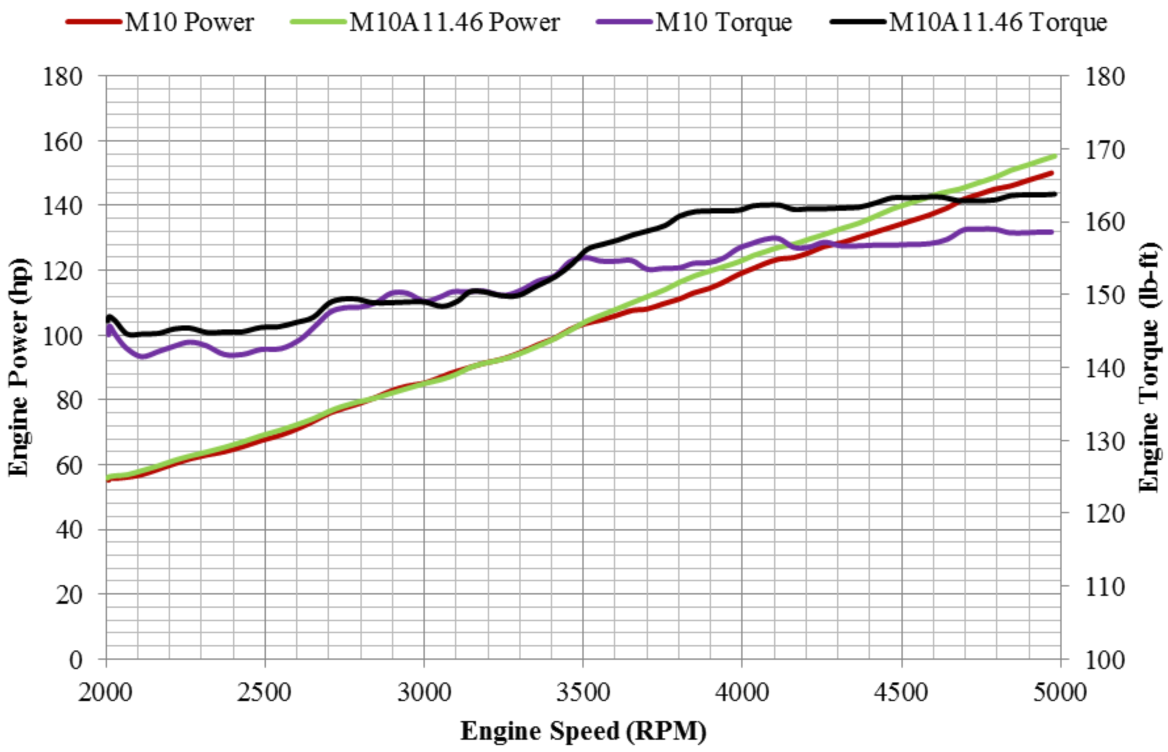
POWER AND TORQUE CURVES OF E20 AND E20A12.90

Dynamometer Results – E30



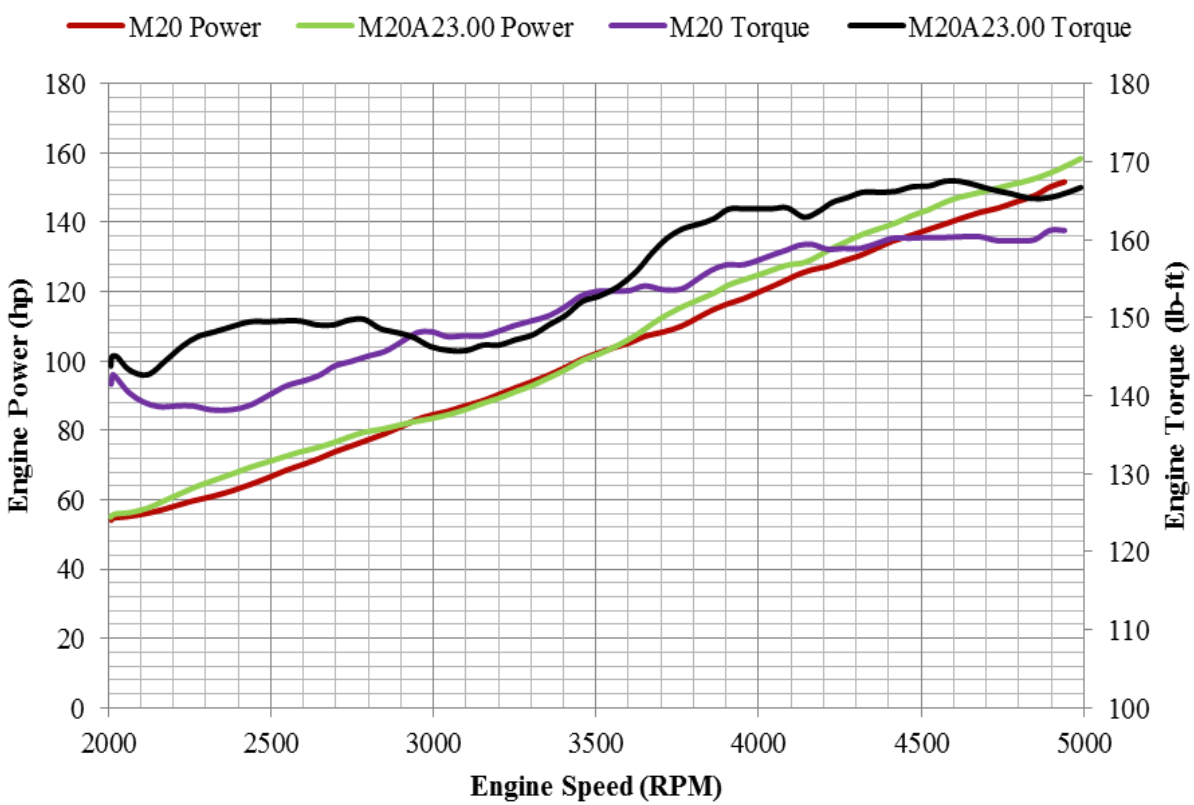
POWER AND TORQUE CURVES OF E30 AND E30A17.35

Dynamometer Results – M10



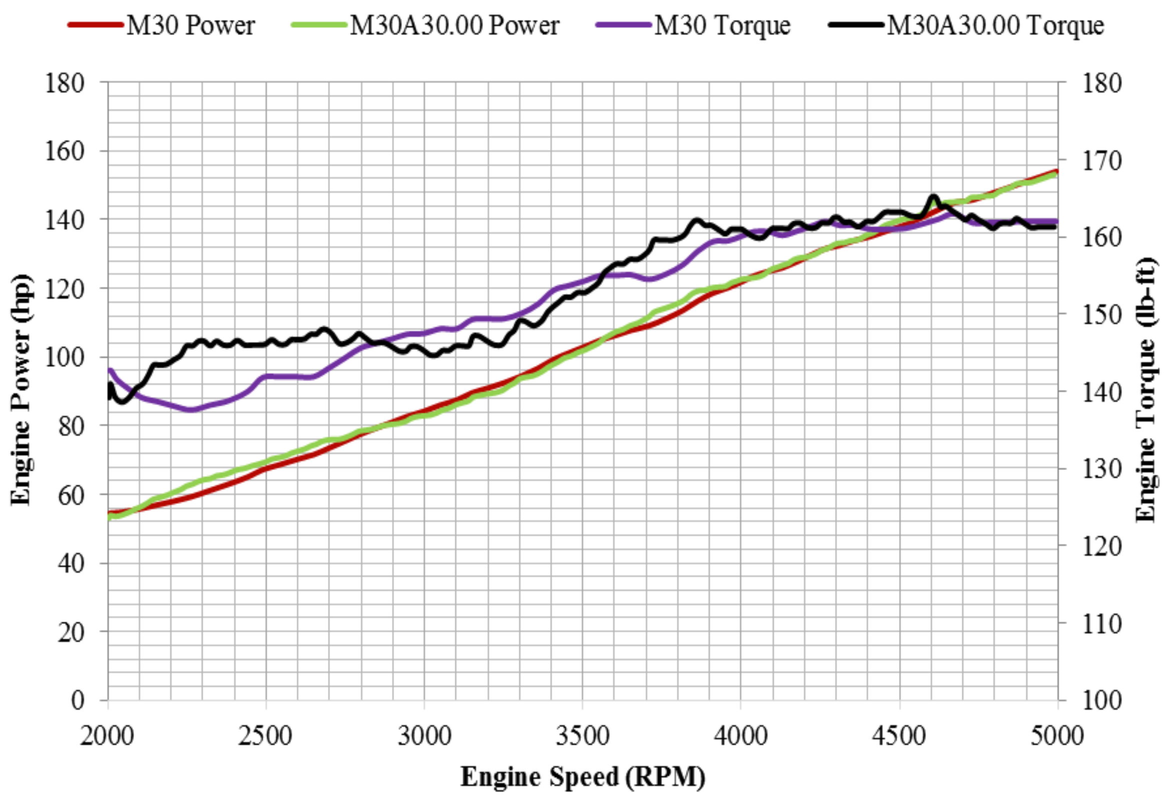
POWER AND TORQUE CURVES OF M10 AND M10A11.5

Dynamometer Results – M20



POWER AND TORQUE CURVES OF M0 AND M20A23.00

Dynamometer Results – M30



POWER AND TORQUE CURVES OF M30 AND M30A30.00

Conclusions

* Gasoline-ethanol/methanol -ammonia fuel blends - feasible
* Minimum new infrastructure needed
* Can be run with existing IC engines
  * Up to 20% of ethanol/methanol and 20% of ammonia
* Ammonia rich fuels performs better
  * @High engine speeds – higher power and torque
  * Hydrogen needs less Oxygen for stoichiometric combustion
* Higher octane number of ammonia – less/no knocking
* Higher blends - with flex fuel engines (E85)

Potential Work

* Emission tests
* Methanol and several commercial cross linkers as emulsifiers
* Theoretical correlation for solubility
* Same tests for diesel/ bio diesel

11. References

1. Aguilera, R. F., Eggert, R. G., C. C, G. L., and Tilton, J. E., 2009, "Depletion and the Future Availability of Petroleum Resources," Energy Journal, 30(1), pp. 141-174.
2. Züttel, A., 2003, "Materials for hydrogen storage," Materials today, 6(9), pp. 24-33.
3. http://www.electrogenhydrofuels.com/engine/Engine.html, May, 2014.
4. Lovegrove, K., Luzzi, A., Soldiani, I., and Kreetz, H., 2004, "Developing ammonia based thermochemical energy storage for dish power plants," Solar Energy, 76(1), pp. 331-337.
5. Reiter, A. J., and Kong, S.-C., 2011, "Combustion and emissions characteristics of compression-ignition engine using dual ammonia-diesel fuel," Fuel, 90(1), pp. 87-97.
6. Duynslaegher, C., Jeanmart, H., and Vandooren, J., 2009, "Kinetics in Ammonia-Containing Premixed Flames and a Preliminary Investigation of Their Use as Fuel in Spark Ignition Engines," Combustion Science and Technology, 181(8), pp. 1092-1106.
7. Einarsrud, M.-A., Justnes, H., Rytter, E., and Oye, H., 1987, "Structure and stability of solid and molten complexes in the MgCl2-AlCl3 system," Polyhedron, 6(5), pp. 975-986.
8. Soloveichik, G. L., Andrus, M., Gao, Y., Zhao, J.-C., and Kniajanski, S., 2009, "Magnesium borohydride as a hydrogen storage material: Synthesis of unsolvated Mg (BH4)2," international journal of hydrogen energy, 34(5), pp. 2144-2152.
9. Graham, K., Kemmitt, T., and Bowden, M., 2009, "High capacity hydrogen storage in a hybrid ammonia borane–lithium amide material," Energy & Environmental Science, 2(6), pp. 706-710.
10. Schäfer, D., Xia, J., Vogt, M., Pérez-Salado Kamps, Á., and Maurer, G., 2007, "Experimental investigation of the solubility of ammonia in methanol," Journal of Chemical & Engineering Data, 52(5), pp. 1653-1659.
11. Huang, L.-J., Xue, W.-L., and Zeng, Z.-X., 2011, "The Solubility of ammonia in ethanol between 277.35 K and 328.15 K," Fluid Phase Equilibria, 303(1), pp. 80-84.
12. Xia, J., Jödecke, M., Pérez-Salado Kamps, Á., and Maurer, G., 2004, "Solubility of CO2 in (CH3OH+ H2O)," Journal of Chemical & Engineering Data, 49(6), pp. 1756-1759.
13. Haputhanththri, S. O., Austin, C., Maxwell, T., and Fleming, J., 2014, "Ammonia and gasoline composite liquid fuel blends emulsified with ethanol and methanol for direct displacement in internal combustion engines," IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11(2), pp. 11-18.
14. Haputhanthri, S., Austin, C., Maxwell, T., and Fleming, J., "Ammonia and gasoline fuel blends for internal combustion Engines," Proc. Proceedings of the ASME 2014 8th International Conference on Energy Sustainability & 12th Fuel Cell Science, Engineering and Technology Conference, ASME.
15. Lemmon, E. W., Huber, M. L., and McLinden, M. O., 2013, " NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 9.1," National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg.
16. Pérez-Salado Kamps, Á., 2005, "Model for the Gibbs excess energy of mixed-solvent (chemical-reacting and gas-containing) electrolyte systems," Industrial & engineering chemistry research, 44(1), pp. 201-225.
17. **Haputhanthri, S.O.**, Austin, C., Maxwell, T., and Fleming, J., "Ammonia gasoline-ethanol/methanol tertiary fuel blends as an alternate automotive fuel," ASME International Mechanical Engineering Congress & Exposition, November 14-20, 2014, Montreal, Canada
18. **Haputhanthri, S.O.**, "Ammonia gasoline fuel blends: Feasibility study of commercially available emulsifiers and effects on stability and engine performance", SAE International Powertrain, Fuels and Lubricants Meeting, October 20-23, 2014, Birmingham, United Kingdom

Questions ?

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