GTA Technologies, Inc.

A Paradigm Shift Occurs in Fuel Additive Technology

1.0 Introduction

The purpose of this paper is to describe new fuel additive technology being marketed by GTA Technologies, Inc. (GTAT) The technology offered by GTAT provides significant opportunity to improve combustion efficiency of engines burning liquid fuels with consequent improvements in power, fuel economy and reduced emissions. Most importantly, the technology provides these benefits by low cost modifications to the fuel rather than relatively high cost modifications to engine design and control systems. Internal combustion engines, in spite of extensive design work over many years, are still relatively inefficient in terms of combustion efficiency. (Scientific American, Improving Automotive Efficiency, December 1994, indicated typical combustion efficiencies of 40% for gasoline automotive engines).

This paper presents combustion technology information gleaned from publications of the Society of Automotive Engineers (SAE) presented at a recent national meeting in Detroit in the Fall of 1995 and provides commentary showing how GTAT's fuel additives can be used to help overcome combustion problems identified by the SAE scientists and engineers. This change in approach to improving combustion by changing the viscoelastic properties of the fuel is a paradigm shift which offers significant potential for gasoline and diesel engines. A synopsis of the selected SAE papers is provided followed by a discussion of how the fuel additive addresses the combustion efficiency problem presented in the SAE papers.

2.0 An Overview of GTAT's Technology

The Company has acquired certain marketing rights to an additive whose principle ingredient is a polymer which when added to fuels in small concentrations induces changes in the extensional viscosity of the fuel as it is introduced into the combustion chamber of an engine. The change in viscosity causes behavioral changes in the fuel which profoundly influence combustion. **The principle changes brought about by the additive are (1) the creation of a more uniform distribution of fuel droplet sizes resulting in more efficient combustion via decreased fractional distillation, (2) elimination of vapor like burning, (3) improving volumetric efficiency by slightly delaying vaporization in 2 and 4 stroke spark ignition engines, (4) promotion of diffusive burning in diesel engines, (5) negation of undesirable droplet aggregation and surface coating effects through transitory increases in surface and bulk rigidity, (6) decrease the extent of vapor explosion before top dead center (TDC) in a diesel, (7) decrease in droplet agglomeration and surface wetting after TDC in a diesel and finally, (8) promotion of diesel fuel jet penetration prior to ignition and diffusive burning. The owner of the technology has applied for US and international patents for its fuel additives.**

3.0 Gasoline Engines

3.1 Is There a New Emphasis on "Real World" Emissions Testing?

SAE paper 960064, Off-Cycle Exhaust Emissions From Modern Passenger Cars With Properly Functioning Emission Controls by Robert Goodwin and Marc Ross, University of Michigan.

The EPA has promulgated a Federal Testing Protocol (FTP) which the authors show under-reports exhaust emissions relative to "real world" driving. Emissions of CO, HCs and NOx rise with the square of the rate of increase (acceleration) in miles per hour. This results in rich conditions at engine speeds over 2,500 RPM. Under enrichment conditions, much more gasoline is injected into the engine per cycle than under moderate conditions resulting in greatly increased emissions with increasing acceleration which is never reached in the FTP.

Commentary: The active ingredient in GTAT's additive prevents selective distillation of the light ends (more volatile molecules) in the fuel thus assuring a more homogeneous distribution of the hydrocarbon components in the air immediately preceding ignition. Clearly, under high load conditions both more fuel and more air must be mixed uniformly to achieve high combustion and mechanical efficiency. Tail pipe emissions increase when more fuel is burned per cycle. GTAT's additive gives the greatest improvement in fuel economy under heavy load conditions over untreated gasoline as shown in tests done by EG & G's Automotive Research Division in San Antonio, TX. It follows that reducing fuel consumption under load conditions will also reduce emissions. The test data showing reduced fuel consumption under load conditions is available.

3.2 What are The Advantages and Disadvantages of Better "Atomizing" Gasoline?

Paper 960460 Effects Of Fuel Atomization On The Lean Burn Characteristics Under Steady Conditions In A Spark Ignition Engine, by Takao Karasawa and Hisao Nakamura, Gunma University.

The authors show that over a wide operational range of air-fuel mixtures, fuel atomization did not have any effect on combustion pressure, fuel consumption and volumetric efficiency. The paper also showed, however, that an internal air blast injector giving a 7 micron mean diameter particle size improved engine stability under most operating conditions. (Stability was defined and measured by the authors by observing the rate of change of crankshaft rotation).

Commentary: The air blast injector most likely resulted in a more homogenous distribution of the droplet sizes in the air-fuel mixture just prior to ignition resulting in the smoother engine operation. The GTAT additive narrows the droplet size distribution by effectively eliminating the ultra-fine droplets, contributing to more homogeneous vapor composition on a molecular basis. The additive also has a second effect decreasing fractional distillation and thereby increasing vapor homogeneity. This would be achieved using a standard injector rather than the impractical air blast injector used by the author of the paper and consequently is a more simple solution. The GTAT approach should also increase volumetric efficiency since liquid vaporization is briefly delayed under turbulent conditions resulting is less fuel vapor back pressure during the intake stroke. The author's use of the air blast injector giving the smaller liquid particles may be desirable but it could also produce a lack of power under rapidly increasing engine RPMs. The use of GTAT's additive would not have this impediment and has the further advantage of passing a greater mass of air.

3.3 What Causes In-Cylinder Air-Fuel Excursions During Load Transients?

Paper 960466 On The Causes Of In-Cylinder Air-Fuel Ratio Excursions During Loading And Fueling Transients In Port-Injected Spark-Ignition Engines, by Nico Ladommatos and Dean Rose, Brunel University

The authors show the effects of simulated "real world" load transients on operating conditions particularly the air-fuel mixture which was found to vary from an initial lean condition for one cycle during the start of the transient to a rich excursion during the next cycle and gradually changing to stoichiometric combustion (balanced air-fuel mixture which provides just the right amount of air to burn all of the fuel) after several more cycles. The transient therefore results in substantial variation in air-fuel mixtures which only settles down when the transient has ended. During such periods of widely varying air-fuel mixtures the engine will consume more fuel than it would otherwise consume under constant air-fuel mixtures.

Commentary: The GTAT additive will improve air fuel homogeneity under all (lean, rich and stoichiometric) conditions due to transient demand for greater output because it acts as the fuel is introduced. There is no time lag at the injection nozzle, although once ejected the droplets are made more rigid for at least 1.5 milliseconds. This is caused by the long chain polymer in the additive stretching upon ejection and increasing the viscoelasticity of the fuel droplets. Prior to the relaxation of the stretched polymer molecule in the additive, there is an effective blockage of fractional distillation of lower boiling point hydrocarbons from the high boiling point ones. This in turn leads to greater compositional homogeneity of the air-fuel charge near the end of the compression stroke and the beginning of the power stroke. The engine then exhibits less cycle to cycle variability under transient, high load conditions, as was very evident under in the increased smoothness observed in the acceleration test conducted by EG & G. In that test, greater air fuel homogeneity, and increased volumetric efficiency led to 35% less fuel consumption in the 0 to 35 mph section of the acceleration test. These data are also provided later in this paper.

4.0 Diesel Engines

4.1 How Does Air Density Affect Fuel Spray Penetration?
Paper 960034, Effects Of Gas Density And Vaporization On Penetration And Dispersion Of Diesel Sprays, by Jeffrey Naber and Denis Siebers, Sandia National Labs

The authors show that gas density in the cylinder head decreases penetration of fuel more than it increases diesel spray dispersion. It is important, however, that the spray penetrate the compressed gas and that it must disperse without impinging on the wall of the combustion chamber. When a vaporizing liquid is injected into a high pressure, high temperature gas, it penetrates 20 % less than a non-vaporizing liquid. The authors explain this to due to an increase in the density of the gas mixture in the spray as it is cooled by evaporating fuel. The higher density mixture slows newly injected fuel progressing through the spray. This slows tip penetration and also contracts the spray into a decreased dispersion angle.

Commentary: It is expected that GTAT's fuel additive with its viscoelastic polymer will eliminate ultra-fine droplets and will increase vaporization delay, and increase spray tip penetration since small particles and individual molecules lack mass and have little momentum for penetrating very far. The viscoelastic polymer in GTAT's additive can be used to get greater penetration and mixing in high pressure and high temperature diesel engines.

4.2 What Drives Efficient Combustion in a Diesel Engine?
Paper 960035, Influences Of Fuel Injection And Air Motion Energy Sources On Fuel-Air Mixing Rates In A DI Diesel Combustion System, by David Timoney and William Smity, university of Dublin

The introduction to the paper states that a "significant portion of the combustion process in direct injection diesel engines takes place in diffusion flames." Fuel and air mixing then depends on the fuel injection process itself, air motion effects, and the geometry of the combustion chamber. The paper views kinetic energy as the fundamental basis of "mixing energy." The two sources of the kinetic energy are fuel injection and air motion.

Commentary: It is intuitive that the introduction of a non-Newtonian component to the fuel injection operation would affect mixing and fuel combustion. ("Non-Newtonian" refers to a substance whose flow properties are dependent on viscosity as well as molecular structure and possibly other parameters).

Generally, high injection pressures are desirable for efficient combustion. High kinetic energy of the injected fuel is therefore desirable, all other air energy and geometrical features remaining the same. The authors, in examining data from past investigations, injection pressure has been shown to have a larger effect on mixing than air energy. Due to the higher density of the liquid this is expected. When the injection pressure is increased, and the other parameters are suitably maintained, lower smoke levels are seen, especially at "high load conditions where oxygen for combustion is in relatively short supply."

The SAE paper does not address such fuel property effects with the exception of vaporization, but provides data which permits drawing some inferences on how viscoelasticity could affect the combustion system. Other experiments mentioned in the paper showed that the chemical reactions of fuel combustion were very fast, but that the rates of combustion were limited by rates of mixing. The rate of dissipation of the turbulence was very important for good burning. The message is that whatever can be done to assure both high turbulence and good liquid particle momentum should facilitate good combustion. The addition of GTAT's additive to suppress ultra-fine, low-momentum particle formation and to suppress jet-retarding vaporization should yield more efficient diffusion flame combustion**.**

4.3   Does Lubricating Oil Contribute To Emissions From Diesel Engines?
Paper 960318, Effects Of Lubrication System Parameters On Diesel Particulate Emissions Characteristics, by RB Laurance, Victor Wong and Alan Brown, Massachusetts Institute of Technology

The contribution of lubricant to total particulate matter in emissions depends on the condition of the diesel engine. It can reach as high as 70% of total particulates and 90% of the soluble organic fraction under light to medium loads. Cylinder wall oil is the source of these emissions, and the thickness of the film is greater with less viscous oils. The authors observed that the greatest particulate rate is at low load, while the lowest particulate rate is at medium load. At high load the oil particulate rate is low, but carbonaceous particulates increase. At low load the carbonaceous particulate is low.

The authors also contend that lubricating oil consumption in a diesel engines causes a significant increase in polycyclic aromatic hydrocarbon emissions from both spark ignition (SI) and compression ignition (CI) engines. It is understandable that these emissions tend not to come from new engines, but from older, more worn engines. These old engines are usually maintained using mineral lubricating oils of low quality.

The mechanisms of oil consumption involve evaporation from the lubricating system, leakage through various seals, piston rings, and valve guide systems. The major effect is that of the piston rings sweeping oil towards the combustion chamber. Another effect is evaporation of oil into the space above the piston. Generally, when this oil sweeping occurs through wear, the engine still operates satisfactorily, but oil consumption increases.

The oil control ring lays down an oil layer that the compression rings move over. When the ring deteriorates, excess oil is swept toward the combustion chamber. The piston speed drops substantially near top dead center and bottom dead center, and the rings then tend to almost touch the surface of the cylinder. This is counteracted by oil from under the compression ring. Oil is left on the cylinder surface after the piston begins to move toward bottom dead center from top dead center. Some of this oil will vaporize and or become involved in the combustion process leading to increased emissions of hydrocarbons in the exhaust. The heat of combustion will also assist in the vaporization of oil into the combustion chamber.

Commentary: The addition of GTAT's polymer to the fuel could impede the removal and emission of this oil in the exhaust. Again, a viscoelastic effect on the cylinder walls may reduce the rates of both oil and carbonaceous particulates in the exhaust.

The GTAT additive should be used in fuel and in the oil of vehicles showing high consumption rates for lubricating oil. Due the high instantaneous viscosity of the droplets of gasoline during the intake stroke, wall wetting should be reduced. During the subsequent compression stroke, fuel vaporization will be more complete, and the oil will remain in place with less tendency to vaporize. The oil remaining on the cylinder and crevice surfaces immediately preceding combustion will be less likely to vaporize due the presence of small amounts of the polymer. The polymer will itself decompose over several cycles but new polymer is always coming in with the intake stroke. One thus expects hydrocarbon and polycyclic aromatic hydrocarbon emissions to be decreased when the additive is used in the fuel. Adding a small quantity of polymer powder to the lubricating oil should have a supplemental effect on reducing hydrocarbon emissions, and have the added benefit of reducing friction.

4.4 What is the Source of Soot Emissions From Diesel Engines?
Paper 960320, <u>Thermophoretic Effects On Soot Distribution In A Direct-Injected Diesel Engine, By John Abraham</u>, University of Minnesota.

Slow mixing and slow combustion correlate with the production of unburned carbon from direct injected diesel engines. The paper suggests that the "catch 22" is that fast mixing and fast combustion generally leads to increased NOx exhaust emissions. Increasing the injection pressure, or retarding the timing can reduce particulate emissions. However, as regulations tighten, it is important to know the mechanism(s) of particulate emissions to be able to control particulate formation and combustion.

Once soot particles are formed, they can be oxidized (a good outcome) or deposited on walls where they cannot be readily oxidized (a bad outcome). They can be stripped off the walls later and make their appearance in the exhaust.

Commentary: GTAT's hypothesis of viscolealstic fuels suggests transient beneficial modification of fuel properties in three ways: (1) elimination of ultra fine droplets which burn like vapor, (2) improved penetration of the droplet spray, and (3) transient decrease in fractional vaporization. The result is better mixing and more uniform and complete combustion via a more uniform mixture in the vapor surrounding each droplet, and in the interior of each droplet. This makes the diffusive burn more uniform in time, since light ends aid in the combustion of heavy ends. More emphasis on a diffusive burn, which is more controlled than an explosive burn, tends to spread the heat delivery over the time near top dead center. An early transient high-temperature, high-pressure peak (knock) is thus avoided, leading to higher mechanical efficiency, less mechanical stress, and less soot. Since both time and temperature are necessary for NOx production, it is likely that the "catch 22" can be somewhat mitigated, and both soot and NOx can be reduced using the viscoelastic polymer additive. GTAT's additive would appear to be providing a breakthrough for direct injected compression ignition engines.

4.5 What Characteristics Of Jet Penetration Affect Diesel Combustion?
Paper 960773, Analysis Of Current Spray Penetration Models And Proposal Of A Phenomonological Cone Penetration Model, by Peter Schihl and Walter Bryzik, US Army, TARDEC, and Arvind Atreya, University of Michigan

The characteristics of liquid fuel jet penetration ultimately affect the fuel burning rate in diesel combustion. The penetration phenomena include spray angle, droplet-size distribution, mixing layer development, and burning rate. Liquid injected from the nozzle begins as an extruded core which begins to break up near the injector tip. The transition is from liquid core, to drops and then to smaller drops. The distance from the nozzle to the end of the liquid core is termed the primary breakup zone. The distance beyond the liquid core tip is termed the secondary breakup zone. Evaporation occurs in both zones, with emphasis on the secondary zone. The spray tip density is thought to be similar to the gas density at the edge of the spray for the inherently high air / fuel ratios characteristic of diesel engines. The model is of an expanding cone with the top of the cone at the injector and the base of the cone at the end of the secondary breakup zone. Air is entrained through the surface of the cone. The authors show that this cone model performs well relative to experimental results for chamber densities for 15 kg/m3 to 50 kg/m3.

Commentary: The model predicts the spray penetration distance from the nozzle. The fuel, however, is assumed to be non-cohesive. An element of cohesion as introduced with increasing GTAT additive concentration will provide a degree of physical control over the angle of the cone and its penetration distance. Increased penetration and mixing may result from the effect of a very low concentration of the additive on reducing the cone angle. This effect on cone narrowing and jet penetration would originate in the liquid body prior to drop formation. This could have a desirable effect on combustion temperature-pressure time plots, and NOx and soot formation.

4.6 What Characteristics Of Spray Evaporation Affect Diesel Combustion?
Paper 960630, An Improved Model To Describe Spray Evaporation Under Diesel Like Conditions, by S. Hoffmann, M. Klingsporn, and U. Renz, RWTH

Diesel fuel is a mixture of substances with different rates of evaporation. The authors employed mixtures of two hydrocarbons with different boiling points as the basis of a simple model for diesel fuel spray evaporation. The atomization region extends out 10 mm from the injector tip. The vaporization region extends from 10 mm to 40 mm. At the beginning of the injection, the droplets are heated up before evaporation is significant. The liquid mass within the spray is constant during the injection period which indicates that the evaporation rate is approximately the same as the injection rate. Typically the vapor mass fraction never exceeded 0.15 over the spray length from 0 to 50 mm. The maximum vapor mass fraction occurs 1 millisecond after the start of injection. In a system consisting of n-decane and alpha-methylnaphthalene (70:30 volume percent, respectively) the decane evaporates first leading to a higher concentration near the nozzle region.

Commentary: The GTAT additive should extend the distance over the spray length for the evaporation of the lower molecular weight hydrocarbons in diesel fuel. Without invoking any other effect of the additive than the transitory decrease in evaporation from droplets containing stretched polymer molecules (high viscosity), the molecular homogeneity should be improved along the spray path. This should change the pressure-temperature characteristics of combustion.

4.7 What Causes Smoke In Exhaust From Diesel Engines?
Paper 960249, White Smoke Emissions Under Cold Starting Of Diesel Engines, by MK Yassine, MK Tagomori and NA Henien, Wayne State University.

White/blue smoke consists of fuel and lubricating oil particles in an unburned, partially burned or decomposed state. Black/grey smoke consists of solid particles of carbon from the incomplete combustion of the fuel. White/blue smoke is associated with mechanical wear of valve and ring components. Black smoke can be caused by dirty air filters and fuel injectors, or by an incorrectly set fuel pump.

Fundamentally, fuel is sprayed into the cylinder as the piston advances towards TDC. An ignition delay is necessary to mix the fuel with air and achieve a homogeneous distribution of fuel and air. That is a problem because charge heterogeneity results in locally over-lean and over-rich mixtures. A spectrum of equivalence ratios is present immediately before auto-ignition, and local rates of oxidation will vary, leading to emissions in some regions.

Commentary: A very large number of ambient factors, engine conditions, and fuel parameters affect the production of white and black smoke from diesel engines. Improved fuel/air homogeneity prior to auto-ignition is considered the route to more uniform and complete combustion. The additive should act to prevent highly lean and highly rich pockets from forming. The GTAT additive could improve homogeneity by several mechanisms beginning with increased fuel spray penetration and mixing, and ending with improved droplet retention of volatiles for well-behaved, diffusion-controlled combustion

5.0 Summary of Conclusions:

The foregoing review and analysis of several SAE recent papers, prepared by automotive and combustion scientists and engineers, clearly indicates that the combustion process in both spark ignition and compression injection engines is the focus of much attention. The concern about combustion efficiency and exhaust emissions arises from the relatively poor conversion of potential energy of the fuel to mechanical work delivered to the wheels. As discussed in the Scientific American article, referenced earlier, mechanical engineering changes are being made to increase efficiency of automobiles. The fuel companies have been improving their product mainly by developing and incorporating cleaning and “keep clean” additives and may believe that significant further improvement is unlikely except through reformulation to reduce emissions. The developer of the fuel additive being marketed by GTAT have taken a quite different approach to solving the problem by changing the physical, not chemical properties, of the fuel with the additive which modifies the viscoelasticity of the fuel and the manner in which it is burned. The commentary relative to the SAE papers shows how combustion efficiency problems identified by the authors are relieved by GTAT’s additive with consequent improvements in combustion efficiency.

In the final analysis, the proof of improved combustion efficiency must be seen by users in their vehicles. Employees and friends of GTAT have been using the additive for about a year and are enthusiastic supporters based on their perceptions of increased power and measurements of improved economy. Claims by users of ‘smoother running” and “more power” and fuel economy improvements of 10 and 20 % are common. Such measurements, however, are imprecise because of the numbers of variables affecting the car’s operation and different analytical capabilities of the drivers. GTAT recognizes this problem and has had some independent and more scientific testing accomplished and continues to have testing done. Test data are synopsized in a companion paper which is continually up-dated as more data becomes available.

The independent tests have demonstrated, however, that the additive results in increased cylinder head pressures (more power) and increases in torque and improvements in fuel economy, particularly under varying load conditions (the way people actually drive their vehicles). It follows logically, that if an engine is burning fuel more efficiently and developing more power with less fuel, then there must be less exhaust gas including less unburned hydrocarbons and less carbon monoxide (it too would burn up and become carbon dioxide). GTAT believes users will view use of the additive as restoring power and economy which was lost when EPA mandated use of reformulated and oxygenated fuels.