PENETRATION PROSPECTS OF EMULSIFIED FUEL IN THE GREEK OIL MARKET

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ABSTRACT

Diesel or compression-ignition (CI) engines are used for transport (passenger cars, light and heavy duty trucks, locomotives, marine), non-road devices (tractors, construction equipment) and non-transport applications (power generators). They display high fuel economy, however, diesel exhaust contain toxic air contaminants. Water-diesel emulsions typically contain 10-20% water and various additives and they are a promising alternative fuel that can be used in conventional engines without any modification. The cooling effect of the presence of water in an engine is known to reduce exhaust pollutants, especially NOx and PM. The fuel-water emulsions are considered the most feasible alternative to the direct injection of water and this is due to the fact that water can be mixed with fuel prior to the introduction of the fuel into the engine. Emulsified diesel is the only technology that controls the emissions of the exhaust gases and simultaneously reduces NOx, PM and CO_2 emissions without the necessity for any technical modifications of the engine. The market price of the emulsified fuels that are distributed today by European manufacturers is higher than the cost of the conventional diesel fuel mainly for two reasons: because (a) of the tax policy on the water content of the emulsions and (b) of the use of expensive surfactants and/or other additives. EEFMA (European Emulsified Fuels Manufacturers Association), the USEPA or EPA (US Environmental Protection Agency) and the CARB or ARB (Clean Air Resources Board) try to exempt the water portion of a diesel fuel/water emulsion from the excise tax on diesel fuel. This would help the business sector and could make the "white diesel" affordable for mass use in transport, boilers and engines. Greece has the ability through existing investments and potential applications of renewable and conventional fuels in the whole range of services, to develop an environmental sustainable industry research, promotion and application of the emulsified fuel technology.

1. Introduction: the technology of emulsified fuels

Urban air pollution caused by transport worldwide is a complex technical and social problem for several decades. Transport is the major contributor to the global energy consumption as well as the greenhouse gases emissions.

The necessity for enhanced engine performance has placed diesel engine to the fore because of its higher efficiency, compared to a petrol engine. However, diesel engines develop increased NOx emissions [1]. The existing legislation for the control of vehicle's exhaust emissions limits NOx emissions to very low levels, and this is the main reason why low fuel consumption is required. In recent years, the technology of emulsified fuels and its application on boilers, burners and engines has attracted much attention from the viewpoint of energy saving and the prevention of air pollution which is caused by the exhaust gases from most combustion engines. The emulsification technology includes a wide variety of industries and the commercial emulsions are designed to a wide range of physical, chemical and biological requirements. The emulsified fuel typically contains between 10 to 30 wt. % of water and various additives that improve certain properties, such as cetane number and lubricity. Surfactants and emulsifying additives are used to stabilize the emulsions.

Fuel emulsions can be applied to new vehicles and to the existing fleet, primarily in the areas of off-road network, construction, mining, and on-road network - especially on buses - [2]. The purpose of such use is to improve air quality by reducing exhaust emissions mainly from transport

vehicles (in particular nitrogen oxide and particulate matter emissions). The type of emulsion fuel which is composed of petroleum fuels and water is divided into two basic types: water-in-oil (W/O) and oil-in-water (O/W) emulsified fuel [3]. The emulsion in general, is a mixture of two or more liquids in which the one is present in the form of droplets of microscopic or ultra-microscopic size, distributed in the other. The emulsions are formed from their constituents either spontaneously or more often by mechanical means such as agitation. It is sufficient that the miscible materials have no or little mutual solubility [4]. Emulsions can be classified according to the nature of the emulsifier or the structure of the system as following:

Table 1:

Nature of Emulsifier	**System Structure**
Simple Molecules and Ions	Nature of Internal and External Phase
Non Ionic Surfactants	O/W and W/O
Surfactant Mixtures	Micellar Emulsions
Ionic Surfactants	Macro-Emulsions
Non Ionic Polymers	Bilayered Droplets
Poly electrolytes	Double and Multiple Emulsions
Mixed Polymers and Surfactants	Mixed Emulsions
Liquid Crystalline Phases	
Solid Particles	

2. The double-phase emulsified diesel fuel

Double-phase emulsions are separated into two types: water-in-oil emulsions and oil-in-water emulsions. The greatest interest lies in the water-in-oil (W/O) emulsions and is derived from the fact that water in the form of small droplets has a positive influence on the combustion of the fuel [1]. The primary interest lies in the water-in-diesel (W/D) emulsions, as the greatest advantages of the incorporation of water in diesel fuel than in gasoline, are the high combustion temperature and the high pressure which are present in diesel engines. Emulsified diesel fuel is a stable mixture of diesel fuel with water along with emulsifiers and stabilizing additives. Additives are used for the manufacture of emulsified diesel and prevent water from contacting the motor. An emulsified diesel fuel can be used in any new or existing diesel engine, as follows: the water is mixed with oil through homogenizer before the injection of the fuel into the chamber. Infusion of emulsified fuel permits effective spraying and the homogeneous dispersion of the fuel in the combustion chamber. This results in a complete combustion with lower fuel consumption, cleaner engine and reduced emissions of NOx, PM, CO and HC.

The main advantage of the combustion of emulsified fuels is the characteristic combustion of atomized droplets of the emulsified fuel, which arises from the included fine water particles in each droplet. The diameter of the liquid fuel droplets sprayed into the combustor lies between 30 to 130 microns. Under conditions of normal atmospheric pressure, the volume of a droplet of water expands approximately 1,700 times more than its original volume due to evaporation process. The water which has a lower boiling point than oil is evaporated and extended 1,700 times by volume, therefore dispersing the surrounding liquid oil. When the emulsified diesel fuel is injected into the combustion chamber or in the engine - as liquid- is exposed to a high temperature. In the high-temperature air in the combustion chamber, the fine water droplets which are contained in each droplet of fuel emulsion explode because of the flasher, and crush the fuel droplet emulsion. This process is called micro-explosion of the fuel droplet leading to key advantages of the process of combustion of fuel emulsions, and promotes atomization of fuel particles - i.e. the mixing of the fuel with the surrounding air -. Because of "miniaturization" of oil, communicating surface with oxygen (air) is increased, thereby improving the combustion efficiency and reducing fuel consumption. In addition to improving the combustion efficiency, there is a corresponding increase in the efficiency of combustion in high temperature boilers and forging furnaces.

3. Commercial emulsified fuels

1. Water-Diesel Emulsion PuriNOx of Lubrizol: It contains up to 20% water, it is a stable emulsion and it exhibits similar properties to skim milk, as far as appearance and consistency are concerned. By using it, up to 20% reduction in NOx and up to 60% reduction in PM are achieved.
2. Gecam white diesel of Pirelli Eco Technology SpA: white diesel (gasolio bianco). It consists of 88% oil, 10.3% water and 1.7% mixture of additives that make the emulsion stable and prevent the separation into its main components.
3. Aquazole of Total: a W/D emulsified mixture. It provides reduction of NOx by 16% and reduction of PM by 60% in diesel vehicles. In late 2001, more than 1,000 trucks and buses in Europe operated with Aquazole.
4. FOE of APT: the fuel oil is designed for boilers applications and small/large gears of internal combustion engines. (A) Low water FOE: an emulsion fuel oil (HFO) with a water content of between 8%-12% (phase emulsion) (B) High water content FOE: a fuel oil emulsion with high water content (15% up to 30%), (O/W).
5. EcoFuel of FEI: a fixed and conventional fuel (usually six to 12 months) which doesn't cause any damage to the equipment and reduces costs concerning engine maintenance. It consists of 28% water and 2% additives and requires only 70% addition of conventional fuel per volume to produce slightly more power and fewer waste products.
6. MSAR® (Multiphase Superfine Atomized Residue): it is the most popular low cost marine fuel emulsion (O/W). It is manufactured by blending refinery residue with water (20% to 30% water content) to produce the emulsified fuel oil and provides 50% reduction in NOx and 20% fuel savings.

4. Taxation of emulsified fuels

Based on the Greek Ministry of Development and Competitiveness we get the following data:

Table 2:

Fuel	Average Retail Price (€/lt)
Unleaded gasoline 95 RON	1.664
unleaded gasoline 100 RON	1.864
LRP	1.796
Automotive Diesel	1.361
Heating diesel	1.259
LPG	0.875

Gasoline engines consume on average 9 litres of fuel per 100 kilometres (medium size engine) and diesel engines consume on average 6 litres of fuel per 100 kilometres.

The emulsified fuels sold today by European manufacturers are more expensive than conventional diesel because of the tax policy (taxes on water content of the emulsified fuels) and the use of expensive surfactants and/or other additives. The emulsified fuel costs 0.06 euro/lt more than conventional/regular diesel. The emulsified fuel produced for use in internal combustion engines contains a minimum of 10% to a maximum of 20% water and the emulsified diesel fuel costs 1.421 €/lt compared to the value of the ordinary diesel fuel (1.361 €/lt) [5]. The taxation of the emulsified fuel, however, is a delicate matter, considering that on average 15% of the mass of the fuel sold is water and the rate of tax per litre of fuel consumed, also applies to the water content.

The fuel emulsions have been distributed in in more than 80 municipalities in Italy for: a) public transport and b) collection and transportation of waste (9,000 vehicles). The fuel emulsions are also used for heating purposes in private houses (100 houses) and public buildings like museums, schools and universities (300 heated buildings). The wide usage of emulsified fuels in Italy is due to the incentive of a tax relief of 36% on fuel emulsions. Excise tax for the emulsion used for propulsion is 0.28050 €/lt and the excise duty on the emulsified heating diesel is 0.24516 €/lt. The

excise duty on heating diesel is 0.40321 €/lt, so due to the emulsion saving in consumption is achieved, that amounts to 0.15805 €/lt. The excise duty on diesel fuel is 0.61740 €/lt, hence the conversion to a fuel emulsion results in saving 0.3360 €/lt. The following table summarizes the "clean" fuels, the already used "clean" technologies and their respective costs [6]:

Table 3:

Clean Fuel/Clean Technology	Engine Type	PM Reduction (%)	NOx Reduction (%)	Cost of Fuel/ Technology
ULSD (ultra-low-sulfur-diesel)	Engine out of road	Enhances the Mode of PM filter technology by 5%-9%		0.025 to 0.06 €/lt more than diesel
Particulate Matter filter	New or already used diesel engine	60%-90%		6,500 € to 13,000 € **(necessity of ULSD)**
Oxidation Catalyst	New or already used diesel engine	20%-30%		1,300 € to 2,600 € **(used with diesel)**
Compressed Natural Gas (with oxidized catalyst)	New CNG engine	70%-90% Catalyst Technology is used to reduce PM, formaldehyde and methane	60% reduction	39,000 € more than a diesel bus (similar cost of CNG fuel and diesel).**[refueling installation required]**
Biodiesel Fuel (B_{20}: 20% biodiesel and 80% diesel)	New or already used diesel engine	%	Biodiesel Increases NOx Emissions (2%)	0.02 to 0.07 €/lt more than die
Emulsified Fuel Diesel	New or already used diesel engine	%	10% reduction	0.06 €/lt more than diesel

The main factor determining the production costs of emulsions is the price of raw materials (e.g. surfactants and antifreeze) that must be added to fossil fuels and water. Further costs constitute: 1. to the cost of logistics (including storage in special tanks and transportation with special trucks) and 2. to production costs. Due to the lower energy value of emulsions in comparison to fossil fuels, the consumption of emulsion fuels is 10% higher. Using fuel emulsions, it imposes additional operating costs on consumers (e.g. cleaning tanks and recirculation systems). The calculations of total emulsions production costs include a fair profit margin of 5%. The goal that has to be achieved is the introduction of a broad partial tax exemption. Regarding the on-road and the off-road fleets that use emulsified diesel, it should cost exactly or less than normal diesel.

5. Conclusion: the present and the future of alternative fuels

The emulsified diesel is the only emission-control technology that simultaneously reduces nitrogen oxides (NOx) and particulate matter (PM) and leads to a significant reduction of the opacity of the exhaust gases. Today, research focuses on emulsion fuel technology (EFT) since they combine urban pollution reduction with reduced CO_2/greenhouse gas (GHG) emissions. Based on the UITP reports (2004), emulsions can reduce opacity by 30-80%, PM emissions by 10-60%, and NOx emissions by 5-25% and can achieve a reduction of carbon dioxide above 5% *[8]*. The Energy Information Agency (US-EIA) presents the following data regarding the Asian fuel market: the market penetration is 5%, and the subsequent production of emulsified fuel - using this penetrator as "base" of fuel equivalent to the expected production of emulsified fuel - is expected to be 9.6 billion litres. The Asian market is a part of the global economy, since it processes the two fastest growing economies - China and India and, therefore, the introduction of EFT in these economies can provide significant environmental benefits and reduction of greenhouse gases in comparison with the adoption of traditional technologies that already exist. Although the technology of emulsified fuels employs scientific study and research since 1900, it is not widely applied because of the significant barriers related to the limited acceptance by the engine manufacturers, the equipment manufacturers, and the existing fleet of vehicles and because of the lack of a European standard. The major problems facing the emulsified fuels are: a. lifetime/stability that encompasses the loss of engine power and the loss of torque, b. compatibility with new engine technologies on the world market, c. the main expansion in individual use vehicles and d. the existence of an imminent wide tax incentive for the wide use of emulsified fuels. Many international agreements and conventions (EEFMA, USEPA and CARB)

have stated the commitment of all their members to adopt environmental programs so as to reduce emissions and improve air quality and consequently contribute to the reduction of unemployment and greenhouse gases, and to the decentralization in an economically viable manner, placing Greece as a forefront within EU [7].

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