Project no. TST5-CT-2006-031241

CLEANENGINE

Advanced technologies for highly efficient Clean Engines working with alternative fuels and lubes

Specific Target Research Project (STREP)

PRIORITY 6.2 Sustainable Surface Transport

PUBLISHABLE FINAL ACTIVITY REPORT

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Project coordinator organisation name: CENTRO RICERCHE FIAT SCpA

1 Summary Of Project Objectives

According to car manufacturer EUCAR consortium beyond the year 2010, the share of engines will depend mainly on:

- legislation
- availability of mature new technologies
- infrastructure of alternative fuels
- availability of modified / synthetic fuels and lubricants
- costs and customer acceptance

CLEANENGINE addresses two of these main aspects; research activities are focused on evaluation of impacts on modern engines of:

- **liquid biofuels coming from biomass** (like biodiesel and bioethanol)
- **environmentally friendly and ash-free lubes and/or lubrication concepts**.

Effects of bio fuels and bio lubes usage on small (ships), medium (car) and large (ship) diesel and/or gasoline engine configurations are evaluated and compatible optimized solutions in materials, geometry and after-treatment are developed considering lifecycle assessment methodologies.

Main expected effects are:

- increase in engines efficiency (by reducing internal friction and improving combustion);
- reduce emissions at the source;
- reductions in NOx, CO and PM when using mixtures of oxygenated biofuels as bioethanol;
- improve the technological and industrial practice related to the use of alternative fuels in combination with environmentally friendly lubricants;
- increase the utilization share of biofuels;
- reduction of the wear originated by the accumulation of biofuels in engine oils.

The advantage that can be gained in this project will:

- help in consolidating strategic knowledge for the European large industrial partners (Fuchs, Fiat, Arizona Chemicals, Guascor, Ecocat) and the SME's (Firad, Abamotor);
- guide politics for environmental legislations.

2 The Consortium

Due to the wide spectrum of considered technologies in the frame of the project a large number of partners is involved.

Partic. no.	Participant name	Participant short name	Country
1	CENTRO RICERCHE FIAT	CRF	IT
2	FUNDACION TEKNIKER	TEKNIKER	ES
3	FEDERAL INSTITUTE FOR MATERIALS RESEARCH AND TESTING	BAM	DE
4	AVL	AVL	AT
5	ABAMOTOR	ABAMOTOR	ES
6	GUASCOR I+D	GUA	ES
7	FUCHS Europe Schmierstoffe GmbH	FUCHS	DE
8	F.I.R.A.D.	FIRAD	IT
9	ARIZONA CHEMICALS	ARZ	NL
10	ECOCAT OY	ECOCAT	FI
11	OBR PR – RESEARCH AND DEVELOPMENT CENTRE FOR PETROLEUM INDUSTRY	OBR	PL
12	ISTITUTO MOTORI - CNR	IM	IT

3 The Coordinator And Contact Details

The project is coordinated by C.R.F. S.C.p.A. , Italy.

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4 Work Performed And Results Obtained

Cleanengine project was organised into seven technical work packages: first two were "input" work packages in which fuel, lubricant and additives developers focused their activities in designing and producing the engine alternative fluids according to end-users requirements. WP3 and WP4 were devoted at the evaluation of the compatibility of

engine materials and sub-systems with the alternative fluids. In WP5 development and/or optimisation of post-treatment systems to reach emissions targets was performed for the three engine applications. In WP6 developed alternative fluids performances were finally assessed in engines. In WP7 a LCA study was carried out to study the environmental impacts in the production and usage phases of the alternative fluids.

In WP1 research activities were focused on **the development of bio-fuels blends according to engine manufactures specifications**, in particular: Bio diesel + gasoil (diesel) , Gasoil (diesel) + bio-ethanol , Petrol + bio-ethanol, Bioethanol + Biodiesel and Mixtures of gasoil (diesel), biodiesel and bioethanol were considered in the project; to fulfil specifications multifunctional additive packages were formulated for all of the biofuel types. These additive packages comprised a broad range of molecules to address specific technical issues in these fuels (improved lubricity, anticorrosive, biodegradability, toxicity and anti-wear additives were analysed). Finally biofuels mixtures and/or biocomponents were delivered for blending to end-users for engine tests.

The aim of **WP2 was the development of 'compatible' lubricants with the abovementioned bio-fuels** combining non-toxicity, bio-degradability characteristics and renewable resources with increased efficiency, reduced emissions and wear control. To achieve these aims the bio-lubricants were based either on ester- or vegetable oils or on polyglycols, with an high amount of renewable resources.
Ester oils in particular combined high viscosity index, lubricity and low evaporation loss, with full compatibility with the world of mineral based lubricants and fuels. The different Clenanengine engine technologies required the formulation of three different oils ester-based oil families: 4-stroke oil for small and medium engines, 4-stroke oil for large engines, 2-stroke oil for small engines.
The candidate base oils from the category of the polyglycols aimed at significantly reduce the viscosities at low temperatures in order to improve the fuel economy in city driving cycles. This was achieved by means of a high, intrinsic viscosity index of the base oils, eventually improved by VI improvers. To study the solubility of alcohol and biodiesels as well as to address the different oxidation and degradation reactions, polyglycols with three different backbone compositions, were considered.
The newly developed alternative oils were characterised by biodegradability and toxicity tests proposed by OECD international organisation. The viscosity characteristics and the ageing stability in presence of bio-fuel dilution were also evaluated: results showed that

the behaviour of the alternative engine oils is better than the conventional reference oils.
Additionally in WP2 an experimental activity was set up to test the Vis-NIR sensor developed by Tekniker and installed on a gas engine; through the sensor measurements some regression models were built to predict different oil quality parameters: results of demonstrated it is possible to perform the oil condition monitoring via the Vis-NIR sensor.

In **WP3 tribological performances of alternatives lubes developed in WP2 and the effect of bio-fuels dilution on friction and wear of mating engine components were evaluated;** alternative coatings were tested to counteract the negative effect of bio-fuel dilution. Also the corrosion effect of bio-fuels and alternative lubes on some engine components materials was evaluated. Different tests applied both to simple geometry specimens and real parts revealed a very good behaviour of the developed alternative oils and of the considered innovative coatings, especially in presence of fuel dilution, both in terms of friction and wear results.

In **WP4 the impact of usage of bio fuels in comparison with standard fuels on injection and combustion phases was evaluated by a numerical and experimental point of view.** Calculations were performed for three different engine applications. For small and large engines Diesel and pure FAME were applied as fuels. For medium engine different blends of biofuels from different sources were used. In general it can be stated that adding biodiesel to fossil Diesel does not principally change the behaviour of the engines. In some cases emissions become better in some cases worse, depending on the configuration. In case of large engines various fuel blend studies were tested and, based on the results, NOx removal was seen necessary to reach EPA 2007 in future applications.
For small engines both geometrical and injection engine parameters were modified to fulfil EPA 2 limits.

WP5 activities were devoted to develop/optimise opportune after-treatment systems for engines working with bio-fuels; based on emission tests results coming from small, medium and large engines, different components were developed: for diesel passenger car application dedicated DOC+DPF solutions were prepared for Euro 4 and Euro 5 configurations, for small engine application a wire mesh catalyst to be assembled in the original muffler was prepared both for diesel and gasoline fuelled configurations, for diesel large engine an hypothesis was done for NOx reduction by SCR catalyst.

An assessment of the developed technologies (fuels, lubricants, modified injection and combustion parameters and post-treatment systems) was carried out by engine/vehicle tests in WP6. For small engine applications (two stroke, gasoline and diesel) several combination of bio-fuels and alternative oils were tested thorough scuffing and endurance tests. For medium engines roller chassis dyno tests were run on the basis of an Euro 5 vehicle equipped with optimised aftertreatment system fuelled with B30 blend and engine bench emission tests were run with B30 and alternative oils; for large engine application an endurance test using optimal ethanol/bio-diesel (FAME) mixture was run. Shorter tests results showed that the current emission limits norms were fulfilled and endurance tests demonstrated that an optimisation of engine materials and the application of dedicated lubricant technologies are welcome to fight against bio-fuels specific deposits formation and the detrimental effects due to enhanced biogenic fuels oil dilution.

The LCA study performed in WP7 had the aim to evaluate by an environmental point of view the so called "CLEANENGINE system" combining the application of bio-fuels and alternative lubes. Based on the available data and using two different evaluation methods it was concluded that the main environmental benefit of the proposed system is the reduced usage of fossil fuels resources.

5 Conclusions

The project brought together many and different aspects of three complementary subjects – engines, biofuels and biolubes – with the objective to identify their interactions in view of defining those common factors allowing the achievement of the EU strategic CO2 and pollutants targets in a high competitive environment at worldwide level.

More specifically the following points were considered:

- engine sizes both for displacement and power output [small (less than 19 kW), medium for car application and large size (higher than 560 kW) for genset and maritime];
- biofuels (ethanol, FAME) blended with diesel fuel;
- alternative oils (ester based oil and polyglycol oils) with suitable additive packages.

A substantial effort was spent by the project in identifying and synthesizing those fuel – engine parameters really affecting exhaust emissions of engines running on biofuels and using biolubes. In establishing the most significant parameters, the project has set up the basis for future development of engines, running on conventional and alternative fuels, in

front of the evolution of the non-road regulations at worldwide level as testified by a number of International regulations recently introduced under development.