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Experimental and numerical assessment of methods to reduce warm up time of engine lubricant oil

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HIGHLIGHTS

- Development of a thermal model of engine, coolant and lubricant.
- Validation through experimental data in engine steady conditions and NEDC.
- Assessment of fuel consumption reduction through experimental tests.
- Proposal of three strategies to reduce oil warm up time.
- Assessment of benefits related to the strategies with the model.

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ABSTRACT

Carbon dioxide emission reduction is the most important challenge concerning on the road transportation. Stringent quantitative commitments have been set, both for automotive and for light and heavy duty vehicles. Future engine (and vehicle) technologies will consider a portfolio of new components, engine layouts, control strategies, integrated functions which will match also new comfort standards and fun to drive options, and complying fuel consumption savings.

Engine thermal management is an area of intervention aimed at reducing the warm up time: in most part of the homologation cycle, both in passenger cars and in light duty vehicles, engines do not reach a stabilized thermal state. This produces a significant pollutants and fuel consumption increase. Engine thermal management can match also more effective cabin heating requirements, improving comfort, which is an important market advantage.

Basic idea of engine thermal management is to reduce or make nil the cooling fluid circulation inside the engine.

In this paper, the oil warm up is considered as the main focus: a faster temperature grow up decreases oil viscosity and improves mechanical efficiency and organic efficiency, during engine cold state. An experimental activity has been conducted on a dynamic test bench, testing the cooling fluid and oil dynamics of a widely known commercial engine, in fixed engine points and during the New European Driving Cycle (NEDC).

A comprehensive mathematical model reproducing both the integrated circuits has been developed and validated: this required an overall engine and vehicle modeling whose input data was determined by the vehicle mission profile. By means of such model, three new technologies have been proposed and verified in terms of warm up time. They are: (a) by pass of the oil cooling, (b) oil heating using exhaust gases, and (c) a partial reduction of the oil quantity inside the sump.

All of them were applied during transients, which revealed they are able to reduce warm up time of about 65–70% with a significant benefit in terms of CO_2 reduction.

1. Introduction

Road transportation sector contributes with about one-fifth of the EU's total emissions of carbon dioxide [1], the main greenhouse gas. Transportation is the only major sector in the EU where greenhouse gas emissions are still rising [2]. In this regard, EU legislation

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Nomenclature

A	heat transfer area
C	specific heat of the fluid
D	cylinder diameter
h	convective heat transfer coefficient
HX	heat exchanger
L	conductive heat transfer reference length
k	thermal conductivity of the material
M	amount of fluid in the sub-volume
$\dot{m}$	mass flow rate
$\dot{q}$	thermal power exchanged
T	temperature
t	time

Subscripts

e	external
fluid	fluid considered (i.e. lubricant or coolant)
i	internal
in	inlet section of the equivalent duct
out	outlet section of the equivalent duct
wall	metallic wall

sets binding emission targets for new car and van fleets. It is required that the new cars registered in the EU do not emit more than an average of 130 g of CO_2 per km (g CO_2/km) by 2015. This means a fuel consumption of around 5.6 L/100 km of petrol or 4.9 L/100 km of diesel. These emission limits are set according to the mass of the vehicle, in such a way that for heavier cars higher emissions are allowed than for lighter cars. The average emissions level of a new car sold in 2014 was 123.4 g CO_2/km, well below the 2015 target. Since monitoring started under current legislation in 2010, emissions have decreased by 17 g CO_2/km (12%). By 2021, phased in since 2020, the fleet average target to be achieved by all new cars is 95 g of CO_2 per km. This means a fuel consumption of around 4.1 L/100 km of petrol or 3.6 L/100 km of diesel. Advanced internal combustion engines technologies and alternative powertrains are under development by the manufacturer in order to fulfill this commitment, with a cost increase on the vehicle market [3,4].

As for vans, the target of an average of 175 g of CO_2 per km by 2017 is set. In terms of fuel consumption, the target corresponds to about 6.6 L/100 km of diesel. In 2014, the average van sold in the EU emitted 169.2 g CO_2/km, which is significantly below the 2017 target. For 2020, the target is 147 g of CO_2 per km, which corresponds to around 5.5 L/100 km of diesel. Similarly, all other countries around the world set emission limits for passenger cars and light commercial vehicles (Fig. 1).

This CO_2 evaluation passes through a homologation procedure according to specific driving cycles, which considers the cold start of the engine. This is a very important specification, because in a typical homologation cycle the engine coolant reaches its thermal steady state very close to the end of the cycle and lubrication oil does not even reach a regime temperature. When these fluids and engine components are below their steady temperature, the thermal efficiency of an ICE is significantly reduced (cold-start phase): combustion quality is poor and mechanical losses are high [6]. Hence, a fast engine warm up decreases the cold phase in the homologation cycle and produces sensible benefits in terms of fuel savings [7,8] and pollutants reduction [9–11].

Most techniques to reduce warm up phase are concerned with "thermal management": this field of interest opens to the opportunity to heat up as fast as possible the metallic components to their stabilized temperatures, instead of waiting that the engine does it "naturally", according to traditional technological solutions.

Engine cooling strategies have recently evolved with the use of electronic components in the cooling system. Electric pumps, thermostats, and fans play major roles in decreasing the losses [12]. The use of switchable pumps reduces parasitic losses from auxiliary components and allows for a better control of the engine temperature achieving the best engine efficiency [13,14]. In the same way, new cooling layouts [15–17] and advanced thermostat [18] were considered. Light metal alloys were also extensively adopted with higher thermal conductivity [19].

Lubricating oil plays an important role in overall engine efficiency: a faster oil warm up would improve mechanical efficiency which is particularly low during homologation cycle when the engine is cold. A decrease in lubricant warm up time, however, is more critical to be reached: oil warm up rate is about three times lower than the coolant one [20] and it does not reach its optimal temperature during a traditional homologation drive cycle [21]. In fact, during the warm up phase, energy balances show that about 50% of the energy causes the engine warm-up, but only 4% is transferred to the lubricant [22–24]. Furthermore, when lubricant is cold, its viscosity is much higher than at regime conditions and so the engine FMEP can be up to 25% higher during the cold phase with respect to the hot stabilized phase [25]. Only recently, the possibility to reduce the warm-up time of the transmission and engine oils have been introduced [26,27] with technological options such as engine

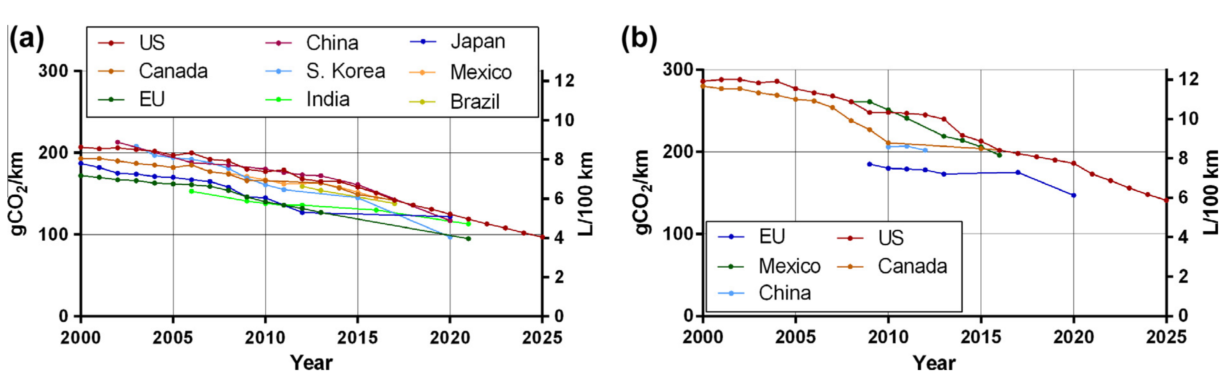

Fig. 1. CO_2 emissions and fuel consumption history and worldwide targets (2013 data [5]) for passenger cars (a) and light commercial vehicles (b).