Applied Thermal Engineering 48 (2012) 18–23

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Transient operation of internal combustion engines with Rankine waste heat recovery systems

Alberto A. Boretti

Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology, Rolla, MO, USA

ARTICLE INFO

Article history:
Received 11 January 2012
Accepted 18 April 2012
Available online 25 April 2012

Keywords:
Rankine cycles
Waste heat recovery systems
Internal combustion engines
Light duty vehicles

ABSTRACT

Prior papers have shown the potentials of gasoline-like internal combustion engines fitted with Rankine cycle systems to deliver Diesel-like steady state fuel conversion efficiencies recovering the exhaust and the coolant waste heat with off-the-shelf components. In addition to the pros of the technology significantly increasing steady state efficiencies – up to 5% in absolute values and much more in relative values – these papers also mentioned the cons of the technology, increased backpressures, increased weight, more complex packaging, more complex control, troublesome transient operation, and finally the cold start issues that prevent the uptake of the technology. This paper further explores the option to use Rankine cycle systems to improve the fuel economy of vehicles under normal driving conditions. A single Rankine cycle system is integrated here with the engine design. A latest turbocharged 1.6 L direct injection engine has the coolant circuit modified to serve as pre-heater for the Rankine cycle fluid. This fluid is then vaporised and superheated in the boiler/superheater coaxial to the exhaust pipe located downstream of the turbocharger turbine and the closed coupled catalytic converter. The exhaust ports are insulated to reduce the heat losses. The pump of the Rankine cycle system is electrically operated. The expander of the Rankine cycle system drives a generator to recharge the traction battery pack. The thermal engine is connected to the transmission through an electric clutch and a motor/generator that permits to supplement/replace the thermal engine energy supply, recover the braking energy and start/stop the thermal engine. The integrated Rankine cycle system is intended to permit short warming-up profiles, reduced heat losses and reduced weight and packaging issues, delivering significant benefits during cold start driving cycles as the NEDC in addition to the long term, constant load and speed extra urban driving.

1. Steady thermal engine results with organic Rankine cycle systems

Prior papers [1–3] have shown the potentials of gasoline-like internal combustion engines fitted with organic Rankine cycle systems to deliver Diesel-like steady state fuel conversion efficiencies recovering the exhaust and the coolant waste heat with off-the-shelf components for what concerns heat exchangers, expanders and pumps. In addition to the pros of the technology significantly increasing the steady state fuel conversion efficiencies – up to 5% in absolute values and much more than that in relative values, being zero the idle fuel conversion efficiency – these papers also mentioned the cons of the technology, increased backpressures, increased weight, more complex packaging, more complex control, troublesome transient operation, and finally the cold start issues, that all prevent the uptake of the technology.

The proposed engine has direct injection, turbo charging with a fixed geometry turbine, charge cooling and variable valve actuation. The main engine parameters are presented in Table 1. The engine has four valves per cylinder and a pent roof combustion chamber with central location of spark plug and direct injector. Fuel is directly injected within the cylinder and the engine is running stoichiometric to lower the emission of pollutants below Euro 4 standards with a Three Way Catalytic (TWC) converter. The piston is modified to run ethanol with an increased compression ratio of 13:1 as well as to better deal with the different fuels spray. The fuel injector is a fast, high pressure fuel injector for gasoline direct injection engines ideal for spray stratified lean combustion applications. The injection pressure from the fast actuating, multiple event high pressure injector is increased from 200 to 300 bar with ethanol. Injection is always performed after Intake Valve Closure (IVC). This has the advantage of injecting into hotter gas which helps to insure complete vaporization of the ethanol and prevents or minimizes wall wetting. The engine has the option to be controlled both by throttle and by reducing the intake valve lift.

E-mail address: a_boretti@yahoo.com.

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doi:10.1016/j.applthermaleng.2012.04.043