Influence of Combustion Condition and Air-Fuel Charge Rotation on Intensity of Heat Transfer in an IC Engine Operating on Gas Fuel

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In the Heat Engineering Chair of Poznan University of Technology, there have been investigations carried out for the last 10 years, of heat transfer processes on the wall of a single action internal combustion engine. Investigations of local heat transfer coefficients were carried out in different combustion conditions and the engine was propelled with a methane-carbon dioxide mixture (65% of CH_4 and 35% of CO_2). There were changes of the timing, the excess air number ($\lambda = 1,05 \div 1,3$), and charge rotation. The authors investigated its influence on intensity of heat transfer in the single action internal combustion engine. The motion of the piston, the surface temperature of the chamber wall and pressure in the combustion chamber were recorded using a digital acquisition system. Then the transient heat flux from combustion gases to the wall was calculated, by solving numerically the unsteady inverse one-dimension heat conduction problem. The authors observed a significant influence of the excess air number, ignition timing and the way of combustion mixture preparation on the process of heat transfer in the combustion chamber. Time dependent plots of heat flux to the wall are presented in fig. 2.

1. Introduction

Thermal load of the combustion chamber of an IC engine is connected directly with a heat flux flowing through the walls surrounding the combustion chamber. Thermal stresses are possible to determine when the temperature field is known and that enables to predict maximum temperatures and maximum temperatures gradients. It is essential to determine a local thermal load and a local heat flux. That issue is important as well in newly constructed IC engines as in well known designs where by optimization of shape it is possible to increase the power of existing engines. The determination of the transient local heat flux still presents topical research issues.

Modern research methods of solving that problem are based on a thin-film surface thermocouple mounted in many places of the combustion chamber. Surface temperatures from many points of the combustion chamber as well as piston motion and pressure inside the combustion chamber are recorded on computer based stands. Thin-film surface thermocouples are possible to buy now but it is still a problem to install it properly and to measure very small signal from it without a noise. The Japanese [2, 3, 4] seem to be pioneers of that kind of research but not only [5, 6].

The most important part of a research stand is a single action IC engine, called in another publications the calorimetric bomb, with moving walls. The motion of the piston towards TDC is obtained by pumping compressed air under the piston. In the work stroke, the piston returns and its motion can be easily controlled. In the stand it is possible to realize spark ignition as well as spontaneous ignition IC. In the stand we can power the engine with different fuels. In recent years we have been interested in gas engines.

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2. Research stand specification

The basic diagram of our research stand is shown in fig. 1. A single action IC engine has a piston of the diameter d = 73 mm and stroke s = 80 mm.

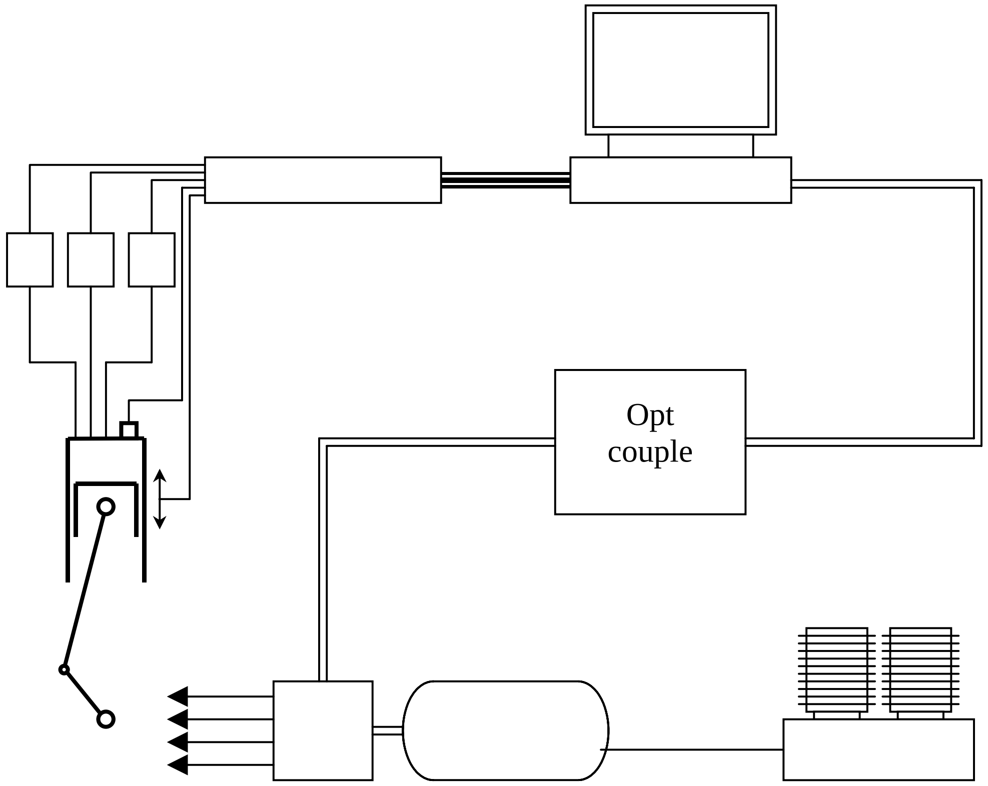

Fig. 1. Diagram of the research stand

The compressor compresses the air to the pressure of 7 MPa. It flows to the compensatory container and then through a system of shut-off valves to the engine. The timing of the shut-off valves is controlled by a computer. It was necessary to add an opt couple between the computer and electro-valves to avoid computer damage.

The signal from three NANMAC thin-film surface thermocouples is amplified in a self-made amplifier and transferred to the IOTech ADC 488/8SA data acquisition system. The pressure in the combustion chamber is measured by the KISTLER system and as a fourth channel transferred to the ADC 488/8SA. A potentiometer system is used to record the motion of a piston.

The data acquisition system is controlled by a LabVIEW self-written application. The ADC 488/8SA data acquisition system samples simultaneously 5 channels at 16-bit resolution and 10 kHz rate. With its 4 MB of memory it can record about 25 s of measurements without the need of transferring data to a HDD.

The data acquisition system can co-work not only with our single action model IC engine. We are planning to measure heat transfer on a real gas engine of HCP (Hipolit Cegielski Poznan) production. A 600 kW gas engine was constructed and built in the HCP factory under research surveillance of Professor Cupiał's team from the Technical University of Częstochowa.

3. Aim of the research

Many different investigations were carried using the described above research stand. In early 90's, burning of carbon oil in a spontaneous ignition IC engine was investigated. Then behavior of rape oil (ecological fuel) as a fuel to a spontaneous ignition IC engine was observed. Since 1995 we have been investigating gas fuels. Wielkopolska, the region where we live, is rich with natural gas. Unfortunately, it is not pure methane but it is a mixture with nitrogen where nitrogen share reaches 35 %. That gas is not easy to burn. In our chair, we constructed and investigated special burners for that gas which produced a very small amount of NO_x in exhaust fumes. Now that gas is in common use in household. Investigations on a single action IC engine with that gas had to answer if it was possible to burn it in gas engines.

Gases obtained out of sewage recycling or from modern rubbish landfill called biogas are also rich with methane but with an essential addition of carbon dioxide, and they are used as fuel in gas engines. Gas engines seem to be the future of IC engines because liquid fuels will run low in 50 years.

4. Description of the research

A methane - carbon dioxide mixture was burned during the investigations. The proportion of ingredients varied, but mostly it was 65% of methane and 35% of carbon dioxide mixture. It is a typical composition of biogas. Biogas (65% CH_4 and 35% CO_2) was fulfilled with air in various amounts. Combustion with a different excess air number λ was obtained by changing the amount of air. The combustion was realized in many ways. The flammable mixture before ignition could be immobile or could swirl. Two-phase ignition was tested as well. Ignition started in rich in the fuel zone and spread to poor in the fuel zone.

The timing of ignition was changed in broad limits. Early ignition caused combustion with high maximum pressure but with small work of thermodynamics circulation. The indicator diagrams includes then a negative loop and circulations work is close to zero or not to say negative. On the contrary, ignition delay caused reduction of maximum pressure and an increase of circulations work. When the delay of ignition was big enough the charge was non-flammable.

5. Research results

Hypothetical curves of transient heat flux to wall of single action IC gas engine are shown in fig. 2, while table 1 presents collected maximum heat fluxes for combustion of a 65 % CH_4 and 35 % CO_2 mixture for different excess air numbers λ and different timing of ignition. The results are both for charge swirled or in standstill before ignition. Full research results are published in [1]. Below, the most essential conclusions are presented.

1. The combustion with swirled charge takes place with more intense heat exchange than the combustion of standstill charge. The heat flux measured when the charge was swirled was on average twice larger than the heat flux of the combustion of the standstill charge.

2. The authors found a significant influence of the excess air number λ on heat exchange. Combustion of mixtures rich in fuel causes more intense heat exchange. Comparing the combustion of an almost stoichiometric mixture ($\lambda = 1.05$) with the combustion of a hardly flammable mixture ($\lambda = 1.3$) we noticed that the heat flux linearly falls down with an increase of the excess air number λ and for the richest mixtures is 1.8 times bigger than for the poorest mixtures.

3. It is significant that ignition timing influences heat exchange. Ignition acceleration intensifies heat exchange. In our experiments, ignition time was changed from 46 ms to 54 ms and even in those narrow limits the heat flux for fast ignition was 1.6 times bigger than the heat flux for slow ignition.

4. The combination of the three above mentioned significant factors causes great dynamics of the heat transfer process. The biggest measured heat flux was nearly 10 times bigger than the smallest one.

5. The curve shape of the temporary heat flux for all the observations was very similar.

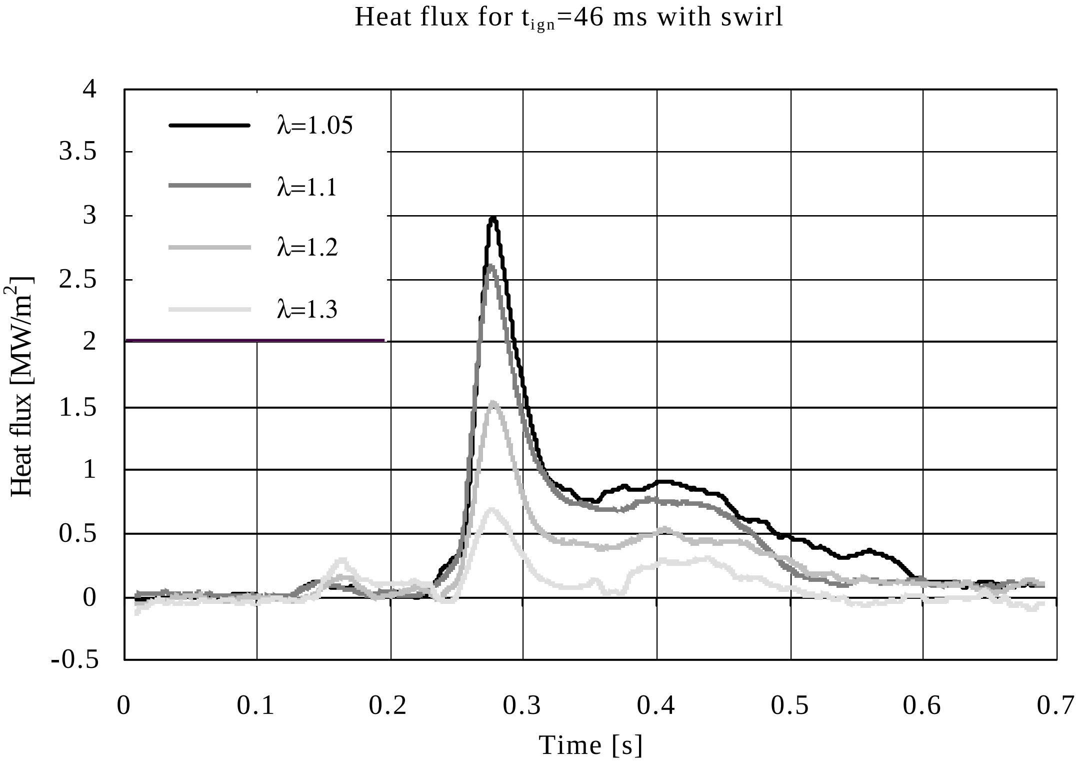

Fig. 2. Hypothetical curves of the transient heat flux to the wall of a single action IC gas engine.

Table 1

Maximum heat flux [MW/m^2]

	with swirl				without swirl			
	λ=1.05	λ=1.1	λ=1.2	λ=1.3	λ=1.05	λ=1.1	λ=1.2	λ=1.3
t_{ign}=46 ms	2.98	2.57	1.52	0.71	1.83	1.44	0.80	0.48
t_{ign}=50 ms	2.07	1.82	1.06	0.55	1.43	1.02	0.56	0.41
t_{ign}=54 ms	1.17	0.99	0.71	0.37	0.79	0.60	0.51	0.32

References

1. Pientka J, Rabiega J, Kuczyk J.: Raport z badań grantu pt. „Procesy termodynamiczne w silniku spalinowym przy zastosowaniu niekonwencjonalnych paliw” Poznań 1994.
2. Enomoto Y., Furuhama S., Takai I, Heat Transfer on the Ceramic Combustion Chamber Wall of Diesel Engine, CIMAC ’87, Warszawa, 0-33.
3. Enomoto Y., Furuhama S., Study on Thin Tilm Termocouple for Measuring Instanteneous Temperatures on Surface of Combustion Chamber Wall in Internal Combustion Engine, Part I, Bulletin of ISME, Vol.28, No.235, January 1985.

4. Enomoto Y., Furuhama S., Study on Thin Tilm Termocouple for Measuring Instanteneous Temperatures on Surface of Combustion Chamber Wall in Internal Combustion Engine, Part II, Bulletin of ISME, Vol.29, No.256, October 1985.
5. Singh V.P., Upadhyay P.C., Samria N.K, Some heat transfer studies on diesel engine piston, Int. J. Heat Mass Transfer, Vol 29, No.5, May 1986.
6. Alkidas A.C., Cole R.M., Transient Heat Flux Measurements in Divided-Chamber Diesel Engine, Journal of Heat Transfer, Transaction ASME Vol.107, No 2, May 1985.