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# THE MODELLING OF HEAT EXCHANGE BETWEEN THE PISTON-RINGS-CYLINDER ASSEMBLY ELEMENTS

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**Summary.** This paper presents problems of the modelling of heat exchange between the piston-rings-cylinder bearing surface assembly (PRC) elements as well as results of simulation tests. Difficulties and hindrances have been showed, which occur during the development of the mathematical and physical model.

**Key words:** blow-by, combustion engines, piston, piston rings, cylinder

## INTRODUCTION

When modelling the problems connected with the operation of piston ring pack (piston packing compression rings in particular) as a sealing unit, the effect of thermal deformations of all elements composing the piston-piston rings-cylinder liner (PRC) assembly should also be taken into account. Obviously, the PRC assembly is subjected to regular variable heat loads during the operation of piston combustion engine. A heat source is the combustion process taking place in the total cylinder volume but also the phenomenon of friction occurring mainly between piston rings and the cylinder bearing surface. However, determination of the effect of friction degree and reciprocal movement of these elements as a phenomenon of heat source is very difficult to be defined in modelling processes and hence is completely ignored in theoretical considerations. On the other hand, problems connected with heat loads in the PRC elements and heat flow to the cooling medium come into prominence. Trends in the construction of piston combustion engines are focused on constant reduction of ring number, which leads to the development of larger heat loads in these elements. At present, constructions with one piston packing compression ring and one piston scraper oil control ring are being used in the newest combustion engines, while research and work aim at only one ring linking the sealing and scraping functions. In the modelling of heat exchange, occurrence of respective inter-ring crevices spaces is being assumed, where it comes to heat exchange between the medium being found in those crevices spaces and the elements of piston, ring and cylinder bearing surface and further to the cooling medium. Also the layer of lubricating oil being found between these elements, the temperature of which depends on the temperature of PRC assembly elements, is of importance [Abramek 2007]. The crevice space of the first piston packing compression ring, where it frequently comes to the formation of carbon deposits and the occurrence of lake tar as well as to the combustion of lubricating oil, takes on a particular importance [Abramek 2005, Serdecki 2002].

## MATHEMATICAL MODELS OF HEAT EXCHANGE

In mathematical models of heat exchange, the authors assume in most cases that the temperature of walls delimiting a given space is identical with that of the flowing medium. This means the isothermic flow, i.e. the occurrence of infinitely large surface film conductance $\alpha_p$. As mentioned previously, piston, piston rings and cylinder are exposed to a direct effect of hot gas, the temperature of which fluctuates broadly during the work cycle. According to the literature [Wiśniewski 1972], a change in the temperature of combustion chamber wall surface is not larger than 1% of periodic working medium temperature changes. This results from a relatively large engine rotational speed. It also results from this assumption that both the piston, piston rings and cylinder liner temperature is constant for engine steady-state conditions. Methods of the determination of temperatures for respective elements have also been described in the literature [Kozaczewski 2004, Wiśniewski 1972, Miksiewicz and Wiśniewski 1999]. Nevertheless, some authors (like [Sygniewicz 1991]) assume that the flow of blown-by exhaust gases between piston, piston rings and cylinder liner is intermediate between the isothermic and the adiabatic flow, and even closer to the adiabatic one. This means that the stream of heat exchange between the flowing gas and the PRC assembly elements is equal to zero. In principle, it is difficult – without simulation tests – to evaluate the rightness of the adopted assumptions. Assumptions of the heat exchange model have after all a significant effect on the evaluation of PRC system sealing degree and the same on the value of crankcase exhaust gas scavenging intensity.

When assuming that heat exchange between the PRC assembly elements is mainly by convection [Kaźmierczak 2005], the Newton's equation is determining the quantity of heat exchanged by penetration:

$$Q = \alpha_p A \tau (T_1 - T_2), \tag{1}$$

where:
$\alpha_p$ – surface film conductance,
$A$ – heat penetration surface,
$T_1$ – flowing medium temperature,
$T_2$ – surface temperature,
$\tau$ – penetration time.

Surface film conductance $\alpha_p$ depends on the physical properties of heat-carrying agent heat-transfer medium, which can be the accumulating carbon deposit or combusted lubricating oil for the first piston packing compression ring or the lubricating oil for other piston rings. Surface film conductance depends also on the geometric features of penetration surface, being different for piston, piston rings and cylinder liner. The value $\alpha_p$ is expressed by means of the following formula:

$$\alpha_p = Nu \frac{\lambda_m}{d_h}, \tag{2}$$

where:
$Nu$ –Nusselt's number:

$$Nu = C(Pr^A Re^E), \tag{3}$$

$\lambda_{rc}$ – heat conductivity of heat-carrying agent,
$d_h$ – hydraulic diameter; a computable value expressing the relation of heat exchange surface to its circumference,
$C$ – factor of proportionality, determined empirically,
$A, B$ – index exponents, determined empirically,
$Pr$ – Prandtl number:

$$Pr = \frac{c_p \eta}{\lambda}, \tag{4}$$

$c_p$ – specific heat of medium,
$\eta$ – absolute viscosity of medium,
$Re$ – Reynolds number:

$$Re = \frac{\dot{m}\, d_h}{\eta}, \tag{5}$$

$\dot{m}$ – mass rate of flow.

In the literature [Woschni 1970], an empirical dependence has been given describing surface film conductance in the combustion chamber of piston combustion engine, which is as follows:

$$a_p(\varphi_i) = 127{,}93 D^{-0{,}217} w^{0{,}786} p(\varphi_i)^{0{,}786} T(\varphi_i)^{-0{,}525}. \tag{6}$$

$D$ – cylinder diameter,
$w$ – mean velocity of medium in the engine working space,
$p(\varphi_i)$ – actual values of pressure in the engine working space,
$T(\varphi_i)$ – actual values of medium's temperature,
$\varphi_i$ – crank angle value.

## RESULTS OF SIMULATION TESTS

In the simulation modelling, the principle of energy conservation was used to determine the thermophysical properties of the medium flowing between the assigned zones:

$$\dot{U} = \Sigma_i i_{c_{In_i}} \dot{m}_{In_i} - \Sigma_j i_{c_{Out_j}} \dot{m}_{Out_j} + \dot{Q} - p\dot{V}, \tag{7}$$

as well as the law of conservation of mass was taken into account:

$$\dot{m} = \Sigma_i \dot{m}_{In_i} - \Sigma_j \dot{m}_{Out_j}. \tag{8}$$

Clapeyron's ideal gas state equation:

$$\dot{p} = p\left(\frac{\dot{m}}{m} + \frac{\dot{T}}{T} - \frac{\dot{V}}{V}\right), \tag{9}$$

where:
$U$ – internal energy,
$i_c$ – specific gas enthalpy,
$\dot{Q}$ – heat exchange stream, for the heat exchanged between medium and labyrinth zone walls,

$m$ – mass of gas,
$p$ – pressure of gas,
indices: $In$ – gas inflow,
$Out$ – gas outflow,
$i$ – inlet channel number,
$j$ – outlet channel number.

The analysed volume zones are connected with each other by channels of variable sections through piston-ring joints and gaps between piston grooves and piston rings, as well as through clearances between piston ring face and cylinder bearing surface. These channels cause throttling of the flowing medium and the modelled changes in their sections result from changes in the value of piston-ring joint clearance as a consequence of piston ring movements in the radial direction. A change in the section of piston-ring joint is also connected with the effect of wear of such elements as cylinder liner, piston rings and piston grooves. On the other hand, a change in the gap between piston rings and piston grooves results from piston movements and piston ring movements in the axial direction.

The model calculations were made for the single-cylinder compression-ignition engine SB-3.1. The data necessary for calculations were collected based on technical documentation, taking into account the fact that the SB-3.1 engine is a section of one cylinder of the SW-680 engine. Technical and geometric properties of the engines can be also found in the literature [Abramek 2005]. On the other hand, the courses of pressures prevailing in the combustion chamber were taken from the indicative diagrams made on the engine test bed.

In this model, different intensity of the heat exchange between gas and walls was adopted, i.e. the isothermic flow where surface film conductance is infinitely large, the adiabatic flow where the heat exchange stream between medium and labyrinth zone walls is equal to zero ($\dot{Q} = 0$), and the intermediate flow determined on the basis of equation (6). Examinations were made for four rotational speeds of engine crankshaft $n_1 = 1000$ min$^{-1}$, $n_2 = 1500$ min$^{-1}$, $n_3 = 1750$ min$^{-1}$ and $n_4 = 2000$ min$^{-1}$. Figure 1 presents simulation tests of the effect of surface film conductance on the value of crankcase exhaust gas scavenging of the SB-3.1 engine.

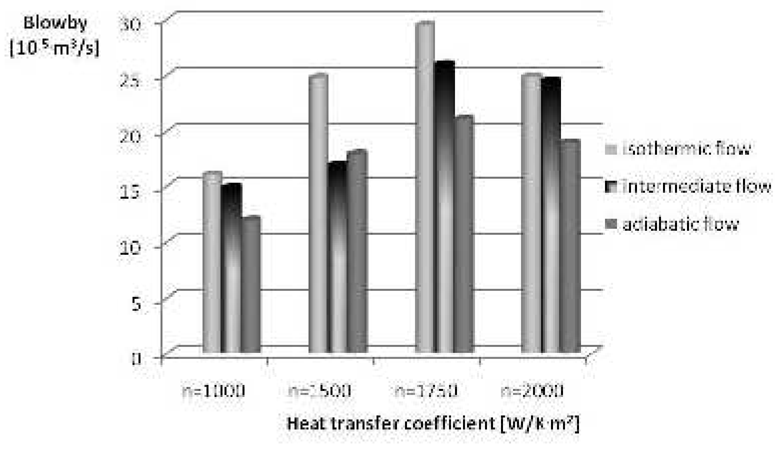


Fig. 1. The effect of surface film conductance on the values of crankcase exhaust gas scavenging determined in simulation tests of the SB-3.1 engine

Figure 2 presents the effect of the course of temperature for the first inter-ring crevice for different adopted intensities of the heat exchange between medium and the surfaces surrounding it.

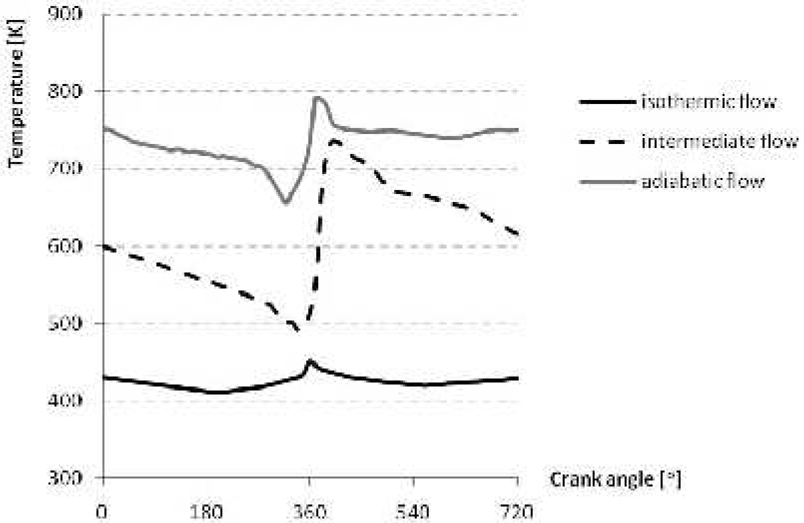


Fig. 2. The course of temperature determine in simulation tests for the first inter-ring crevice

## CONCLUSIONS

When analysing the obtained results of simulation tests, it is possible to notice that the intensity of heat exchange between gas and the walls surrounding it at respective stages [degrees] of labyrinth sealing had a fundamental effect on the results of not only crankcase [crankshaft casing] exhaust gas scavenging intensity but also gas temperatures. The larger heat exchange intensity, the smaller were the mean temperatures in the thermodynamical cycle. It should be stated that the value of surface film conductance calculated and adopted from the literature has had a very large effect on the results of examinations of the temperatures in inter-ring crevices.

The course of temperature for the volume determined between the first and the second piston ring differ remarkable for the adopted intensity of heat exchange. It is possible to notice that mean temperatures in the cycle were much smaller for large intensity of heat exchange than those calculated for small intensity of heat exchange (Fig. 2).

When analysing the obtained results, it is also possible to notice that the temperature of medium is more susceptible to the value of surface film conductance adopted in the model than the value of exhaust gas scavenging. For infinitely large surface film conductance (isothermic flow), the value of exhaust gas scavenging was by 45% larger than for exhaust gas scavenging calculated for the adiabatic flow of medium (Fig. 1).

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## MODELOWANIE WYMIANY CIEPŁA POMIĘDZY ELEMENTAMI ZESPOŁU TŁOK-PIERŚCIENIE-CYLINDER

**Streszczenie.** W artykule przedstawiono zagadnienia modelowania wymiany ciepła pomiędzy elementami układu tłok-pierścienie tłokowe-gładź cylindra (TPC) oraz wyniki badań symulacyjnych. Wskazano na trudności i utrudnienia występujące podczas tworzenia modelu matematycznego i fizycznego.

**Słowa kluczowe:** przedmuchy, silnik spalinowy, tłok, pierścienie, cylinder