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A new conception of two-stroke engine with closed cycle

Abstract: Applying of a closed work cycle in the piston engine leads usually to delivering of heat to working medium through a heat exchanger (Stirling engine). The heat may get from any type of fuel in an external combustion chamber, which allows on precisely control of combustion process. The paper describes a new conception of two-stroke engine with working medium being in the close system, the best with the perfect gas as argon or helium. The engine has the conventional crank-piston system and an inlet and outlet valves placed in the cylinder head. The delivering process of working medium with high temperature from the heat exchanger takes place through the inlet valve during a few dozen degrees of CA rotation in piston position at TDC. Expansion stroke takes place until outlet valve opens shortly BBDC. The outlet period from the cylinder follows almost at constant pressure and at low temperature to an adiabatic chamber, from where the working medium is compressed by an adiabatic compressor to pressure near pressure being in the heat exchanger. The engine works in two-stroke cycle and enables to get low temperature and pressure as early as BDC through a long time of opening of the outlet valve. The paper presents the ideological scheme of the engine system and theoretical thermal cycle. On this basis one presents the mathematical description of the individual thermodynamic processes with determination of thermal parameters of the characteristic points of the cycle with taking into account of work of the compressor and amount of delivering heat to the exchanger. This article determines also the thermal efficiency of such closed cycle. The presented engine may have a practical applying as a stationary engine in energetic systems, where as fuel may be biomass, which globally influences on decreasing of CO_2 and NOx by temperature control of the combustion process.

Keywords: *transport, combustion engine, thermal cycles, closed system*

Nowa koncepcja silnika dwusuwowego w obiegu zamkniętym

Streszczenie: Zastosowanie zamkniętego obiegu pracy w silniku tłokowym prowadzi zwykle do dostarczenia ciepła do czynnika roboczego poprzez wymiennik ciepła (silnik Stirlinga). Ciepło można uzyskać z dowolnego paliwa w zewnętrznej komorze spalania, co pozwala na dokładniejszą kontrolę procesu spalania. Artykuł opisuje nową koncepcję silnika dwusuwowego z czynnikiem roboczym będącym w układzie zamkniętym, najlepiej gazem doskonałym takim, jak hel czy argon. Silnik ma konwencjonalny układ korbowo-tłokowy oraz zawór dolotowy oraz zawór wylotowy umieszczone w głowicy. Proces dostarczenia czynnika gazowego o wysokiej temperaturze z wymiennika ciepła zachodzi przez zawór dolotowy przez kilkadziesiąt stopni OWK przy położeniu tłoka w GMP. Proces rozprężania odbywa się się do czasu otwarcia zaworu wylotowego krótko przed DMP. Okres wylotu gazu z cylindra następuje prawie przy stałym ciśnieniu i niskiej temperaturze do adiabatycznego zbiornika, skąd czynnik roboczy jest sprężany przez sprężarkę adiabatyczną do ciśnienia panującego w wymienniku ciepła. Silnik pracuje w cyklu dwusuwowym i zapewnia uzyskanie niskiej temperatury oraz ciśnienia począwszy od DMP przez długi czas otwarcia zaworu wylotowego. Artykuł przedstawia schemat ideowy układu oraz teoretyczny obieg cieplny. Na tej podstawie przedstawiono opis matematyczny poszczególnych przemian termodynamicznych z określeniem parametrów termicznych charakterystycznych punktów obiegu z uwzględnieniem pracy wykonanej przez sprężarkę oraz dostarczonego ciepła w wymienniku. W pracy określono również sprawność cieplną takiego obiegu. Przedstawiony silnik może mieć praktyczne zastosowanie jako silnik stacjonarny w układach energetycznych, gdzie paliwem może być biomasa, co globalnie wpływa na zmniejszenie emisji CO_2 oraz NOx przez kontrolowanie temperatury procesu spalania.

Słowa kluczowe: *transport, silnik spalinowy, obiegi cieplne, układ zamknięty*

1. Introduction

In energetic sector the combustion of biomass fuel is increasingly important, because of decreasing of fossil fuel and environmental requirements with respect to harmful components of exhaust gases. In such cases direct combustion of biomass in internal combustion engines is not possible. Only gasification of the biomass is widely used for obtaining of gaseous fuel or applying the fluidization of the biomass by using Fischer-Tropsch method [2]. This method enables obtaining both gasoline or diesel oil fuels. However this technology requires big financial sources and very complicated chemical reactors, which is considered in whole world, also in Poland in respect to fluidization and gasification of coal. In small energetic sectors, small factories or for the energy needs of small population centers it is only possible way to used directly the biomass in thermal machines for production of the heat and electric power. Usage of biomass and alternative fuels is widely described in literature [7, 9].

There are many possibilities of driving systems in electric and heat generation, such as gas turbines, water turbines, steam turbine, internal and external combustion engines or numerous non-conventional driving systems. In transport sector more popular are hybrid driving systems [3, 13]. All of them have possibilities to use the biomass or fossil fuels in combustion process. The gas, steam and water turbines required high technology [11] and are very expensive and for local electric power generation are not possible to apply them. Direct combustion of biomass is possible in the boilers, which can be external source of heat for feeding both turbines and reciprocating engines. Particularly the applying of piston engines is very promising, because of their common application in the transport sector and industry sector. There is known many thermal machines including the piston engines with external combustion chamber.

The engines with external combustion chamber particularly are designated for stationary application such electric power generation, industry and agriculture works. Because of environmental protection in respect to exhaust gas emission utilization of the biomass is highly recommended. Formation of CO_2 during combustion process in the boiler is consumed by the plants in the process of photosynthesis and we have the close cycle of CO_2 production. On the other hand the combustion process in the boiler takes place at lower temperature and this is a reason that formation of NOx is at lower level. Therefore the biomass combustion in the boiler for heat production is economic and ecologic and does not require so much investment in building the systems including the piston engines as driving units for the electric generators. Taking into account all this requirements and environmental protection the author presents a new idea of the piston two-stroke engines with external combustion chamber working at low temperature for different application.

2. Requirements of piston engine working in closed cycle

There are known several thermal machines working in closed cycle with external combustion chamber designed for industry applications such Stirling engine or Ericsson engine [6]. The first uses the cooler- regenerator-heater system for transfer the heat from "hot" cylinder to "cold" cylinder in order to change the heat on mechanical work. This engine has two cylinders with special crank mechanism uses the heat deriving from combustion or ambient heat. There are many types of Stirling engines described by Zmudzki [14] and applied also in submarine boats or electric power generators in big farms. The second case with the Ericsson engine concerns also to heat exchange between two cylinders, where delivering of the heat follows during expansion process at constant temperature. Outflow of gas to the second cylinder takes place also at constant temperature during compression process. Both systems work in the closed cycle without gas exchange with the atmosphere or ambient medium and may use the noble gases such as helium, argon, krypton, xenon or radon and also the air. Each theoretical thermal cycle of the engine should be near the Carnot cycle with high thermal efficiency. In order to maintain the fixed thermodynamic parameters the best solution is to apply a noble gas with high and constant heat ratio coefficient. The ideal gas used in the engine with closed cycle enables working in adiabatic conditions.

From mechanical point of view the engine working in two-stroke mode in comparison to four-stroke engine is the best solution enabling to obtain higher indicated mean pressure (*imep*) and smooth working of the engine. The temperature of the gas delivering from the boiler to the engine should not be so high in respect to resistance of materials used in the boiler and engine. Thus the engine should work at low temperature below 1100 K. In respect to thermodynamic efficiency the temperature difference should be big between high and low heat sources. In such case the flowing out gas from the cylinder to the boiler containing the heat exchanger has to be cooled in order to obtain lower temperature during gas outflow. It can be done by water injection directly in the cylinder or by cooling the flowing gas in a special chamber by cold water flown in the coil pipe. The gas in the heat exchanger of the boiler is at high pressure and takes the heat from combustion process of the biomass. The whole engine system emits the same harmful components as in the conventional engines fuelled by fossil fuels, but with CO_2 being consumed by nature and lower NO_x content.

3. Design of two-stroke engine with external combustion chamber

In order to obtain high thermal efficiency the thermal engine cycle in p-V system should be near rectangular form. The proposed design of the two-stroke engine includes both inlet and outlet valves locating in the cylinder head. Working of conventional two-stroke engine is detailed described in literature [1, 5],The inlet valve opens the flow of the hot gases from the boiler to the cylinder and the outlet valve opens the gas flow from the cylinder do the external chamber with constant pressure. The biomass is burnt in the boiler and the released heat Q_1 is delivered by convection and conductivity to the gas in the coin pipes. The boiler works at constant (ambient) pressure and temperature. Temperature of combustion should be controlled and it should not exceed the creep temperature of the used materials. The mass of inflow and outflow gases in the closed cycle is the same. The inlet valves are opened shortly BTDC (several CA degree) in order to equal the pressure inside the cylinder after compression process. The hot gases are delivered to the cylinder through the inlet valves. The filling process with the gas lasts tens CA degrees and can be assumed that takes place partly at constant volume and constant pressure. The greater part of filling process occurs when pressure inside the cylinder and in the boiler is the same.

The diagram of two-stroke engine with external combustion chamber working in closed cycle is shown in Fig. 1. The black thick line shows the gas flow in the system. The final temperature of the charge in the cylinder after closing of inlet valves is lower than temperature in the heat exchanger. The real expansion process lasts until the outlet valves begin to open. Opening of the outlet valve is over a dozen CA degrees BBDC.

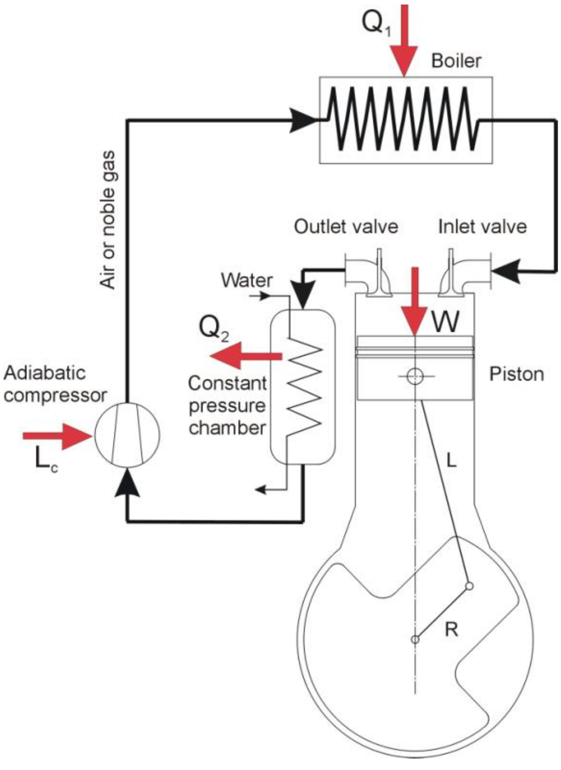

Fig. 1. Diagram of two-stroke external combustion engine

Next the gas flows through the outlet valves to the chamber with constant pressure during motion of the piston in direction of TDC. The gas outflow is caused mainly by pressure difference between the cylinder and the chamber. Because of constant pressure inside the chamber one can say that greater part of the gas outflow takes place at constant pressure with small change of gas temperature in the cylinder. For practical point of view one can apply the poppet valves or rotational valve, which can be driven from the crankshaft. A proposal of engine design with rotational valves is shown in Fig. 2. The valves have longitudinal holes, which are opened and closed by the housing walls. Filling and emptying of the cylinder from the charge is depended on valve timing. Determination of the initial values of valve’s opening and closing angles may be obtained from the computer simulation of thermodynamic engine cycle with taking into account the charge exchange [4, 10].

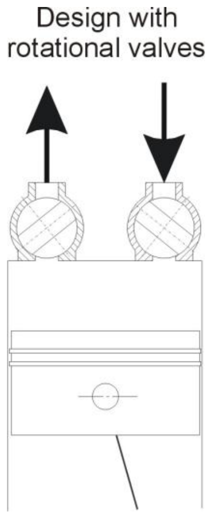

Fig. 2. Engine with rotational valves

The gas in the chamber is cooled by water in order to decrease the temperature. In such case amount of heat Q_2 is consumed by the water and may be used for heating any device (for example house). Before delivering of the cold gas to the heat exchanger of the boiler it is compressed adiabatically in the piston compressor, which may be driven from the crankshaft. There is needed external power for driving of the compressor defined as L_c (Fig. 1). From the compressor the gas under assumed pressure flows into the heat exchanger in the boiler. The thermal efficiency of the boiler is high, because of constant parameters of the combustion process [10] and takes place at adiabatic conditions. For today’s gas boilers thermal efficiency reaches value almost 92%. Because of lower temperature of the gas delivered to the cylinder there is low heat transfer to the walls and such engine may be treated as adiabatic engine. Such solution enables obtaining a high thermal work in comparison to known thermal cycles of piston internal combustion engines. This new conception of two-stroke external combustion engine is proposed for local energetic sector in order to use the biomass instead of fossil fuels with high thermal efficiency.

Valve timing of this engine is shown in Fig. 3. Compression process and heat delivering take place in very short period. In order to prevent escaping of the gas into the inlet pipe at the beginning of valve opening, the cylinder pressure at the end of compression should be lower than in the inlet pipe.

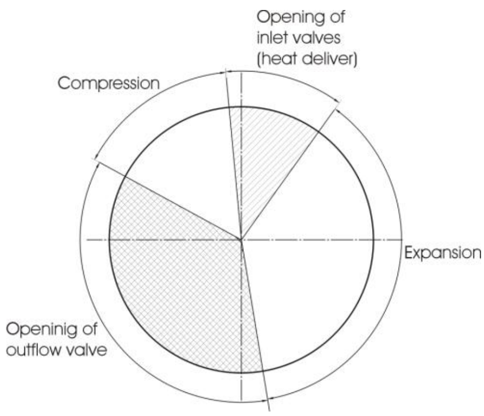

Fig. 3. Phases of engine work

4. Engine thermal cycle

Thermal closed cycle of the two-stroke external combustion engine is presented in Fig. 4. Heat delivering takes place in two thermodynamic processes: isochoric with quantity Q_{d1} and isobaric with quantity Q_{d2}. The main part of the delivering heat occurs in isobaric process. During inflow process temperature of the gas inside the cylinder increases from value T_3 to mean value T_5. Expansion process in the engine occurs from point 5 to point 6 and for the ideal gas the polytrophic expansion coefficient is equal constant adiabatic coefficient $m=k$, where k is specific heat coefficient ratio [8, 12]. Temperature T_6 and pressure p_6 depends on volume V_5, temperature T_5 and pressure p_5.

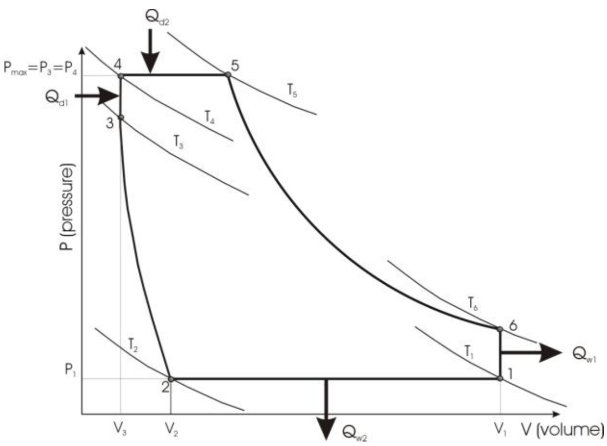

Fig. 4. Theoretical cycle of two-stroke external combustion engine

Outflow of the gases at low temperature begins at point 6 and the first period takes place at constant volume during over a dosen of CA degrees to point 1. The proper gas outflow begins from BDC, while the pressure inside the cylinder changes with small value and this period may be defined as isobaric process. Pressure at point 2 is equal to pressure in the chamber behind the outlet pipe. Because of long outflow time temperature of the gas is very low despite there is any scavenging period as in the classic engines. Next the residual gas with mass m_2 is compressed by the piston motion in the TDC direction. The compression period is treated as isentropic process at constant specific heats ratio k.

Each thermal cycle of working machine may be presented in temperature-entropy *T-s* system. Such cycle of the new external combustion two-stroke engine is shown in Fig. 5. The cycle has six processes: the divided inflow process (deliver of heat), the divided outflow process, expansion and compression processes, which may be presented as isentropic processes.

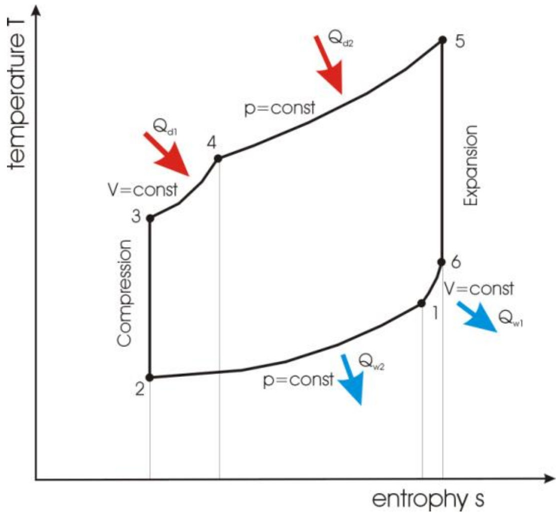

Fig. 5. Engine cycle in T-s system

The thermal cycle of the engine is closed to Carnot cycle, however in the Carnot cycle delivering of the heat follows at constant temperature. In the considered engine the heat is delivered shortly at constant volume and mostly at constant pressure close to pressure in the boiler's heat exchanger. Main mass of the gas first is cooled in the external chamber and next is compressed by adiabatic compressor and is pumped to the boiler. Theoretically the heat delivered to the gas Q_d by convection and conductivity in the boiler is equal the heat delivered to the cylinder during inlet process.

5. Mathematical model of engine cycle

Mathematical model of theoretical engine cycle enables elaboration of computer program for simulation of engine parameters. The accurate model requires determination of inflow and outflow phenomena with variation of gas flow through the valves. Theoretical consideration enables a rough determination of temperature and pressure in the defined points of the cycle.

Compression ratio is defined as ratio of maximal volume $V_1=V_6$ and minimum engine volume $V_3=V_4$ and takes form as follows:

$$\varepsilon = \frac{V_1}{V_3} \quad (1)$$

For ideal gases the specific heat ratio k is defined by formula:

$$k = \frac{c_p}{c_v} = \frac{c_v + R}{c_v} \quad (2)$$

where:

c_p - specific heat at constant pressure,

c_v - specific heat at constant volume,

R - individual gas constant.

Each specific heat is determined as a function of k and individual gas constant R:

$$c_v = \frac{R}{k-1} \quad (3)$$

$$c_p = \frac{k}{k-1}R \quad (4)$$

The mass of residual gas stayed in the cylinder after outflow process is determined from the gas state formula and amounts:

$$m_2 = \frac{p_2 V_2}{RT_2} = \frac{p_1 V_2}{RT_2} \quad (5)$$

Pressure in the point 2 is equal pressure p_{ch} in the chamber. The final pressure p_3 of the compression process is determined from the formula:

$$p_3 = p_2 \left(\frac{V_2}{V_3} \right)^k \quad (6)$$

and temperature of this point may be presented in two forms:

$$T_3 = T_2 \left(\frac{V_2}{V_3} \right)^{k-1} \qquad T_3 = T_2 \left(\frac{p_3}{p_2} \right)^{\frac{k-1}{k}} \quad (7)$$

Pressure in the point 4 is equal pressure in the heat exchanger of the boiler p_b. The following parameters in the points 3 and 4 have the same value:

$$V_4 = V_3 \quad (8)$$

$$p_4 = p_b \quad (9)$$

The heat delivered to the cylinder in the first period at constant volume is defined as follows:

$$Q_{d1} = m_{d1} c_p T_b = m_{d1} \frac{k}{k-1} RT_b \quad (10)$$

where:

m_{d1} - the mass entered during this period,

T_b - gas temperature in the heat exchanger.

Mass of the gas at point 4 amounts:

$$m_4 = m_2 + m_{d1} \quad (11)$$

On the other hand the energy balance in point 4 takes form:

$$(m_2 + m_{d1}) c_v T_4 - m_2 c_v T_3 = Q_{d1} \quad (12)$$

From eq (12) gas temperature in point 4 is determined in the following way:

$$T_4 = \frac{m_{d1} c_p T_b + m_2 c_v T_3}{(m_{d1} + m_2) c_v} = \frac{m_{d1} k T_b + m_2 T_3}{m_{d1} + m_2} \quad (13)$$

The heat delivered during main period of the inlet process may be performed by the formula:

$$Q_{d2} = m_{d2} c_p T_b = m_{d2} \frac{k}{k-1} RT_b \quad (14)$$

Total delivered heat amounts:

$$Q_d = Q_{d1} + Q_{d2} \quad (15)$$

and total mass of gas amounts:

$$m_d = m_{d1} + m_{d2} \quad (16)$$

At assumption that heat delivered to the cylinder and the boiler are equal the following expression is true:

$$Q_d = m_d c_p T_b = \frac{k}{k-1} m_d RT_b \quad (17)$$

The gas mass in the point 5 amounts:

$$m_5 = m_2 + m_d \quad (18)$$

The final parameters at point 5 may be determined from energy balance:

$$m_5 c_v T_5 = m_2 c_v T_3 + Q_d \quad (19)$$

$$m_5 c_v T_5 = m_2 c_v T_3 + \frac{k}{k-1} m_d RT_b \quad (20)$$

In such way temperature in the point 5 is:

$$T_5 = \frac{m_2}{m_5} T_3 + \frac{k}{k-1} \frac{m_d}{m_5} \frac{R}{c_v} T_b = \frac{m_2}{m_5} T_3 + k \frac{m_d}{m_5} T_b \quad (21)$$

Pressure in the points 4 and 5 theoretically are equal to pressure in the heat exchanger:

$$p_5 = p_4 = p_b \tag{22}$$

The gas state equation can be written as follows:

$$p_4 V_5 = (m_d + m_2) R T_5 = m_5 R T_5 \tag{23}$$

From eq. (23) temperature in the point 5 amounts:

$$T_5 = \frac{p_b V_5}{m_5 R} \tag{24}$$

The delivered mass m_d during inlet process is defined from gas state equations in the points 3 and 5:

$$m_d = \frac{p_b V_5}{k R T_b} - \frac{m_2}{k} \frac{T_3}{T_b} \tag{25}$$

Pressure and temperature of final point of compression process is determined by formulas:

$$p_6 = p_5 \left(\frac{V_5}{V_6} \right)^k = p_5 \left(\frac{V_5}{V_1} \right)^k \tag{26}$$

$$T_6 = T_5 \left(\frac{p_6}{p_5} \right)^{\frac{k-1}{k}} \tag{27}$$

It is required an assumption of certain equal parameters:

$$V_6 = V_1 \quad m_6 = m_5 \qquad p_1 = p_{ch} \tag{28}$$

Internal energy at final point of expansion is determined as follows:

$$Q_6 = m_6 c_v T_6 = m_6 \frac{R}{k-1} T_6 \tag{29}$$

The outflow process of gas from the cylinder is much more complicated. It requires knowledge of mean mass flow rate and mean outflow temperature. In the first period of outflow the heat in the cylinder decreases with value:

$$Q_{w1} = m_{w1} c_v (T_6 - T_1) = m_{w1} \frac{R}{k-1} (T_6 - T_1) \tag{30}$$

and mass of the gas decreases with value m_{w1}:

$$m_{w1} = m_6 \frac{c_v}{R} (k-1) \frac{T_6}{T_6 - T_1} - \frac{p_1 V_1}{R} \frac{k-1}{k} \frac{1}{T_6 - T_1} \tag{31}$$

The heat of the gas flowing into the chamber during second period may be calculated on internal energy difference in the points 1 and 2:

$$Q_{w2} = m_{w2} c_p (T_1 - T_2) = m_1 c_v T_1 - m_2 c_v T_2 \tag{32}$$

Total outflow heat is defined in two ways as follows:

$$Q_w = Q_{w1} + Q_{w2} = Q_6 - Q_2 \tag{33}$$

$$Q_w = m_6 c_v T_6 - m_2 c_v T_2 \tag{34}$$

It should be noted that the inlet mass is equal the outflow mass. Then we may write:

$$m_d = m_w = m_{w1} + m_{w2} \tag{35}$$

Pressure during the outflow process occurs at constant pressure and the pressure in points 1 and 2 are equal to pressure in the chamber.

$$p_2 = p_1 = p_{ch} \tag{36}$$

Temperature in point 2 is calculated from the gas state equation:

$$T_2 = \frac{p_2 V_2}{m_2 R} = \frac{p_{ch} V_2}{(m_6 - m_w) R} \tag{37}$$

6. Engine work and efficiency

Theoretical absolute work of the engine is determined by integration of engine thermal cycle in p-V or T-s system and it is described by formula:

$$L_t = \oint p dV = L_{4-5} + L_{5-6} + L_{1-2} + L_{2-3} \tag{38}$$

The area of the work is determined by the absolute work taking place at constant pressure and expansion and compression processes. During delivering of the heat the work is determined as follows:

$$L_{4-5} = p_4 (V_5 - V_4) \tag{39}$$

The work during expansion process at adiabatic conditions with constant specific fuel ratio k is described by the following expression:

$$L_{5-6} = \frac{p_5 V_5}{k-1} \left[1 - \left(\frac{p_6}{p_5} \right)^{\frac{k-1}{k}} \right] = \frac{m_5 R}{k-1} (T_5 - T_6) \tag{40}$$

Outflow of the gas from the cylinder is determined by absolute work at constant pressure:

$$L_{1-2} = p_1 (V_2 - V_1) \tag{41}$$

Finally the work of the compression process in the cylinder is presented in the form:

$$L_{2-3} = \frac{p_2 V_2}{k-1} \left[1 - \left(\frac{p_3}{p_2} \right)^{\frac{k-1}{k}} \right] = \frac{m_2 R}{k-1} (T_2 - T_3) \tag{42}$$

Mean temperature T_m at inlet of the chamber is defined on the amount of energy delivered during outflow process to the chamber from the cylinder:

$$T_m = \frac{1}{m_w}\int T_w dm_w = \frac{1}{m_d}\int T_w dm_w \quad (43)$$

Cooling of gas in the chamber heat exchanger from temperature T_m to T' at constant pressure p_2 enables energy recovery of amount:

$$Q_{ch} = m_w c_p \left(T_m - T'\right) \quad (44)$$

Adiabatic work of compressor L_{ad} is additional inserted work to the engine cycle. Final temperature of the adiabatic compression process from point ' to point " amounts:

$$T'' = T'\left(\frac{p_b}{p_2}\right)^{\frac{k-1}{k}} \quad (45)$$

In external path mass of the gas is constant and amounts m_d and is equal the mass m_w. Then the adiabatic work of the compressor working at assumed efficiency η_{ad} is given by expression:

$$L_c = L_{ad} = \frac{1}{\eta_{ad}} m_d c_v (T'' - T') \quad (46)$$

The boiler works at constant conditions and it is a reason that boiler efficiency η_b is very high. Heat delivered from the boiler to the engine may be performed as follows:

$$Q_d = \frac{1}{\eta_b} m_d c_p \left(T_b - T''\right) \quad (47)$$

Having all absolute works of the processes it can be possible to determine the total thermal efficiency as a ratio of useful work to the inserted work (heat):

$$\eta_t = \frac{L_t + Q_{ch}}{Q_d + L_{ad}} \quad (48)$$

The analysis of thermal efficiency requires additional information about gas mass flow rate through the valves. The engine cycle can be simplified by moving point 6 to point 1 and point 3 to point 4. Then the engine cycle would have only for processes; two at constant pressure and two as isentropic processes.

7. Conclusions

Nowadays the researchers are looking for new driving sources and new fuels. This work concerns the both issues, because presents a new idea of the energetic engine fuelled by the biomass with external combustion process taking place in constant conditions. The engine is the unit for production of mechanical work mainly for driving electric generator and also as a source of the heat for industry or local utilization. The engine design is based on two-stroke cycle with higher useful work than in four stroke engine. The work present preliminary consideration of the engine cycle and gives the simple mathematical model of its theoretical processes. On basis of the presented considerations the following observations can be made:

1. The engine is working on the heat delivered from the external boiler with burning of biomass fuel in different various forms.
2. Controlling of the combustion process in the boiler is simpler than in the internal combustion engine, because the process takes place at constant conditions and at lower temperature.
3. The engine works in two-stroke cycle with six processes, where outflow process occurs at constant pressure and compression process occurs in short period with residual gas only.
4. The engine work in such configuration enables to obtain higher thermal efficiency despite the inserted work in the adiabatic compressor.
5. For adiabatic processes in the whole system a noble gas may be used as a working medium, which gives constant specific heat ratio.
6. Total emission may be neglected, because CO_2 is consumed by nature during photosynthesis and circulates in a closed cycle.
7. Thermal loads of the engine are lower because of lower combustion temperature in the boiler.
8. Resistance temperature of used materials determines upper limits of temperature in the boiler and in the cylinder.

This paper is an access to further studies of the ecologic engine with external combustion chamber working in two-stroke cycle.

Nomenclature/*Skróty i oznaczenia*

TDC	top dead centre/*górne położenie tłoka*
BDC	bottom dead centre/*dolne położenie tłoka*
BBDC	before bottom dead center/*przed dolnym położeniem tłoka*
BTDC	before top dead center/*przed górnym położeniem tłoka*
imep	indicated mean effective pressure/*średnie ciśnienie indykowane*
CA	Crank Angle/*kąt obrotu wału korbowego*

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