International Conference on Industrial Engineering

The research of influence characteristics of heat-storage material on thermodynamic process in heat storage, installed in system of waste-heat recovery of internal combustion engines

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Abstract

The article outlines the results of the research of influence characteristics of heat-storage material on thermodynamic process in heat storage, installed in system of waste-heat recovery of internal combustion engines. It is shown that the highest average temperature and dampening effect among 4 analyzed heat-storage materials is reached by means of utilization of tripartite eutectic mixture $\text{7NaNO}_3/40$, $\text{NaNO}_2/53\text{ KNO}_3$ and $\text{LiNO}_3$, due to appropriate thermophysical properties.

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Peer-review under responsibility of the organizing committee of the International Conference on Industrial Engineering (ICIE-2015)

Keywords: internal combustion engine, exhaust gases, heat storage of transition curve, heat-storage material, thermophysical properties, temperature, temperature variations.

1. The research of influence characteristics of heat-storage material on thermodynamic process in heat storage.

The article outlines the results of the research of influence characteristics of heat-storage material on thermodynamic process in heat storage, installed in system of waste-heat recovery of internal combustion engines. It is shown that the highest average temperature and dampening effect among 4 analyzed heat-storage materials is reached by means of utilization of tripartite eutectic mixture $\text{7NaNO}_3/40$, $\text{NaNO}_2/53\text{ KNO}_3$ and $\text{LiNO}_3$, due to appropriate thermophysical properties.

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During last years the humanity witnesses the dramatic boost of automobiles. Thus, due to the analytic centre “Alfastrakhovanie”, the number of registered cars has grown twice for the last 10 years. Motor park increase leads to augmentation of influence on the environment. Main ecological problems of car utilization are: high toxicity of exhaust gases, heat and noise pollution, natural energy resources depletion. It is extremely important to introduce new technologies in auto industry to decrease the harmful influence of exhaust gases on the atmosphere in the future.

It is a well-known fact that up to 45% of heat energy, generated by an engine is extracted into the atmosphere with exhaust gases. There are groundbreaking reserves of amplification of engine performance in case of energy utilization by systems based on the Stirling engines, steam engines, gas turbines, thermoelectric generators, air expansion machines, etc.

The operation of waste treatment plants and oxidation catalyst demand stable and high temperature of air inflow, regardless engine operating condition [1,2]. However the temperature of exhaust gases of conventional engines changes in wide range depending on engine operating condition. So, on the basis of the research it is proven that the temperature of exhaust gases of KamAZ-740 engine on different engine operating conditions varies from 80 to 650 °C [3].

It is possible to lower the oscillatory amplitude of the exhaust gases temperature by means of installation in car exhaust system device, containing heat-storage material of transition curve.

The device can be named as damper of temperature variations of exhaust gases.

Fig.1. Damper of temperature variations of exhaust gases.

Dampers of temperature variations of exhaust gases of shell and tube type with transition curve are the most acceptable for the target implementation. The construction of damper of temperature variations of exhaust gases consists of frame with built in metal tubes, conducting exhaust gases of internal combustion engine. The space between the tubes is heat-storage material of phase transition.

In case the temperature of exhaust gases, flowing through the vibration damper is higher than the heat-retaining material’s then the emission of heat takes place, consequently the temperature falls down. If exhaust gas is cooler than the heat-storage material, it gives some warmth to gas, boosting their temperature. Thus, damping vibrations of exhaust gases temperature takes place, flowing through the device.

The main structural component of damper of temperature variations – is heat storage material. Thus, the paramount priority is to choose the most suitable one.

It is worthwhile to choose substances for heat storage material, which are not degradable in smelting and not dissolvable in spill water. They are crystallizing as separate crystals, featuring comfortable melting temperature from the exploitation point of view, high definitions of latent heat of transition curve, heat conduction coefficient and specific heater in solid and liquid phases, low price, sufficient level of safety during operation, etc. Optional limitations connected with the damper construction are possible [4].

New materials are offered by now, providing approximately any level of melting temperature within the range of exhaust gases temperatures. Salinas and bases – are the most numerable and investigated substances for heat storage. They are used for heat accumulation for both exhaust gases and chemical reactor of oxidation catalyst. Moreover in the original form, binary and trinary systems of salinas and bases, the melting temperature can be more suitable. Finally, the price of such composed substance is much lower than the pure one, as it consists of the composition of expensive and cheap substances [5].
For heat energy accumulation the following bases are appropriate: lithium, sodium, potassium hydroxide, different binary systems composed of bases. Lithium hydroxide is considered to be the best among 400 analyzed heat-storage substances [6]. However, while choosing salinas and bases, it is important to take into account their excessive corrosion aggressiveness, typical for crystalline hydrates, alteration of volume during smelting and low conductivity. Nitrates are also used, as they are low-melt and resistible in the air molecular entity, nevertheless their fundamental defect –is explosive risk. From the point of view of productive heat transmission, it is possible to use alloys as heat-storage material. In comparison with salinas, alloys possess the same melting equivalent.

Except for inorganic compound in working systems with the temperatures up to 120°C, different organic materials, as heat storage materials, can be used, for example: polyoxyethylene glycol, octadecane.

Nowadays, mixtures and alloys of organic and nonorganic substances are considered for usage, allowing to provide necessary melting temperature and longtime working lifespan. Slastilova S.V. [7] and some other researchers investigate heat-storage materials on the basis of aluminium, cuprum, silicon, magnesium alloys. Tests results showed the concordance of such heat-storage material to major requirements.

While examining exhaust gases, on the output of conventional engine and then following through damper of temperature variations, we deal with flow of matter, which means – open thermodynamic system. As the gas flow through the damper of temperature variations is accompanied with heat transmission from exhaust gases to working medium of damper of temperature variations (heat-storage material) or vice versa, from heat-storage material to exhaust gases, and their movement is rather fast, so basically the process is unbalanced. However making a suggestion about quasi-equilibrium (the following suggestion concerning exhausting process is related to the second order of approximation [8], one can use thermodynamic relations for stationary state and obtain major processes characteristics, free of nonequilibrium state.

2. Experimental results of usage of heat-storage material.

During the development of numerical scheme, we got the simultaneous differential equations, which described heat exchanging process in damper of temperature variation with phase transition. Adequacy of the suggested physico-mathematical model is proved with help of testing researches [9]. The experiment with the help of software suit MathCAD was made to estimate characteristics of heat-storage material for thermodynamic processes in damper of temperature variations.

The detailed formula depends on type of tasking and bank of initial data. While obtaining the observed characteristics of operation mode in actual environment of exploitation of conventional engine, the research discovered the influence of major design values of damper of temperature variations and features of some heat-storage materials on temperature smoothing of exhaust gases and their energy datum.

Characteristics of researched heat-storage materials are depicted in table 1.

| Type of Heat-storage material | Melting temperature, K | specific thermal heat capacity of heat-storage material J/(kg·K) | Heat-transfer capacity of heat-storage material W/(m·K) | mass density of heat-storage material kg/m³ |
|-----------------------------|------------------------|-------------------------------------------------|--------------------------------------------------|-----------------------------|
|                             | Liquid state | Hard phase | Liquid state | Hard phase |                                      |
| LiNO₃                      | 525      | 2040       | 2020        | 2.7       | 1.35       | 2360                              |
| LiOH                       | 744      | 3900       | 3300        | 2.6       | 1.3        | 1460                              |
| NaOH                       | 591      | 2090       | 2100        | 1.8       | 0.92       | 2170                              |
| 7NaNO₃/40NaNO₂/53KNO₃      | 415      | 1860       | 1340        | 0.5       | 0.5        | 2146                              |

Fig. 2 presents the average temperature and its variations of the researched heat-storage materials and exhaust gases on the output from the damper in 3 minutes from the working point of damper of temperature variations. The determined range (ΔT) shows corresponding thermophysical properties of heat-storage material and exhaust gases.
Obviously, the temperature of the heated heat-storage material is higher in case its thermal heat capacity is lower, under the conditions of the same temperature of exhaust gases and heat-transfer environment. The investigations discovered that the highest average temperature and dampening effect among viewed 4 heat-storage materials is reached by using ternary eutectic mixture 7NaNO3/40 NaNO2/53 Ko3 (760 K) and LiNO3 (755 K).

The level of an average temperature of exhaust gases on the output from the damper of temperature variations is disproportional in correspondence with an average temperature of the considered heat-storage materials. Probably, it is connected with diverse heat transfer capacity of the used materials. Determined ranges ΔT are due to corresponding thermophysical properties of heat-storage materials and exhaust gases.

Thus, we can conclude that heat-storage material has an influence on dampening of temperature variations and energy datum of exhaust gases. Considered characteristics of temperature variations of different heat-storage materials and exhaust gases on the output from damper of temperature variations mostly depend on thermophysical properties of heat-storage material and they are extremely important for dampening of temperature variations of combustion material before their penetration into the oxidation catalyst. Dampening of temperature variations is of main interest in case the heat on the output of damper of temperature variations of exhaust gases is used for starting the utilization engine.

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