THERMAL ANALYSES OF EXHAUST SYSTEM ON COMBUSTION ENGINE

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Abstract

Nowadays there are more and more discussions on acquisition of energy from sources other than natural sources of energy. Many scientific research centres deal with the issue of energy recovery as well as use of energy from renewable sources. The communities associated with the automotive industry devote a lot of attention to the issue of improving the energy efficiency of vehicles. Since a combustion engine uses less than half of the energy produced during the combustion process, thus the issues of recovery of thermal energy and its conversion into electrical energy evoke increasing interest.

The article presents the process of examination of the temperature of the exhaust system in a car engine operating in a laboratory environment. Measuring equipment was used to the temperatures' determine.

Analysis of distribution of temperatures in the exhaust system creates grounds for rational selection of the places where the thermal energy recuperation systems should be installed. At present, the possibilities of recovery of thermal energy are still seriously restricted by the properties of the materials of which the elements of the thermal energy recovery systems are made. High propensity of these elements to thermal defects is a serious problem in practical application of these materials in thermal energy recovery systems. The results obtained in an experiment serve as the basis for determining the locations where thermoelectric generators should be installed while accounting for their thermal limitations.

Keywords: *cogeneration of energy, exhaust system, thermoelectric generator*

1. Introduction

Demand for energy continues to grow in our civilization while the non-renewable natural sources of energy are inevitably vanishing. Oil mining is becoming increasingly difficult and expensive. Also other sources of energy are used, e.g. natural gas, shale gas, solar energy, wind energy, however there is increasing talk about efficient use of energy and recovery of energy. Automotive industry develops new systems and methods of re-use of the energy lost in the process of its generation, including also re-use of thermal energy.

As we know from the heat balance of a combustion engine, there is no possibility of transforming the entire thermal energy obtained in the process of burning the air-fuel mixture into mechanical energy. Only 25-40% of the heat supplied to the engine is transformed into mechanical energy. Part of this energy is used for powering the systems located inside the engine, such as e.g. the timing gear system or the cooling system pump. The remaining part of the energy, some 60-75%, is emitted together with the exhaust fumes or is absorbed by the cooling agent. It is expected that recovery of 6% of the energy lost in the process could reduce fuel consumption by 10% [1, 2].

In order to employ thermal energy recovery systems, which are based on thermoelectric generators, a relevant operating environment should be designed in which the cells will not be damaged. According to Indian scientists [3], TEG cells can resist temperature of up to 220 degrees centigrade. Peltier cell manufacturers publish data, which indicates that the top temperature limit is generally 200 degrees centigrade. Once the limit is exceeded, the semi-conductor connectors (bismuth telluride Ti_2Te_3) are damaged. The connectors are the basic element responsible for recovery of energy in thermoelectric generators [4]. Also, other energy recovery systems are exposed to damage in such temperatures. As it is well known, the temperatures of an engine's elements range from ambient temperature to very high temperatures occurring in the combustion process, that is to temperatures in the range of a thousand degrees centigrade

In the research, we focused on developing detailed temperature maps of the exhaust system, from the exhaust manifold to the last muffler. Diverse measurement devices, described in the further part of the article, were used in the research.

2. Description of the test bed

The research was conducted while using the ECOTEC X18XE engine installed at the testbed located in the Integrated Environmental Laboratory of Mechatronic Systems of Vehicles and Machines at the Faculty of Automotive and Construction Machinery Engineering (SiMR) at the Warsaw University of Technology.

Fig. 1. Photo of the test bed with ECOTEC X18XE engine

An infrared camera and a temperature sensor (thermoelement), also called a pyrometer were used in the course of the research, along with the dedicated, detachable elements of the exhaust system which were developed for the needs of the experiment. Places in the exhaust system were selected where temperatures were checked for various engine speeds (various engine loads). Locations of measuring points are presented in Fig. 2. The temperatures in the selected points were measured throughout the duration of the experiment.

At the moment of starting the engine, the exhaust fumes started heating the exhaust system, thus leading to sudden growth of the temperature of the examined pipe. Initially the measurements were performed with a pyrometer and then with an infrared camera. Fluctuation of temperature was noted while the elements were heating. The fluctuation was caused by the operation of the radiator fan (Fig. 1). The fan, which was activated by too high temperature of the cooling agent, blew air, which flew by the measuring elements, thus leading to momentary decrease of temperature.

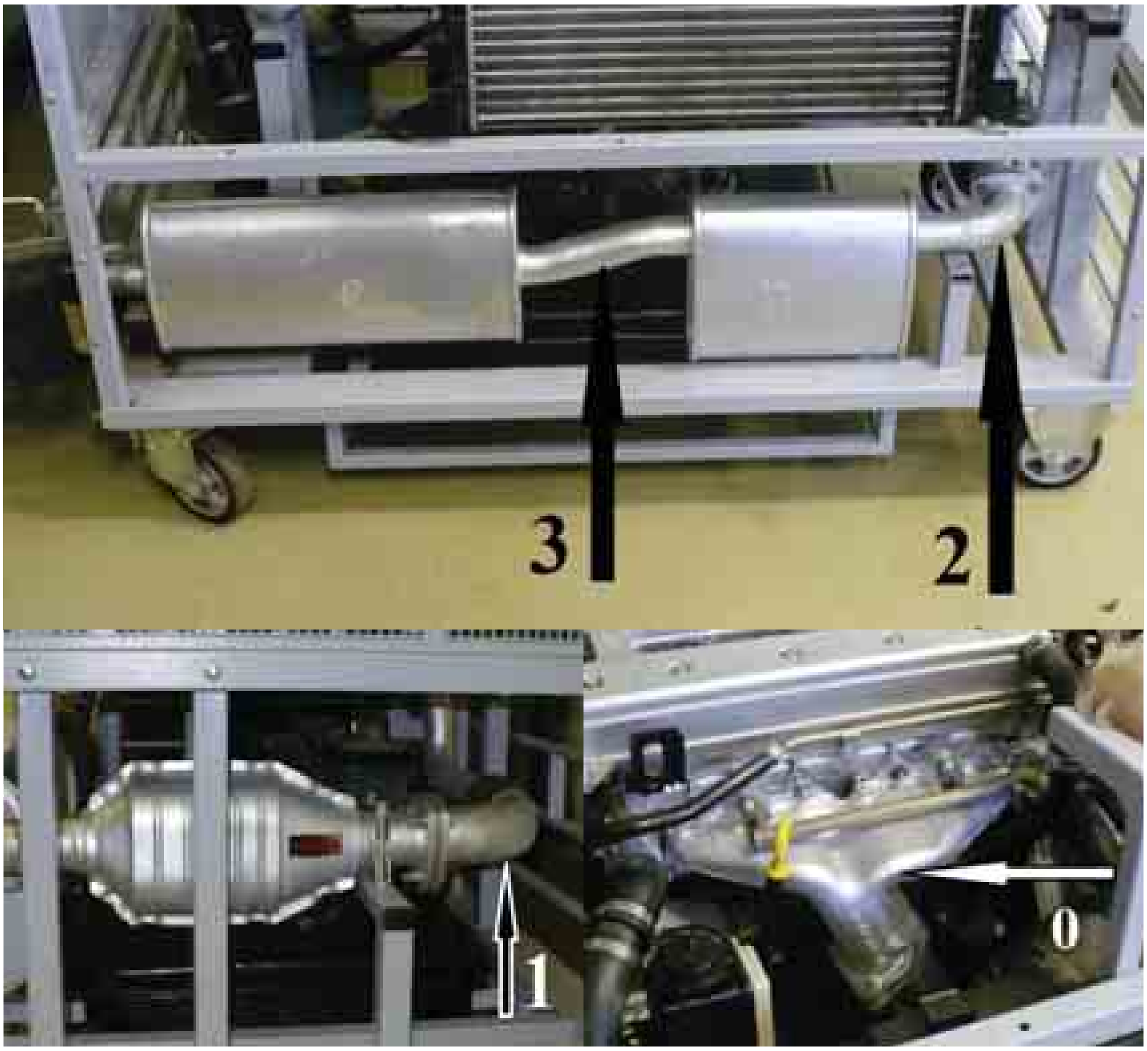

Fig. 2. Photos presenting the measuring points

3. Results of the research

During the experiment, we noted that the first muffler had lower surface temperature than the second muffler. In all other measurement points, the surface temperatures were decreasing from a measurement point to the next. The temperatures in respective points are presented on the photos from the infrared camera (Fig. 3–10).

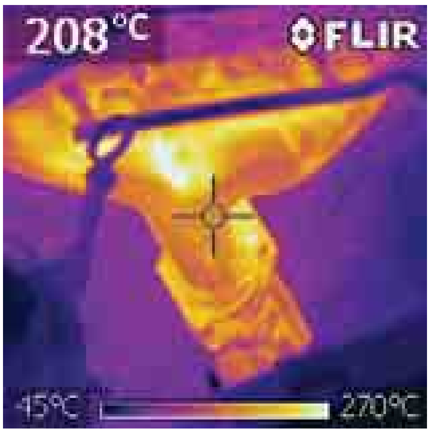

Fig. 3. Photo of the 0 measurement point for 2000 rpm

Fig. 4. Photo of the 1st measurement point for 2000 rpm

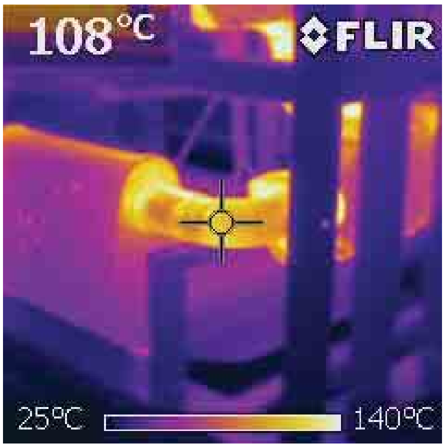

Fig. 5. Photo of the 2nd measurement point for 2000 rpm

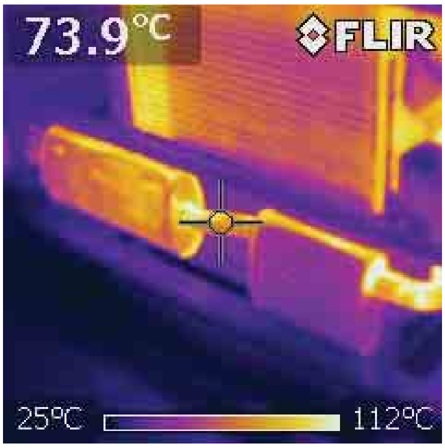

Fig. 6. Photo of the 3rd measurement point for 2000 rpm

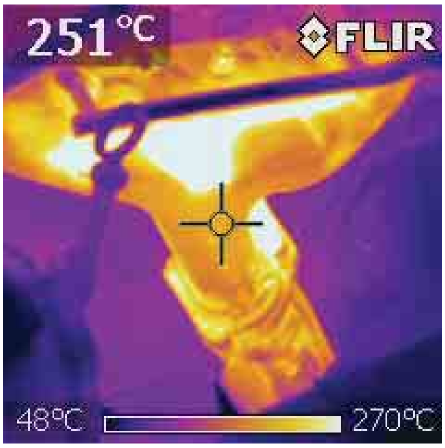

Fig. 7. Photo of the 0 measurement point for 3000 rpm

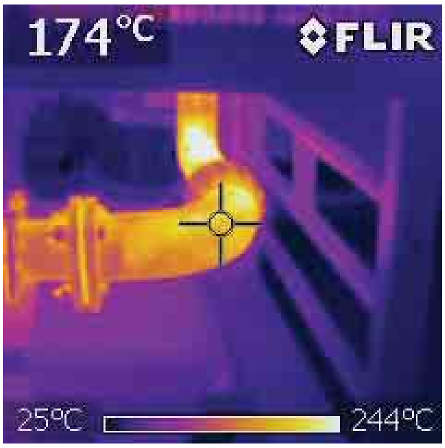

Fig. 8. Photo of the 1st measurement point for 3000 rpm

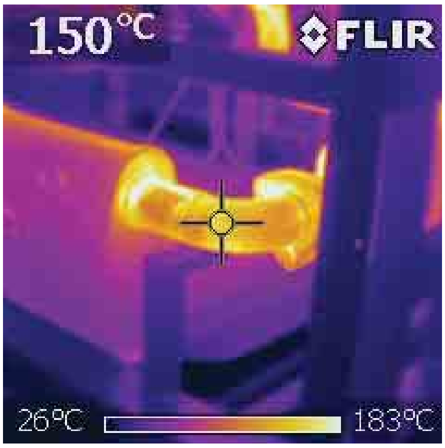

Fig. 9. Photo of the 2nd measurement point for 3000 rpm

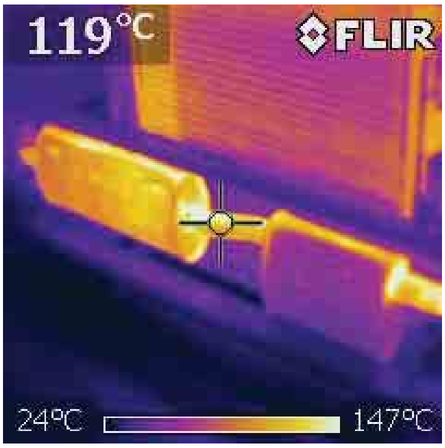

Fig. 10. Photo of the 3rd measurement point for 3000 rpm

Other research done with the use of an infrared camera involved registration of the time in which the selected spots in the exhaust system heated up.

The photos taken with the camera not only reduce the time required for the research but also show to the user the temperature in the vicinity of the analyzed spot, thus creating a temperature map (temperature characteristics). These maps support analyses of thermal dynamics of the entire surroundings of the measurement points rather than just analyzing the selected points. Thanks to such analyses, it is possible to observe the flow of thermal energy. Photos from the examination of thermal dynamics of a selected point are presented in Fig. 11.

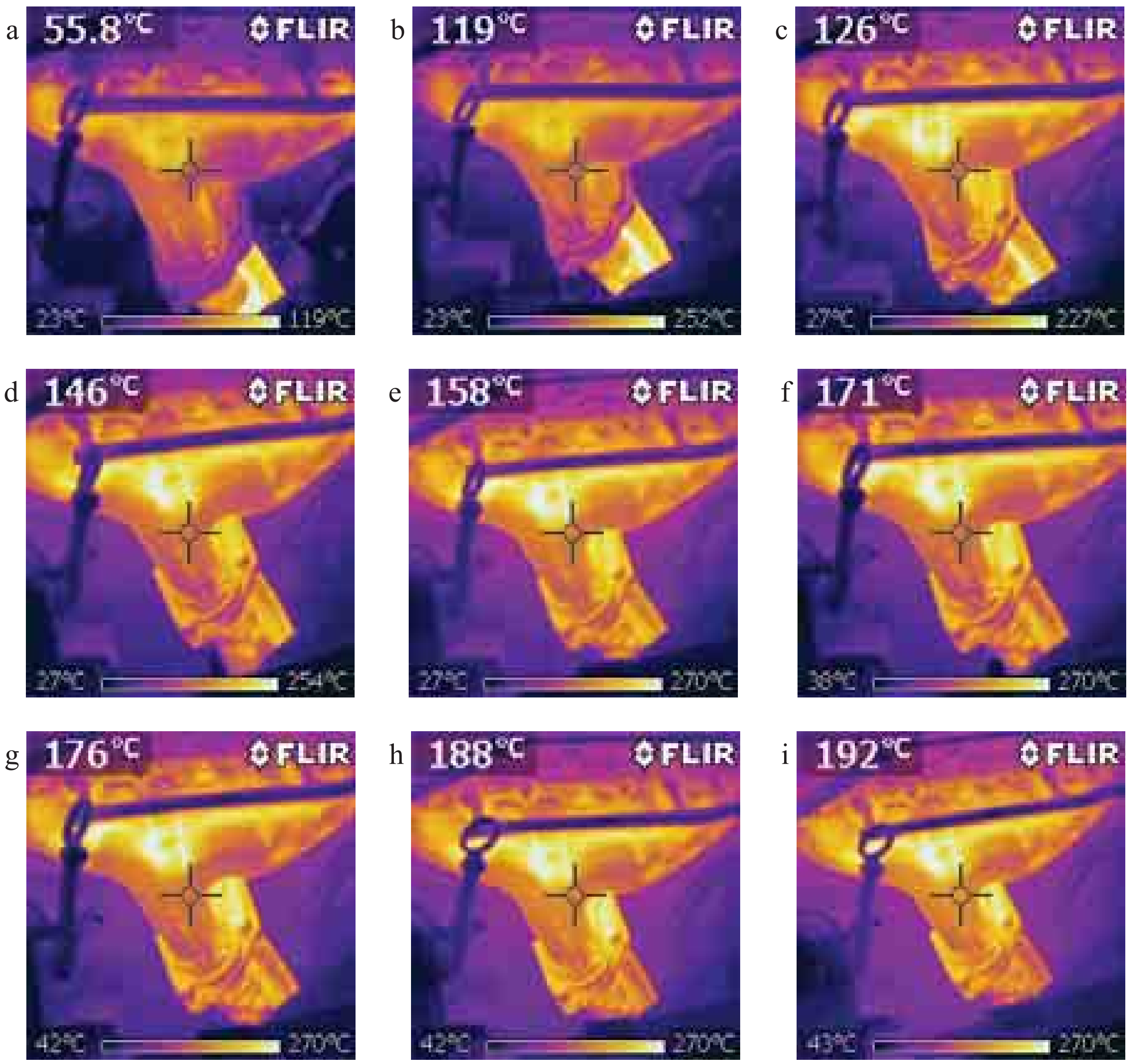

Fig. 11. Photos of the heating point "0" registered at two-minute time intervals

4. Conclusions

Both, Fig. 6 and 10 demonstrate that the surface temperature of the first muffler is much lower than the temperature of the surface of the second muffler. The measurements were confirmed by examining the temperatures of these surfaces of the exhaust system while using a pyrometer.

In addition it is possible to observe on the photos that the temperature is higher on the welds of the muffler and in the places where the mufflers are welded to the exhaust system's pipes. Simultaneously one can observe how the bolts heat up in the flanges connecting the exhaust system and it is possible to detect which part of the exhaust manifold heats up most, which could suggest that the wall is the thinnest there.

By looking at Fig. 8 we can conclude that thermoelectric generators should be installed behind the catalytic converter where the threat of exceeding the temperature of 200°C does not exist. Otherwise a system, which limits the stream of exhaust gases should be, installed which will regulate surface temperature.

Figure 11, which presents a series of thermal maps from an exhaust manifold where temperatures were recorded at two-minute time intervals, shows that the manifold heated up to the temperature of 200°C when the engine operated in neutral gear. However upon any change of operation of the engine, including increase of the engine speed, the temperature exceeded 200°C (Fig. 3) and, as Fig. 7 shows, the measurement point heated up to around 250°C.

During further operation the temperature in the examined point exceeded the registration scale of the infrared camera, namely 270°C.

The article demonstrates that analysis of distribution of temperatures in an exhaust system is the necessary stage of the research, which precedes installation of energy recuperation systems.

It has been demonstrated that analysis of the results of the exhaust system's temperature measurements creates the grounds for a rational selection of the places where thermal energy recuperation systems should be installed while taking into account their thermal resistance. Lack of such an analysis will expose these systems to damage arising from unforeseen growth of temperature of the exhaust system's elements due to changes of the engine's operating conditions.

References

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