Microwave Heating of Exhaust Systems from Combustion Engines for Improvement of After treatment Systems

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Abstract. The cold start effect of combustion engines leads to high rate of NOx emissions because the gases temperature of the exhauster is lower than the functioning temperature of selective catalyst reduction systems. This paper aim to present preliminary research, in terms of modelling the thermal field and experimental procedure, for heating the exhaust gases using microwave heating. The experimental procedure was focused on different levels of microwave injected power from 600 W to 3000 W. Two sources of gas were considered in experimental procedure: Corgon with flow rate from 5 l/min to 30 l/min and compressed air at 4 bar pressure. The results of thermal field simulation revealed levels of temperature up to 113 °C. The simulation has been validated by experimental procedure where the levels of temperature were 140 °C for Corgon at 1800 W microwave injected power and 120 °C for compressed air.

Keywords: microwave heating · thermal field · NOx emissions

1 Introduction

The effects of cold starting of internal combustion engines (CSE - Cold Start Effect) are studied considering that the initiation of the catalysis process takes place at a certain level of the exhaust gas temperature being one of the important aspects for meeting the emission requirements. Nowadays, a significant challenge for the rapid achievement of NOx reduction is the presence of moisture in the catalyst at lower temperatures. The researches have been oriented in heating of exhausted gases before entering in selective catalyst reduction (SCR) in order to create proper conditions for reducing the NOx. A heater based on electrical resistance (with net power 1000 W) has been used to increase the temperature from ambient to required temperature for catalytic reaction. The results were a significant decrease of NOx emissions down to 67% as result of heating the exhausted gas. In addition, the maximum temperature was 180 °C that represents a lower temperature than required in normal functioning of SCR. However, the heating

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time was long (about 5 min) and therefore the level of NOx was high [1]. Other negative point is related to energy consumption taking into consideration the total energy required for achieving the initiation temperature of SCR.

Microwave heating represents an advanced technology that can be used for fast heating of materials. Previous researches of the author have been focused on microwave heating of ceramic monolith substrate (cordierite material) in order to increase the level of temperature of the gases inside SCR device from inland waterway transport systems [2, 3]. Preliminary results of the studies revealed that for 1200 W microwave injected power, the temperature of cordierite core has increased up to 250 °C in less than 2 min. However, additional auxiliary devices must be fabricated due to the fact that at this level of microwave power often leads to occurrence of thermal runaway phenomenon and microwave plasma initiation [4–6]. The microwave plasma can affect the microwave generator antenna and this phenomenon can be avoided by creating polymers protective panels between reaction chamber and microwave generator [7].

2 Microwave Heating of Exhausted Gases

This paper aims to present researches related to microwave heating of exhausted gases in order to obtain the catalytic temperature before SCR. The study contains the modelling and simulation of the temperature distribution followed by validation of the simulated model through experimental program in laboratory conditions. In order to achieve simulation of temperature distribution, a concept of experimental device has been design and presented in Fig. 1.

The system consists of 6000 W microwave generator water-cooled, refractory brick for conversion of microwaves into heat and a pipe connected to exhauster.

The monitoring system consist of two thermal detectors of the temperature of the inlet gases and outlet gases as well as an infrared pyrometer for monitoring the temperature at the surface of the refractory material. The exhauster was simulated using a compressor and a bottle with Corgon having 82% Ar and 18% CO_2.

2.1 Modelling and Simulation of the Temperature Distribution

In modeling the temperature distribution because of the microwave thermal activation of the exhaust gas, the following boundaries conditions were considered:

- Starting from the experimental research on the heating capacity of the refractory brick, an injected microwave power equal to 600 W, 1200 W, 1500 W, 1800 W, 2400 W and 3000 W was established, similar to the heating process of the cordierite ceramic core in the construction of the commercial catalyst
- The temperature developed on the inner surface in contact with the copper exhaust pipe was considered as a reference point for modeling the temperature distribution by thermal conduction in steady state.

Figure 2 shows the assembly made using the drawing mode from the SolidWorks 2016 software application. The simulation model was conduction heating from refractory

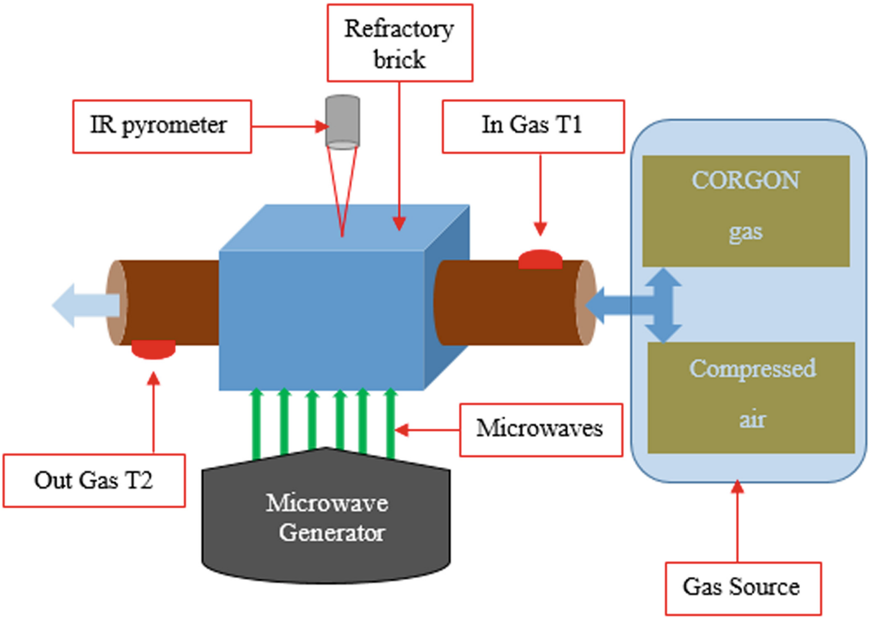


Fig. 1. Concept of microwave heating device for experimental program

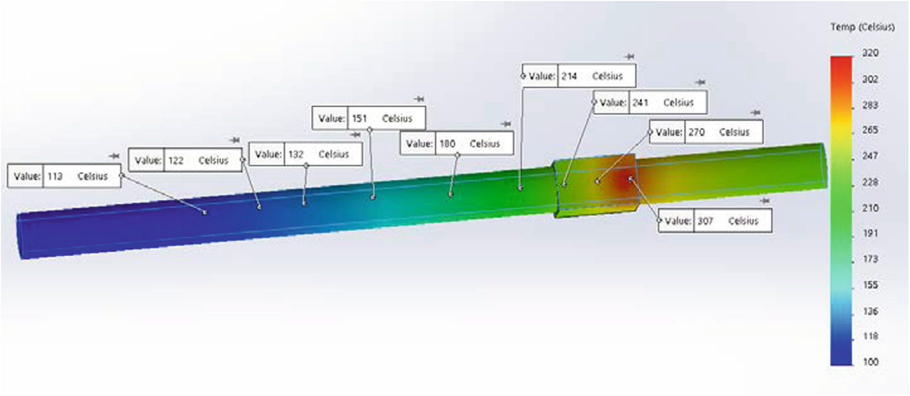


Fig. 2. Temperature distribution considering refractory brick close to engine exhauster

brick to the copper pipe starting considering the ceramic material as thermal source heated by microwaves. The dimensions considered in the simulated model are those used in the experimental microwave heating application: the length of the copper pipe was 64 mm, the inner diameter 30 mm, and wall thickness 1 mm. The size of the refractory brick was length 37 mm and the height of the parallelepiped was 55 mm. The depth of refractory brick was 34 mm.

By placing the refractory brick close to engine exhauster, the temperature distribution was high in the proximity of exhauster reaching 214 °C, but near the SCR device, the

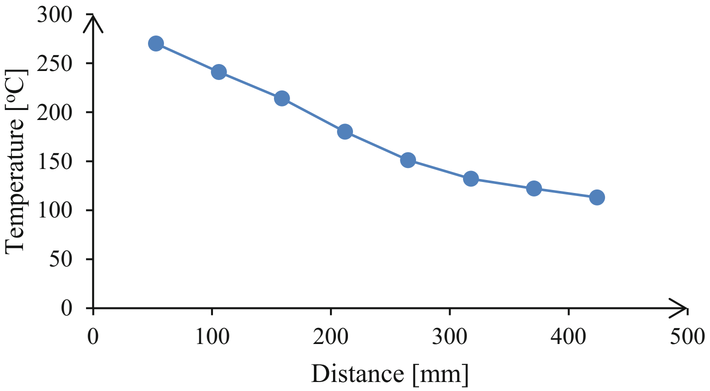


Fig. 3. Temperature distribution among exhauster pipe considering the refractory brick near to engine exhauster

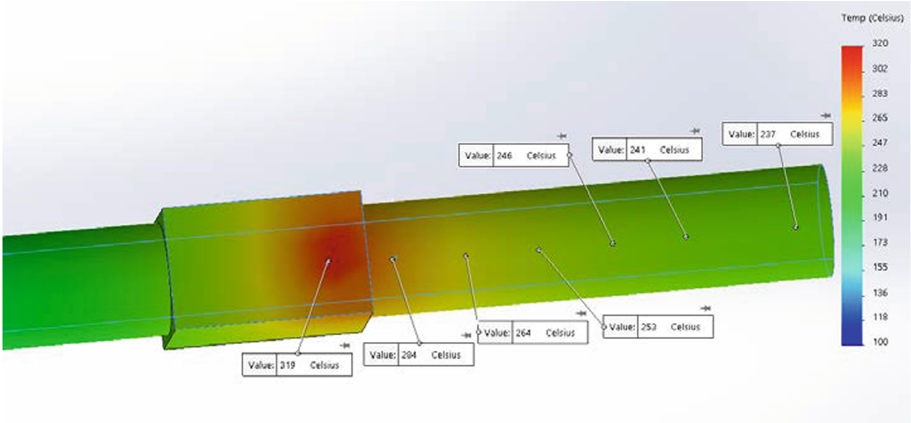


Fig. 4. Temperature distribution considering refractory brick close to SCR device

values of temperatures were lower. The temperature of the gas that flows inside the SCR device has been determinate, based on simulation result, to be 113 °C. The equation for temperature distribution corresponds to a logarithmic model:

$$T = 81.62 \cdot \ln d + 610.15 \tag{1}$$

where T represents the temperature evolution from the hot point to the SCR device and d represents the distance between points of sampling the temperature. The graph of temperature evolution is presented in Fig. 3.

Considering the location of refractory brick near the SCR device, the temperature distribution in the section between them can be simulated using the same heat conduction equations (Fig. 4).

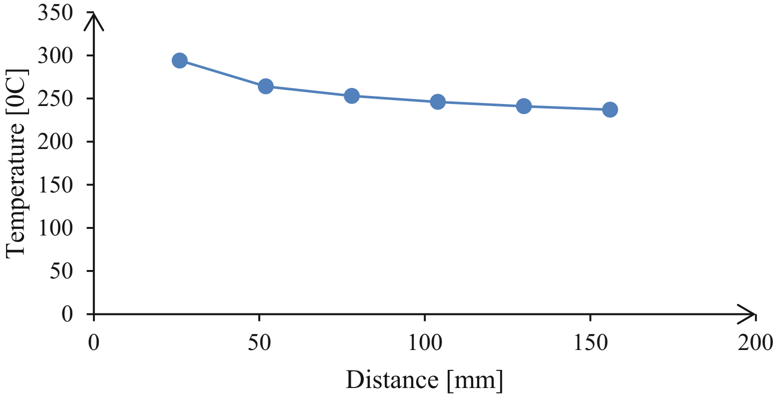


Fig. 5. Temperature distribution considering the refractory brick near the SCR device

The temperature distribution in exhausting pipe is governed by the following equation:

$$T = 31.29 \cdot \ln d + 392.1 \quad (2)$$

The representation of the values obtained through simulation of the temperature in exhausting pipe is presented in Fig. 5.

The results obtained from simulation model of the temperature distributions revealed the following conclusions:

- The positioning of refractory material must be close to SCR device in order to ensure the necessary temperature for initiation of catalytic reaction
- The materials used for exhausting pipe must have high thermal conductivity in order to ensure the level of temperature along its distance for a low level of microwave injected power as well as low heating time.

2.2 Experimental Procedure for Microwave Heating of Exhausting Pipe

The experimental procedure consists of microwave heating of refractory brick and monitoring the gas temperature for the case of placing the heating point near the exhauster. Two gases have been used in the experimental procedure: Corgon gas and compressed air. The flow rate of Corgon gas was set manually for 5 l/min, 10 l/min, 15 l/min, 20 l/min, 25 l/min and 30 l/min. The pressure of compressed air was set at 4 bar. The level of microwave injected power was set for interval between 1200 W and 1800 W. The microwave installation contained a Muegge GmbH microwave generator and power source with powers between 600 W and 6000 W. An automatic tuner for matching load impedance type Tristan drove the microwave heating process. The temperature of the refractory brick was monitored with an infrared pyrometer from Optris GmbH with range between 0 °C and 700 °C. The temperature of exhausting pipe and gases was measured using thermal sensor based resistance type PT100 connected to a measurement device

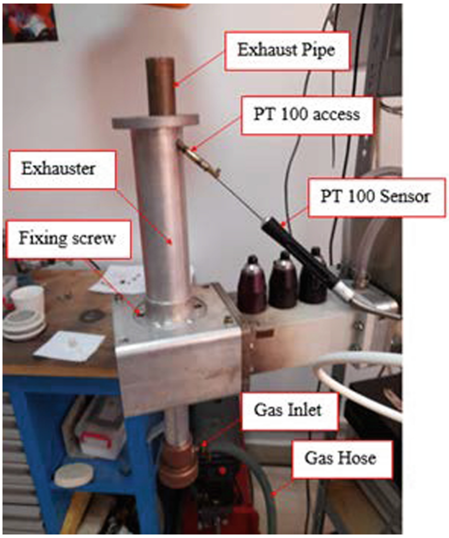


Fig. 6. Experimental device for microwave heating of exhauster/gas

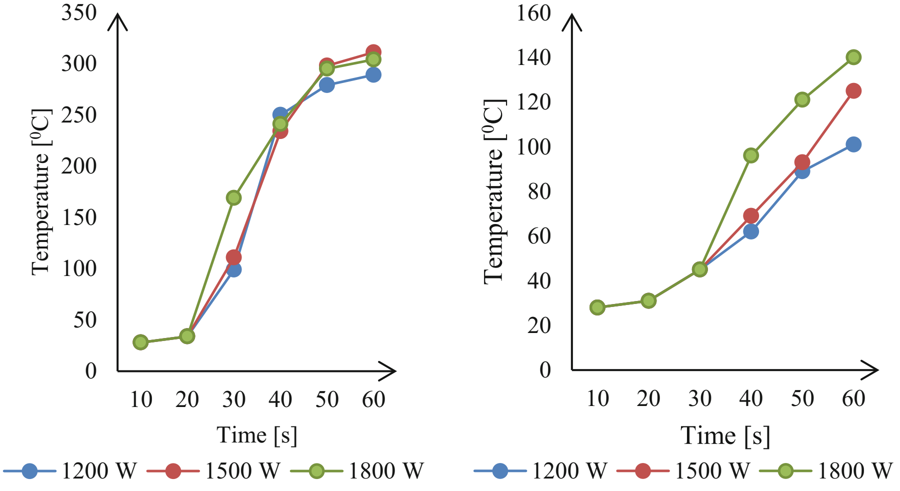
type Lutron 509. The total heating time has been established at 1 min for each heating experiment. The experimental device and the gas sources are presented in Fig. 6.

The process of recording and interpreting the data from the heating processes is performed separately for each experimental program. The final section is dedicated to the conclusions through the comparative analysis of each experiment in order to further optimize the heating process. The process of heating the corgon and the compressed air shall be carried out in accordance with those presented in the previous paragraph. There are 3 separate fiches for the evolution of the gas temperature, depending on the injected microwave power to the corrugated exhaust pipe and 5 separate fiches for compressed air.

2.3 Results and Discussions

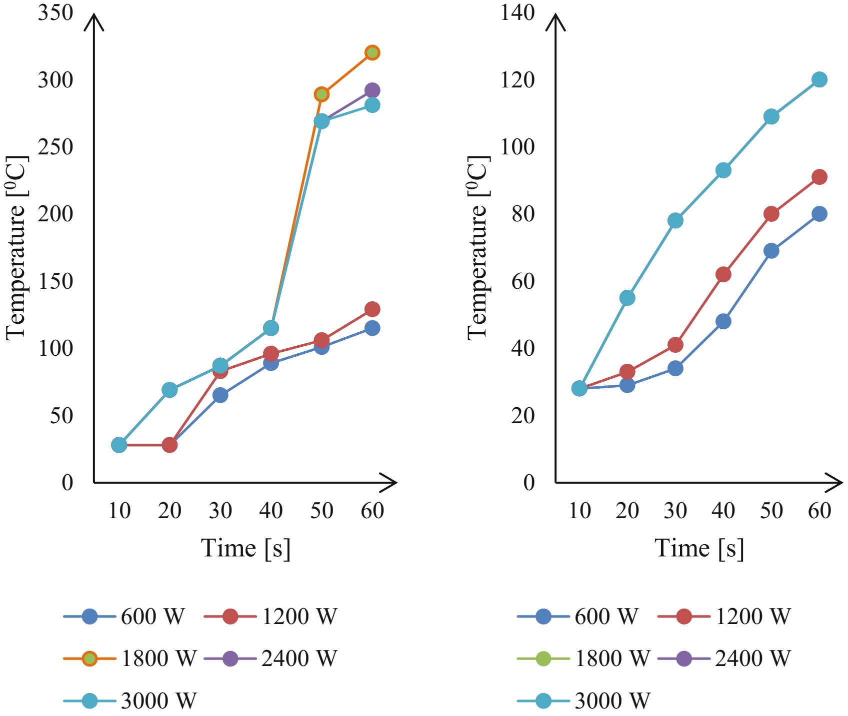
The experimental procedure consists of microwave heating of refractory brick and monitoring the gas temperature for the case of placing the heating point near the ex.

The Figs. 7a and 7b present the evolution of the temperature of the refractory brick and Corgon gas used in microwave heating process. The Figs. 8a and 8b present the evolution of the temperature recorded for compressed air case. It can be observed that the values of temperature for Corgon gas are lower than the temperatures of the refractory brick. These values can be explained by the heat loss from refractory brick to the exhauster pipe and Corgon gas. However, these values recorded represent an important indicator of the necessary level of microwave power that are required in order to obtain the required temperature interval (from 250 °C to 350 °C) by the SCR device.



a. b.

Fig. 7. Temperature evolution during microwave heating: a. refractory brick, b. Corgon gas



a. b.

Fig. 8. Temperature evolution during microwave heating: a. refractory brick, b. compressed air

3 Conclusions

The main conclusions of simulation and experimental program are:

- it was found that for the highest injected power (1800 W) there was also the highest heating of both the refractory brick (304 °C) and the CORGON gas (140 °C)
- temperature differences every 1 min are minimal for CORGON gas which requires the use of less power to optimize the energy consumption of the heater
- the thermal field modeling is validated by the experimental research corresponding to a microwave power equal to 1500 W and the gas is CORGON. Temperatures reached at the far end from the SCR are similar to the experimental model.
- the process was stable for 600 W, 1200 W and 1800 W. Above this power, the refractory brick cracked and the compressed air temperatures at powers of 2400 W and 3000 W were lower than in previous cases
- the highest temperature was obtained at 1800 W, when the refractory brick had a temperature of (320 °C) after one minute, and the temperature of the compressed air at the exhaust was (120 °C)
- regardless of the value of the injected power, in case of compressed air heating the temperature of 120 °C could not be exceeded
- modeling the temperature distribution is verified by the experimental model for an injected microwave power of only 600 W. This validation is of real importance because it shows that temperatures close to the initiation temperatures of catalysis reactions can be obtained in relatively short times (2–3 min).

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