EVALUATION OF THERMAL STATE IN REACTOR DURING PLASMA PYROLYSIS OF POLYMERS

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Summary

Thermal conditions existing in the reactor, especially around the plasma jet, greatly influence on the course of the plasma pyrolysis including synthesis of derivative compounds. Measurements of the temperature distribution in the reactor will be helpful in carrying out the experiment of the plasma pyrolysis of polymers and also will be utilized to build the model of the plasma pyrolysis.

Keywords: plasma pyrolysis, temperature, thermal conditions, polymer.

OCENA STANU CIEPLNEGO W REAKTORZE PODCZAS PIROLIZY PLAZMOWEJ POLIMERÓW

Streszczenie

Warunki termiczne panujące w reaktorze, szczególnie w otoczeniu strumienia plazmy, mają istotny wpływ na przebieg pirolizy plazmowej, w tym na syntezę związków wtórnych. Pomiar rozkładu temperatury w reaktorze będzie pomocny w przeprowadzaniu eksperymentu pirolizy plazmowej polimerów, a także posłuży do budowy modelu pirolizy plazmowej.

Słowa kluczowe: piroliza plazmowa, temperatura, warunki termiczne, polimer.

1. INTRODUCTION

In the paper the temperature distribution during plasma pyrolysis of polymers was examined. Rubber waste was subject to plasma pyrolysis.

The thermal transformations occurring at temperatures of thousands and even tens of thousands of Kelvin are the basis of the phenomena ruling plasma pyrolysis. It seems reasonable to assume that the reactions of thermal decomposition of rubber powder will take place inside of the plasma jet (13000 K [1]), and reactions between plasma pyrolysis byproducts will take place outside the plasma jet, that is in the plasma reactor. That is why it is important to know the temperature distribution in the plasma reactor to anticipate what processes might occur inside the reactor. The knowledge of the temperature distribution will enable controlling plasma pyrolysis in more precise way.

2. EXPERIMENT SET-UP

For the measurement of the temperature in the plasma reactor [2] a thermometer EMT – 07 was used. The principle of its operation is based on thermocouples [3]. The temperature measured by that thermometer ranges from 190 K do 1500 K.

The temperature was measured in the four cross-sections of the plasma reactor, I-IV (fig. 1).

The cross-section I was established right over the nozzle of the plasmatron, prior to the outlet of the plasma jet, in the place out of the direct influence of the plasma jet. The cross-sections II and III were established to measure the space, where samples of gas products are taken to the analysis. The measurement in the cross-section IV was established to evaluate the temperature of gas outgoing from the reactor. Regarding to relatively small diameter of the outlet opening (60 mm) of the reactor, the thermocouple was inserted to the cross-section IV at angle (15 - 30°).

The thermocouples were inserted into the plasma reactor through openings, which were secured to limit the presence of ambient air inside of the reactor.

The gas temperature in the cross-section I was measured in the selected points in the distance of 4 cm to 14 cm to the longitudinal axis. In the cross-sections II and III the temperature was measured in the axis and points distant to the axis from 1cm to 14 cm. In the cross-section IV the gas temperature was measured only in two points – in the longitudinal axis of the plasma reactor and in the distance of 3 cm of the axis.

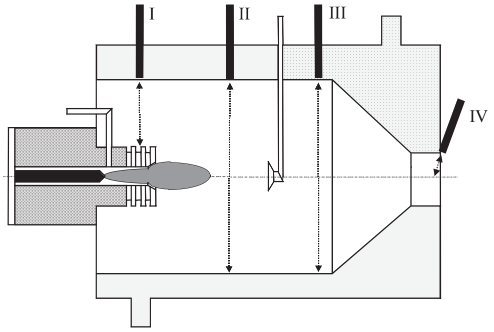

Fig. 1. Scheme presenting the cross-sections in the reactor where the temperature was measured

3. RESULTS

The temperature distribution in the cross-section I of the plasma reactor is presented in the fig. 2. The measurement was carried out for Ar plasma (gas flow rate Q=5808 l/h, current I=500 A, no rubber - g=0 kg/h). According to the fot. 2 it follows that the temperature in the plasma reactor decreases while the distance to the longitudinal axis increases. The maximum temperature in that cross-section equals to 621 K.

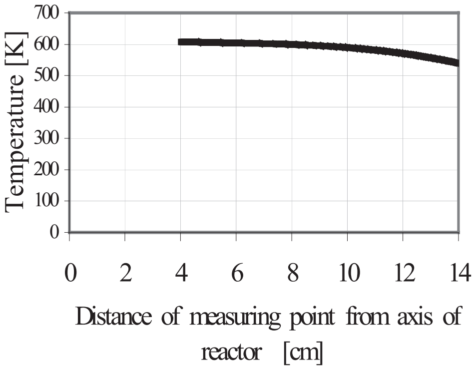

Fig. 2. Temperature distribution in the cross-section I of the reactor: Ar plasma, Q=5808 l/h, I=500 A, g=0 kg/h

In the cross-section II four series of measurements were carried out: for "clean" Ar plasma (Q=5808 l/h, I=500 A, no rubber), for "clean" Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, no rubber) and during the plasma pyrolysis of the rubber powder in Ar plasma (Q=5808 l/h, I=500 A, g=4.39 kg/h) and in Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, g=4.39 kg/h). The temperature distribution in the cross-section II is presented in the fig. 3. It results from the figure, that the temperature inside of the plasma reactor increases while approaching to the axis of the reactor. However, in the axis of the plasma reactor the temperature is lower than it is nearby (from 18 K to 85 K in the examined range of work parameters of the plasmatron). It seems that the reason of the decrease of the temperature in the axis of the reactor is relatively small distance of the cross-section II from the outlet of the plasma jet from the nozzle-anode of the plasmatron. That decrease of the temperature might be caused by the huge axial velocity of the plasma operating gas, gas transporting the rubber powder and outgoing gas flow rate. The maximum temperature in the cross-section II occurred for "clean" Ar + 5.9 % H_2 plasma. It is equal to 1096 K.

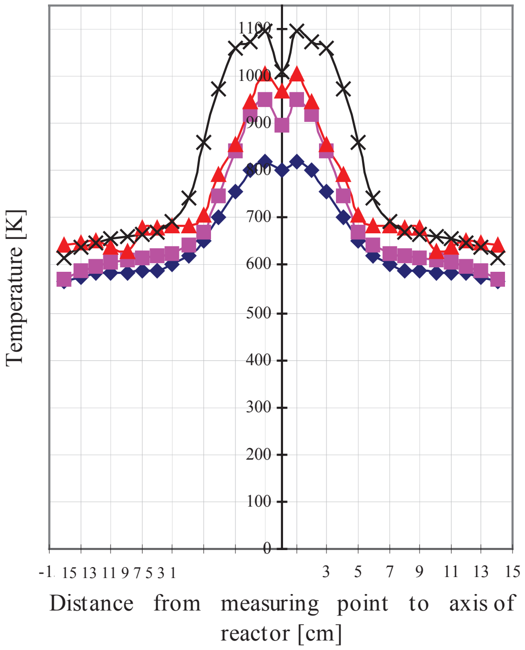

Fig. 3. Temperature distribution in the cross-section II of the reactor:

■ - Ar plasma (Q=5808 l/h, I=500 A)
◆ - Ar plasma (Q=5808 l/h, I=500 A, g=4.39 kg/h)
× - Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A)
▲ - Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, g=4.39 kg/h)

In the cross-section III also four series of measurements were carried out, i.e. for "clean" Ar plasma (Q=5808 l/h, I=500 A, no rubber), "clean" Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, no rubber) and for the plasma pyrolysis of the rubber powder in Ar plasma (Q=5805 l/h, I=500 A, g=4.39 kg/h), Ar + 5. % H_2 plasma (Q=5538 l/h, I=500 A, g=4.39 kg/h). The results of the measurements in the cross-section III of the plasma reactor were shown in the fig. 4. The temperature distribution in the cross-section III does not have a minimum in the axis of the reactor. In the cross-section III the temperature in the axis is maximal and it equals 848 K. The reason of that state is fact that the cross-section III is situated almost in twice longer distance away from the outlet of the plasma jet from the nozzle-anode than the cross-section II. The lowest temperature (573 K) was registered along the walls of the reactor for the pyrolysis of the rubber powder in Ar plasma (Q=5808 l/h, I=500 A, g=4.39 kg/h), and highest for "clean" Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, g=0 kg/h).

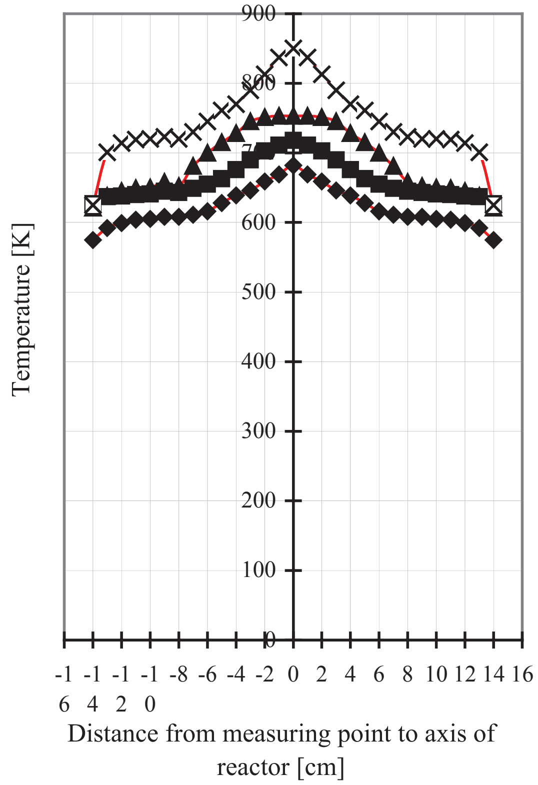

Fig. 4. Temperature distribution in the cross-section III of the reactor:

–▲– - Ar plasma (Q=5808 l/h, I=500 A)

–◆– - Ar plasma, (Q=5808 l/h, I=500 A, g=4,39 kg/h)

–×– - Ar + 5,9 % H_2 plasma (Q=5538 l/h, I=500 A)

–■– - Ar + 5,9 % H_2 plasma (Q=5538 l/h, I=500 A g=4,39 kg/h)

In the cross-sections II and III similar influence of work parameters of the plasmatron on change of temperature was observed: injection of the rubber powder into the plasma jet was causing the decrease of the temperature in the reactor and adding of H_2 to the plasma operating gas was increasing the temperature.

In the cross-section IV of the reactor, i.e. nearby the outlet of the reactor, the temperature was measured only in two points, because of its small diameter. The first measuring point was established in the axis of the reactor, and the second in the distance of 3 cm away from it. The temperature was measured for "clean" Ar plasma (Q_1=5325 l/h, I_1=500 A and Q_2=6970 l/h, I_2=500 A; in both cases with no rubber powder in the plasma jet), for "clean" Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, no rubber), for the pyrolysis of the rubber powder in Ar plasma (Q_1=5325 l/h, I_1=500 A and Q_2=6970 l/h, I_2=500 A; g=4.39 kg/h in both cases) and Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, g=4.39 kg/h). The results of the measurements were presented in the fig. 5.

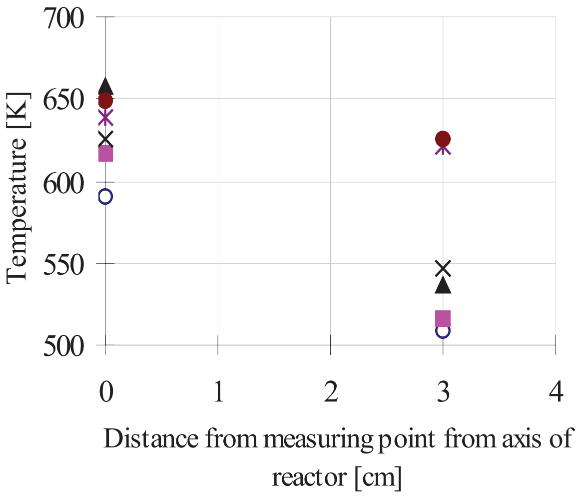

Fig. 5. Temperature distribution at the outlet of the reactor (cross-section IV):

▲ - Ar plasma (Q_1=5325 l/h, I_1=500 A)

■ - Ar plasma (Q_2=6970, I_2=500 A)

× - Ar plasma (Q_1=5325 l/h, I_1=500 A, g_1=4.39 kg/h)

○ - Ar plasma (Q_2=6970 l/h, I_2=500 A, g_2=4.39 kg/h)

✱ - Ar plasma + 5.9 % H_2 (Q=5538 l/h, I=500 A)

● - Ar + 5.9 % H_2 plasma (Q=5538 l/h, I=500 A, g=4.39 kg/h)

The lowest temperature (509 K) appeared in the distance of 3 cm from the axis of the plasma reactor for the case of the pyrolysis of the rubber powder in Ar plasma. At the same time it is the lowest registered temperature in the reactor. The highest temperature (657 K) was registered at the axis of the reactor for "clean" Ar plasma (no rubber). The influence of the work parameters of the plasmatron on the temperature in cross-section IV was different than in the cross-sections II and III: the temperature measured during the pyrolysis of the rubber powder in Ar and Ar + 5.9 % H_2 plasmas is higher than the temperature registered for "clean" Ar and Ar + 5.9 % H_2 plasmas. The difference could have been caused by the direct contact of the outgoing gas from the reactor with the surrounding atmosphere. It is important to pay attention to slight differences between the measured temperatures nearby the outlet of the reactor.

The longer the distance from the plasma jet in the longitudinal axial direction of the reactor was, the lower the temperature occurred. That dependence is illustrated in the fig. 6.

In order to examine the influence of the plasmatron power on the temperature in the reactor, two series of measurements were carried out for: "clean" Ar plasma (Q=5808 l/h, no rubber) and plasma pyrolysis of the rubber powder in Ar plasma (Q=5808 l/h, g=4.39 kg/h).

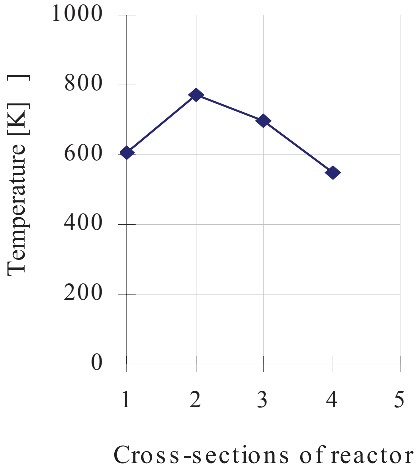

Fig. 6. Temperature distribution in the reactor along its longitudinal axis for Ar plasma (Q=5808 l/h, I=500 A, g=0 kg/h). The temperature measured in the distance of 3 cm away from the axis of the reactor

The measurements were done in the cross-section II of the reactor, in the axis. The received dependencies of the temperature in the function of the plasmatron power are presented in the fig. 7. According to the fig. 7 the temperature in the axis of the reactor is increasing while the plasmatron power is increasing. The higher temperatures occur for “clean” Ar plasma than during the plasma pyrolysis of the rubber powder.

4. CONCLUSIONS

Adding up, on the basis of the carried out measurements it results that at the constant work parameters of the plasmatron the temperature in the reactor decreases while the distance to the longitudinal axis and the distance to the plasma jet in axial direction increases. It is reasonable. Adding H_2 to Ar results in the increase of the temperature in the reactor in the case of “clear” plasma as well as in the case of the plasma pyrolysis of the rubber powder. However generally, spraying the rubber powder into the plasma jet causes the decrease of the temperature in the reactor. The reason of such a state might be more intensive cooling of the plasmatron, caused by the increased total flow rate of the gas by the flow of Ar transporting the rubber powder. The other reason of that decrease of the temperature can be consumption a part of the energy of the plasma jet for decomposition of the rubber powder during plasma pyrolysis.

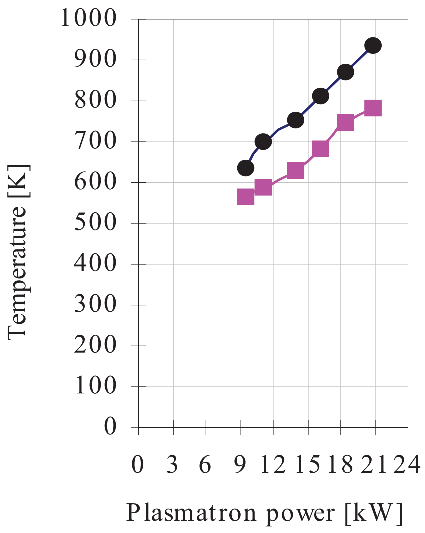

Fig. 7. Temperature in the cross-section II in the axis of the plasma reactor as the function of the plasmatron power:

● -Ar plasma (Q=5808 l/h)

■ - Ar plasma (Q=5808 l/h, g=4.39 kg/h)

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