Research of the leidenfrost temperature on structured surfaces

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Abstract. The paper shows the results of studying the effect of structures formed on the metal surface during laser, plasma, ion and electronic treatment by Leidenfrost temperature value. A description of the experimental unit and the measurement procedure is given. Also in the course of the study limiting wetting angle and roughness parameter were measured.

1. Introduction
In many fields of the power generating industry associated with heat exchangers, there is a tendency to reduce the size of the equipment by increasing the parameters of the working fluid and the density of the heat flux in order to increase the efficiency of the entire process generation. However, the increase in the temperature of the heat-carrying agents is limited by the allowable bubble boiling regime, since a transition to sheet boiling can lead to an emergency damage to the heat exchange surface, as for instance at a nuclear power plant. These transitions are caused by the burnouts.
For a number of investigated working surfaces obtained as a result of laser, plasma, ion and electron treatment, the Leidenfrost temperature shifts to a high temperature region, which together with other positive changes gives a great potential for the use of these technologies in heat exchange equipment [1].

2. Roughness and limiting wetting angle studies
A study of surface roughness and a description of the structure, including local fusion zones, were carried out. Data on the characteristic parameters of irregularities were obtained using an automated microscope LEXT OLS4000.

The static limiting wetting angles for all samples were measured using an automated KRUSS DSA25 unit. The measurements were performed many times, for two initial droplet volumes, in different areas of surfaces.

3. Description of the experimental unit for determining the Leidenfrost temperature.
In order to determine the Leidenfrost temperature in the temperature range of up to 450 °C, the specialized unit shown in Fig. 1 was developed and manufactured when the samples interacted with water. The main element of the experimental unit is a cylindrical heating block 2 made of copper. The heating unit is equipped with a cartridge heater 3, the power of which is regulated manually by Laboratory Autotransformer (LATR) 9. Three thermocouples 5 are placed into the heating unit located on the axis of the copper cylinder 10 mm apart. The hot junction of one of the thermocouples is located directly on the surface of the copper block. Cold junctions of thermocouples are in a Dewar vessel 6, the temperature in which is kept at 0 °C by melting ice. The thermocouple signal is...
processed by an analog-to-digital converter 7 and is displayed on the computer screen 8. The heating block is wrapped into a high-temperature heat insulator with cladding. Using a small amount of thermal paste, the test sample 1 is attached to the surface of the heating block. The thermocouple is fixed on the work surface, and the signal is also processed by the ADC 7 and is displayed on the screen 8. The dispenser 10 allows to obtaining liquid droplets of constant volume.

4. Methods of conducting experiments
The Leidenfrost temperature is determined by the dynamics of the liquid evaporation. The surface of the sample is heated to the temperature obviously greater than the required Leidenfrost temperature for this material (experimentally selected). After that the power of the heater is set in such a way that the working surface of the sample cools down at a rate of 0.5 ÷ 1.5° С / min. A drop of water is placed on the surface of the sample using a dispenser with a period of about a minute. The dispenser makes it possible to obtain drops of liquid of constant volume. This procedure is carried out before the surface temperature decreases to the temperature, at which there is obvious boiling of the liquid. The experiment is fixed by the video camera, and the thermocouple readings are recorded with the help of the analog-to-digital conversion complex. The data are processed after the experiment: the surface temperatures of the sample correspond to the evaporation time of the drop. Since the Leidenfrost temperature characterizes the formation of a vapor film between the liquid and the sample and corresponds to a minimum of the heat flux density, the peak obtained in the experiment can be observed – the maximum value of the time that determines the Leidenfrost temperature. In order to verify the obtained data, experiments are performed more than once for each sample. To ensure the uniformity of the temperature of the working surface during the experiments, the surface was surveyed with a thermal scope. Figure 2 shows the examples of such photographs.
5. Results
Figure 3 shows the dependence of the evaporation time of a water drop on the surface temperature of an aluminium sample treated with a plasma beam at a KSPU-T unit, 0.5 MJ/m². The graph shows that the Leidenfrost temperature is in the range of 268÷282° C. The Leidenfrost temperature for untreated aluminium is 235÷265° C [2].

Figure 4 shows the dependence of the evaporation time of a water drop on the surface temperature of a steel sample treated with a plasma beam at a KSPU-T unit, 1 MJ/m². The graph shows that the Leidenfrost temperature lies in the temperature range of 249÷268° C.
Figure 4. Dependence of the evaporation time of a water drop on the surface temperature of a steel sample treated with a plasma beam at a KSPU-T unit, 1 MJ/m².

The results for a number of samples are shown in Table 1. The results show that for most samples, there is no significant change in the wetting contact angle and the Leidenfrost temperature during treatment. There is a significant change in these parameters only in Sample No.4, although Samples No.1, 2 and 4 have approximately the same roughness characteristics. The treatment of Samples No. 1, 2 and 3 did not significantly affect the wetting contact angle and the Leidenfrost temperature. However, the changes in the roughness indices of Sample No. 3 significantly exceed the unevenness indices of Samples No. 1 and 2. Consequently, it can be concluded that the size of the microstructures, formed as a result of the impact on the samples, does not affect the wettability and the Leidenfrost temperature, and the effect is exerted by a more complex combination of roughness characteristics and physical and chemical properties of the surface.

6. Conclusion
Based on the results, we can make a conclusion that the effects of laser, plasma, ion and electronic treatment of the metal surface depend on the processing parameters and the material being processed. The values of the limiting wetting angle and the Leidenfrost temperature can be shifted both in the region of larger and smaller values compared with the initial surface. By adjusting the processing parameters it is possible to obtain a surface with the necessary characteristics. A decrease in the limiting wetting angle, as a rule, leads to a shift in the Leidenfrost temperature and, correspondingly, to the boiling crisis in the high temperature region, which can potentially be used to increase the parameters of the working fluid in heat exchange equipment.
| Sample number | Sample characteristics and processing method | Limiting wetting angle | Unevenness indices (μm): maximum, minimum and average value for 10 surface areas | Leidenfrost temperature, °C of sample (original surface), °C |
|---------------|---------------------------------------------|------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------|
|               |                                             | Before processing      | After processing | Ra          | Rc          |                                                             |                                                          |
| № 1           | A sample of copper, processed at the Kalmar plant, 0.1-0.5 MJ / m² | 83,6                   | 82,8              | 3,256       | 3,11033     | 13,34                                          | 239÷255                                                |
|               |                                             |                        |                   | 2,541       | 2,541       | 8,268                                           | (237÷250)                                               |
|               |                                             |                        |                   | 8,103       | 10,6874     |                                                 |                                                          |
| № 2           | Sample of steel plate treated with KSPU-T unit, 1 MJ / m² | 82,1                   | 82,6              | Far area:   | Far area:   | 249÷268                                         | (250÷260)                                               |
|               |                                             |                        |                   | 2,137       | 2,137       | 4,6484                                          |                                                          |
|               |                                             |                        |                   | 0,920       | 0,920       | 8,986                                           |                                                          |
|               |                                             |                        |                   | 1,3492      | 1,3492      | 2,752                                           |                                                          |
|               |                                             |                        |                   | Central area: | Central area: |                                                 |                                                          |
|               |                                             |                        |                   | 1,175       | 1,175       | 6,035                                           |                                                          |
|               |                                             |                        |                   | 0,489       | 0,489       | 2,557                                           |                                                          |
|               |                                             |                        |                   | 0,7877      | 0,7877      | 3,6731                                          |                                                          |
| № 3           | A sample of an aluminum plate treated on a KSPU-T installation, 0.5 MJ / m² | 78,7                   | 77,7              | 29,983      | 29,983      | 98,271                                          | 270÷284                                                |
|               |                                             |                        |                   | 13,044      | 13,044      | 51,628                                          | (235÷265)                                               |
|               |                                             |                        |                   | 20,9195     | 20,9195     | 77,8974                                         |                                                          |
| № 4           | A sample of stainless steel, processed at the Kalmar plant, 3 shots, 500 J, 100 ns. | 72,4                   | 77,1              | Area 1:     | Area 1:     | 340-346                                         |                                                          |
|               |                                             |                        |                   | 3,135       | 3,135       | 11,443                                          |                                                          |
|               |                                             |                        |                   | 1,674       | 1,674       | 3,271                                           |                                                          |
|               |                                             |                        |                   | 2,4213      | 2,4213      | 8,3278                                          |                                                          |
|               |                                             |                        |                   | Area 2:     | Area 2:     | (282÷325)                                       |                                                          |
|               |                                             |                        |                   | 2,431       | 2,431       | 17,144                                          |                                                          |
|               |                                             |                        |                   | 1,144       | 1,144       | 2,877                                           |                                                          |
|               |                                             |                        |                   | 1,7751      | 1,7751      | 7,9203                                          |                                                          |

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**References**  
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