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Effect of surrounding parameters on the surface wetting by droplets

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Abstract

The paper presents results of experimental research that enables estimation of the effect of surrounding parameters on the surface wetted by a liquid droplet. Surrounding is composed of a system of a solid body surface and gas phase. In research, liquid droplets were introduced to the surrounding, as understood above. Dynamic spreading of droplets of water, aniline, and benzene, respectively, was considered in the paper. Analysis concerned the process of droplet spreading on three kinds of wall surfaces, that is, for surfaces made of: 1H18N9 stainless steel, CuCr1Zr copper alloy, and ordinary glass, respectively. The surfaces were characterized with various values of roughness.

Keywords: Surface wetting; Droplets; Spreading process

Nomenclature

c	–	specific heat, J/(kg K)
C	–	parameter, Eq. (2)
Ca	–	capillary number, Eq. (6)
d	–	diameter of droplet in atomization, m
D	–	diameter of wetting area, m
g	–	gravity, m/s^2
H	–	height, m

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N	–	dimensionless mass flux of vapor
p	–	partial pressure, N/m^2
R	–	roughness parameter
Re	–	Reynolds number, Eq. (5)
t	–	temperature, °C
T	–	absolute temperature, K
u	–	contact velocity, m/s
V	–	volume, m^3
We	–	Weber number, Eq. (4)
β	–	spreading coefficient, Eq. (1)
κ	–	coefficient, Eq. (14)
λ	–	thermal conductivity, W/(m K)
ν	–	kinematic viscosity, m^2/s
ρ	–	density, kg/m^3
σ	–	surface tension, N/m

Subscripts

c	–	contact
g	–	gas
l	–	liquid
max	–	maximal
n	–	saturation
w	–	surface, wall
v	–	vapor
z	–	wetting
0	–	initial
∞	–	infinity

1 Introduction

Phenomenon of wetting the solid body surface by liquid droplets is being often applied in various heat and mass transfer technologies [4, 5]. Data concerning the wetting process is relevant, among others, in the process of coating various surfaces of solid bodies. In such a case, optimization of the dropper operation allows to save on the component used to coat the surface. In turn, in thermal engineering, streams of droplets directed on the heated surface of a solid body are due to form a thin liquid film, and dropper operation, as well as application of cooling liquid, are expected to provide a continuous film of liquid and prevent the formation of dry areas on the surface. Wide range of parameter changes concerning the interaction of droplets with the surrounding impedes the creation of a generalized description of the phenomenon.

Present paper shows the analysis of effects of surrounding parameters, (parameters of humid air), on the size of wetting area of the surface wetted by a liquid droplet. Surrounding is understood here as a system: solid body surface – gas phase. Liquid droplet was introduced to the system and the process of its dynamic spreading was analysed. Some initial research results are given in papers [17-25].

Droplet, after its contact with the solid body surface, spreads on it. Characteristic state of droplet spreading is the phase where the liquid covers the maximal area of the solid body surface. The wetting area can be estimated by means of spreading coefficient defined as ratio of spreading area diameter to diameter of droplet in atomization:

$$\beta_z = \frac{D_z}{d_0} \tag{1}$$

Most of all, chemical and physical properties of phases in contact, as well as initial droplet energy in the moment of its contact with the surface, decide about the size of the wetted area. The main parameters are: kind of liquid and its temperature, material of surface and its initial temperature, oxidation and, roughness, etc.

Trela proposes parameter C defined with the formula [11]:

$$C = \frac{\sigma_{wl} - \sigma_{wv}}{\sigma_{lv}}\,, \tag{2}$$

to be applied for description of the phenomenon. Parameter C depends on forces in the system: droplet – surrounding, on both macroscopic and microscopic levels. The parameter is a function of surface tensions on borderlines of particular phases. Determination of values of the above parameter is the main objective of the present research.

On the other hand, the range of droplet spreading is determined by its initial energy, that is, by droplet energy in the moment of its contact with the wall surface and its transformation into other forms of energy during the process of liquid spreading.

Paper [17] presents the specific assumptions and the simplified model for the liquid droplet spreading process. It is assumed in the model, that droplet is a thin disc in the state of its maximal spreading, and dissipation of the liquid, induced by droplet viscosity, occurs in the process of its spreading. Solutions of equations of mass and energy conservation allows to form the following final relation:

$$\left[3(1+C) + \frac{4\mathrm{We}}{\sqrt{\mathrm{Re}}}\right] \beta^3 - (12 + \mathrm{We})\,\beta + 8 = 0 \tag{3}$$

where droplet initial energy is characterized with Weber number given with the formula:

$$\mathrm{We} = \frac{\rho_l\, d_0\, u_0^2}{\sigma_{lv}} \tag{4}$$

in turn, energy dissipation, resulting from liquid viscosity, is characterized with Reynolds number:

$$\mathrm{Re} = \frac{u_0\, d_0}{\nu_l}\,. \tag{5}$$

Quotient of the above numbers is a capillary number defined on the basis of contact velocity:

$$Ca = \frac{u_0}{\frac{\sigma_{lv}}{\rho_l \, \nu_l}} = \frac{\mathrm{We}}{\mathrm{Re}} \tag{6}$$

In this paper it has been proposed to use Eq. (3) for calculation of coefficient C, when the remaining parameters for the equation are known.

If the surface of solid body remains for a longer period in contact only with the gas phase, then as a result of mutual molecule exchange between the phases, a thin liquid film can form. The film forms in the vicinity of the solid body surface as a result of adsorption of molecules in the gas phase. Intermolecular forces are responsible for the formation of liquid microfilm. The forces provoke additional pressure that is called "disjoining pressure". Increase of liquid pressure on the surface in the liquid-gas inter-phase to the pressure value of the gas phase prevents evaporation of the liquid microfilm [10, 12].

Liquid microfilm on the solid body surface has a relevant effect on the liquid droplet spreading process. Covering the surface of the solid body with liquid microfilm acts in favour of better droplet spreading. In turn, absence of liquid microfilm makes it necessary to create the film in the vicinity of the front of droplet spreading, prior to the spreading process. In this case, a part of energy is consumed to create the liquid film, and thus droplet spreading area is smaller. A microscopic region (Fig. 1) occurs between droplet and absorbed liquid film. It is characterised with the change of curvature of the liquid-gas interfacial surface by a few orders of magnitude. Phenomena of adsorption and desorption, as well as evaporation and condensation, that occur in the above region, affect the process of liquid droplet spreading [1, 3, 6-8, 10, 13-16].

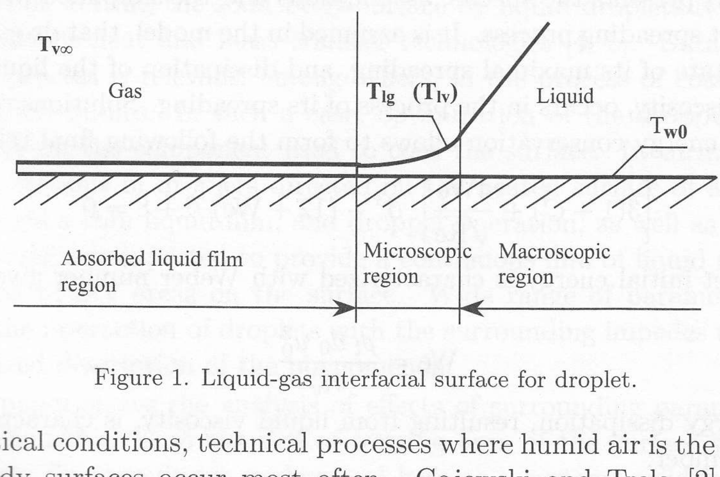

Figure 1. Liquid-gas interfacial surface for droplet.

In practical conditions, technical processes where humid air is the surrounding of solid body surfaces occur most often. Gajewski and Trela [2] proposed a description of the effect of the humid air parameters by means of parameter N.

This parameter is dimensionless mass stream of vapor exchanged between the thin liquid microfilm and the surrounding. The parameter relates to the effect of both partial pressures and temperatures on the stream of exchanged mass of vapor:

$$N = 1 - \frac{T_{lv}}{T_{v\infty}} \frac{p_{v\infty}(T_{v\infty})}{p_{v\ln}(T_{lv})}. \tag{7}$$

It was presumed in paper [2], that a small overheating of the liquid occurs, and this fact confirms the validity of the following assumption:

$$T_{lv} = T_{v\infty} \tag{8}$$

then the Eq. (7) is in the form:

$$N = 1 - \frac{p_{v\infty}(T_{v\infty})}{p_{v\ln}(T_{lv})}. \tag{9}$$

Determination of temperature on the surface in the liquid-gas interfacial surface is very difficult. Because of that, it has been assumed that interfacial surface temperature equals the liquid temperature and the liquid temperature equals, in turn, the wall surface temperature:

$$T_{lv} = T_l = T_w \tag{10}$$

and thus

$$p_{v\ln}(T_{lv}) = p_{v\ln}(T_l) = p_{vwn}(T_w) \tag{11}$$

hence the next equation:

$$N = 1 - \frac{p_{v\infty}(T_{v\infty})}{p_{v\ln}(T_l)} = 1 - \frac{p_{v\infty}(T_{v\infty})}{p_{vwn}(T_w)}. \tag{12}$$

Papers [18-25] show that parameter N , defined with the formula (12), correctly describes the effect of changes of surrounding parameters on the surface wetting conditions described by means of parameter C. If values of parameter N are smaller than zero, then condensation of water vapor from the surrounding air occurs on the liquid-gas interfacial surface. If $0 < N < 1$, then process of liquid evaporation from the interfacial surface occurs. Zero value of parameter N means that neither condensation nor evaporation occur. In turn, if condition N=1 is met, water evaporation is most intensive.

2 Testing stand and research methodology

Experimental research has been carried out on modified research stand, described in paper [18]. Fig. 2 shows the scheme of testing stand. The main element of the stand was hygrometric cabinet with an electric heater inside. Liquid droplets with given volumes were dropped by means of an automatic pipette on the top, horizontal surface of a sleeve with diameter of $20 \cdot 10^{-3}$ m. The exchangeable sleeve was placed on the heating element. Just under the test surface of the sleeve, two Cu-Const thermocouples were mounted. One of them controlled the temperature regulator and thus the power of heater could be controlled. The other one was the measuring thermocouple that made it possible to determine the solid body surface temperature (accuracy ±0.5°C [26]). Its indications were remitted to the millivoltmeter and to the data acquisition system. In order to measure temperature and air humidity inside of the cabinet, a thermohygrometer was applied (accuracy: ±0.2°C and 2%). Additionally, the surrounding air temperature was measured by means of a mercurial thermometer (accuracy ±0.1°C). In order to measure the air parameters outside the cabinet, a mercurial thermometer (accuracy ±0.1°C), Assmann psychrometer (accuracy ±1%), and mercurial barometer (accuracy ±0.1mmHg) were applied. The liquid droplet spreading process was registered by means of a video camera.

Experimental research was carried out in three stages. In the first stage, it was investigated how surrounding parameters and the kind of material the surface was made of influence the water droplet spreading process. In the next stage, it was analysed how temperature and humidity of the air, as well as the roughness of the wall surface affect the spreading of water droplets. Spreading processes for a few chosen liquids (water, aniline, benzene) on the same surface, by changing parameters of humid air, were under research in the third stage.

Liquid droplets' spreading process was carried out on surfaces made of 1H18N9 stainless steel, made of CuCr1Zr copper alloy, and of ordinary glass, respectively.

Surfaces under research were characterized with various values of roughness, according to treatment methods. In case of the sleeve made of 1H18N9 steel, its measuring surface was prepared in three ways of technological processing: turning, grinding with the magnetic grinder, polishing – first with the small-graded sand paper and then with the polish. Measuring surface of the sleeve made of CuCr1Zr copper alloy was prepared in two ways: turning and polishing. In case of glass, the surface was not prepared. For all surfaces under research, roughness measurements of tested areas were made by means of profilometer. Results of these measurements are presented in Tab. 1.

Surfaces of sleeves, after they had been prepared for experiments, were scoured with a detergent to get rid of mechanical impurities and particles of the polish. Next, they were washed thoroughly with distilled water and dried. A day before measurements, each from the surfaces chosen for measurements was additionally washed with distilled water and dried with soft cosmetic pads. Basic measurements were carried out 12 hours after the above activities. In the above time, the

Table 1. Characteristic parameters of roughness for surfaces under research.

Roughness parameters	Surface material and treatment $[10^{-6}$ m]						
	1H18N9	CuCr1Zr	Glass	1H18N9	CuCr1Zr	1H18N9	1H18N9
	polishing	polishing	–	polishing	polishing	turning	grinding
	P_1	P_2	P_3	P_4	P_5	P_6	P_7
R_z	2.59	0.79	1.04	1.00	1.14	19.54	6.94
R_{3z}	1.47	0.41	0.34	0.68	0.75	15.47	5.46
R_{3zm}	2.05	0.56	1.03	0.82	0.96	17.38	6.75
R_{zISO}	2.88	1.01	1.58	1.09	1.24	20.28	7.38
R_a	0.30	0.07	0.08	0.12	0.14	3.96	1.16
R_{max}	4.74	1.25	2.63	1.30	1.47	21.61	7.85

system: solid body surface – humid air reached slowly the state of quasi -stated equilibrium.

For the given liquid, experiments were made for droplets with the same volumes. On the basis of initial measurements, the droplet volume was determined, at which droplets dropped from the pipette by means of their own weight. In case of water and aniline, the volume equalled $V_0 = (15.0 \pm 0.1) \cdot 10^{-9}\text{m}^3$, and the volume of benzene droplets was equal to $V_0 = (8 \pm 0.1) \cdot 10^{-9}\text{m}^3$. It was assumed that droplets were regular spheres in the air, before their contacted the surface. Thus diameters of droplets in atomisation equalled: $d_0 = (3.060 \pm 0.007) \cdot 10^{-3}$m for water and aniline, and $d_0 = (2.48 \pm 0.01) \cdot 10^{-3}$m for toluene.

Pipette ending was placed in chosen heights in relation to the tested area of the sleeve. Height changes were within the range: $(2.4 \div 9.0) \cdot 10^{-3}$m. The initial droplet velocity was assumed to be zero, because the droplet dropped by its own weight. It was also assumed that the transformation process of droplet potential energy into its kinetic energy occurred in the moment of its contact with the surface. On the basis of the above assumptions, droplet velocity in the moment of its contact with the surface was determined:

$$u_0 = \sqrt{2gH}. \qquad (13)$$

Research was carried on for the non-heated surface, and for the surface with the initial temperature of approximately 50°C . The value of air relative humidity inside the hygrometric cabinet was also a controlled parameter. It was controlled by means of changes of the humidifying system.

The measuring procedure is shown below. A day before the measurements the

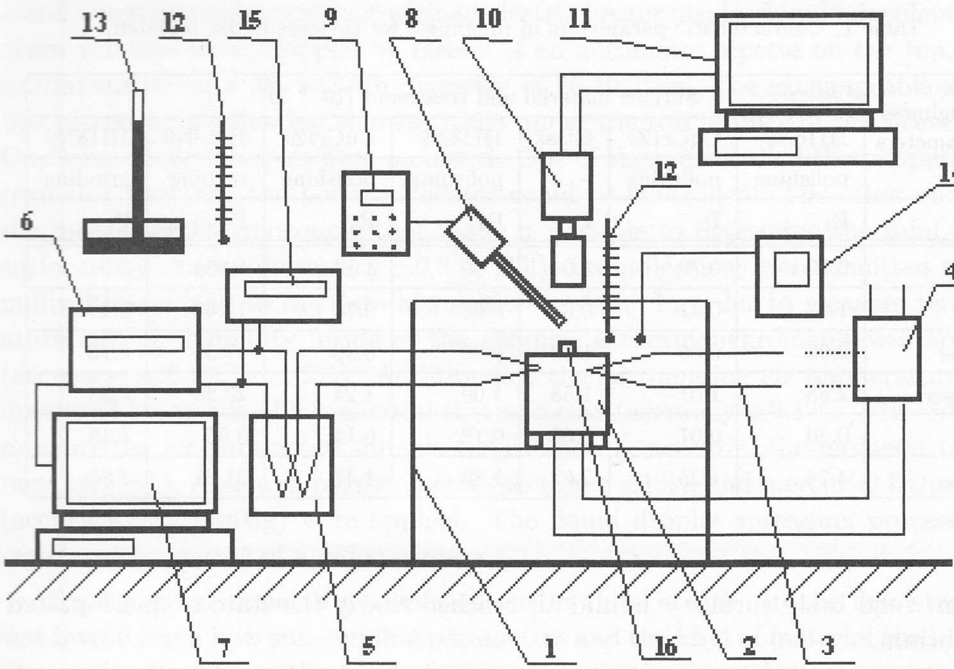

Figure 2. Scheme of testing stand: 1. higrometric cabinet (type SH-1); 2. heater; 3. thermocouple Cu-Const; 4. temperature controller (type GCD); 5. dish with ice; 6. data acquisition system (type Therm 5500-3); 7. PC computer; 8. automatic pipette; 9. control system of the pipette; 10. digital camera (type Fastcam-PCI 500); 11. monitor; 12. mercurial thermometer; 13. mercurial barometer; 14. humidity meters (types LB701 and HT3003), 15. millivoltmeter (type V534); 16. tested area of sleeve.

tested surface was prepared (cleaning, drying). For research on the non-heated surface, and for current parameters of the humid air, it was only proved if the measuring system reached the quasi-stated state and then the first measurements were done. In case of measurements on heated surface, the heating system was set in operation and so controlled that the system surface – surrounding reached the quasi-stated state. Then the first measurement was done. Afterwards, the humidifying system was set in operation and time changes of characteristic parameters in the system were controlled. When the above changes were relatively small, the next measurement was done. The new state of quasi-static equilibrium was reached after a few hours. Before each measurement, just before the droplet was dropped, air humidity and air temperature both inside, as well as outside the testing chamber were measured. Pressure of air and temperature just under the tested area were also measured. Next, video camera and automatic pipette were switched on. The picture was registered just before droplet reached the surface. Picture registration rate was 500 frames per second, which means that pictures were registered at the intervals of 0.002 s. Obtained pictures were processed with the computer picture analysis tools. The analysis required prior determination of the magnitude of picture zooming. The zooming, expressed in pixel to 1 mm, was determined on the basis of a fixed size of a control plate. During the measurements, the height of the camera suspension, as well as the height of lens were not changed and thus the zoom was a constant value. A moment in which droplet reached the state of its maximal spreading on the surface (picture denoted as 0 ms in Fig. 3) was searched for in each registered cycle of droplet spreading. Diameter of maximal spreading was measured in four various cross-sections. Mean value of droplet spreading diameter $D_{z\,max}$ was analysed, and it was assumed that the wetting area was a circle. In reality, the shape of wetting area depended on the spot in which the contact line stopped, that is, on the heterogeneity of the surface.

Diameter of the droplet in atomization d_0, as mentioned before, was calculated on the basis of its volume V_0. Droplet spreading coefficient β_{zmax} was determined according to the Eq. (1):

$$\beta_{z\,max} = \frac{D_{z\,max}}{d_0}$$

On the basis of calibration characteristics of thermo-couple Cu-Const, values of temperatures just under the tested area of sleeve. It was assumed that the above temperatures were equal with initial temperatures of the surface. Next, coefficient κ was calculated:

$$\kappa = \left(\frac{\lambda_l\, c_l\, \rho_l}{\lambda_w\, c_w\, \rho_w} \right)^{1/2} \tag{14}$$

and then contact temperature was determined, on the basis of surface and liquid temperatures:

$$T_c = \frac{T_l\,\kappa + T_w}{1+\kappa}. \tag{15}$$

The contact temperature and parameter κ were defined by Seki et al. [9].

On the basis of air temperature measurements in a significant distance from the tested area, and on the basis of contact temperature, values of respective partial pressures were calculated. In order to make the calculations easier, a simplified approximation equation was applied. The above equation described changes of water vapor saturation pressure to temperature:

$$p = 6.117 \cdot 10^{-4} + 4.335 \cdot 10^{-5} \cdot t + 1.535 \cdot 10^{-6} \cdot t^2 + 2.446 \cdot 10^{-8} \cdot t^3 + \\ +2.687 \cdot 10^{-10} \cdot t^4 + 3.138 \cdot 10^{-12} \cdot t^5 \quad [\mathrm{Pa}] \tag{16}$$

The equation was valid for air temperature range $t = 2 \div 67°\mathrm{C}$.

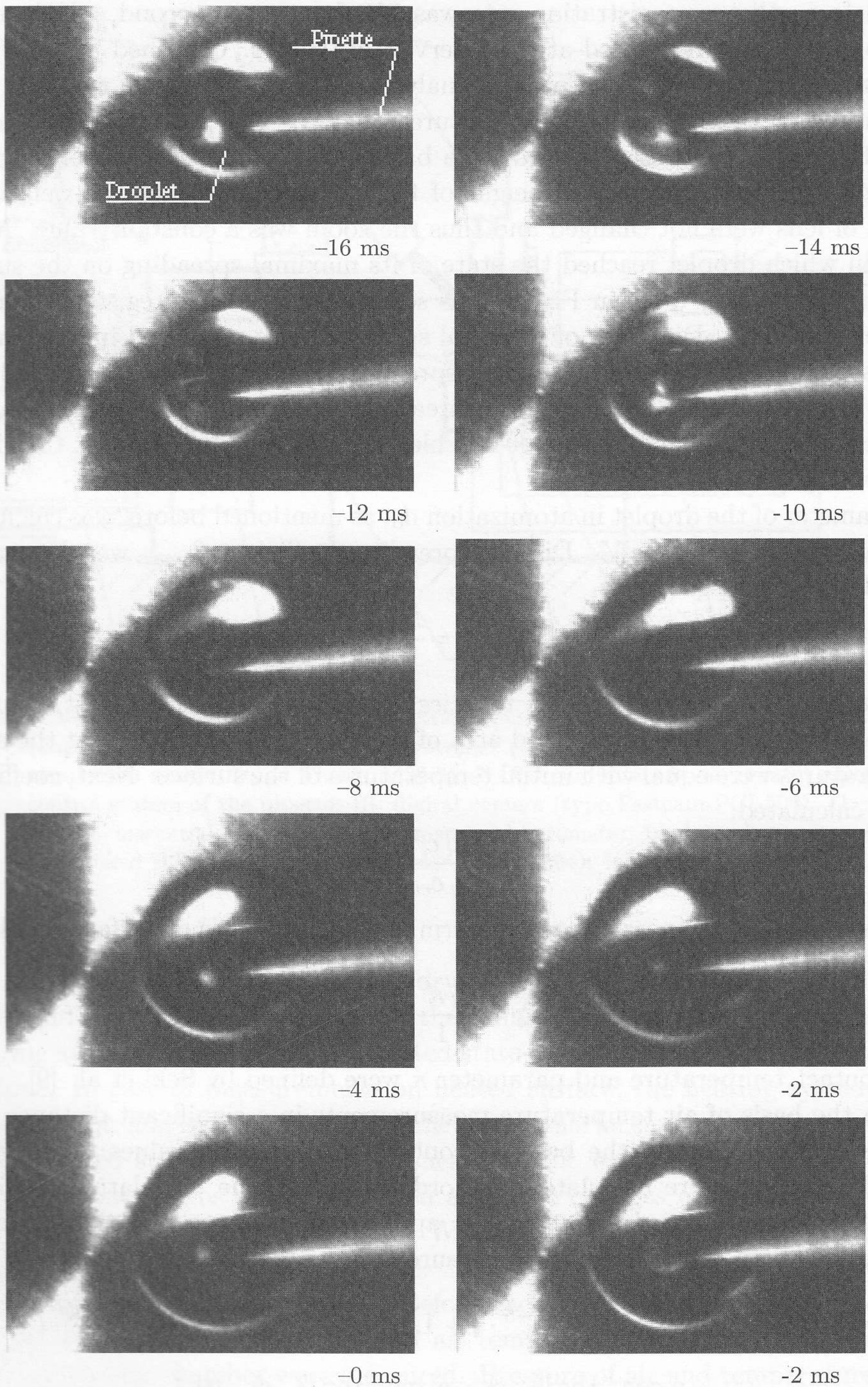

Figure 3. Sample cycle of droplet spreading on the surface made of 1H18N9 stainless steel (P_1).

Parameter N , dimensionless stream of mass exchanged between the water microfilm and humid air, was determined from the Eq. (12).

In turn, parameter C was determined from the modified formula (3):

$$C = \frac{(12 + \mathrm{We})\,\beta}{3\beta^3} - \frac{8}{3\beta^3} - \frac{4\mathrm{We}}{3\sqrt{\mathrm{Re}}} - 1 \tag{17}$$

after values of Weber and Reynolds numbers have been determined from equations (4) and (5), respectively.

The methodology of evaluation of measurement errors was presented in paper [26]. The measurement errors for water droplets were following: $\Delta D_{z\,\max} = \pm 3.7 \cdot 10^{-5} m$, $\Delta\beta_{z\,\max} \cong \pm 0.004$, $\Delta T_c = \pm 0.49K$, $\Delta N = 0.0010 \div 0.0018$, $\Delta \mathrm{We} = 2.15 \pm 0.09$ or $\Delta \mathrm{We} = 7.42 \pm 0.10$ and $\Delta \mathrm{Re} = 735 \pm 23$ or $\Delta \mathrm{Re} = 1280 \pm 25$.

3 Results of research and discussion

In the first stage of research, it was analysed how parameters of humid air affected the process of wetting the surface by a water droplet when the kind of material the surface was made of changed. Three of surface were under scruting: surface made of 1H18N9 stainless steel (P_1), surface made of CuCr1Zr copper alloy (P_2), and surface made of common glass (P_3). Detailed results are given in papers [19-25].

Figure 4 presents relations between water droplet spreading coefficient and parameter N for the three surfaces under research. Results of investigations were compared in relation with two values of Weber number, and for two different contact temperatures. Straight lines were drawn, so that they connected the respective measurement points and thus trends of changes of analysed parameters could be illustrated. Continuous lines referred to the lower contact temperatures (initial surface temperatures), and dotted lines referred to the higher values of the above temperatures. On the basis of analysis of data shown in Fig. 4, it could be stated that the influence of parameters of humid air was increasingly relevant with decreasing values of Weber number. Weber number concerned most of all the effect of dropping velocity, that means, also the initial spreading velocity. And thus, effect of the gas phase on the wetting process should be considered mainly in placement process of droplet on the surface.

For We= 7.43, trend lines covered each other and they were nearly horizontal. The above fact means that parameters of the surrounding do not affect relevantly the process of liquid droplet spreading. In order to make the analysis of results of research for Weber number We= 2.16. Fig. 5 was plotted. It was stated that spreading coefficient diminished with the increase of parameter N. Thus, more intensive evaporation of water microfilm that formed in the vicinity of contact

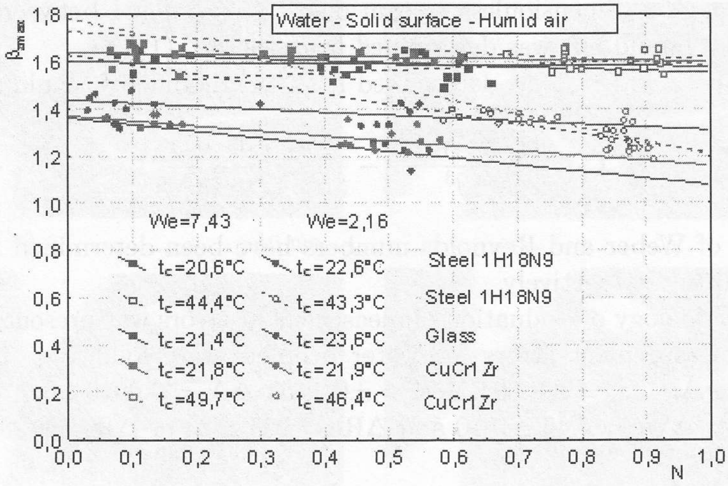

Figure 4. Relationship between water droplet spreading coefficient $\beta_{z\,\max}$ and parameter N for surfaces made of: 1H18N9 (P_1), CuCr1Zr (P_2) and glass (P_3), respectively.

area (higher value of parameter N) aggravated the conditions for water droplet spreading on surfaces under research. In case when temperature of the surface was equal with temperature of the surrounding, most significant changes of spreading coefficient for water droplet were observed for steel surface, whereas the smallest changes of the spreading coefficient were observed for the glass surface. For the heated surface, the same values of spreading coefficient for water droplet were obtained at higher values of parameter N.

Figure 6 illustrates the change of $\beta_{z\,\max}$ spreading coefficient with coefficient C. It shows that higher values of coefficient C relate to lower values of spreading parameter.

Figures 7 and 8 present the relation between coefficients C and N for non-heated and heated surfaces, respectively, for two different values of contact velocities. As it has already been mentioned, with lower values of Weber number, effect of humid air parameters on the wetting process is significant. Analysis of results of research presented in Fig. 7 shows that parameter C grows with the increase of parameter N. Linear tendency line between analysed parameters was assumed. Thus, stronger evaporation of water microfilm resulted in the change of surface energies (surface tensions) on borderlines: solid body – liquid, or solid body - gas. Similar relation between parameters C and N was obtained in case of spreading of water droplets on heated surfaces (Fig. 8). It could be assumed that the change of initial surface temperature changed the contact temperature, and changed the physical parameters of media under research, as well. In turn,

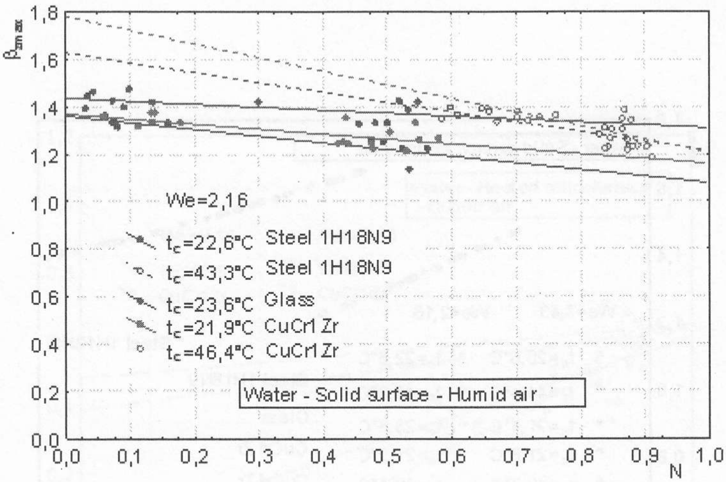

Figure 5. Relationship between water droplet spreading coefficient $\beta_{z\,\max}$ and parameter N for analysed material of surfaces; We= 2.16.

the above fact affected the values of parameter C. Fig. 9 illustrates the change of parameter C with parameter N for Weber number We= 2.16, and for two contact temperatures under research.

However, surfaces analysed in the first phase of measurements were characterised with different values of roughness. Parameter R_z, that characterised the mean roughness for steel, copper, and glass surfaces, respectively, equalled: $2.59{\cdot}10^{-6}$ m, $0.79{\cdot}10^{-6}$m and $1.04{\cdot}10^{-6}$ m, respectively. Because of the above fact, a series of measurements for two materials with similar roughness was repeated. Surfaces made of 1H18N9 (P_4) steel and of CuCr1Zr (P_5) copper alloy with parameter R_z equal with: $1.00\cdot10^{-6}$; $1.14\cdot10^{-6}$ m, respectively, were chosen for scruting. Figures 10-12 show the processed results of research. Measurements were carried out for initial surface temperature equal with the surrounding temperature (non-heated surface). On the basis of the analysis of data shown in Figs. 10–12, it was stated that if surfaces under research had the similar roughness characteristics, effect of humid air parameters on the spreading process of water droplets was independent from the kind of material the surface was made of.

In the next phase of research, analysis of effect of humid air parameters and of surface roughness on the size of area wetted by water droplet [24, 25] was made. The spreading process of water droplet on the surface made of 1H18N9 stainless steel was analysed. Three surfaces with various roughness values (Tab. 1) were under research. The first surface was characterised with concentrically placed irregularities resulting from turning (P_6). The second surface was selected and

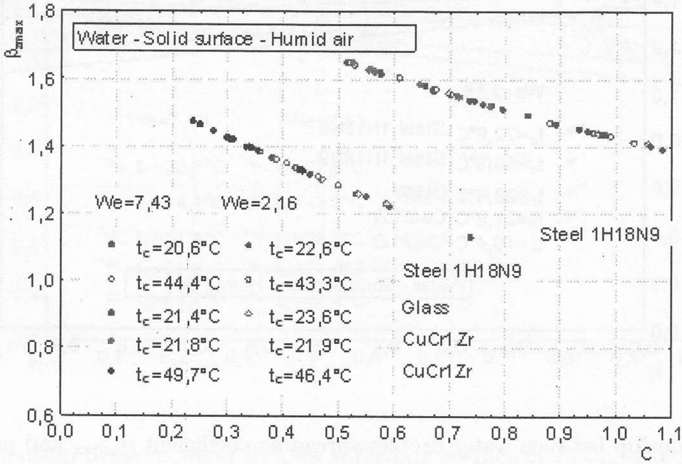

Figure 6. Relationship between water droplet spreading coefficient $\beta_{z\,\max}$ and parameter C for analysed material of surfaces.

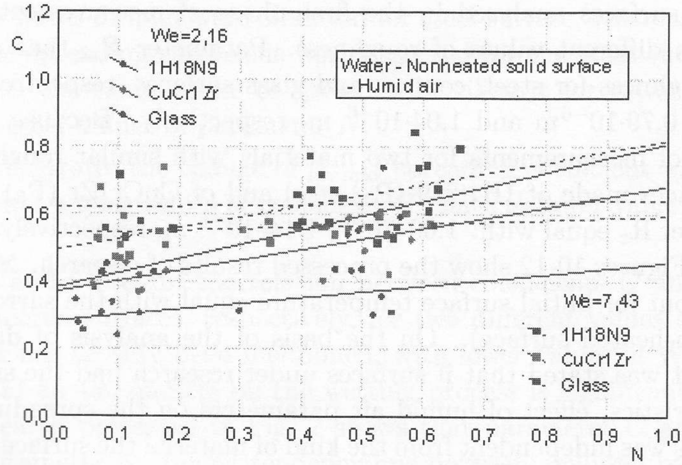

Figure 7. Relationship between parameter C and parameter N for analysed material of surfaces; for non-heated surface.

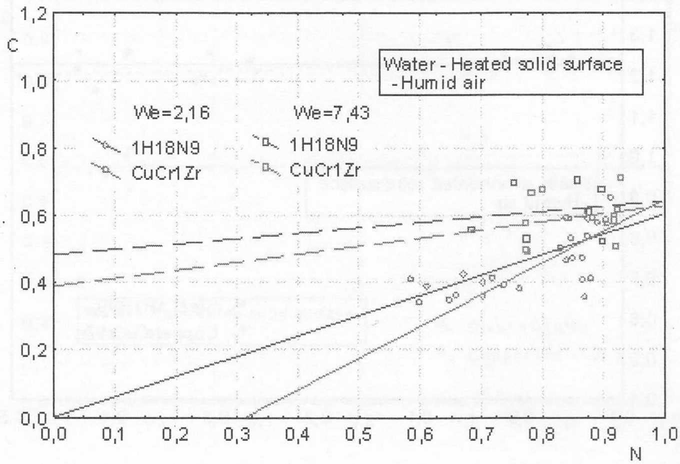

Figure 8. Relationship between parameter C and parameter N for analysed material of surfaces; for heated surface.

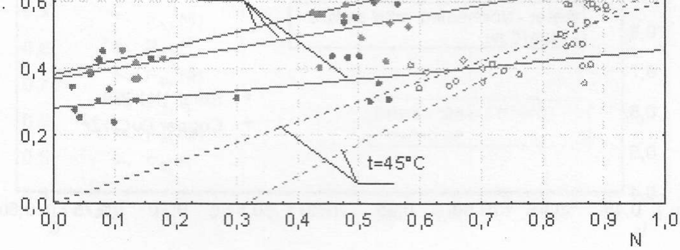

Figure 9. Relationship between parameter C and parameter N for analysed material of surfaces.

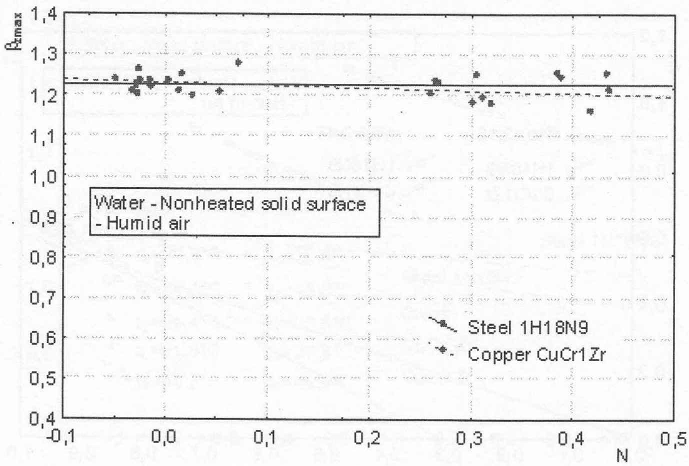

Figure 10. Relationship between water droplet spreading coefficient $\beta_{z\,\mathrm{max}}$ and parameter N for surfaces made of 1H18N9 (P_4) and CuCr1Zr (P_5); We= 2.16.

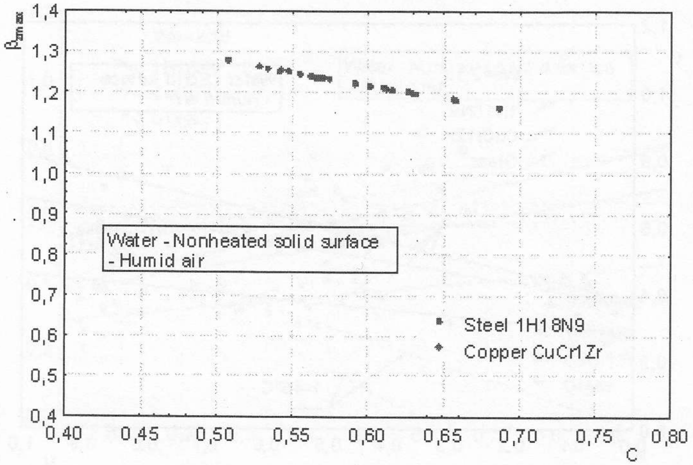

Figure 11. Relationship between water droplet spreading coefficient $\beta_{z\,\mathrm{max}}$ and parameter C for surfaces made of 1H18N9 (P_4) and CuCr1Zr (P_5); We= 2.16.

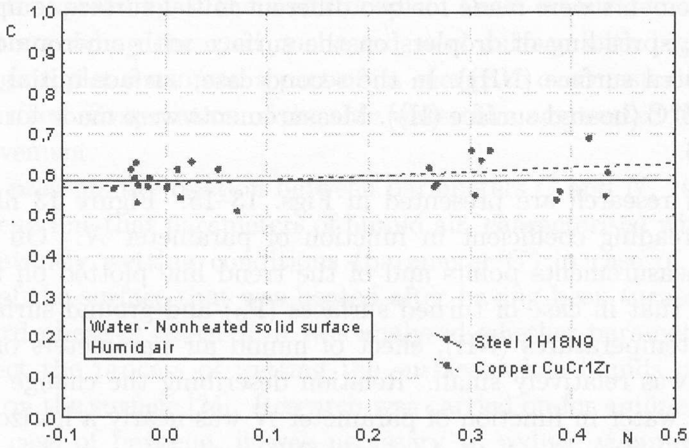

Figure 12. Relationship between parameter C and parameter N for surfaces made of: 1H18N9 (P_4) and CuCr1Zr (P_5); We= 2.16.

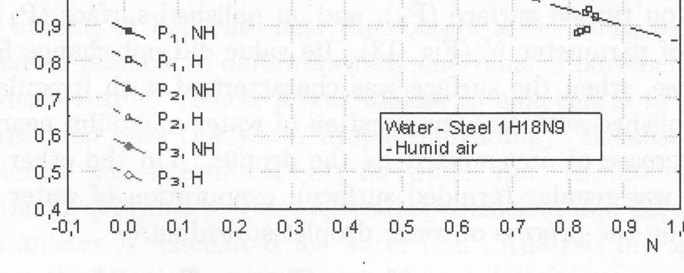

Figure 13. Relationship between water droplet spreading coefficient $\beta_{z\,\max}$ and parameter N for surface made of 1H18N9T.

then manually polished, first with sand paper, graded 400, and then with the polishing paste (P_1). In this case, irregularities were random. The third surface was prepared by means of a magnetic grinder and irregularities were parallel (P_7). Measurements were made for two different initial surface temperatures. In the first case, spreading of droplets on the surface with environment temperature (non-heated surface (NH)). In the second case, surface initial temperature equalled ca 50°C (heated surface (H)). Measurements were made for Weber number We= 2.16.

Results of research are presented in Figs. 13–15. Figure 13 illustrates the change of spreading coefficient in function of parameter N. On the basis of position of measurements points and of the trend line plotted on these points, it was stated that in case of turned surfaces (P_6) and ground surfaces (P_7), at environment temperatures (NH), effect of humid air parameters on the size of wetting area was relatively small. Relation describing the change of spreading coefficient for water in function of parameter N was nearly a horizontal line. In case of polished (P_1), non-heated surface (NH), spreading coefficient $\beta_{z\ \max}$ for water diminished with increase of parameter N. Thus, it could be stated that for non-heated surfaces with small roughness, the microfilm that formed in the vicinity of contact line filled in "thoroughly" the valleyes in the surface. As a result, better spreading of water was possible and spreading coefficient reached higher values. On the other hand, if the surface was characterised with high roughness, valleyes in the surface, even if covered with the water microfilm, were relevant enough to restrain the droplet movement on the surface. Besides, the spreading water was constrained to push out the air present in the valleyes of the surface. Thus, in the latter case, effect of the microfilm on water spreading was much lower.

For water droplets dropped on heated surfaces (H), it was stated that spreading coefficient on turned surface (P_6), and on polished surface (P_1) diminished with increase of parameter N (Fig. 13). Its value did not change for a grinded surface. In case, when the surface was characterised with irregular roughness (turned and polished surfaces), evaporation of water microfilm near the contact line caused decrease of area wetted by the droplet. On the other hand, when the roughness was regular (grinded surface), evaporation of water film had no relevant effect on the process of water droplet spreading.

Figure 14 presents the change of spreading coefficient for water droplet in function of parameter C. Parameter C had positive values in the range from 0.3 to 1.1. In turn, spreading coefficient $\beta_{z\ \max}$ changed in the range from 0.9 to 1.4. As it is shown in Fig. 14, parameter C decreased, and spreading coefficient $\beta_{z\ \max}$ increased with lower roughness of the surface. It could also be stated that the highest values of spreading coefficient were obtained for heated, polished and grinded surface, and the lowest values of spreading coefficient were obtained for heated, turned surface.

It could be concluded that heating the steel surface with low roughness provided the better spreading of the water droplet. Least favourable conditions for water droplet spreading occurred on heated steel surface with high roughness. The spreading droplet consumed a part of its energy to overmaster the irregularities of the surface. Evaporation of the thin water film aggravated the conditions for liquid movement.

Figure 15 presents the relation between parameters C and N. It results from analysis of trend line that parameters of humid air, characterised with parameter N, affect relevantly wetting conditions (parameter C) in case of the polished surface, and of the surface that was heated after having been turned.

In the third phase of research, it was analysed whether parameters of humid air could affect the process of wetting the surface, when liquids different from water spread on the surface [24]. Research was carried on for aniline and benzene droplets. In case of benzene, it was necessary to reduce volumes of dropped droplets.

Before droplets of aniline and benzene were dropped on the surface, the surface was in contact only with humid air for a long time. As a result absorption and desorption of water vapor molecules on the surface, a thin water film could form. Its appearance could affect the process of spreading of droplets aniline, or of benzene. It was the aim of research to prove if processes that occurred on the surface before droplets were dropped could have effect on the spreading of droplets of aniline, or of benzene. Partial pressure of vapour of the liquid (aniline, or benzene) equalled zero in a long distance from the liquid-gas interphase surface, because concentration of vapour of liquid in humid air also equalled the value of zero. Thus, parameter N, according to Eq. (12), acquired the value of $N = 1$ each time. The above fact meant a very intensive evaporation of liquid microfilm (of aniline, or benzene) near the contact area. Thus, research in such conditions made it possible to determine only one value of parameter N, for each of liquids under scruting. Hence, it was useless to plot charts as in the case of the earlier presented ones (for water droplet spreading). Because of the above fact, parameter N was determined only for water film. Results of research are presented in the form of charts where spreading coefficient and parameter C were related to parameter N calculated for water film. Analysis of Figs. 16 and 17 confirmed, that the effect of water film on the spreading process of aniline and benzene droplets on the surface was minimal.

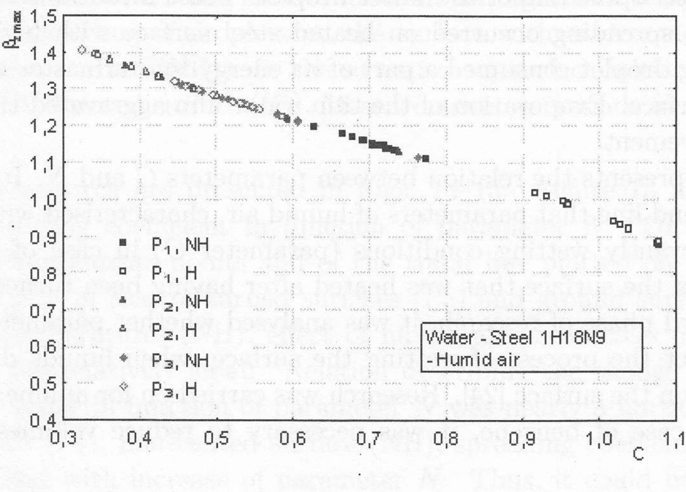

Figure 14. Relationship between water droplet spreading coefficient $\beta_{z\,\max}$ and parameter C for surface made of 1H18N9.

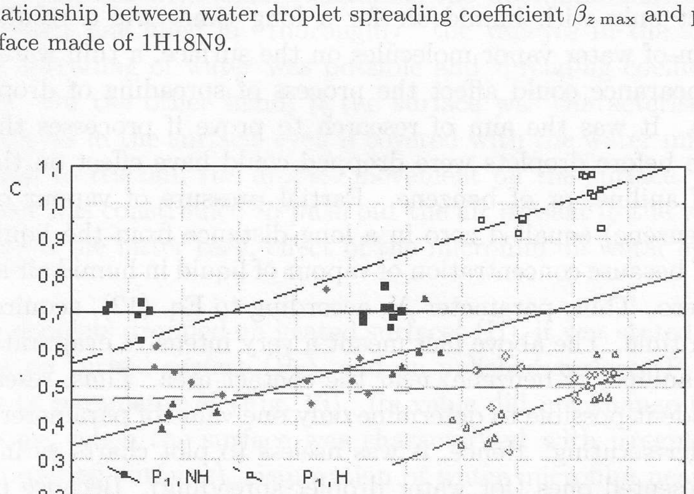

Figure 15. Relationship between parameter C and parameter N for surface made of 1H18N9.

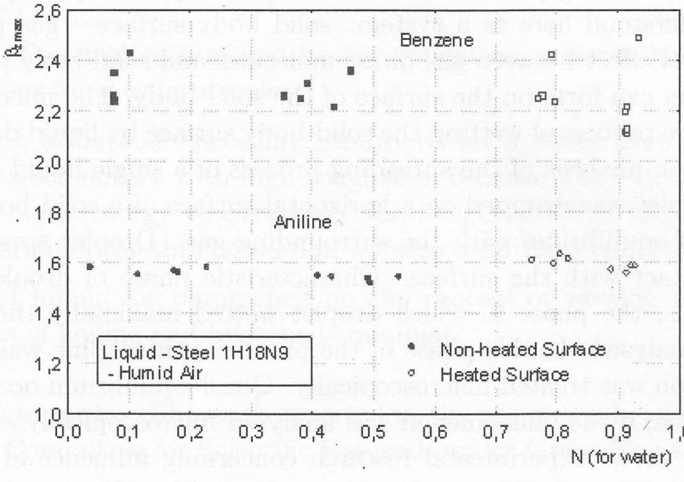

Figure 16. Relationship between aniline and benzene droplet spreading coefficients $\beta_{z\,\max}$ and parameter N (evaluated for water).

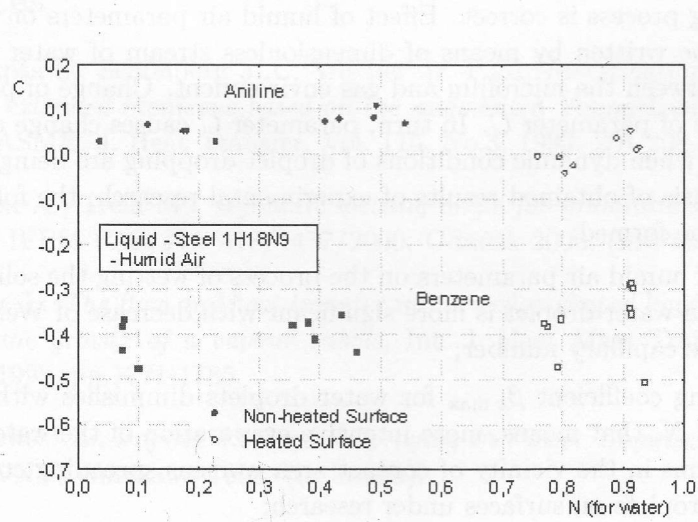

Figure 17. Relationship between parameter C and parameter N (evaluated for water).

4 Conclusions

The present paper deals with the problem of the influence of surrounding parameters on the wetting process of a solid body by liquid droplets. Surrounding should be understood here as a system: solid body surface – gas phase. As a result of mutual effect between gas phase molecules and solid body phase, a thin liquid microfilm can form on the surface of the solid body. The microfilm affects significantly the process of wetting the solid body surface by liquid droplets. The paper focuses on analysis of the spreading process of a single liquid droplet.

Liquid droplet was dropped on a horizontal surface of a solid body that was in the state of equilibrium with the surrounding gas. Droplet spread, as a result of its contact with the surface. Characteristic phase of droplet spreading process, that is, the phase in which droplet wetted maximally the solid body surface, was analysed. In this phase of the process, contact line was retained, if the phenomenon was treated macroscopically. Quasi-equilibrium occurred in the microscopic area, if the phenomenon was analysed microscopically.

The paper shows experimental research concerning influence of the kind of material and roughness of the surface, as well as of humid air parameters, on the process of wetting the solid body surface by droplets of water, aniline, and benzene, respectively. On the basis of carried out analysis and obtained research results, it can be stated that application of parameters C and N in description of the wetting process is correct. Effect of humid air parameters on the wetting process can be written by means of dimensionless stream of water vapor mass exchanged between the microfilm and gas environment. Change of parameter N causes change of parameter C. In turn, parameter C causes change of spreading coefficient β (when dynamic conditions of droplet dropping are being preserved).

On the basis of obtained results of experimental research, the following conclusions can be formed:

1. effect of humid air parameters on the process of wetting the solid body surface by a water droplet is more significant with decrease of Weber number, or of the capillary number;
2. spreading coefficient $\beta_{z\ \max}$ for water droplets diminishes with rise of parameter N, that means, more intensive evaporation of the water microfilm that forms in the vicinity of contact area worsens spreading conditions for water droplets on surfaces under research;
3. for a given value of parameter N, values of spreading coefficient $\beta_{z\ \max}$ for water droplet are lower, with rise of surface initial temperature;
4. parameter C rises with the rise of parameter N, which in turn causes, that spreading area of water droplet diminishes, and thus spreading coefficient $\beta_{z\ \max}$ is lower;

5. roughness of the surface affects significantly the wetting process;
6. if surfaces under research have similar characteristics of roughness, effect of humid air parameters does not depend on kind of material surfaces are made of;
7. heating the steel surface and its low roughness preserve better spreading conditions for a water droplet;
8. the least favourable spreading conditions for a water droplet occur on a heated steel surface with high roughness, because water droplet consumes a part of its energy to overpower the irregularities of the surface, while evaporation of the thin liquid film worsens conditions of droplet movement;
9. effect of humid air parameters on the process of wetting the surface by droplets of aniline and benzene is minimal.

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