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Experimental investigations of hydraulic jump created by a two-phase impinging jet on a solid surface

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Abstract

In the paper the results of experimental investigations concerning the hydraulic jump formed by an aerosol impinging jet have been presented. Results of carried out experiments yield that aerosol impinging jet enables to form significantly higher diameter of the hydraulic jump, as compared with single phase, liquid impinging jet. This is caused by shear stresses, between liquid layer, formed by liquid deposited from aerosol, and gas, which is the second component of aerosol.

Keywords: Hydraulic jump; Impinging jet

Nomenclature

d_h – diameter of a hydraulic jump created by a two-phase impinging jet

d_{kr} – maximal diameter of liquid droplets in a two-phase jet

d_0 – diameter of a hydraulic jump created by a single-phase impinging jet

H – nozzle to surface distance

$\bar{m}_p$ – mass flow rate of air in a two-phase jet

m_w – mass flow rate of water in a two-phase jet

m_p – mass flow rate of air in a two-phase jet

P_{bar} – barometric pressure

Re_p – Reynolds number of air

W_p – velocity of air

ν_p – kinematic viscosity of air

ρ_w – density of water

σ_w – surface tension of water

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1 Introduction

Investigations of phenomena accompanying surface wetting by a two-phase liquid-gas jet can be found quite often in the literature. One of these phenomena is the hydraulic jump. It consist in forming a circular-symmetrical area in which thickness of liquid film is order or more lower than out of the area. Symmetry center of the area is located in a spot, where the jet hits the surface. A border between areas of a low and much higher thickness of liquid layer is very distinct. On a circumference, where the thickness of liquid layer increases dramatically, equilibrium between forces, caused by the momentum change of liquid layer before and beyond the hydraulic jump and hydraulic pressure, takes place. Interest of this phenomenon is caused by the fact, that in the area where the liquid film is thin, heat exchange between the film and the solid surface is very intensive. Besides, the hydraulic jump may be easily created and its parameters precisely controlled. It allows to cool intensively (or to heat), selected elements of electronic instruments or chosen areas with large surfaces. Majority of published papers concern the hydraulic jump formed on a solid surface by a single-phase impinging jet, usually a liquid jet [1-2]. Area of a small thickness film formed by single-phase liquid jet, is relatively small and flow rate of cooling liquid is substantial. It may cause limitation in application of this cooling method, especially when the used liquid is expensive, as for instance oil, the more, application of such liquids are taken into consideration for heat treatment of chosen areas of large elements.

It is possible that mentioned above limitations in application of this phenomenon can be reduced when a two-phase jet, i.e. aerosol, will be applied instead of a single-phase liquid jet.

The reason for formation of a much larger area of a thin liquid film, due to impinging jet consisting of the aerosol, as compared with liquid impinging jet, are shear stresses between liquid film formed from aerosol, and gas which is the second component of aerosol.

The paper presents results of experimental investigations of a hydraulic jump formed on the brass flat plate by aerosol impinging jet consisting of air and water.

2 Schematic diagram of experimental apparatus

Experimental apparatus shown schematically in Fig. 1 consists of two loops:

- open loop, consisting of: air compressor, air flow-meter, nozzle and hosepipes
- closed water loop created by: water tank, water pump, water flow-meter, gauze filter, control valve, nozzle and hosepipes.

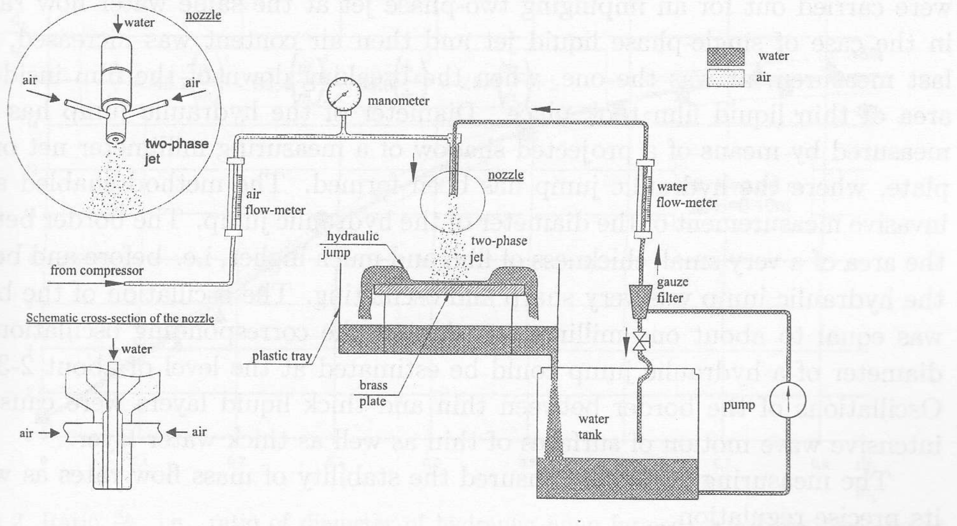

Figure 1. Schematic diagram of experimental apparatus.

Water circulating in the loop, was distillated and the gauze filter was used to eliminate solid contaminations. The surface on which the jet impinges was made of a three millimeter thick brass plate. The plate was exchangeable, to enable carry out experimental investigations concerning the influence of the plate material as well as surface conditions on the phenomenon.

The element creating the aerosol jet was the nozzle shown in Fig. 1. Nozzle to plate distance H, was respectively equal to 60 mm and 100 mm, and internal diameter of water supply pipe to the nozzle was 0.6 mm. Internal diameter of the nozzle was 2 mm. During experiments the impinging jet has been directed to the center of the plate, but the assembly is equipped with a special device, which enables direction of the jet to an arbitrary point of the plate, at arbitrary angle as well as from optional distance H. Using such apparatus it was possible to carry out experimental investigations in a wide range of mass flow rate of water and air, creating the impinging jet. Experiments, of which the results have been presented in this paper, were carried out at low water mass flow rates, because these experiments concerned a hydraulic jump formed with the low amount of water.

3 Method of carrying out experimental investigations

The first recording was always a measurement of the diameter of hydraulic jump formed by an impinging single phase water jet. Subsequent measurements were carried out for an impinging two-phase jet at the same water flow rate a in the case of single-phase liquid jet and then air content was increased. Th last measurement was the one, when the breaking down of the film inside th area of thin liquid film took place. Diameter of the hydraulic jump has bee measured by means of a projected shadow of a measuring millimeter net on th plate, where the hydraulic jump has been formed. The method enabled a no invasive measurement of the diameter of the hydraulic jump. The border betwee the area of a very small thickness of film and much higher, i.e. before and beyon the hydraulic jump was very sharp and oscillating. The oscillation of the borde was equal to about one millimeter, whereas the corresponding oscillation of diameter of a hydraulic jump could be estimated at the level of about 2-3 mm Oscillations of the border between thin and thick liquid layers were caused b intensive wave motion of surfaces of thin as well as thick water layer.

The measuring apparatus ensured the stability of mass flow rates as well a its precise regulation.

4 Results of experimental investigations

In this paper results of investigations of the diameter of hydraulic jum formed on a brass plate by perpendicular two-phase water-air impinging jet hav been presented. Presented in the Table 1 range of parameters at which inves gations were carried out allow to obtain the diameter of hydraulic jump startin from a single-phase, water impinging jet, up to the hydraulic jump formed b aerosol impinging jet at subsonic velocity.

Results of experimental investigations are shown in Fig. 2 as a ratio of d_h i.e, the ratio of a diameter of hydraulic jump, formed by impinging aerosol j to a diameter of hydraulic jump caused by single-phase water jet at the sam mass flow rate, as a function of the ratio of mass flow rate of air and wat m_p/m_w. The investigations were carred out for mass flow rate of water equ $7\ l/h$ and nozzle to plate distance 0.06 and 0.10 m. Carried out investigatio did not yield the influence effect of the nozzle to plate distance on the course phenomenon and on the diameter of hydraulic jump. From among various typ of mathematical functions, the results of experiments, show the best consiste when are approximated using a fourth order polynominal in the form:

$$\frac{d_h}{d_0} = 45.2\Big(\frac{\dot{m}_p}{\dot{m}_w}\Big)^4 - 89.4\Big(\frac{\dot{m}_p}{\dot{m}_w}\Big)^3 + 34.5\Big(\frac{\dot{m}_p}{\dot{m}_w}\Big)^2 + 25.6\Big(\frac{\dot{m}_p}{\dot{m}_w}\Big) + 1.$$

To characterize the aerosol jet, calculations of maximum diameter of wa droplets d_{kr} flowing in the aerosol have been done. The diameter is determ

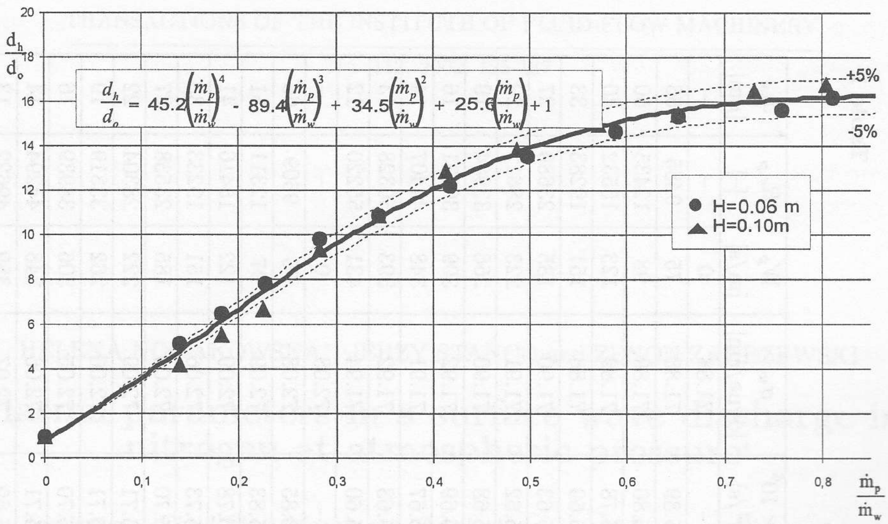

Figure 2. Ratio $\frac{d_h}{d_o}$, i.e. ratio of diameter of hydraulic jump formed on a brass plate by an aerosol impinging jet to diameter of hydraulic jump caused by single-phase water jet as a function of ratio of mass flow rate of air and water $\frac{\dot{m}_p}{\dot{m}_w}$.

by the following correlation

$$d_{kr} = \frac{585}{W_p}\sqrt{\frac{\sigma_w}{\rho_w}}, \tag{2}$$

taken from [3].

Dimensions of the physical quantities in the formula (2) are as follow: d_{kr} [μm], ρ_w [g/cm^3], σ_w [dyne/cm], W_p [m/s].

As shown in Tab. 1, maximum diameter of droplets d_{kr}, in the aerosol, which is mainly a function of air velocity W_p, is equal 17÷70 μm.

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Table 1

$m_w \approx 7$ l/h, $d_o = 0.012$ m, $d_d = 0.0006$m, $P_{bar} = 767$mm Hg

Lp.	H [m]	$\frac{m_p}{m_w}$	d_h/d_w [–]	V_p [l/h]	d_h [m]	t_w [^{0}C]	t_p [^{0}C]	P_{man} [kG/cm^2]	$\nu_p \times 10^6$ [m^2/s]	σ_w [dyne/cm]	W_p [m/s]	$R_{e,p}$ [–]	d_{kr} [μm]
1		0	1	0	0.012	25.1	–	–	–	71.88	0	–	–
2		0.139	5.16	800	0.062	25.1	22.1	0.10	15.89	71.88	75	9485	66
3		0.182	6.5	1000	0.078	25.1	21.2	0.20	15.80	71.89	98	12435	50
4		0.228	7.83	1200	0.094	25.0	20.9	0.30	15.78	71.89	123	15532	40
5		0.283	9.83	1400	0.118	25.2	19.9	0.46	15.69	71.86	151	19283	33
6		0.344	10.82	1600	0.130	25.0	19.3	0.68	15.63	71.90	185	23689	27
7		0.417	12.17	1800	0.146	24.9	19.1	0.94	15.62	71.91	223	28612	22
8	0.06	0.497	13.49	2000	0.162	25.0	19.7	1.24	15.68	71.90	266	33984	19
9		0.588	14.67	2200	0.176	24.9	19.9	1.50	15.69	71.92	309	39431	16
10		0.653	15.33	2400	0.184	24.9	19.7	1.66	15.67	71.91	348	44407	14
11		0.7588	15.65	2600	0.188	24.8	19.2	1.90	15.63	71.92	393	50328	13
12		0.81	16.17	2800	0.194	24.7	18.9	2.00	15.60	71.94	431	55220	12
13		0	1	0	0.012	23.9	–	–	–	72.08	0	–	–
14		0.139	4.17	800	0.050	23.9	21.6	0.10	15.85	72.08	75	9509	66
15		0.181	5.5	1000	0.066	23.8	21.5	0.18	15.83	72.09	97	12311	51
16		0.226	6.66	1200	0.080	23.8	20.9	0.28	15.78	72.09	122	15416	41
17		0.283	9.33	1400	0.112	24.0	20.3	0.46	15.73	72.06	151	19233	33
18		0.344	10.83	1600	0.130	23.8	20.0	0.68	15.70	72.09	185	23538	27
19		0.414	12.82	1800	0.154	23.8	20.1	0.92	15.71	72.09	222	28304	22
20	0.10	0.487	13.83	2000	0.166	24.0	20.1	1.16	15.71	72.06	262	33319	19
21		0.57	15.0	2200	0.180	24.0	20.0	1.44	15.70	72.05	306	38939	16
22		0.653	15.45	2400	0.186	24.0	20.1	1.66	15.71	72.06	348	44294	14
23		0.73	16.5	2600	0.198	23.9	19.9	1.84	15.69	72.07	389	49622	13
24		0.804	16.8	2800	0.202	23.9	19.9	1.96	15.69	72.07	428	54541	12