International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

TuEngr Group

PAPER ID: 10A11B

LONGITUDINAL FLOW OF A CONICAL DEFLECTOR WITH A STREAM OF VISCOUS INCOMPRESSIBLE LIQUID

Alexander I. Esin [a*], Dmitry A. Solovyev [a], Galina N. Kamyshova [a], Larisa A. Zhuravleva [a], Dmitry G. Goryunov [a]

[a] *Saratov State Agrarian University named after N.I. Vavilov, RUSSIA*

ARTICLEINFO

Article history
Received 01 May 2019
Received in revised form 09 July 2019
Accepted 25 July 2019
Available online 31 July 2019

Keywords:
Jet flow; Conical nozzle; Water film thickness; Correction factor; Friction forces; Froude number; Trajectory; Jet departure distance.

ABSTRACT

This article deals with a longitudinal jet axisymmetric flow around a conical deflector by an averaged turbulent flow of an incompressible fluid. An equation is given to determine the thickness of a water film that comes down from the deflector, and depends on the work of friction forces and kineticity of the incident flow. The distance of departure of the jet (radius of the deflector) and comparison with the experiment is given.

1. INTRODUCTION

The longitudinal axisymmetric flow around a turbulent jet of a conical deflector is so complicated that at present. It is not possible to describe this process not only on the basis of the differential Navier – Stokes equations but also using the averaged Reynolds equations [1]. Wrapping conical deflectors is of great practical importance in the design of short-jet sprinkler heads. The flow of the fluid flowing around the conical deflector takes a fairly stable close to the conical shape of the film. It remains at some distance from the vanishing point of the surface of the deflector. After this, it loses stability and is broken up into separate drops. According to the experiments [2, 3], the disintegration of the jet begins from the peripheral part. Therefore, droplets forming in the central zone of the jet have the greatest range. The point of their fall is the point of maximum departure of the jet. The concept of “jet path” in this case refers to any axial section of an axisymmetric flow, with theassumption that the transverse dimensions of the compact part of the liquid film are small compared with the range and height of departure. In fact, it is believed that all the liquid moves along a single trajectory connecting the center of the living section of the film and the point of maximum departure, and is the envelope of the trajectories of all the droplets of the jet [2]. In the axisymmetric

*Corresponding author (Alexander I. Esin). E-mail: esinai@yandex.ru. ©2019 International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies. Volume 10 No.9 ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8 Paper ID:10A11B http://TUENGR.COM/V10A/10A11B.pdf DOI: 10.14456/ITJEMAST.2019.129

case, the transverse dimensions of the compact part of a liquid film are uniquely determined by the thickness of the film that comes down from the deflector. Historically, the determination of the film thickness, as well as force interaction between the fluid and the deflector, is calculated without taking the friction forces into account [2-6]. In [7] it was established (Figure 1) that thickness of the film on the deflector depends on the full hydraulic drag coefficient ζ (zeta), and Froude numbers of the incoming flow:

$$\delta = -\frac{r}{\cos\beta} + \sqrt{\frac{r^2}{\cos^2\beta} + k_0\frac{r_0^2}{\cos\beta}} \quad (1),$$

where

r, r_0, β – geometrical parameters of the deflector pair (nozzle - deflector),

$k_0 = \sqrt{\frac{\alpha_1+\zeta}{\alpha_0-\frac{2}{Fr_0}}}$ – correction factor that takes into account the work of friction forces and the kineicity of the incident flow, α_0, α_1 – Coriolis coefficients, $Fr_0 = \frac{V_0^2}{gz_0}$ – Froude number.

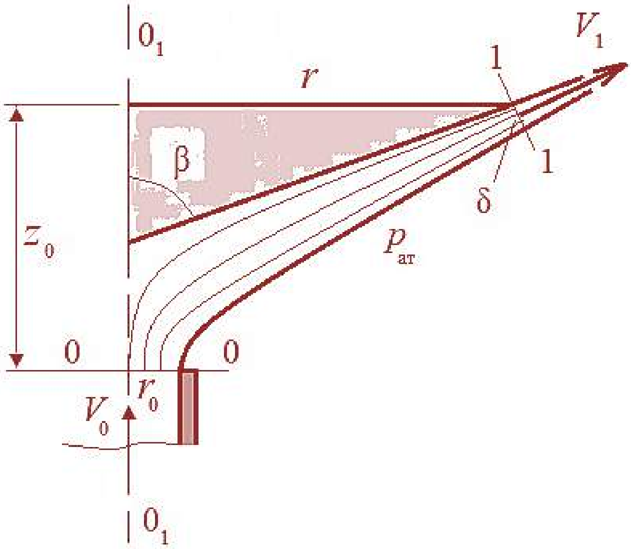

Figure 1: Scheme of jet flow around a conical deflector.

The average velocities in the calculated living sections 0–0 and 1–1 are related by:

$$V_0 = k_0 V_1 \quad (2).$$

From Equation (1), it is inferred that the coefficient k_0 can be determined empirically by the known geometrical parameters of the deflector pair and the film thickness.

Consider the trajectory and the departure length of the jet L (range nozzle). Neglecting the wind speed, let us imagine that the origin of coordinates is placed in the center of gravity of the living section 1 - 1 (see Figure 1). The distance from the center of gravity of the living section 1 - 1 to the surface of the earth will be $z_{\text{нас}}$ + 0.5δcosα.

Insofar as $z_{\text{нас}}$ >> 0.5δcosα, then we will later consider only $z_{\text{нас}}$ – deflector installation height.

With axisymmetric fluid motion in the deflector for any axial flow section in the absence of air resistance, the jet trajectory equation can be written as [8]:

$$z = xtg\alpha - \frac{g}{2V_1^2\cos^2\alpha}x^2.$$

Excluding speed V_1 using equation (2), we get:

$$z = xtg\alpha - k_0^2\frac{g}{2V_0^2\cos^2\alpha}x^2.$$

For cylindrical nozzle speed V_0 can be represented by [8]:

$$V_0 = \mu\sqrt{2gH},$$

where μ is the coefficient of speed (consumption) nozzle; *H* is head in front of the nozzle.

Then the jet trajectory equation takes as

$$z = xtg\alpha - \frac{k_0^2}{4\mu^2H\cos^2\alpha}x^2.$$

Energy loss to overcome air resistance when α < π/4 approximately equal to [8]:

$$h_f \approx \lambda\frac{l}{4R_1}\frac{V_1^2}{2g} = \frac{\lambda}{k_0^2}\frac{x}{4R_1\cos\alpha}\frac{2g\mu^2H}{2g} = \lambda\frac{\mu^2}{4k^2}\frac{Hx}{R_1\cos\alpha}\ ,$$

where λ is drag coefficient; R_1 is the hydraulic radius of section 1 - 1. Then, the final view of the jet's trajectory is written as:

$$z = xtg\alpha - \frac{k_0^2x^2}{4\mu^2H\left(1-\frac{k_0^2}{4\mu^2H\cos\alpha}\frac{K}{}x\right)\cos^2\alpha} \quad (3),$$

where $K = \lambda\frac{\mu^4}{k_0^4}\frac{H}{R_1}$ is dimensionless parameter depending, in general, on r0, r1, α, δ, H, and resistance in the deflector and air.

From Equation (3) with z =$-z_{\text{нас}}$, the radius L of the action nozzle can be determined from

$$-z_{\text{нас}} = Ltg\alpha - \frac{k_0^2L^2}{4\mu^2H\left(1-\frac{k_0^2}{4\mu^2H\cos\alpha}\frac{K}{}L\right)\cos^2\alpha} \quad (4).$$

The solution of the quadratic equation (4) has the following form [9]:

$$\left.\begin{aligned} L &= L_0 \cos\alpha, \\ L_0 &= z_{\text{нас}} \frac{\sqrt{(aK-\sin\alpha)^2+4a(1+K\sin\alpha)}-aK+\sin\alpha}{2a(1+K\sin\alpha)}, \\ a &= \frac{k_0^2 z_{\text{нас}}}{4\mu^2 H}. \end{aligned}\right\} \quad (5)$$

Hydraulic radius R1 living section 1 - 1, which is a truncated cone with a generator δ (see Figure 1) is approximately equal to δ. Thus, the parameter K takes the form

$$K = \lambda \frac{\mu^4}{k_0^4} \frac{H}{\delta} \quad (6).$$

Friction coefficient λ, included in parameter (6), can be determined from the experimental data of A.I. Didebulidze [2].

According to calculations [7], the correction factor K_0 is very weakly dependent on the Froude number Fr_0. Therefore, we further neglect the distance z_0 (see Figure 1) and the Froude number.

The maximum value of L (the range of the nozzle), which depends on the angle α, can be found numerically [10] using the algorithm (1), (5), (6), without solving the cumbersome extremum problem. Figure 2 shows a graph of dependence (4) according to [7, 11]:

Q = 0.957 l/sec; H = 10 м; d_0 = 10 мм; d = 50 мм; μ = 0.87; $z_{\text{нас}}$ = 2.0 м (7),

which shows that the maximum length of departure of the jet (range nozzle) Lmax = 6.165 м is achieved when β = 67°, see Figure 2.

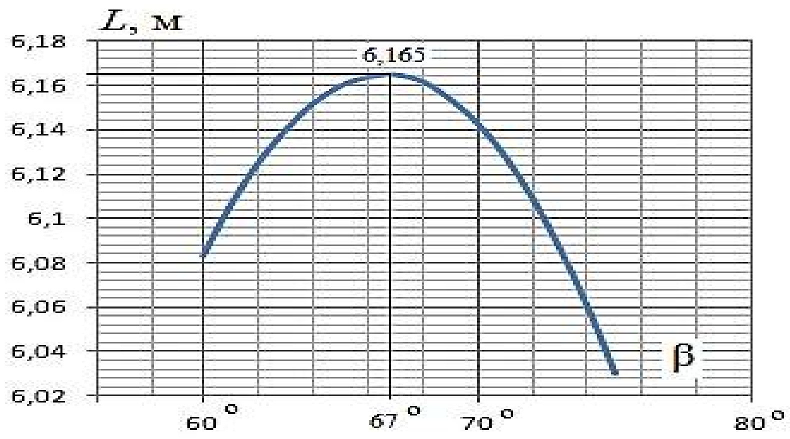

Figure 2: Determination of the range of action nozzle.

The calculation of the trajectories of the hydraulic jets according to equation (3) with the data (7) for different values of the deflection angle is presented in Figure 3.

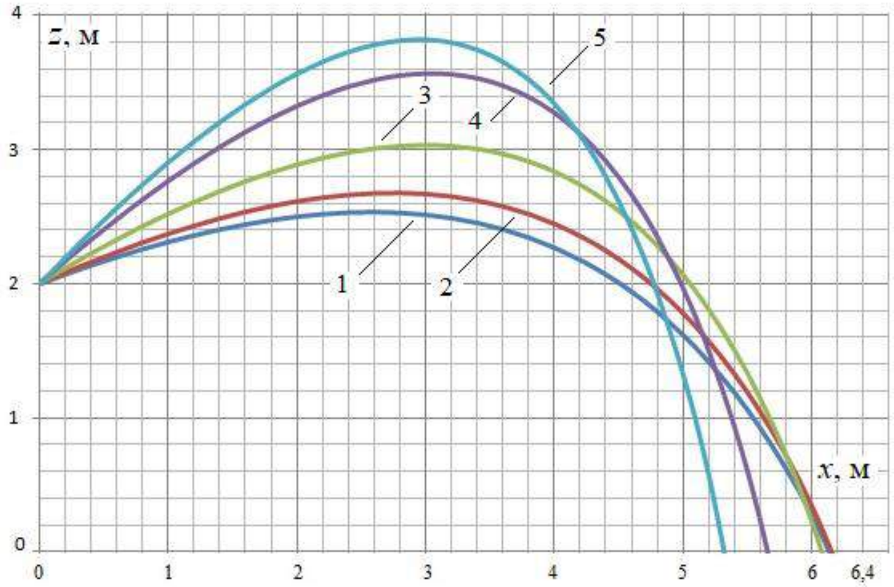

Figure 3: The trajectory of the hydraulic jets at different values of the angle of taper:
1 – β = 70°; 2 – β = 67°; 3 – β = 60°; 4 – β = 50°; 5 – β = 45°.

Using the algorithms (1), (5), and (6), it is possible to construct a theoretical dependence of the range of the nozzle on the head in front of the nozzle for different values of the nozzle diameter (Figure 4). Experimental confirmation of the curves in Figure 5 can be found in the work of N.F. Ryzhko [12].

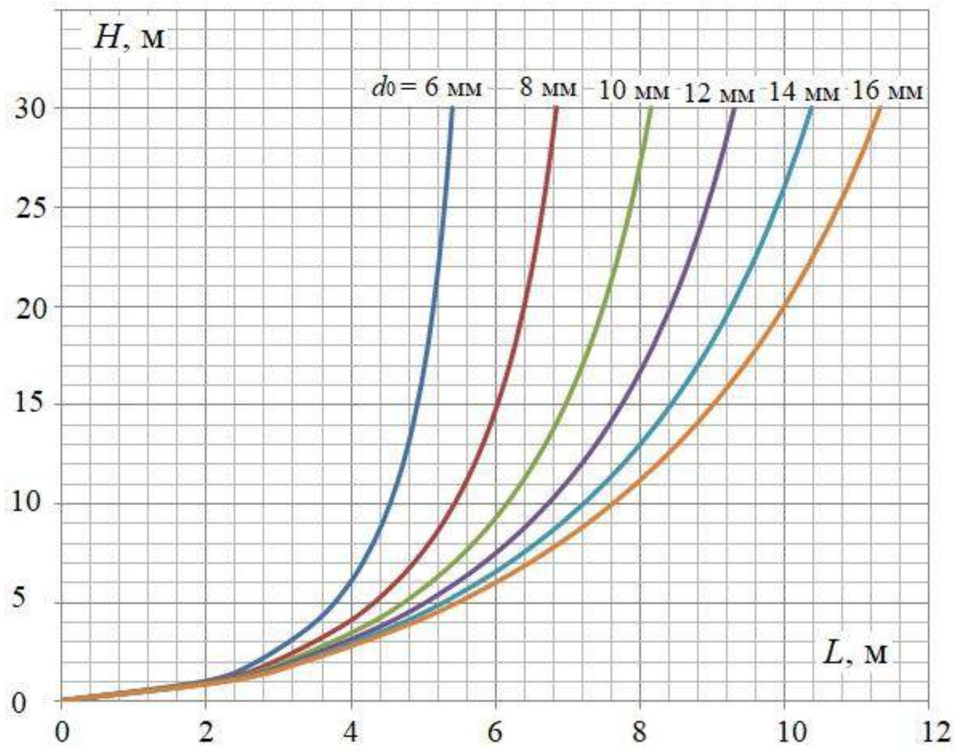

Figure 4: Nozzle range at installation height 2 м.

An empirical formula to determine the radius of action of a conical nozzle installed at a height of 2 м from the soil surface is also proposed there:

$$L = \frac{H}{0.728 + 0.942\frac{H}{d_0}} \quad (8),$$

where H – head before nozzle in м, d_0 – nozzle diameter in мм.

In Figure 5, there is a graph that compares the values of the nozzle range, calculated theoretically by the algorithm (1), (5), (6), as well as the empirical formula N.F. Ryzhko (8). Obviously, it is an enough good coincidence of the two dependencies.

Considering the specific features of conducting field experiments with operating sprinkler machines, the above studies allow us to conclude that some parts of the field tests can be replaced by computational experiments on appropriate models [10, 13].

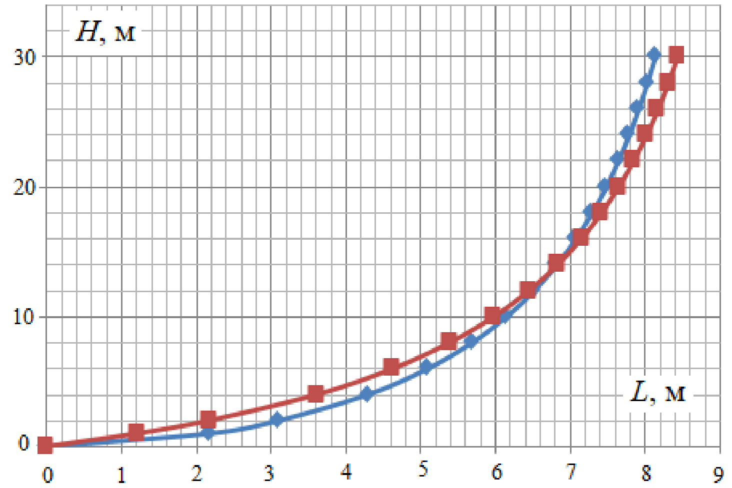

Figure 5: Comparison of the calculated and experimental values of the nozzle range according to (7): ♦ - theoretical calculation; ■ - empirical formula (8)

Simulations of this kind [10] have been successfully used in various areas of the water sector, e.g. in water supply [14], and in hydraulic engineering [15-16].

2. CONCLUSION

This work focuses on a longitudinal jet axisymmetric flow around a conical deflector by an averaged turbulent flow of an incompressible fluid. The mathematical models are discussed to determine the thickness of a water film that comes down from the deflector, and depends on the work of friction forces and kineticity of the incident flow. The distance of departure of the jet (radius of the deflector) and comparison with the experiment is also discussed.

3. AVAILABILITY OF DATA AND MATERIAL

Data used or generated from this study can be requested to the corresponding author.

4. REFERENCES

[1] Loitsyansky L.G. Fluid and gas mechanics / L.G. Loitsyansky. - M .: Drofa, 2003. - 840 p.

[2] Isaev, A.P. Hydraulics sprinkler machines / A.P. Isaev. - M .: "Mechanical Engineering", 1973. - 216 p.

[3] Lebedev, B. M. Sprinkling machines: theory and design / B. M. Lebedev. - M .: Mashinostroenie, 1977. - 246 p.

[4] Borodin, V.A. Spraying a liquid / V.A. Borodin. - M .: Mashinostroenie, 1967. - 263 p.

[5] Bashta, T.M. Hydraulics, hydraulic machines, and hydraulic drives / TM. Bashta et al. - M .: Mechanical Engineering, 1982. - 423 p.

[6] Pilgunov, V.N. Verification of mathematical models of typical local hydraulic resistances [Electronic resource] / VN Pilgunov, K.D. Efremova // Engineering Bulletin. - 2013. - № 11. - P. 29 - 56. - Access mode: http://engsi.ru/issue/622075.html.

[7] Esin, A.I. Flow around a conical deflector with a flow of a viscous incompressible fluid / A.I. Esin, A.V. Rusinov, A.P. Akpasov, Yu.V. Bondarenko, L.A. Zhuravleva // Scientific life ”. - 2018. - № 4. S. 14 -19.

[8] Shterenlicht, D.V. Hydraulics / DV Shterenlicht. - M .: Koloss, 2004. - 656 p.

[9] Korn G. Mathematics Handbook for Scientists and Engineers / G. Korn, T. Korn. - M .: Science, 1973. - 832 p.

[10] Esin A.I. Numerical hydraulics. Monograph / A.I. Esin. - Saratov: Publishing House Sarat. agrarian University, 2013. - 160 p.

[11] Akpasov A.P. Improving the design of deflector nozzles to increase the uniformity of irrigation / A.P. Akpasov // "Problems and prospects for the development of land reclamation in modern

[12] Ryzhko N.F. Improvement of rain-forming devices for multi-support sprinkler machines. Monograph / N.F. Ryzhko. - Saratov: Saratov State Agrarian University, 2009. - 176 p.

[13] Esin A.I. Mathematical modeling of a water-conducting belt of irrigation machines / A.I. Esin, D.A. Soloviev, L.A. Zhuravlev // "Scientific Life". - 2017. - № 9. P. 20 -28.

[14] Esin A.I. Mathematical modeling of the increase in the roughness of pressure pipelines under conditions of long-term operation / A.I. Esin, T.N. Southkin. // Mathematical methods in engineering and technology - MMTT. - 2014. - № 8 (67). Pp. 31-34.

[15] Esin A.I. Mathematical modeling of the spillway construction according to the scheme of discharge from under the shield / A.I. Esin // Environmental Management. - 2011. - № 5. P. 83-86.

[16] Esin A.I. Mathematical modeling of the distribution of impurities in irrigation and drainage channels / A.I. Esin, M.P. Gorbachev // Mathematical methods in engineering and technology - MMTT. - 2014. - № 8 (67). Pp. 31-34. No. 7-1 (66). Pp. 29-33.

Professor Dr. Alexander I. Esin is Professor at the Department of Technosphere Safety and Transport and Technological Machines, Saratov State Agrarian University named after N.I. Vavilov, Russia. He holds a Doctor of Technical Sciences. His scientific research directions are Fluid and Gas Mechanics, Open Flow Hydrodynamics, Mathematical Modeling in Hydraulics and Land Reclamation.

Dr.Dmitry A. Solovyev is Head of the Department of Technosphere Safety and Transport and Technological Machines, Saratov State Agrarian University named after N.I. Vavilov, Russia. He earned a Doctor of Technical Sciences degree. His directions of scientific research are Land Reclamation Machines, Irrigation Systems.

Dr.Galina N. Kamyshova is Head of the Department of Mathematics, Mechanics and Engineering Graphics, Saratov State Agrarian University named after N.I. Vavilov, Russia. She has a PhD degree in Mathematics. Her main area of expertise is Mathematical Modeling and Data Analysis in Management and Environmental Engineering.

Dr.Larisa Zhuravleva is an Associate Professor at the Department of Technosphere Safety and Transport and Technological Machines", Saratov State Agrarian University named after N.I. Vavilov, Russia. She holds a Doctor of Technical Sciences degree. Her areas of research are Machines and Equipment for Environmental Engineering, Technology and Technical Means of irrigation.

Goryunov Dmitry Gennadievich is an Associate Professor at the Department of Technosphere Safety and Transport Technological Machines, Saratov State Agrarian University named after N.I. Vavilov, Russia. He is a Candidate of Technical Sciences. His research areas include Optimization of the Fleet; Construction and Maintenance Work on Irrigation Systems, Fire Ponds.