HYDRAULIC MODEL OF TRICKLE-IRRIGATION LATERALS

Nina Philipova
Institute of Mechanics, Bulgarian Academy of Sciences,
Acad. G. Bonchev Str., Bl.4, Sofia 113, Bulgaria,
e-mail:philipova@imbm.bas.bg

Abstract: A model for hydraulic design of a drip irrigation lateral is developed by applying the theory of spatially varied flow. A block-scheme is made by using SIMULINK-MATLAB for solving the determined two differential equations. As a result, diagrams for distribution of lateral flow rate, pressure head, head loss, emitter discharge for each dripper along the pipe length and some other characteristics are obtained.
The influence of the temperature on the kinematics viscosity of water is read by a coefficient in the formula of Darcy-Weisbach for head loss due to friction. The friction coefficient is reported as a function of Reynolds number. The coefficient of Boussinesq is determined for laminar and turbulent flow conditions. The develoed model of hydraulic design of drip lateral is compared with experimental data for Israeli Netafim "Typhoon 16250" with emitter discharge $q = 1{,}75 \text{l/h}$ and spacing between emitters $s = 0{,}3\text{m}$.

Key words: Irrigation system; Trickle irrigation; Pipe flow; Hydraulic design.

1. Introduction

Drip irrigation is a precise irrigation technology. It gives an opportunity to meet crop requirements for water and nutrient elements in an optimum way. On the other hand, drip irrigation systems require adequate hydraulic design, ensuring uniform distribution of emitter discharge over the irrigated area and precautionary measures for their maintenance, preventing from emitter clogging.

Numerous methods of optimum hydraulic designing drip irrigation lateral have been developed. Wu and Gitlin (1975), and Wu and Yue (1993) apply energy-gradient line approach considering constant emitter discharge along the lateral for determining the lateral pressure head and the flow rate profiles.

Warrick and Yitayew (1988) and Yitayew and Warrick (1988) have developed a model based on the differential equation of conservation of energy and the continuity equation. The Darcy-Weisbach equation for head loss due to friction is used as an accurate formula for a small diameter smooth pipes. The friction coefficient is reported for different ranges of Reynolds number variation (from laminar to fully turbulent flow conditions). The velocity head is neglected, but the variable discharge is included in the basic derivation.

Hathoot et al. (1993), (2000) have presented a model applying the energy equation for two successive emitters, which is a forward-step calculation method. The friction coefficient is also reported for different ranges of the Reynolds number variation. The Darcy-Weisbach equation for head loss due to friction is used. The change of pressure head due to a momentum change at the emitter is reported.

Kang and Nishiyama (1996a), (1996b), (1996c) have developed the model of designing single as well as pared laterals, based on the equation of conservation of energy. The change of emitter discharge along the lateral length is approximated by a polynomial to the power of n $(n = 3 \div 7)$. The coefficients of the polynomial are determined using the least square method at a given inlet flow rate of lateral and at an inlet pressure head of lateral. The Darcy-Weisbach equation for head loss due to friction is used too. The friction coefficient is considered as a function of Reynolds number for different flow conditions (from laminar to fully turbulent).

Kosturkov and Simeonov (1990), have developed a model of designing horizontal, non- deformable trickle lateral on the basis of the momentum approach. The longitudinal projection of discharged velocity is considered as a linear function of the averaged flow velocity. An analytical decision of the two differential equations obtained is proposed (the momentum equation and the conservation of mass equation) (Kosturkov, 1990).

Yildirim and Agiralioglu (2004) have performed a good comparative analysis of the developed hydraulic methods in design of microirrigation laterals.

Von Bernurth (1990), Holzapfel et al. (1990), Bagarello et al. (1995) take into account the influence of temperature on the viscosity change in the hydraulic design of drip irrigation system. It is proved that when the water temperature changes from 15,5º C to 37,7º C (from 60º F to 100º F) the density decreases by less than 1% but viscosity decreases by about 40% (Munson, Young and Okishi, 1990). That is why the influence of temperature and Reynolds number will be taken into account when the change of water kinematic viscosity is considered.

The objective of the work presented in this paper is a model derivation for hydraulic design of a drip lateral on the basis of theory of spatially varied flow and with application in the drip irrigation practice.

2. Theoretical backgrounds of the developed model of trickle irrigation laterals

The deduced model by Petrov (1951) is an one-dimensional hydraulic equation, based on the momentum approach. It describes a steady spatially varied flow with averaged velocities, and inconstant flow area at slope with a gradient $\frac{dz}{dx}$. The head loss due to friction is calculated by means of the formula of Darsy-Weisbach that is accurate for a small diameter smooth pipes. The pipe is considered as non-deformable one. In the case of lateral outflow along the pipe with a constant diameter, the equation is as follows:

$$\frac{1}{\rho}\frac{dp}{dx}+\alpha V\frac{dV}{dx}+\frac{dz}{dx}+\lambda\frac{V^2}{2}\frac{1}{D}+\alpha\frac{(V-\theta)V}{Q}\frac{dQ}{dx}=0, \quad (1)$$

where: V is the averaged flow velocity throughout the cross-section; p is the pressure assumed to be constant throughout the cross-section; α is a coefficient of Boussinesq; θ is the longitudinal projection of discharged velocity , $\theta=\delta V$; δ is a coefficient of proportionality between the longitudinal projection of discharged velocity and the averaged flow velocity throughout the cross-section; Q is the flow rate in m^3/s; γ is the specific weight of water, $\gamma=\rho g$ (for incompressible fluid); g - gravity acceleration.

The last term of the equation (1) reports discharging the flow along the lateral length according to the theory of Meshterski (Petrov, 1951) and the previous term represents the head loss due to the friction per unit length.

Taking into account the outflow at a distance between emitters s, the equation of the conservation of mass is as follows:

$$\frac{dQ}{dx} = -q = -\frac{k}{s} h^{k_1}, \qquad (2)$$

where: q is the discharged flow per unit length in l/h (emitter outflow per unit length); kh^{k_1} is the exponential relationship of the dripper; k, k_1 are constants depending on the type of the dripper and its flow regime; h is the pressure head; s is the distance between drippers.

Expressing the discharged flow per unit length q in m^3/s, the equation (2) obtains the following form:

$$\frac{dQ}{dx} = -q = -F_Q \frac{k}{s} h^{k_1}, \qquad (3)$$

where: F_Q is the coefficient converting from liters per hour to cubic meters per second, $F_Q = 2{,}7777\text{x}\,10^{-7}$.

3. Formulas used for deriving model equation

The following basic equations are used:

3. The normal projection of friction forces for a lightly changed flow are neglected and the pressure is constant throughout the cross-section. The pressure is as follows:

$$p = \rho g h. \qquad (4)$$

2) The formulae for the ground slope:

$$\sin\psi = -\frac{dz}{dx}, \qquad (6)$$

where: ψ is the lateral slope angle;

3) The Darsy-Weisbach formulae for head loss which is due to friction per unit length can be expressed as:

$$\frac{\Delta h_f}{l} = K_{loc} K_0 F_Q^n D^m Q^n, \qquad (7)$$

where: $\frac{\Delta h_f}{l}$ is the head loss due to the friction per unit length; n is the exponent of the flow rate; m is the exponent of the pipe diameter; D is the pipe diameter, K_{loc} is the Benami and Offen coefficient (Benami and Offen, 1984) of the local head loss of emitters, read as a function of the dripper type (online or inline), the distance between the drippers and the pipe diameter; K_0 is the coefficient reading the kinematic viscosity change as a function of temperature and Reynolds number.

4. The derived equation of the model

The following equation is derived on the basis of aforementioned equations (4) – (7), the momentum equation of Petrov (1), and the equation of conservation of mass (3) for steady flow movement with lateral outflow along the lateral length, where the cross-section of the pipeline is assumed to be constant:

$$g\frac{dh}{dx} - g\sin\psi - \frac{1{,}6\alpha Q}{D^4}kh^{k_1}\left(2-\delta\right) + K_{loc}K_0F_Q^n\,D^mQ^n = 0, \qquad (8)$$

The other form of the derived model equation is the following:

$$g\frac{dh}{dx} - g\sin\psi - \frac{1{,}6\alpha Q}{D^4 s}\left[kh^{k_1}(2-\delta)\right] + \left(\frac{\Delta h_f}{l} + \frac{\Delta h_{loc}}{l}\right)g = 0 \qquad (9)$$

where: Δh_{loc} are the local head loss due to the emitters. Using this equation the formula of Provenzano and Pumo (2003) can be used for estimating local head loss of "in-line" drippers. Comperative analysis between the two approaches of local head loss estimating for "in-line" emitters is performed in Philipova (2007a). The formula of Y. Reddy (2003) could be used for estimating local head losses "on-line" emitters. Comperative analysis between the two approaches of local head loss estimating for "in-line" emitters is performed in Philipova (2007b)

Boundary conditions of the model are the following:

$x = 0 \quad Q = Q_0 = Nq \quad h = h_0,$

$x = l \quad \dfrac{dQ}{dx} = -q_k$

where: Q_0 is the inlet flow rate of the lateral; N is the number of emitters; q is the nominal emitter discharge; h_0 is the inlet pressure head; l is the length of the lateral, q_k is the last emitter discharge of the dripline

5. Head loss estimation due to friction

The head loss due to friction is a function of the Reynolds number (Warrick and Yitayew, 1988, Hathoot et al.,1993, Kang and Nishiyama, 1996a).

1) The friction coefficient λ for laminar flow $\mathrm{Re} \le 2000$, is defined below:

$$\lambda = \frac{64}{\mathrm{Re}},$$

$$\frac{\Delta h}{l} = 40{,}745\,\nu\,Q\,D^{-4} = K_0\,Q\,D^{-4}, \qquad (10)$$

$$K_0 = 40{,}745\,\nu, \qquad (10')$$

where: ν is the kinematic viscosity of water.

$$n = 1; \quad m = -4. \qquad (10'')$$

2) The friction coefficient λ for turbulent flow in a smooth pipe $2000 < \mathrm{Re} \le 10^5$, according to the Blasius equation is as follows

$$\lambda = a\,\mathrm{Re}^b; \quad a = 0{,}316; \quad b = -0{,}25;$$

$$\frac{\Delta h}{l} = 0{,}2413\,\nu^{0,25}D^{-4,75}\,Q^{1,75} = K_0D^{-4,75}\,Q^{1,75}, \qquad (11)$$

$$K_0 = 0{,}2413\,\nu^{0,25}, \qquad (11')$$

$$n = 1{,}75; \quad m = -4{,}75. \qquad (11'')$$

3) Watters and Keller (1978) derived the following formula for the friction coefficient λ for fully turbulent flow $10^5 < \mathrm{Re} < 10^7$,

$$\lambda = 0{,}13\,\mathrm{Re}^{-0{,}172} \quad ,$$

$$\frac{\Delta h}{l} = 0{,}9977\,\nu^{0{,}172}\,Q^{1{,}828}\,D^{-4{,}828}, \tag{12}$$

$$K_0 = 0{,}9977\,\nu^{0{,}172}, \tag{12'}$$

$$n = 1{,}828; \quad m = -4{,}828\,. \tag{12''}$$

The coefficient K_0 is calculated on the basis of equations (10'), (11'), (12') and data from kinematic viscosity dependence on temperature are taken from Lo'tziyanski (1987). The values of coefficient $K_0 = f(\mathrm{Re}, x)$ are cited in Philipova (2005).

6. Program in SIMULINK –MATLAB

A block-scheme is made (shown in Fig. 1-Fig. 4) by using program SIMULINK – MATLAB on the basis of the equations (8), (3) and the formulae for the head loss per unit length (10), (11), (12).

The Reynolds number Re is calculated for every step equal to the distance between drippers. The values of n, m are assumed in correspondence with the values (10''), (11''), (12'').

7. Coefficients estimation

The Boussinesq coefficient α (momentum coefficient) for laminar and turbulent flow is defined as follows:

1) For laminar flow in cylindrical pipe (May, 2005):

$$\alpha = \frac{1}{AV^2}\int_A v^2 dA = \frac{1}{AV^2}\int_0^R v^2 (2\pi r)dr$$

where: A is the cross-sectional area; V is the averaged velocity; v is the local flow velocity; R is the pipe radius; r is the radius from the pipe centerline.

The velocity distribution for laminar viscous flow in a cylindrical pipe is in accordance with a parabolic low:

$$v = v_{\max}\left[1 - \left(\frac{r}{R}\right)^2\right] \tag{13}$$

where: $v_{\max}$ is the maximum velocity and $V/v_{\max} = 0{,}5$.

The value obtained for Boussinesq coefficient for laminar flow conditions is $\alpha = 1{,}33$

2) The Boussinesq coefficient α for turbulent flow is in the interval of $\alpha = 1{,}01 - 1{,}10$ (Kosturkov, 2001, Ghidaoui, 2005).

The coefficient of proportionality between the longitudinal projection of the discharged velocity and the averaged flow velocity throughout the cross-section - δ is in the interval $\delta = 0{,}1 - 0{,}9$. The values of coefficients α and δ are varied in the aforementioned intervals with steps $0{,}01$ and $0{,}1$, respectively. The obtained data from the model for q are compared with the experimental data for q of the NETAFIM "Typhoon 16250" dripline. A program in FORTRAN is made for calculating:

$$F_{SUM} = \sum_{j=1}^{N} \left[q_{TEOR} - q_{EXP} \right]^2 \qquad (14)$$

where: N is the number of emitters along lateral; q_{TEOR} is the data for emitter discharge obtained by the model, and q_{EXP} is the experimental data for the flow rate and then the minimum of the function F_{SUM} have to be searched. The optimum values for the obtained α and δ, as a result, are $\alpha = 1{,}10$, $\delta = 0{,}1$, respectively. The minimal value of δ is due to the small dimensions of the dripper and the sensitive decrease of the flow velocity just next to the dripline wall.

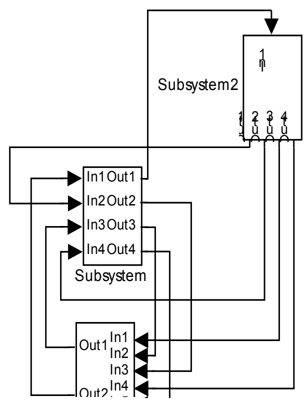

Fig.1. .Block-scheme of the model by program SIMULINK –MATLAB

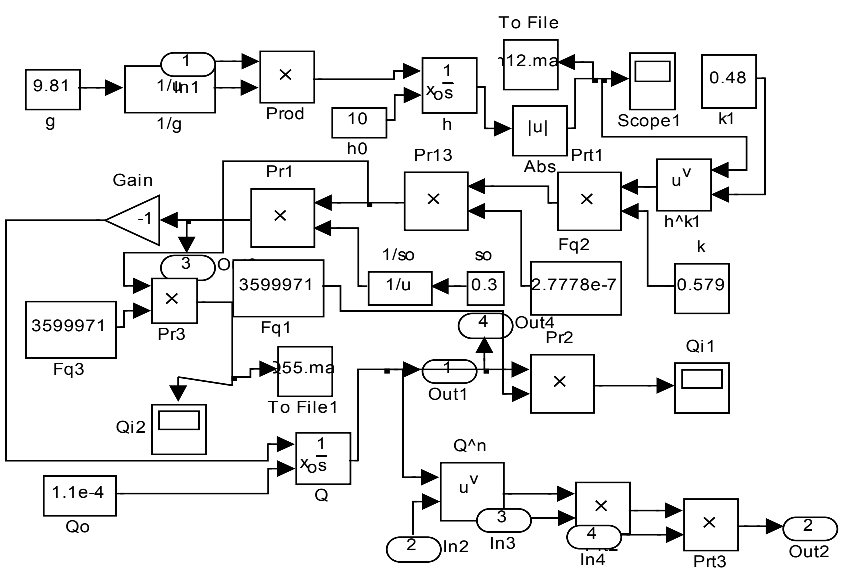

Fig. 2. Block-scheme for solving Equation (3) (Subsystem in Fig.1)

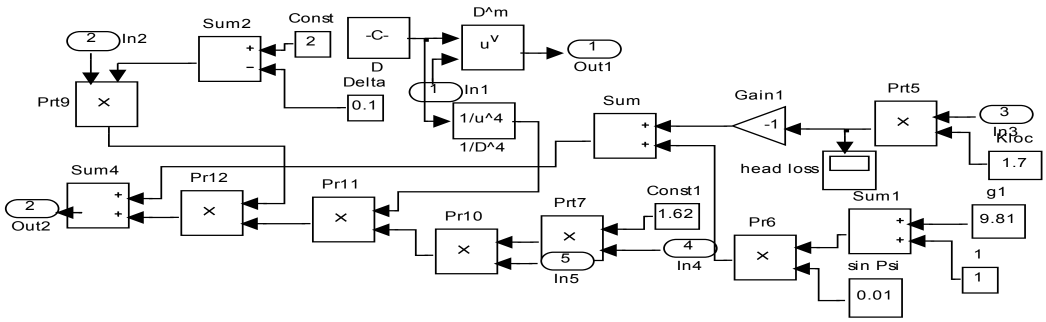

Fig.3. Block-scheme for solving Equation (7) (Subsystem1 in Fig.1)

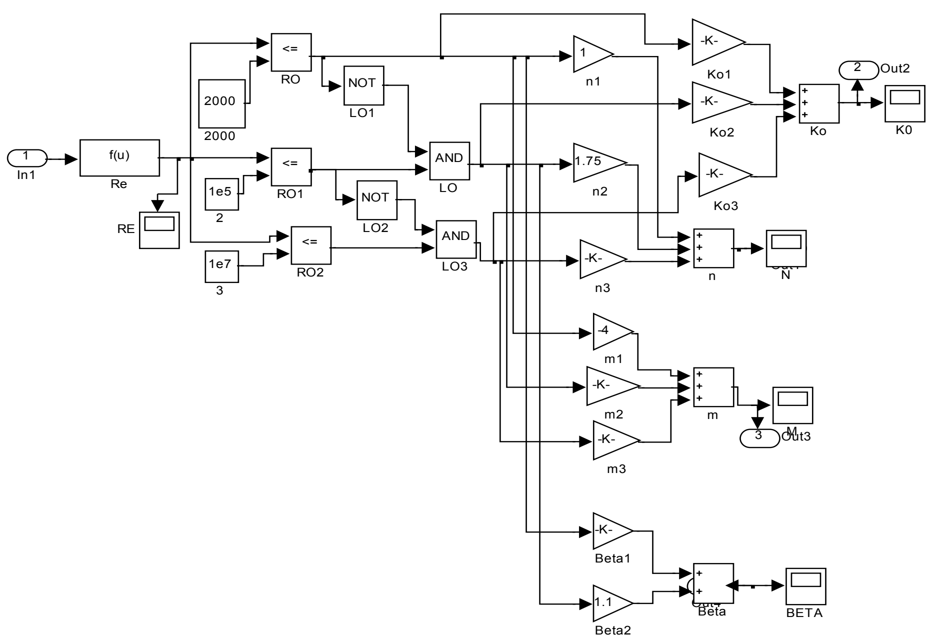

Fig. 4. Block-scheme for determining the values of coefficients K_o, n, m depending on the value of Re (Subsystem2 in Fig.1)

The data used in the program are the following: the NETAFIM Typhoon 16250 dripline with a nominal emitter discharge $q_{nom} = 1{,}75\,\text{l/h}$, a nominal pressure head $h_{nom} = 10\,\text{m}$, a distance between drippers $s = 0{,}3\,\text{m}$, a number of drippers $N = 233$, lateral length $l = 70\,\text{m}$, the inside diameter of dripline is $D = 15{,}4\,\text{mm}$. The lateral slope is a 1% down slope. The coefficient $K_{loc} = 1{,}70$ is taken into account for reading local head loss (Benami and Offen, 1984). The coefficients of the exponential relationship of the dripper in the equation (2) are $k = 0{,}579$ and $k_1 = 0{,}48$ (taken from the catalog of Netafim, 2004). $K_0 = 4{,}1029\text{x}10^{-5}$ for $T = 20^\circ\text{C}$ and $\text{Re} \le 2000$, $K_0 = 7{,}6439\text{x}10^{-3}$

for $2000 < \mathrm{Re} \le 10^5$, $K_0 = 9{,}2794\mathrm{x}10^{-2}$ for $10^5 < \mathrm{Re} \le 10^7$. The coefficient of Boussinesq for laminar flow is $\alpha = 1{,}33$ and for turbulent flow is $\alpha = 1{,}10$. The coefficient of proportionality between the longitudinal projection of discharged velocity and the averaged flow velocity throughout the cross-section is $\delta = 0{,}1$.

The first boundary condition of the model for the given example is:

$x = 0 \quad Q = Q_0 = Nq = 407{,}75\mathrm{l/h} \quad h = h_0 = 1\mathrm{bar}$

The second boundary condition is calculated by the program.

The results calculated are drawn in diagrams: pressure head $h = f(x)$ along the lateral length is shown in Fig. 5; dripline flow rate $Q = f(x)$ in Fig. 6; emitter discharge q in Fig.7 ; $\mathrm{Re} = f(x)$ in Fig. 8; $n = f(\mathrm{Re}, x)$ in Fig. 9; $m = f(\mathrm{Re}, x)$ in Fig. 10; $K_0 = f(\mathrm{Re}, x)$ in Fig. 11; coefficient of Boussinesq α in Fig. 12, respectively.

8. Results from the program

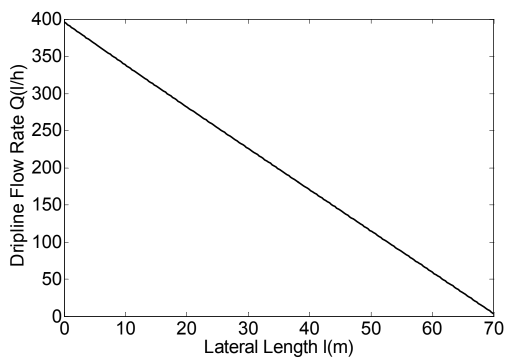

Fig.6. Distribution of pressure head h along the lateral length l

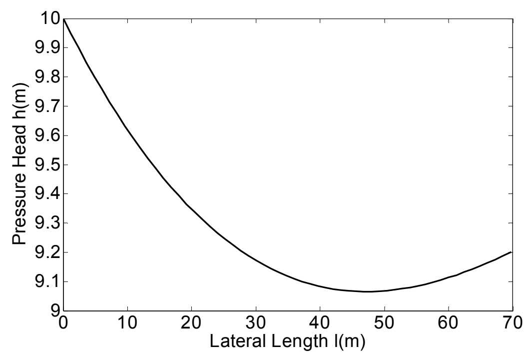

Fig.7. Distribution of drip line flow rate along the lateral length l

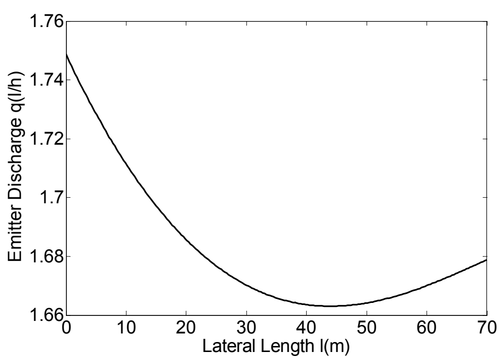

Fig.8. Distribution of emitter discharge along the lateral length l

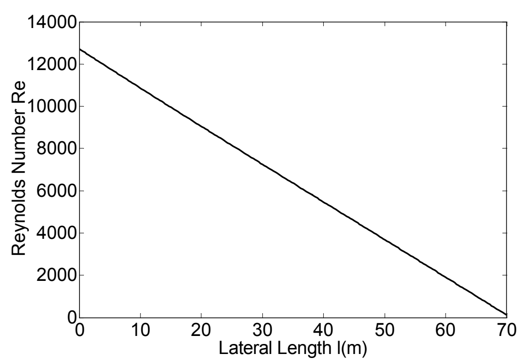

Fig.9. Distribution of Reynolds number along the lateral length

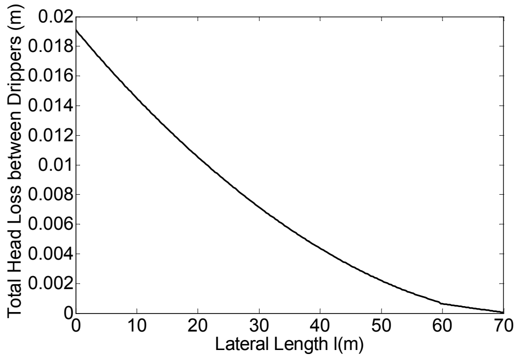

Fig.10. Total head loss between drippers along the lateral length l

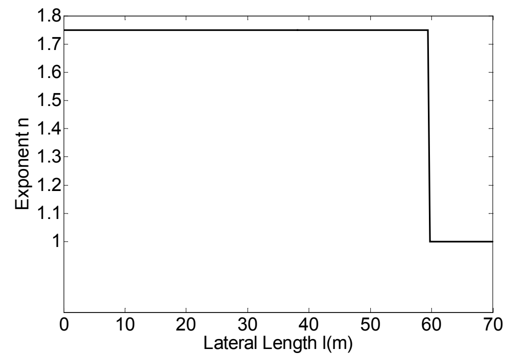

Fig.11. Distribution of exponent n along the lateral length l

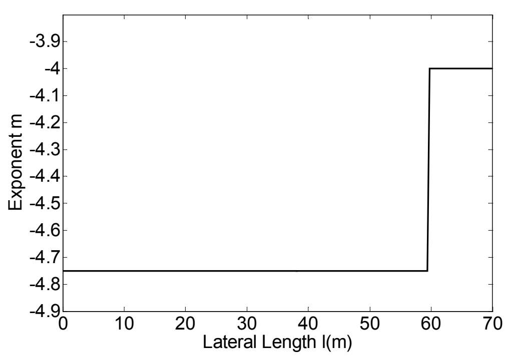

Fig.12. Distribution of exponent m along the lateral length

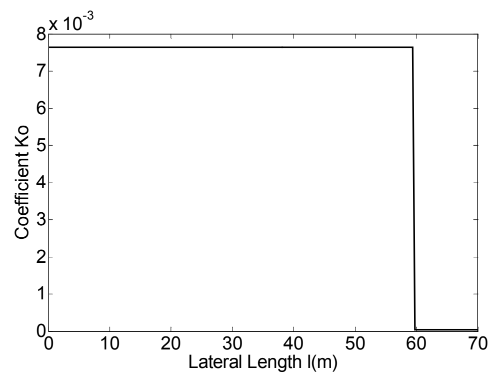

Fig.13. Distribution of coefficient K_0 along the lateral length

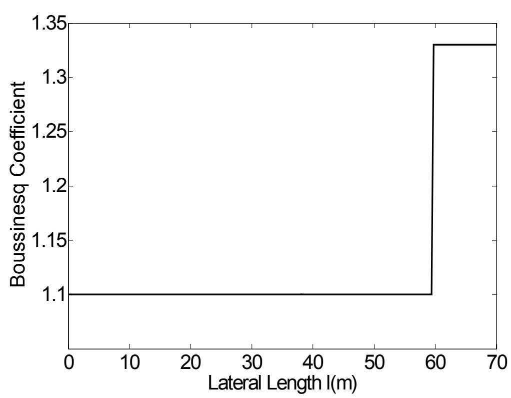

Fig.14. Distribution of Boussinesq coefficient along the lateral length.

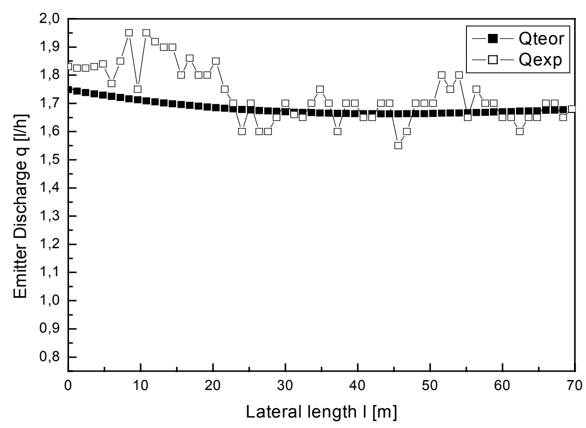

Fig.15. Correlation between the model data and the experimental data.

6. Calibration of the model

Calibration of the model is shown in Fig.13. The comparison between the model data and the experimental data gives a good agreement. The value of correlation coefficient is 0,7.

7. Analysis of the obtained results.

The deviation of hydraulic head along the lateral length is in the limits of 9%, calculated according to the formula $\frac{h_0 - h_{\min}}{h_0}$, where h_0 is the hydraulic head at the lateral beginning, $h_{\min}$ is the minimum hydraulic head for the whole lateral length.

The deviation of emitters discharge is in the limits of 5%, calculated according to the formula $\frac{q_0 - q_{\min}}{q_0}$, where q_0 is the emitter discharge at the lateral beginning, and $q_{\min}$ is the minimum emitter discharge for the whole lateral length.

The total head loss for $l = 10\text{m}$ are $0{,}015\text{m}$, and for $l = 50\text{m}$ are $0{,}002\text{m}$. The diagrams of exponents n, m, the one of coefficient K_0, reading temperature influence on the kinematic viscosity and the coefficient of Boussinesq report that flow regime turns from turbulent to laminar at $l = 60\text{m}$.

The "potential" emission uniformity of the drippers "Typhoon 16250", calculated for the model data with local head loss reading by means of the Benami and Offen coefficient is calculated according to the formula (Keller и Karmeli (1974)):

$$EU = 100\left(1{,}0 - 1{,}27\frac{C_V}{\sqrt{N_p}}\right)\frac{q_{\min}}{q_a} \qquad (3.5.1.1)$$

where: EU is the emission uniformity, %; C_V is the coefficient of the manufacturer variability; N_p is the drippers number per plant; $q_{\min}$ is the minimum emitter discharge along the lateral length; q_a is the average emitter discharge along the lateral length .

The "potential" emission uniformity for $C_V = 3\%$, $N_p = 8$, $q_{\min} = 1{,}665 l/h$, $q_a = 1{,}68261$ is $EU_{teor} = 97{,}6\%$. The "real" emission uniformity for the experimental data $q_{\min} = 1{,}55$, $q_a = 1{,}7239$ is $EU_{\exp} = 89\%$. The "real" emission uniformity is always less than " the potential" emission uniformity .

Burt и Styles (1994) point out, that the "potential" emission uniformity varies about 90%, and the "real" emission uniformity for California is about 70%.

8. Conclusions

A model for hydraulic design of a drip lateral on the basis of theory of spatially varied flow is derived in this paper

The developed model and the program in SIMULINK-MATLAB give an opportunity for more accurate hydraulic design of trickle laterals. The model is theoretically based and the program is open for substituting with different lateral parameters. It is estimated in this paper that the deviation of hydraulic head along the lateral length is in the limits of 9%, that is within the limits of the allowable pressure and discharge variations. It was established in this paper that the deviation of emitters discharge is in the limits of 5%. For inline emitters it could be recommended $\delta = 0{,}1$. For online emitters averaged values for $\delta = 0{,}5$ and $\alpha = 1{,}05$ could be assumedm for turbulent flow conditions, because of the very little effect on the calculated F_{SUM}. $\alpha = 1{,}33$ for laminar flow. The good agreement between the model data and the experimental data prove the suitability of the model in the drip irrigation practice.

Acknowledgments

The auther would like to thank to all lecturers from CINADKO Course "Modern Irrigation Systems and Extension" (Israel,1998), especially to Anat Levingart, for the consultations about the model to Prof. I. Ivanov and for the assistance to Assoc. Prof. G. Welkovski, both from the Institute of Water Problems (Bulgarian Academy of Science).

The presentation of this work on 13th World Water Congress is supported by the Project NoBG051PO001/07/3.3-02/55.

REFERENCES

1. Bagarello, V., V. Ferro , G. Provenzano. Experimental study on flow-resistance law for small diameter plastic pipes. *Journal of Irrigation and Drainage Engineering ,* **121**(1995), No5, 313-316.
2. Benami, A., A. Offen. Irrigation engineering, 1st Ed., IESP, Haifa, 1984.
3. Burt, Ch., S. Styles, Drip and Microirrigation for Trees, Vines, and Row Crops, California Polytechnic State University, San Luis Obispo, California, 1994.
4. Ghidaoui, M. Fundamental laws of hydraulics for a control volume (steady flow). (2005), http://teaching.ust.hk/~civil/Lecture/Chapter2.pdf
5. Hathoot, H., A. Al-Amoud, F. Mohammad. Analysis and design of trickle-irrigated laterals. *Journal of Irrigation and Drainage Engineering,* **119**(1993), No5, 756-767.
6. Hathoot, H., A. Al-Amoud, A. Al-Mesned. Design of trickle irrigation lateral as considering emitter losses. *ICID J.,* **49**(2000), No 2, 1-14.
7. Holzapfel, E., M. Marino, A.Valenzuela. Drip irrigation non-linear optimization model. *Journal of Irrigation and Drainage Engineering,* **116** (1990), No4, 479-496.

8. Kang, Y., S. Nishiyama. Analysis and design of microirrigation laterals. *Trans. ASAE,* **38** (1996), No5, 1377-1384.

9. Kang, Y., S. Nishiyama. Analysis of microirrigation systems using a lateral discharge equation. *Trans. ASAE,* **39** (1996), No 3, 921-929.

10. Kang, Y., S. Nishiyama. A simplified method for design of microirrigation laterals. *Trans. ASAE,* **39** (1996), No5, 1681-1687.

11. Keller, J., D. Karmeli, Trickle Irrigation Design Parameters, *Trans ASAE*, 17 (1974), No 4, 678-683.

12. Kosturkov, J. Method for hydraulic design of microirrigation system. *Proc., 14th ICID Congress,* (1990), Rio de Janeiro, 37-49.

13. Kosturkov, J., G. Simeonov. Identification of the parameters of pressurized delivery pipe model. *Techn. Thought,* **27**(1990), No 2,51-56, (in Bulgarian).

14. Kosturkov, J. "Examination of pressure flows with variable volume quantity along their length, PhD Thesis, Sofia, 2001,(in Bulgarian).

15. Lo'tzyanski, L.. Fluid and gas mechanics, Nauka, Moscow, 1987, (in Russian).

16. Mays, L. Flow process and hydrostatic forces. (Nov. 20, 2005). http://users.rowan.edu/~orlins/wre/Chap3.pdf

17. Munson, B., D. Young, T. Okiishi. Fundamentals of fluid mechanics. John Wiley & Sons, New York – Chichester - Brisbane-Toronto – Singapore, 1990.

18. Netafim, Drip Irrigation Products (Israel). (2004) http://www.netafim.com/Irrigation_Products/Drip_Irrigation/Thin_Wall/Typhoon.html

19. Petrov, G. Movement of spatially varied flow, State Publisher of Construction Literature, Moscow – Leningrad, 1951, (in Russian).

20. Philipova, N. Modeling drip lateral flow on the base of the theory of spatially varied flow. *Journal of Theoretical and Applied Mechanics,* **35** (2005), No 4, 21-32.

21. Philipova N., Lateral Design Model of In-line Drippers Based on the Theory of Spatially Varied Flow, Jubilee conference, UACG, Sofia 17-18 May 2007, 41-56

22. Philipova, N., Lateral Design Model of On-line Drippers "KP 4,6" Based on the Theory of Spatially Varied Flow, Jubilee conference, UACG, Sofia 17-18 May 2007, 57-71.

23. Provenzano, G., D. Pumo, Assessing a Local Losses Evaluation Procedure in Drip Integrated Laterals Design, http://afeid.montpellier.cemagref.fr/Mpl2003/AtelierTechno/AtelierTechno/Papier%20Entier/N%C2%B062%20-%20ITALIE_BM.pdf

24. Reddy ,Y., Evaluation of On-line Trickle Irrigation Emitter Barb Losses, http://www.ieindia.org/publish/ag/1203/dec03ag3.pdf

25. von Bernurth, R. D. Simple and accurate friction loss equation for plastic pipe. *Journal of Irrigation and Drainage Engineering,* **116**(1990), No 2, 294-298.

26. Warrick, A., M. Yitayew. Trickle lateral hydraulics. I: Analytical solution. *Journal of Irrigation and Drainage Engineering,* **114**(1988), No 2, 281-288.

27. Wu, I.., H. Gitlin. Energy gradient line for drip irrigation laterals. *Journal of Irrigation and Drainage Engineering,* **101** (1975), No 4, 323-326.

28. Wu, I. R. Yue. Drip lateral design using energy gradient line approach. *Trans. ASAE,* **36**(1993), No 2, 389-394.

29. Yildirim, G., N. Agiralioglu, Comperative analysis of hydraulic calculation methods in design of microirrigation laterals. *Journal of Irrigation and Drainage Engineering,* **130** (2004), No3, 201-217.

30. Yitayew, M., A. Warrick. Trickle lateral hydraulics. II: Design and examples. *Journal of Irrigation and Drainage Engineering,* **114**(1988), No 2, 289-300.