Study on effects of temperature changes on emitters outflow of drip irrigation

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(Received : March, 2011)

ABSTRACT

The uniformity of emitter flow rate depends on many factors such as water temperature. Temperature variations influence water properties, especially viscosity, which may make significant changes in emitter outflow. The laboratory studies and field surveys are expensive and time-consuming. Computational fluid dynamics (CFD) is a helpful tool to study flow behaviour in water channels. Thus, in present study the effect of temperature on the discharge of three samples of a kind of tape emitter were tested under six pressures of 2, 4, 6.1, 9.2, 12.25 and 16.33 mH2O and each pressure in six temperatures of 5, 15, 20, 25, 35, 45 and 55°C were simulated by CFD. Verification of results showed that results obtained from simulation were in good consistency with laboratory results. Also results indicated that emitter discharges were insensitive to temperature variations and the computational fluid dynamics can be a very appropriate tool to study the hydraulic performance of emitters in less time and at a lower cost.

Key words : Computational fluid dynamics, discharge, emitter, temperature changes

INTRODUCTION

Considered as the most important component of drip irrigation, emitter is used to reduce water pressure in laterals and its uniform outflow (Zhang et al., 2007). Emitters should be so performed to keep their outflow almost consistent. In most studies made on the emitter assessment, the discharge changes have been considered in terms of pressure changes, while the uniformity of emitters flow depends on other factors like manufacturing coefficient of variation, emitters clogging and water temperature (Wu et al., 2003). The manufacturer coefficient variation of emitter not controlled by drip irrigation system designer is small, about 0.1, for the most tortuous path emitters. Emitters clogging may also be controlled by selection of a proper filtration system. But, water temperature is an uncontrollable and variable parameter affecting the quantity and the uniformity of emitters flow (Von Bernuth and Solomon, 1986). Water temperature affects the emitter by contraction and expansion of emitter structure components, on one hand, and makes changes in water viscosity which causes the emitter discharge to differ, on the other hand. Thus, Reynolds Number also varies with changes in water viscosity (Peng et al., 1986). In addition, changes in temperature can also have impact on the friction factor of lateral and emitters. Parchomchuk (1976) showed that microtube and emitters with laminar and unsteady flow regime had discharge variations up to 53% for water temperature variation between 20° and 60°C. Orifice emitters had little change in discharge with water temperatures ranging from 7° to 38°C, while eddy emitters had an 8% decrease in discharge as water temperature changed from 8° to 38°C. Similar results were reported by Decroix and Malaval (1985) for long path (x> 0.5) emitters (increasing discharge with increasing water temperature) and eddy (x< 0.5) emitters (decreasing discharge with

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increasing water temperature). Zur and Tal (1981) measured the discharge sensitivity of three spiral emitters to water temperature. It was observed that discharge variations were significantly less than results predicted on viscosity changes. Clark et al. (2005) determined the discharge of two tape emitters under three pressures and at five different temperatures and concluded that the discharge of Robert’s Ro-Drip emitter was sensitive to temperature variation and the T-Tape emitter showed no sensitivity to temperature variations. Also, it was shown that increasing the emitter wall thickness would decrease the temperature impact on its outflow. Studying six kinds of emitter, Sinobas (1999) showed that with increase in temperature, the discharge of long-path emitter would increase 0.7% and the discharge of eddy emitter decrease 0.4%. In general, as a result from their study, they concluded that in laminar flow regime the emitters discharge was highly dependent on water temperature, but in turbulent flows the friction factor does not change significantly with the changes in Reynolds Number and, it can be generally said that friction factor in turbulent flow emitters (emitters with a discharge exponent of x=0.5) is independent of Reynolds Number.

In some regions such as South of Iran, in a few months of the year, the temperature even exceeds 50°C. Therefore, it seems necessary to conduct more researches in this respect. On the other hand, laboratory and field researches are always expensive and time consuming and they give little information on hydraulic performance of flow in emitter channels. Computational fluid dynamics provides a promising tool to study of the flow behaviour of water passing through the channel of labyrinth. Wei et al. (2004), Wei et al. (2006a), Wei et al. (2006b), Wei et al. (2006c), Li et al. (2006), Yan et al. (2007), Wang et al. (2006), Li et al. (2008), Delghandi et al. (2009) and Delghandi et al. (2010) studied on hydraulic property of emitters by computational fluid dynamics. But so far the effect of temperature on emitter discharge using CFD hasn’t been done. Therefore, in this research, for the purpose of examining temperature impact on the discharge of tape emitters, the flow behaviour in the channels of a kind of emitter was simulated in different temperatures. FLUENT software was used for modeling fluid flow because of its high efficiency.

MATERIALS AND METHODS

Various emitters available in the market were examined to select three samples of one type of tape emitter which is almost rigid. Selected emitters were coded A1, A2 and A3. Length of flow path in emitters was 27 mm. This emitter was selected for the present study because of two reasons. Firstly, the simple geometry of water channels enabling the measurement of channels size by existing instruments and, secondly, its rigidity would result in minimizing temperature effect on the emitter dimensions.

In order to determinate the structural parameters of emitter channel, the selected emitters were destroyed and several samples of longitudinal and latitudinal cuttings of emitters channel were provided. By taking photos of these samples by Scanning Electronic Microscope (SEM), structural parameters for each sample were determined and by calculating their average, structural parameters for each sample of emitter (A1, A2 and A3) were obtained. The shape of structural of emitter’s channel is illustrated in Figs. 1 and 2. The structural parameters of labyrinth

![](image)

Fig. 1. Geometry of the emitter drawn with solid work software.

<table>
<thead>
<tr>
<th>Emitter type</th>
<th>d (mm)</th>
<th>W1 (mm)</th>
<th>W2 (mm)</th>
<th>W3 (mm)</th>
<th>A (deg)</th>
<th>B (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, A2, A3</td>
<td>0.658</td>
<td>0.930</td>
<td>1.386</td>
<td>1.747</td>
<td>124</td>
<td>82</td>
</tr>
</tbody>
</table>
channels are given in Table 1 in which \( w \) and \( d \) are the width and depth of the emitter channels. Channel size of emitters A1, A2 and A3 were same as mentioned in Table 1.

### Theoretical Analysis

The Reynolds Number, \( Re \), is generally used to distinguish between laminar and turbulent flow. Considering velocity average of the flow in emitters channel and channel dimensions, \( Re \) ranges from 57 to 150 assuming a water density of 998 kg/m\(^3\) and a viscosity of 0.001003 kg/(m.s.). According to the traditional hydrodynamics, if \( Re \) number is low (<1100), viscous forces dominate and the flow is laminar. However, some studies (Pfahler et al., 1990; Kandlikar et al., 2003) indicated that the transition from laminar to turbulent in the channels with an area of about 1.0 mm\(^2\) occurs at a \( Re \) ranging from 100 to 700. Therefore, in this study both laminar flow model and turbulent model are applied in the simulation.

#### Laminar Flow Model

**Mass conservation**

\[
\frac{\partial u_i}{\partial x_i} = 0
\]  

**Momentum conservation**

\[
\rho \frac{\partial u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right]
\]

Where, \( \rho \) (kg/m\(^3\)) is the fluid density, \( x \) the displacement vector and \( u_j \) is the velocity vector in the \( j \)th direction.

#### Turbulent Model

The standard \( k-\varepsilon \) turbulent model is generally used for most engineering calculations, so it is chosen to describe the flow in drip emitters in this study. In the \( k-\varepsilon \) model the modelled transport equations for \( k \) and \( \varepsilon \) (Eqs. 3 and 4) are solved (Davidson, 2003):

**\( k \) equation**

\[
\frac{\rho}{\partial x_i} \left[ \frac{\partial u_i}{\partial x_j} \right] = \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + G_k - \rho \varepsilon
\]

**\( \varepsilon \) equation**

\[
\frac{\rho}{\partial x_i} \left[ \frac{\partial u_i \varepsilon}{\partial x_j} \right] = \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i \varepsilon}{\partial x_j} + \frac{\partial u_j \varepsilon}{\partial x_i} \right) \right] + C_{\mu} \frac{\varepsilon}{k} G_k - C_{\mu} \frac{\varepsilon^2}{k}
\]

Where, \( k, \varepsilon, u, P, x, \rho \) and \( \mu \) are turbulent kinetic energy, rate of dissipation, velocity of the flow, pressure, displacement vector, fluid density, fluid viscosity, respectively. Also \( C_{\mu}, C_{\varepsilon}, \sigma_k, \sigma_\varepsilon \) are the correcting coefficients.

The following values are chosen for the correcting coefficients as proposed by Launder and Spalding (1974) as : \( C_{\mu} = 0.09, C_{\varepsilon} = 1.44, C_{\varepsilon} = 1.92, \sigma_k = 1.0 \) and \( \sigma_\varepsilon = 1.3 \).

Compared with the impact of water pressure, the effect of gravity is low, so the gravity of water is neglected here. Additionally, because the pressures applied on the water passing through drip emitters were low, water was assumed to be incompressible and the rate of water flow was assumed to be steady i.e. it did not change with time.

#### Model Solutions and Boundary Conditions

The commercial CFD software, FLUENT, was used to solve the \( k-\varepsilon \) turbulent and laminar flow model described above. The 3D tetrahedron meshes of the emitter channels were generated by using of GAMBIT software. Flow rate of emitter under six pressures of 2, 4, 6.1, 9.2, 12.25 and 16.33 mH\(2\)O and each pressure in six temperatures of 5, 15, 20, 25,
35, 45 and 55°C were simulated by CFD. In the calculation the pressure inlet boundary condition \((p_i)\) is used with a value of 2 to 16.3 m\(\text{H}_2\text{O}\) pressure head, and the outlet is treated as standard atmosphere condition \(p_o=0\) because the water flows out into the air, and the velocity vectors along the channel walls were set to zero.

**Verification of Simulations**

Verification of the results obtained from the CFD simulation was conducted according to ISO 9261, (ISO, 2004). Six tests with three replications for the relationship between pressure and rate are conducted in the pump Laboratory of Water Engineering, Shahid Chamran University, Ahwaz, Iran. Emitter discharge tests were conducted at six pressure settings (2, 4, 6.1, 9.2, 12.25 and 16.3 m\(\text{H}_2\text{O}\)) and 20°C. Pressure settings were the same as those used in CFD simulations to calculate the discharge of emitters. For two low pressures (2 and 4 m\(\text{H}_2\text{O}\)), one constant head was maintained by a constant head tank equipped by a hydraulic elevator and for pressures more than 4 meters a pumping system was used. Water pressure at the emitter inlet is regulated with a pressure regulator and measured by using a pressure gauge. The outflow from each of the emitters within a given time, t (30 min), was collected in a gauged beaker. The average outflow per 30 min was considered as emitter discharge.

**Discharge-pressure Relationship**

The emitter discharge can be expressed as function of operating pressure (Keller and Blaisner, 1990).

\[
q = kh^x
\]  

Where, \(q\) is the flow rate \((\text{l/h})\); \(k\) an emitter constant; \(h\) the pressure head \((\text{m H}_2\text{O})\); \(x\) is the emitter flow rate exponent. The magnitude of \(x\) is indicated that how sensitive the emitter flow rate is to pressure head.

**Temperature-discharge Ratio (TDR)**

Temperature-discharge ratio can be described in the following equation (Keller and Blaisner, 1990; ASAE Standards, 2003):

\[
\text{TDR} = \frac{q_t}{q_{20}}
\]

Where, \(q_t\) is flow rate in \(t^\circ\C\) and \(q_{20}\) is flow rate in 20°C.

**RESULTS AND DISCUSSION**

Emitter flow rate obtained from three models, laboratory, laminar and turbulent, is presented in Tables 2 and 3. According to Table 3, flow rate of emitters A1, A2 and A3 is same.

The data of flow rates and pressure heads obtained by calculation and experiments were processed by the linear multivariable regression method; the coefficients are listed in Table 4. In this research to compare experimental results and the laminar and turbulent models, the following regression equation was used:

\[
Y = \lambda X
\]

In which \(\lambda\), X and Y are gradient line,
experimental and simulated results, respectively. In this regard average of the results, using the three models, is used. Average of prediction error percentage ($E_r$) for each of the regression equation is calculated by using Equation 13. The regression results are given in Table 5.

$$E_r = |(1 - \lambda)| \times 100$$ (11)

Table 5 indicates that the calculated discharges with laminar model are higher than those measured. As shown in Table 5, $E_r$ value of laminar and turbulent models are 4.3 and 9.2%, respectively. Comparing the results of turbulent and laminar models showed that discharge estimated by the laminar model was lower than that of turbulent model. This is reasonable, because turbulence increases momentum exchange in boundary layers. Therefore, according to results it is obvious that average error of both laminar and turbulent models is low and appropriate and can be said that there was good agreement between the simulated and measured values. Therefore, CFD method and FLUENT software are powerful techniques to determine hydraulic flow behaviour through labyrinth channels. Thus, this software is capable to simulate emitter discharge in other temperatures. Simulated emitter discharge in various pressure and temperatures and also calculated TDR values are given in Tables 7 and 8, respectively.

As shown in Tables 6 and 7, emitter discharge increased with increasing pressure, but increase in temperature has little impact on emitter outflow. In low pressures (2, 4 and 6.1 mH$_2$O) the emitter outflow shows no sensitivity to temperature changes but in higher pressures the simulated discharge by laminar model increases almost linearly. This discharge increase can be ignored because maximum discharge increase due to temperature change from 5 to 55°C occurs at a pressure of 16.33 mH$_2$O i. e. about 4.5%. In turbulent model, the temperature change has also no impact on the emitter outflow in high pressures. In general, concerning the studied emitter, with the increase in temperature no change occurs in the emitter outflow. Considering that the exponent of the emitter discharge equals about 0.5, this emitter is a kind of turbulent flow emitter. According to the
results of Keller and Karmelli (1975), Parchomchuk (1976) and Decroix and Malaval (1985) the discharge of turbulent flow emitters is insensitive to temperature changes. This is also confirmed by the results from the present survey and, thus, it is proved that the emitters outflow has been well simulated using computational fluid dynamic. As the emitter discharge is not sensitive to temperature changes, it can be applied in drip irrigation projects in arid and warm regions.

In model solution also it was shown that in low temperatures the two models were converged almost within the similar time but with the increase in temperature the laminar model became converged very slowly and its convergence is much more time-consuming than the turbulent model. This indicated that turbulent model was more appropriate for flow simulation in high temperatures likely due to decrease of water viscosity and, as a consequence, decrease of friction lost enhancing the flow tendency to turbulence.

CONCLUSION

Simulation of the flow in channels of emitter showed that both laminar and turbulent models have estimated discharge at a rate a little higher than the measured values. The average prediction error of laminar and turbulent models is about 4 and 9%, respectively, and laminar model has estimated discharge at a lower rate than turbulent model. With such prediction accuracy, it can be said that CFD and FLUENT are very efficient tools for the simulation and study hydraulic flow in the channels of emitter.

Discharge of the emitter increased with increase in pressure, but increase in temperature has little impact on flow rate at the emitter outlet. In general, in the studied emitter the temperature changes have no impact on emitter discharge. Therefore, it can be applied in drip irrigation projects in arid and warm regions. In model solution also it was shown that with the increase in temperature the laminar model became converged very slowly and its convergence is much more time-consuming than the turbulent model. This indicated that turbulent model was more appropriate for flow simulation in high temperatures.

REFERENCES


