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ORIGINAL ARTICLE

Experimental Investigation of Dissolved Oxygen in Downstream of Hydraulic Jump

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ABSTRACT
Hydraulic jump aeration is the commonest way for transferring Oxygen in a system without major costs or difficulties. It is a cost-effective method. The evaluation of the quality of water is done by measuring the amount of Oxygen that has been solved in the water. The level of Oxygen concentration in water depends on the number of air molecules that have been solved in the water. The transfer of a pollutant or solved Oxygen in the water is not done solely by water stream (mass stream). Depending on the level of concentration, the Oxygen or pollutants are moved in the water stream by dispersion processes and longitudinal dispersion. Mass stream of a mixed pollutant in the water means the transfer of this pollutant with water. Dispersion is a process that occurs as a result of concentration slope, the movement of molecules and their collision, and the changing of molecules directions. Dispersion processes are divided into two types: molecular dispersion and turbulent dispersion. In this research, the solved Oxygen and its related parameters in hydraulic jump and also the aeration in the hydraulic jump in a laboratorial flume with a length of 12^{m}, a width of 40 ^{cm}, and a height of 50^{cm} were examined. It was observed that there is a positive linear relation between the efficiency of aeration in hydraulic jump and energy dissipation along the hydraulic jump. The larger the Froude number in the upstream of the jump, the higher the level of the jump.
Keywords: *Aeration; Hydraulic jump; Solved Oxygen*

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INTRODUCTION

Hydraulic jump is one of the fast changing streams with which we are faced in scientific investigations. It is a change in the condition of stream from above-critical to below-critical in cases that the condition of water stream is above-critical in a part of the route and it seeks to change condition due to the characteristics and shape of the canal. The depth of the streams along a relatively short route is increased substantially, energy is dissipated noticeably, and speed is reduced significantly. These important phenomena occur in open canals in which there is a surface turbulence in the stream of water. This is accompanied by rolling tides and the solution of air in the water. Hydraulic jump is a fast changing stream which occurs during the passage from above-critical to below-critical period. It leads to the dissipation of stream's energy. It is always accompanied by rolling tides and the solution of air in the water. The most important role of hydraulic jump is energy dissipation. It protects the downstream structures against the destructing forces of stream. Stilling basins, sharp-crested and non-sharp-crested weirs, lumps and holes are among the different types of hydraulic structures which can be used for making a hydraulic jump. These structures are built in the downstream of hydraulic systems, in which there is the possibility of downstream destruction by the potential energy of the water. These structures are built in a way that the jump occurs inside them and there is no jump in the downstream or outside the structure.

Throughout the hydraulic jump, various forces are exerted on the structure, the most important of which are hydrodynamic forces, hydrostatic forces, and the elevating forcers accompanied by severe pressure fluctuation at the bottom of stilling basin. This pressure might lead to the deformation and rising of the structure. A lot of studies have been conducted on hydraulic jump from different perspectives. Some studies have investigated hydraulic jump in relation to the speed and pressure of the stream direction. Other studies have examined hydraulic jump and its relationship with pressure fluctuation at the bottom of stilling basin. However, few studies have been conducted to examine hydraulic jump in relation to the amount of solved Oxygen in the downstream. The conducted studies in Iran have mainly focused on the hydraulic of the stream in terms of speed, pressure, and numerical methods. Few studies, at least in Iran, have been conducted to investigate the issue of Oxygen solution in the downstream of hydraulic jump. So, this is one of the first studies that have been conducted in this area of research.

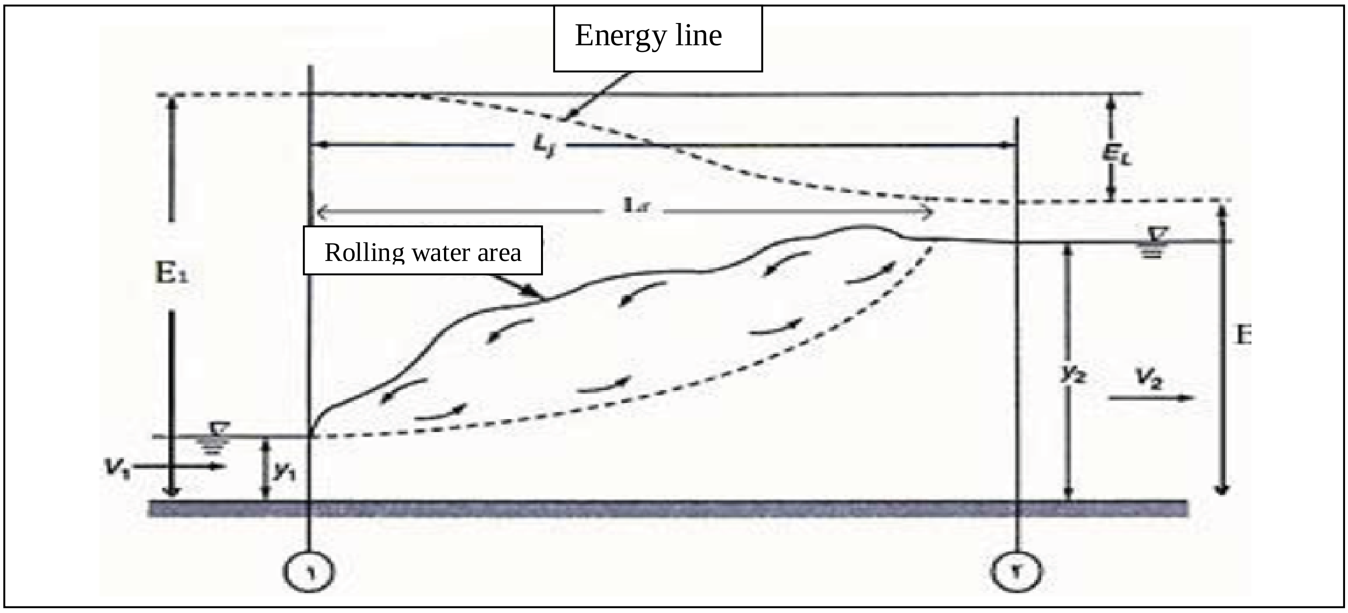

Fig 1. The general form of hydraulic jump on a flat bed

Instruments and Method

Hydraulic jump or leap is one of the fast changing streams with which we are faced in many applied operations. It is the changing of stream condition from above-critical to below-critical. If water stream condition is above-critical in some part of the route and seeks to change condition because of the characteristics of the canal, the depth of the water is increased substantially throughout a relatively short space, energy is dissipated, and speed is reduced noticeably. This is one of the most important phenomena in the open canals in which there is turbulence in the surface of the water from the beginning to the end (Figure 1). In this condition and in proportion to the intensity of the jump, some turbulence is observed on the surface of the water. When we move toward the end of the jump site, the intensity of turbulence is reduced and proportionately, due to the change of energy into heat, the energy of water is reduced. In addition, due to the turbulence and the collision of air and water, some air is solved in the water on the surface and then transferred to the downstream and finally released in the form of bubbles.

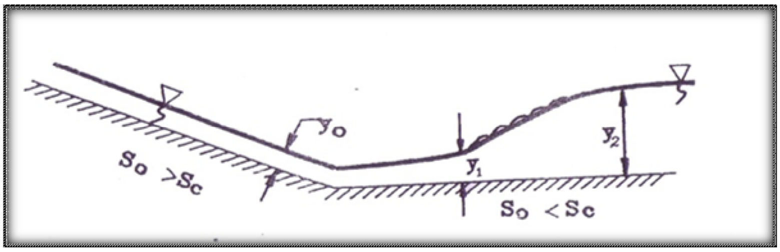

Figure 2. Hydraulic jump

Hydraulic jump might be produced in two ways: free stream with sectional surface of homogeneous liquid or a liquid whose density is compliant with different densities. In both conditions, the jump is accompanied by stream turbulence and energy dissipation.

For water jumps in non-slope floors and by using the principle of movement quantity, the following equation can be applied for the beginning and ending of the leap:

$$\frac{Q^2}{gA_1} + A_1\bar{y}_1 = \frac{Q^2}{gA_2} + A_2\bar{y}_2$$

In rectangular sections, the above equation is simplified in the following way:

$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8\,Fr_1^2} - 1\right)$$

$$y_1 = \sqrt{\frac{y_2^2}{4} + \frac{2g^2}{gy_2}} - \frac{y_2}{2}$$

$$y_2 = \sqrt{\frac{y_1^2}{4} + \frac{2g^2}{gy_1}} - \frac{y_1}{2}$$

$$\Delta E = \frac{(y_1 - y_2)^{\;3}}{4y_1y_2}$$

(ΔE): The amount of energy dissipation

The values of $\frac{y_2}{y_1}$ in the canals with various sections are not the same. This point can be seen in figure 1.2.

As it can be observed in the figure, for a fixed F_{r1}, the fixed values of $\frac{y_2}{y_1}$ for rectangular canals are higher compared to these values for trapezium, triangular, and parabolic canals. In figure 3.3, the value of *k* in the trapezoid is:

$$k = \frac{b}{zy_1}$$

b= the width of trapezoid

z= the value of slope at the edges of trapezoid

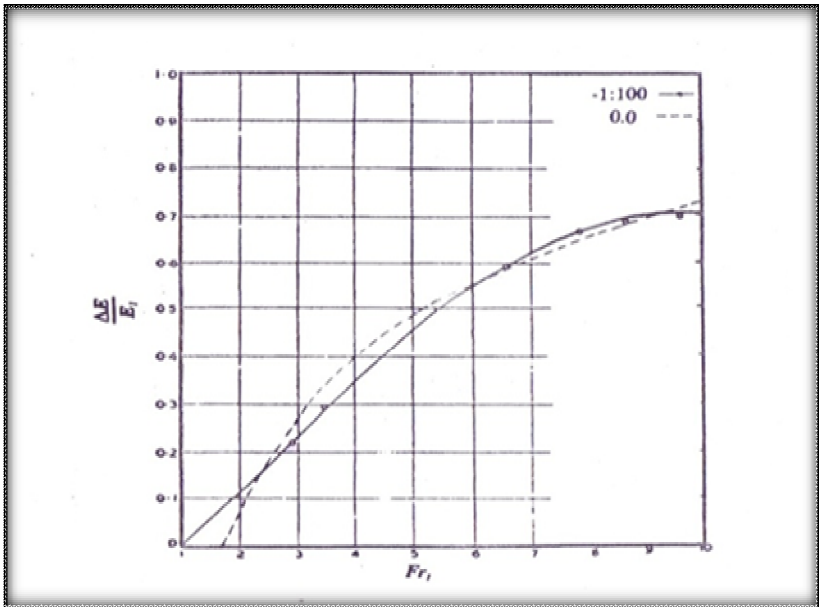

Figure 3. Energy dissipation in hydraulic jump for sections with different shapes

Also, the amounts of energy dissipation (ΔE), while F_{r1} is equal for different sections of the canals, are not the same. In figure 3.3, the comparison has been shown on the diagram. The figure 1.4 shows the amount of energy dissipation for horizontal rectangular canals which has been studied by USBR. It can be seen that the results of the experiments are consistent with the equation $\Delta E = \frac{(y_1 - y_2)^{\;2}}{4y_1y_2}$

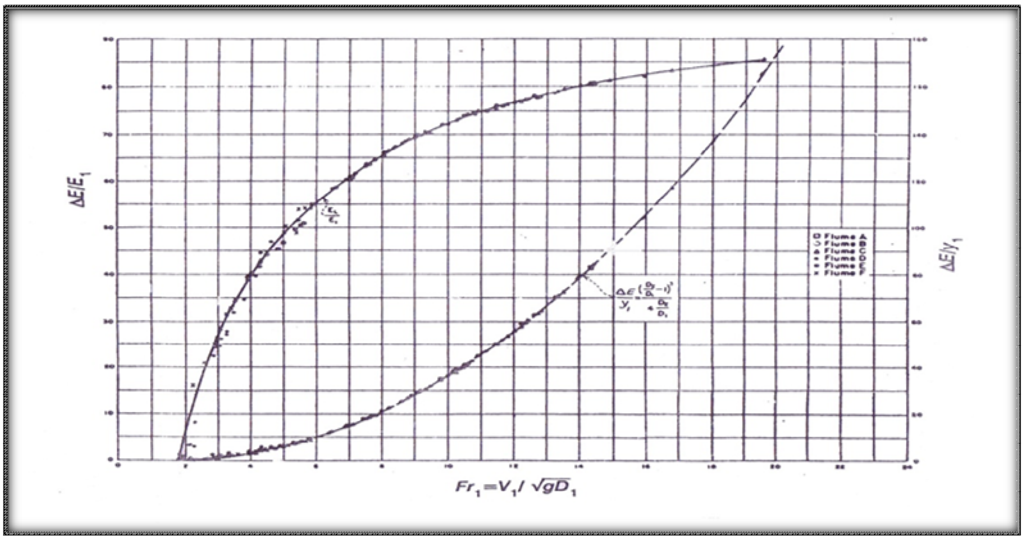

Figure 4. Energy dissipation in horizontal rectangular sections (After 1983, USBR)

These experiments were conducted in the hydraulic laboratory of Azad University of Shooshtar in a canal whose length, width, and heights were 15, 0.40, and 0.50 meters respectively.

In this experiment, considering this fact that there were various discharges by using control valve, discharge was obtained for all of the cases.

$$q = \frac{Q}{b} = \frac{0/00523}{0/395} = 0/0132$$

By this information, we can calculate the initial depth in the upstream.

$$y_1 = \frac{q}{V_1} = \frac{0/.132}{0/012} = 0/39$$

By using the equation *Q=AV*, we can obtain the initial speed *A=b.y* In this condition, by using the depth of upstream and discharge, we can calculate the depth in the downstream:

$$y_2 = \frac{y_1}{2} = \left[-1 + \sqrt{1 + \frac{8q^2}{gy_1^2}}\right]$$

Now, the upstream and downstream Froude numbers are obtained by the following equations:

$$Fr_1 = \frac{q}{\sqrt{gy_1^3}} \qquad Fr_2 = \frac{q}{\sqrt{gy_2^3}}$$

Also, by using the equation $E_1=E_2+\Delta Z \rightarrow E_1=E_c+\Delta Z$, the critical depth is calculated

$$y_1 + \frac{V_1^2}{2g} = \frac{3}{2}y_c + \Delta Z$$

$$38/5 = \frac{3}{2}y_c + 36/5 \rightarrow y_c = \frac{2}{3}(38/5 - 36/5)$$

$$y_c = 1/3 \qquad y_c = \sqrt[3]{\frac{q^2}{g}} = 1/3$$

Now, by the critical depth, we can calculate the critical speed

$$V_c = \sqrt{gy_c} \quad \rightarrow \quad \sqrt{9/81^m \times 0/13^m} \quad \rightarrow \quad V_c = 1/13 \ {}^m/_s$$

By using the critical depth, we can calculate special energy by the following equation

$$y_c = \frac{3}{2}E_c E_c = \ y_c + \frac{V_c^2}{2g}$$

In this experiment, the height of jump (h_j), the length of jump (L_j), energy dissipation (H_{Lj}), and the efficiency of jump (ΔE) are calculated as followings:

$$L_j = A\,(y_2 - y_1) = 6(0/05 - 0/03) = 0/12$$

$$h_j = y_2 - y_1 = 0/05 - 0/03 = 0/02$$

$$H_{Lj} = \frac{(y_2 - y_1)^3}{4y_1 y_2} = \frac{(0/05 - 0/02)^3}{4(0/02)(0/05)}$$

$$\Delta E = e_j = \frac{E_2}{E_1} \times 100 = \frac{E_1 - H_{Lj}}{E_1} \times 100 = \frac{y_1 + \frac{V_1^2}{2g} - H_{Lj}}{y_1 + \frac{V_1^2}{2g}} = \frac{\frac{0}{05}}{\frac{0}{03}} \times 100 = 3 \times 100$$

$$\Delta E = 1/3$$

In the final stage, the amount of solved Oxygen in the water is measured by D_o-meter. We measured the D_o of the solution twice in the morning and at noon. The first experiment was conducted at 14 o'clock with 5 different discharges. In each discharge, D_o was measured in three different jump points. The first point was in the jump upstream, the second point was in the jump itself, and the third point was in the jump downstream. They have been mentioned in two separate tables.

Table 1: D_os related to various discharges

	Jump upstream		Jump		Jump downstream	
Q (lit/s)	D_o	Tc°	D_o	Tc°	D_o	Tc°
2	7.64	29.4	7.64	29.4	7.68	28.7
5	7.74	28.5	7.71	28.7	7.68	28.8
9.6	7.59	29	7.55	29.3	7.53	29.4
14.7	7.53	29.3	7.48	29.4	7.48	29.4
20.2	7.51	29.4	7.46	29.5	7.44	29.5

In this condition, the T_c and the D_o of the water pool was obtained

D_o	Tc°
7.69	29

RESULTS AND DISCUSSION

Hydraulic jump or leap is one of the fast changing streams with which we are faced in applied operations. Hydraulic jump is a change in the condition of water stream from above-critical to below-critical. If the condition of water is above-critical in a part of the route and it seeks to change condition due to the special shape and characteristics of the canal, the depth of the stream is increased substantially throughout a relatively short part of the route. Consequently, a noticeable dissipation of energy and a major reduction in speed are observed. Hydraulic jump is one of the most important phenomena in the streams of water in the open canals in which there is turbulence on the surface of the water from the beginning to the end (Figure 1.3). In this condition and proportionate to the intensity of the jump, some turbulences are observed on the surface of the water. These turbulences gradually lose their intensity as we move toward the end of the jump. Due to the turning of energy into heat, the level of water energy is reduced proportionately. In addition, due to the turbulence and the collision of water and air, some air is mixed with water on the surface of the water which is transferred to the downstream and finally released in the form of bubbles.

In this experiment, the slope of the bed and stream were regulated and the temperature was measured several times throughout the measurement of aeration.

So, the mentioned experiment shows that as the domestic, agricultural, and industrial sewages are discharged into the rivers, we should expect that the amount of solved Oxygen in the different parts of a river to be different. These differences in the amounts of solved Oxygen are various in different seasons and are changed as the temperature rises.

As domestic, agricultural, and industrial sewages are discharged into the streams of water, the level of solved Oxygen in the water is reduced. When the streams pass through slopes and collide with the obstacles along the route, the amount of solved Oxygen in the water is increased. The increase and decrease of the solved Oxygen is a continuous process. Also, in different seasons and as the temperature

changes, the level of solved Oxygen is reduced. As the temperature of the environment rises, the tendency of water for Oxygen absorption is reduced and some part of Oxygen goes out of the system by vapor.
The transfer of a pollutant or solved Oxygen in water is not done exclusively by water stream (mass stream). Depending on the concentration, these pollutants or solved Oxygen in the mass of water stream are moved. Because of dispersion processes and longitudinal spread, these pollutants and solved Oxygen are moved and spread throughout water. The mass stream of a mixed pollutant means its transfer with the stream of water. Dispersion is a process which occurs as a result of concentration slope, molecule movements, their collision with each other, and the changing of molecule directions. Dispersion processes are divided into two types: molecular dispersion and turbulent dispersion.

CONCLUSION

Proportionate to the intensity of the jump, some turbulence is made on the surface of the water. As we move toward the end of the jump, the intensity of turbulence is reduced, and the energy of the water is also reduced, because the energy is turned into heat. In addition, due to the turbulence and the collision of air with water, some air is mixed with water on the surface of the water which is transferred to the downstream and finally released in the form of bubbles. This shows that there is a positive relation between aeration efficiency and energy dissipation along the hydraulic jump. As the efficiency of aeration increases, energy dissipation is also increased. The results of the present study show that there is positive linear relation between aeration efficiency and energy dissipation along hydraulic jump. As the Froude number increases in the upstream of the jump, the length and size of the jump is also increased. The results of this experiment show that as we move farther from the place of the jump, the amount of solved Oxygen in the water is reduced and the temperature is increased. This experiment shows that some part of water energy has been turned into heat along the route. This increase in temperature leads to the reduction of D_o along the route. The obtained results show that as the energy is reduced along the route, the amount of solved Oxygen in the water is increased in the long term. This long term increase in the amount of solved Oxygen continues for a long distance. Depending on the intensity of the jump, this condition continues for some kilometers. Gradually, the solved Oxygen goes out of aeration cycle, but it is never completely excluded from the cycle. This process might happen several times along the route. Consequently, flowing waters always contain some amount of solved Oxygen.

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