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Oxygen Transfer by Multiple Inclined Plunging Water Jets

Surinder Deswal

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***Abstract*—**There has been a growing interest in the oxygenation by plunging water jets in the last few years due to their inherent advantages, like energy-efficient, low operation cost, etc. Though a lot of work has been reported on the oxygen-transfer by single plunging water jets but very few studies have been carried out using multiple plunging jets. In this paper, volumetric oxygen-transfer coefficient and oxygen-transfer efficiency has been studied experimentally for multiple inclined plunging jets (having jet plunge angle of 60^0) in a pool of water for different configurations, in terms of varying number of jets and jet diameters. This research suggests that the volumetric oxygen-transfer coefficient and oxygen-transfer efficiency of the multiple inclined plunging jets for air-water system are significantly higher than those of a single vertical as well as inclined plunging jet for same flow area and other similar conditions. The study also reveals that the oxygen-transfer increase with increase in number of multiple jets under similar conditions, which will be most advantageous and energy-efficient in practical situations when large volumes of wastewaters are to be treated. A relationship between volumetric oxygen-transfer coefficient and jet parameters is also proposed. The suggested relationship predicts the volumetric oxygen-transfer coefficient for multiple inclined plunging jet(s) within a scatter of ±15 percent. The relationship will be quite useful in scale-up and in deciding optimum configuration of multiple inclined plunging jet aeration system.

***Keywords*—**Multiple inclined plunging jets, jet plunge angle, volumetric oxygen-transfer coefficient, oxygen-transfer efficiency.

I. Introduction

A water jet, which after passing through the surrounding atmosphere plunges into a water bath, entrains into this bath a substantial amount of air and forms a submerged two-phase region with a considerable air-water interfacial area. This process is called plunging water jet entrainment and aeration (or oxygenation). It is basically a combination of hydrodynamic and aerodynamic forces interacting between water jet and ambient air [1]. Plunging jet applications include aeration and floatation in water and wastewater treatment, oxygenation of mammalian-cell bio-reactors, biological aerated filter, fermentation, bubble floatation of minerals, plunging columns, cooling system in power plants, stirring of chemicals as well as increasing gas-liquid transfer, plunging breakers and waterfalls [2]-[6]. Oxygenation by a plunging water jet is an attractive way to effect oxygen-transfer than conventional oxygenation systems for various reasons[2], [7], [8]: it does not require compressor blower; it facilitates make-up of the "closed" system, which enhance complete utilization of oxygen and volatile reactants; it is simple in design, construction and operation; it does not require separate stirring devices because the water jet itself achieves aeration and mixing; it is energetically attractive as a means of straightforward contacting mechanism in fouling or hazardous environments; and it is free from operational difficulties such as clogging in air diffusers, limitations on the installation of mechanical aerators by the tank width, etc. Supported by these potential advantages, there has been a growing interest in the oxygenation by plunging water jets in the last few years.

A substantial number of researchers have studied air-water oxygen transfer by single plunging jets [9]-[17]. Some of these researchers have also presented their data in the form of empirical relationships. The simplest relationships for single circular water jets plunging vertically (i.e. jet plunge angle, $\theta = 90^0$) as proposed by [18], [14] and [12] respectively are:

$$K_L A_{(20)} = 3.1\times 10^{-4} + 4.85\times 10^{-2} v_j^3 d_j^2 \quad (1)$$

$$K_L A_{(20)} = 9\times 10^{-5} P \quad (2)$$

$$K_L A_{(20)} = 0.029\left(P/V\right)^{0.65} \quad (3)$$

where $K_L A_{(20)}$ is volumetric oxygen transfer factor at standard conditions (m^3/h); v_j is jet velocity at exit (m/s); d_j is jet diameter (m); P is jet power (W); $K_L A_{(20)}$ is volumetric oxygen transfer coefficient at standard conditions (1/s); and P/V is jet power per unit volume (kW/m^3).

Recently, [19] studied the effects of liquid property on air entrainment and oxygen transfer rates of plunging jet reactors, [20] investigated air entrainment by two-dimensional plunging jet, [21] by conical plunging jet aerator and [6] investigated the air/water oxygen transfer in a biological aerated filter. References [8], [22] and [23] have reported the role of jet geometry (i.e. nozzle shapes) in air entrainment and oxygen transfer. Thus, much useful information is available on the oxygen transfer characteristics of single plunging water jets.

Earlier researchers have identified jet velocity, jet diameter, jet plunge angle and jet geometry as the four operating variables affecting the oxygen transfer of a plunging water jet aeration/oxygenation system. So far an important factor that may affect the performance of a plunging jet oxygenation

Surinder Deswal is with the National Institute of Technology, Kurukshetra -136119, Haryana, India (corresponding author to provide phone: +91-1744-233356; fax: +91-1744-238050; e-mail: deswal.leo@gmail.com).

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system and has not been discussed specifically/conclusively in literature is number of jets. The effect of multiple jets can be significant because perfect mixing cannot be expected in a very large pool with only one plunging jet [2], [24] and [25]. A review of existing studies on multiple plunging jets indicates that apart from the study of multiple plunging jets plunging vertically, $\theta = 90^0$ [24]-[25], most of the works have been carried out by using two plunging water jets only [10], [11] and [13]. However, it seems that there is no definite conclusive and extensive study on oxygen transfer by multiple inclined plunging jets.

The objective of this paper is to study oxygen transfer, in terms of volumetric oxygen-transfer coefficient at standard conditions ($K_L A_{(20)}$) and oxygen-transfer efficiency (OTE), by multiple inclined plunging jets and the effect of varying numbers of jets. A jet plunge angle of $\theta = 60^0$ has been selected for the multiple inclined plunging water jets in the present study. This selection of jet plunge angle is on the basis of findings of [13] which revealed that the inclined jets have to be preferred to vertical jets and concluded that the optimum jet plunge angle is 60^0. Relationship for multiple inclined plunging jets has also been presented in the paper to predict volumetric oxygen-transfer coefficient $K_L A_{(20)}$ as a function of jet parameters.

II. Oxygen Transfer by Plunging Water Jets

In the "closed" system of the plunging liquid jet aerators, perfect mixing for the liquid phase in the pool and plug flow in the circulation pipe can be assumed [2]. In such a case, an oxygen balance equation relating the instantaneous rate of change in dissolved oxygen (DO) concentration (dC/dt) to the rate of oxygen mass transfer between air and water can be written as:

$$\frac{dC}{dt} = K_L \frac{A}{V}[C_s - C] \tag{4}$$

where K_L is bulk liquid film coefficient.; C_s is the saturation dissolved oxygen concentration in water at prevailing ambient conditions; A is the air-water contact area; and V is the volume of water associated with this. The term A/V is called the specific surface area (a) or surface area per unit volume; while the term $K_L A$ is called the volumetric oxygen-transfer factor. Integrating Eq.4 between the limits of $C = C_0$ and $C = C$ and $t = t_0$ and $t = t$,

$$\int_{C_0}^{C} \frac{dC}{C_s - C} = (K_L a)\int_0^t dt \tag{5}$$

which after simplification can be written as:

$$K_L a = \frac{1}{t} \mathrm{In}\left[\frac{C_s - C_0}{C_s - C_t}\right] \tag{6}$$

where C_0 and C_t are dissolved oxygen concentrations in the water at start and at the time t of aeration respectively; and $K_L a$ is volumetric oxygen-transfer coefficient. Equation (6) shows that values of $K_L a$ can be obtained by substituting the measured values of C_s, C_0, C_t and t. In order to have a uniform basis for comparison of different systems, $K_L a$ is generally normalized at 20^OC standard. The temperature dependence of $K_L a$ can be expressed using the following empirical equation [26]:

$$K_L a_{(20)} = K_L a_{(T)} \times (1.024)^{(20-T)} \tag{7}$$

where $K_L a_{(20)}$ is oxygen-transfer coefficient at standard conditions (1/s) and $K_L a_{(T)}$ is oxygen-transfer coefficient at T ^{O}C (1/s).

The oxygenation performance of plunging water jets is generally expressed in terms of the oxygen-transfer efficiency OTE (kg O_2/kW.h), and given by (8):

$$OTE = \frac{O_R V}{P} \tag{8}$$

where O_R is oxygen-transfer rate (mg/L/h) at 20^OC and 1 atmosphere (standard conditions); and P is jet power (kW). O_R and P can be expressed as:

$$O_R = K_L a_{(20)}.3600\ .C_s^* \tag{9}$$

$$P(in\ kW) = \left(\frac{1}{2}\rho Q v_j^2\right)\frac{1}{10^3} = \left(\frac{\pi}{8}\rho n d_j^2 v_j^3\right)\frac{1}{10^3} \tag{10}$$

where C_s^* is saturation dissolved oxygen (DO) concentration in water at standard conditions (mg/L); ρ is density (kg/m^3)and Q is discharge or jet flow rate (m^3/s).

III. Experimentation

A. Experimental Setup

To conduct experiments a "closed" system with a complete re-circulation of the water and a constant water holdup was used in the present study. A schematic representation of the experimental set-up is shown in Fig. 1. The experimental set-up consisted of a water tank, a water pump, a flow regulating valve, an orifice meter, a thermometer, a multiple plunging jets device, a piezo meter and a scale. All experiments on oxygen-transfer by single and multiple plunging jets were carried out in a water tank with dimensions of 1.02 m long x 1.02 m wide x 1.0 m deep. The water-depth in the tank was kept at 0.6 m for all experiments and measured with the help of a piezo meter fitted to the water tank alongside a scale. The water in the experimental set-up was circulated by a centrifugal pump. A flow regulating valve was provided at the location identified in Fig. 1. A pre-calibrated orifice meter was installed in the pipeline for flow measurements. A digital thermometer was used for the temperature measurement. The multiple plunging jets device was fitted to the vertical inflow pipe and adjusted such that the jets impinge centrally in the pool. The jet length (L), vertical distance between exit of the jet and water surface in the pool, was kept as 0.1 m through out the experimentation.

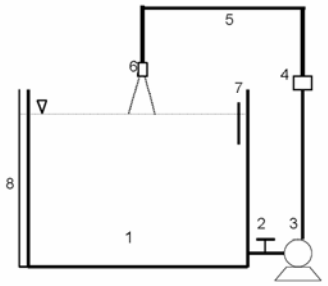


Fig. 1 Experimental set-up: (1) water tank; (2) flow regulating valve; (3) water pump; (4) orifice meter; (5) inflow pipe; (6) multiple plunging jet device; (7) Thermometer probe; (8) piezo-meter with scale.

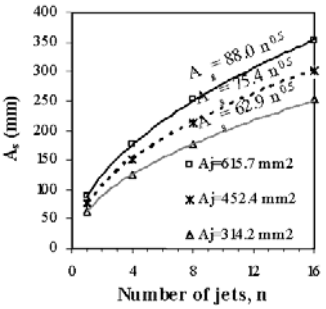
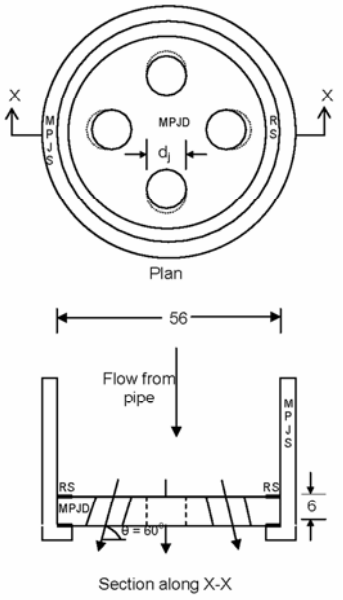


Fig. 3 Variation of A_s with n for a constant flow area (A_j)



(All dimensions in mm)

Fig. 2 Details of multiple plunging Jets device: MPJD is multiple plunging jets disc for n=4; RS is rubber seal; MPJS is multiple plunging jets socket

TABLE I
SINGLE AND MULTIPLE PLUNGING JETS CONFIGURATION

No. of jets n	Jet diameter d_j (mm)	Jet plunge angle θ (^{0})	Cross-sectional area of jet(s) or flow area $A_j = n\frac{\pi}{4}d_j^2$ (mm^2)	Surface area of jet(s) in contact with atmosphere per unit jet length $A_s = n\pi d_j$ (mm)
1	28	90	615.7	88.0
1	28	60		88.0
4	14	,,		176.0
8	10*	,,		248.3
16	7	,,		352.0
1	24	90	452.4	75.4
1	24	60		75.4
4	12	,,		150.9
8	8.5	,,		213.7
16	6	,,		301.7
1	20	90	314.2	62.9
1	20	60		62.9
4	10	,,		125.7
8	7	,,		176.0
16	5	,,		251.4

* The diameter of 2 holes was 9.5 mm so as to keep the cross-sectional area of jets constant.

B. Multiple Plunging Jet Device

Fig. 2 shows the details of the multiple plunging jets device used to produce four numbers (n=4) of multiple inclined plunging jets each of diameter d_j (=14 mm) with jet plunge angle of $\theta = 60^0$. The device has two main components, namely (1) multiple plunging jets socket (MPJS) and (2) multiple plunging jets disc (MPJD). The MPJS was fabricated using cast iron. It has internal threads so that it can be fitted to the inflow pipe after placing a MPJD in it. A MPJD is a 6 mm thick Perspex disc of 56 mm diameter in which circular hole(s) of desired diameter d_j were drilled to produce multiple inclined plunging jets with jet plunge angle of $\theta = 60^0$. Twelve numbers of such MPJDs were fabricated to produce multiple inclined plunging jets of different configurations in terms of diameter d_j and number of jets n (Table I). Similarly, three discs were also fabricated to produce single vertical plunging jet with jet plunge angle of $\theta = 60^0$ (Table I).

In this study, the MPJDs were fabricated for three different cross-sectional areas of jet(s) or flow areas (A_j) equal to 615.7 mm^2, 452 mm^2 and 314.2 mm^2. For each flow area (A_j), the numbers of jets (n) have been varied as 1, 4, 8 and 16 as given in Table I. By doing so, the surface area of multiple jets in contact with atmosphere per unit jet length ($A_s = n\pi d_j$) increases by $\sqrt{n}$ times than the surface area of a single jet in contact with atmosphere per unit jet length. In doing so, the cross-sectional area of jet(s) or flow areas (A_j) is kept constant (Fig. 3). By increasing the surface area of multiple jets in contact with atmosphere per unit jet length in this manner, it is expected that the oxygen-transfer might be increased for a given flow area (A_j) and jet flow rate (Q) as more and more oxygen will be carried into the water tank.

C. Experimental Procedure

In this study, a series of laboratory experiments were carried out on single (vertical and inclined) and multiple inclined plunging water jets to study and compare their volumetric oxygen-transfer coefficient at standard conditions ($K_L A_{(20)}$) and oxygen-transfer efficiency (OTE). Each multiple jet configuration was tested at four different jet flow rates or discharges (i.e. 1.33 x 10^{-3}, 1.8 x 10^{-3}, 2.5 x 10^{-3} and 3.1 x 10^{-3} m^3/s). To begin with an experiment, the multiple plunging jets device with disc of desired configuration was fitted to the inflow pipe. Tap water was then filled in the water tank. The opening of the regulating valve was set at desired flow rate using the pre-calibrated orifice meter in the supply line. Water in the tank was deoxygenated by adding an estimated quantity of sodium sulfite (Na_2SO_3) and in addition cobalt chloride ($CoCl_2$) was added to act as a catalyst. A representative sample of the deoxygenated water was taken

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and the initial dissolved oxygen concentration (C_0) was determined by azide modification method [27]. Aeration was then carried out for a fixed duration of time (t = 60 seconds). The representative samples of the aerated/oxygenated water were then taken for the determination of dissolved oxygen concentration after time t (C_t). The water temperature (T) was recorded during the course of experiment. The value of $K_L a_{(T)}$ was calculated by using (6) and volumetric oxygen-transfer coefficient at standard conditions ($K_L a_{(20)}$) was obtained by using (7). The OTE and P values were calculated by using (8) and (10) respectively.

IV. Results and Discussions

The following sections discuss the effect of jet plunge angle (θ) on overall volumetric oxygen transfer coefficient ($K_L a_{(20)}$), variation of $K_L a_{(20)}$ values for multiple inclined plunging water jets with the jet velocity v_j and jet power per unit volume P/V in Figs. 4, 5 and 6 respectively; the derivation of empirical relationship between $K_L a_{(20)}$ and jet parameters; and the variation of OTE of multiple inclined plunging water jets and its comparison with single inclined jets in Fig. 7.

The effect of jet plunge was studied by comparing the volumetric oxygen-transfer coefficients by single vertical ($\theta = 90^0$) and single inclined ($\theta = 60^0$) jets of same configurations and under similar flow conditions. It can be observed from Fig. 4 that the inclined jet has a higher volumetric oxygen-transfer coefficient $K_L a_{(20)}$ than the vertical jet at a given jet power per unit volume P/V. This result is in accordance with the finding of [13]. After verifying this, the experiments were conducted on different configurations of multiple inclined jets (Table I) having jet plunge angle θ of 60^0.

The effect of jet velocity on volumetric oxygen-transfer coefficient of multiple plunging jets is shown in Fig. 5. It can be observed from Fig. 5 that variation in $K_L a_{(20)}$ is closely related to number of jets n in the multiple plunging jets device. The $K_L a_{(20)}$ increased remarkably as v_j increased in all the experiments. The increase in $K_L a_{(20)}$ with increase in jet velocity may be ascribed to the increased momentum of the jet flow. The values of $K_L a_{(20)}$ for multiple inclined jets were greater than those for single inclined jets ($n = 1$). The $K_L a_{(20)}$ increases with the increase in number of jets, at a given jet velocity. This increase in $K_L a_{(20)}$ for multiple inclined plunging jets with increasing number of jets may be ascribed to more quantity of air/oxygen entrained due to increased surface area of multiple jets in contact with atmosphere per unit jet length (A_s).

To study the effect of number of jets (n) on the volumetric oxygen-transfer coefficient, the $K_L a_{(20)}$ data for single and multiple inclined jets are compared in Fig. 6 in terms of the jet power per unit volume (P/V). It was observed that the values of $K_L a_{(20)}$ increases with the increase in jet power per unit volume over the whole range of experiments. Moreover, number of jets n was closely related to $K_L a_{(20)}$ at a given jet power per unit volume (Fig. 6). The volumetric oxygen-transfer coefficient gradually increases as the values of n were increased for the multiple plunging jets device. This increase in $K_L a_{(20)}$ value was further strengthened with the increase in the jet power per unit volume.

The multiple plunging jets device with n =4 and 8 jets was found to have higher values of $K_L a_{(20)}$ than those for n =1 jet over the entire range of jet power per unit volume. The multiple plunging jets device with n =16 jets was found to

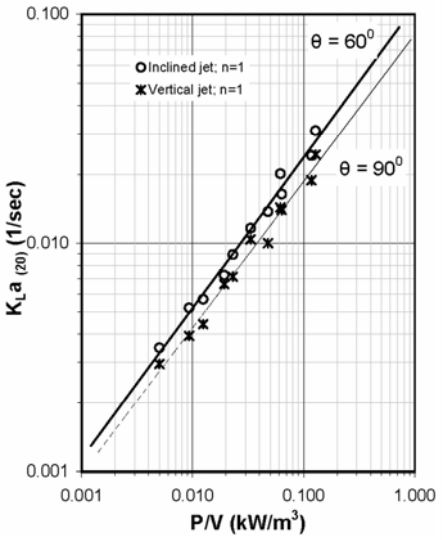


Fig. 4 Effect of jet plunge angle on oxygen-transfer.

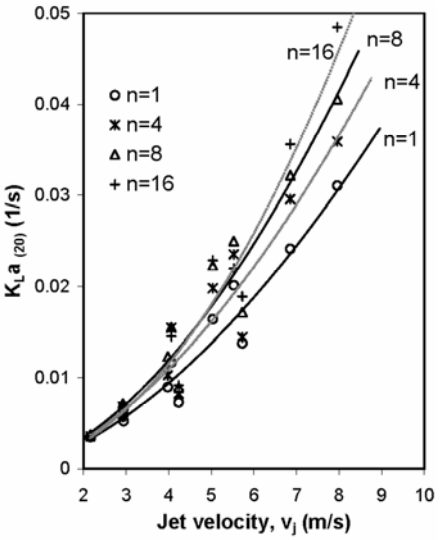


Fig. 5 Oxygen-transfer as a function of jet velocity.

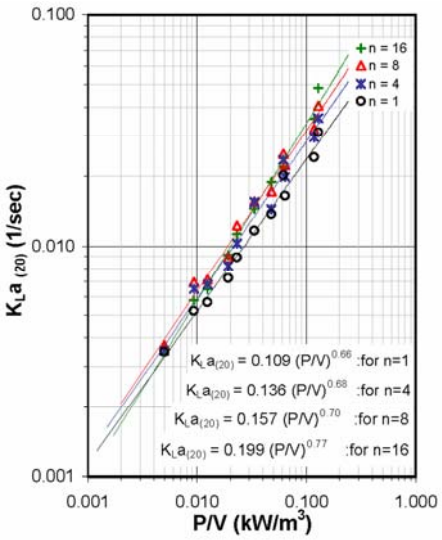


Fig. 6 Oxygen-transfer as a function of jet power.

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have lower values of $K_L a_{(20)}$ than those for n =1, 4 and 8 jets at very low values of jet power per unit volume (less than 0.003, 0.011 and 0.013 kW respectively); however, their performance started to improve as P/V was increased. This suggests that as the jet power per unit volume increases, multiple plunging jets with more number of jets perform better in terms of volumetric oxygen-transfer coefficient. For predicting the volumetric oxygen-transfer coefficient $K_L a_{(20)}$ by single inclined plunging water jets and multiple inclined plunging water jets having jet plunge angle of $\theta = 60^0$, the following relationships between $K_L a_{(20)}$ and P/V were obtained from the plot between $K_L a_{(20)}$ v/s P/V (Fig. 6):

$$K_L a_{(20)} = 0.109\,(P/V)^{0.66} \quad \text{for } n = 1 \tag{11}$$

$$K_L a_{(20)} = 0.136\,(P/V)^{0.68} \quad \text{for } n = 4 \tag{12}$$

$$K_L a_{(20)} = 0.157\,(P/V)^{0.70} \quad \text{for } n = 8 \tag{13}$$

$$K_L a_{(20)} = 0.199\,(P/V)^{0.77} \quad \text{for } n = 16 \tag{14}$$

These relationships (11)-(14) are similar (2) and (3) proposed by [14] and [12] for single vertical plunging jets having jet plunge angle of $\theta = 90^0$. But the above equations can predict $K_L a_{(20)}$ for a particular value of n only. To have a single relationship to predict $K_L a_{(20)}$ for different values of n, multivariate linear regression was applied to formulate an equation/relationship between $K_L a_{(20)}$ for multiple inclined water jets with jet plunge angle of $\theta = 60^0$ and jet parameters represented by P (i.e. n, v_j and d_j). The following relationship was developed:

$$K_L a_{(20)} = 0.103\, n^{0.81}\, v_j^{2.11}\, d_j^{1.43} \tag{15}$$

The correlation coefficient between the experimental values of $K_L a_{(20)}$ and predicted values of $K_L a_{(20)}$ using (15) is 0.98. A plot between experimental $K_L a_{(20)}$ and predicted $K_L a_{(20)}$ values obtained by using (15) shows a scatter within $\pm$ 15% of the line of perfect agreement (Fig. 7). Equation 15, thus, can be helpful in providing information about the oxygen-transfer of multiple inclined plunging jets having jet plunge angle of $\theta = 60^0$ with fair precision. This relation also suggests that simple selection of jet velocity (in m/s), diameter (in m) and number of plunging jets is therefore sufficient to predict the volumetric oxygen-transfer coefficient (in 1/s) for single and multiple inclined plunging jets with jet plunge angle of $\theta = 60^0$.

Fig. 8 shows the oxygen-transfer efficiency (OTE) for single and multiple inclined plunging jets as a function of the number of jets (n). It was observed that oxygen-transfer efficiency decreases as the jet power per unit volume increases for single and multiple inclined plunging jets as is the case with all types of aeration devices. However, the most significant aspect of the finding is that the value of OTE generally goes on increasing as the number of jets (n) are increased for a given jet power per unit volume (Fig. 8). This is particularly true at higher P/V values. Though, at very low values of P/V, the performance of multiple jets with n=16 shows a decreasing trend. This may be ascribed to lower values of $K_L a_{(20)}$ for n=16 as compared to $K_L a_{(20)}$ for n=4 at lower values of jet power per unit volume. It means that simply increasing the number of jets may not necessarily result in higher $K_L a_{(20)}$ and/or OTE. In fact, there exist an optimum configuration of multiple jets, in terms of n and d_j, for a given jet power per unit volume, which can be obtained with the help of (15).

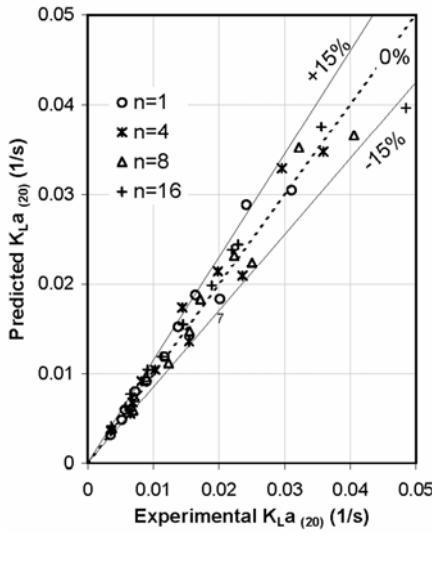


Fig. 7 Experimental $K_L a_{(20)}$ v/s predicted $K_L a_{(20)}$

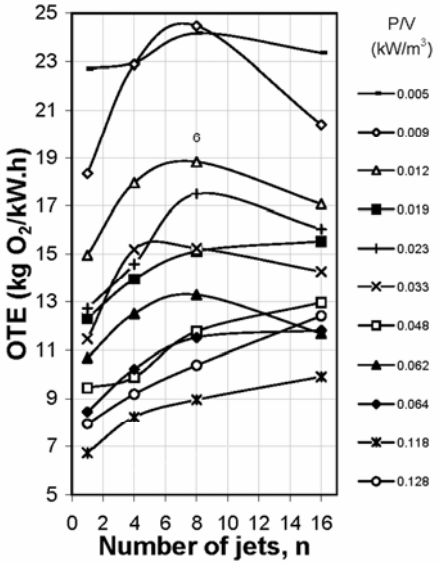


Fig. 8 Effect of multiple-jets on oxygen-transfer efficiency

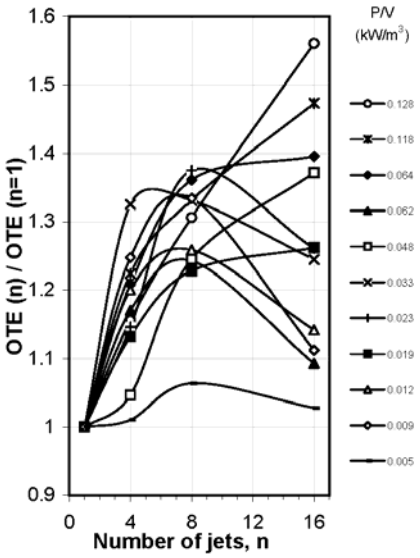


Fig. 9 Comparison of oxygen-transfer efficiency of multiple-jets with single jet

In the present study the oxygen-transfer efficiency of multiple inclined plunging jets is about 1.01 to 1.56 times

higher than that of single inclined plunging jet (Fig. 9). Further, the enhancement in the oxygen-transfer efficiency of multiple inclined plunging jets is more at higher jet powers per unit volume as can be observed from Fig. 9. This is particularly advantageous in practical situations where large volumes of wastewaters are to be aerated. Table II provides a comparison of oxygen-transfer efficiency of the multiple inclined plunging jets with other types of aeration/oxygenation equipments. It can be observed from this table that the multiple inclined plunging jets device studied here has not only performed better than single inclined plunging jet under similar conditions but is also useful and competitive with the other conventional aeration/oxygenation equipments.

TABLE II
OXYGEN-TRANSFER EFFICIENCY FOR VARIOUS TYPES OF EQUIPMENTS

S. No	Equipment	*OTE* (kg O_2/kW.h)	Remarks
1	Small bubble size disperger	1.36 – 1.8	Cited from [12].
		0.95	
2	Large bubble size disperger	0.98	
		0.64	
3	Turbine agitator	1.2 – 1.38	
4	Surface aeration by mechanical agitator	1.68	
5	Deep shaft aerator	3.0 – 6.0	
6	Gas jet aerator	1.64	
7	Eddy jet mixer	4.78	
8	Plunging Jet	0.92 – 3.9	
9	Plunging venturi device	2.2 – 8.8	Reference [8].
10	Vertical single plunging jet ($\theta=90^0$)	5.2 – 19.3	Reference [24].
11	Vertical multiple plunging jet ($\theta=90^0$)	6.0 – 21.3	
12	Conical plunging jet	2.56 – 10.73	Reference [21]
13	Inclined multiple plunging jets ($\theta=60^0$)	8.2 – 24.5	Present work

V. CONCLUSION

The following conclusions can be drawn from the present experimental study:

- The volumetric oxygen-transfer coefficient of a plunging jet is higher at a jet plunge angle of 60^0 than at 90^0, which means that inclined plunging jets having plunge angle of 60^0 should be preferred than vertical plunging jets.
- The effect of number of jets (n) is significant on the volumetric oxygen-transfer coefficient and oxygen-transfer efficiency for multiple inclined plunging jets device.
- The volumetric oxygen-transfer coefficient for the single and multiple inclined plunging jets increases with the increase in jet velocity. For a given jet velocity, the $K_L a_{(20)}$ values increases with increase in the number of multiple jets for a constant flow area due to increase of surface area of multiple jets in contact with atmosphere per unit jet length.
- The volumetric oxygen-transfer coefficient for multiple inclined plunging jets is higher than that for a single jet at a given jet power. For multiple plunging jets device, the volumetric oxygen-transfer coefficient gradually increases as the n values were increased from 1 to 16; and this increase in $K_L a_{(20)}$ value was further strengthened with the increase in the jet power per unit volume. The multiple plunging jets device should therefore be recommended for aeration/oxygenation instead of a single plunging jet at higher jet powers as in practical situations where large volumes of wastewater at higher discharges are to be oxygenated.
- The volumetric oxygen-transfer coefficient for multiple inclined plunging jets is well correlated with the jet parameters (representing jet power). The relationship, represented by (15), predicted the $K_L a_{(20)}$ from jet parameters used in this study within a scattering range of $\pm$ 15%. The relationship would be quite useful in comparing the performance of single and multiple inclined plunging jets of different configurations; and also in deciding the optimum configuration of multiple inclined plunging jets for given flow conditions.
- The oxygen-transfer efficiency of multiple inclined plunging jets was increased with the increase in the number of jets and was higher (up to 1.56 times) than that of a single inclined jet under similar conditions. The enhanced oxygen-transfer efficiency of multiple inclined plunging jets at higher jet powers per unit volume is particularly advantageous in practical situations where large volumes of wastewaters are to be aerated. Further, the *OTE* of multiple inclined plunging jets was very much competitive with the other conventional aeration/oxygenation equipments and thus suggest their practical application.
- In a practical situation, involving variations/fluctuations in the inflow to the aeration unit, multiple inclined plunging jet devices suggested in the present study can be quite useful due to their flexibility in comparison to other aeration devices. A replacement by the multiple plunging jet discs of different configuration can meet the changed requirement. Further, in real situations, where perfect mixing cannot be expected in large size aeration tanks with one plunging jet, multiple plunging jets have a distinct advantage over a single plunging jet.

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Surinder Deswal was born in Panipat, India on 15th of August 1966. Presently, he is Assistant Professor in Civil Engineering Department of National Institute of Technology, Kurukshetra, India. Ph.D. in Environmental Engineering, Kurukshetra University, Kurukshetra, India, 2005. M.E. in Environmental Engineering, Panjab University, Chandigarh, 1992. B.E. in Civil Engineering, Gulbarga University, Gulbarga, India, 1988. The areas of interests are aerobic wastewater treatment, water resources management and application of modeling and statistical tools in environmental management.

He has been in teaching and research since 1994. He has supervised many Post-graduate dissertations and is also supervising Ph.D. research scholars. He has published more than forty research papers in journals and conferences, and also authored six books in the subject area of environmental engineering. He is life-member of many professional organizations including IAEM, IE(I), ISTE, IPHEI, and Ass. of Agrometeorologists.

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