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# Modelling for Simplified Vortex Manhole

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***Abstract*** **- Vortex drop manhole has been improved to solve number of problems associated with conventional drop systems. It dissipates the flow energy, protecting the drop structure from intensive corrosion and abrasive wear. The aim of this present study is to investigate the hydraulic performance of a simplified eccentric vortex drop shaft in order to keep the configuration of vortex shaft elements as simple as possible to facilitate its construction and minimize the construction and maintenance cost ,at the same time be ensured that the vortex shaft hydraulically efficient and stable. Two models have been constructed to investigate the use of centric and eccentric vertical shaft. Results showed that the use of eccentric chamber reduces the vortex chamber height by 25% and it is allowed to pass 19% flow rates more than the centric chamber. Results also showed that the eccentric shaft rises the dissolved oxygen concentration by 14% than the centric shaft at the maximum discharge. In addition, decreasing the enlargement angle from 270º to 220º increasing the amount of flow rate passing through the shaft by 18% and decreasing the water depths above the vortex channel by 29%.**

***Keywords: Hydraulic structure - Vortex Manhole - Energy Dissipation - Hydraulic Performance-Wastewater Aeration.***

## 1. INTRODUCTION

Vortex drop shaft is considered one of the deep structure which solves the problem of connecting the sewer system from street level to the underground tunnel. It has been widely used in waste water and storm water application as an effective solution for problems of sewer drop and an effective energy dissipation and aerator. Simply vortex shaft is a simple drop manhole that improved with a vortex chamber and a vertical shaft, [5] & [19].

In the vortex drop shaft the water moves from inlet pipe to the vortex chamber then it's get inside the vertical shaft through a special top cut, the flow become tangent to the wall of vertical shaft creating a stable air core. The air is entrained and mixed with the flow which makes aeration of wastewater and rises the percent of dissolved oxygen in the wastewater and oxidize hydrogen sulfide (H2S), [19].

Vortex drop shaft were firstly introduced by [4] as an over flow structure for dams, after that [12] studied some different types of vortex manhole according to its shape and they are recommended spiral for steep approaching channels when the flow is supercritical flow.

The design guidelines of the vortex chamber and energy dissipation are currently available in literature [9] and for Hydraulic features of air and water flow through the shaft in literature [13]. Regarding tangential intake literature [18] presented them in detailed and the hydraulic features of outlet structure can be found in literature [3].

Regarding the hydraulic features of vertical drop shaft and its influence of venting system, literatures [15] & [17] studied the energy dissipation and the air entrainment inside the shaft. After that research [2] studied the hydraulic features of the incoming flow and the hydraulic behavior of the shaft elements.

The main two types of vortex chamber, namely circular vortex chamber and spiral vortex chamber with respect to it's alignment to the vertical shaft. The main difference between the two types is the geometry and configuration of the vortex chamber.

Construction process of spiral vortex drop manhole is a complicated process due to the variation in the radius of curvature of the vortex chamber; however it might be molded in special factories which increases the fabrication and maintenance cost. Therefore, in this research simplified models of circular (centric) and spiral (eccentric) vortex shaft have been investigated.

## 2. EXPERIMENTAL WORK

Experimental works investigated the hydraulic and geometric features of a simplified eccentric vortex drop shaft and compared its hydraulic performance with the centric shaft and with the theoretical equations of the typical eccentric vortex shaft .In addition, changing the vortex chamber open cut entrance angle (ɵ) from 270º to 220º has been investigated to illustrate its effect on the water levels for both centric and eccentric vortex models and its effect on the shaft capacity. Finally dissolved oxygen (DO) levels in the outlet water discharge have been measured and compared to the inlet water (DO) in order to identify the ability of the vortex shaft models on the water aeration.

## 3. MEASUREMENTS

Dissolved oxygen concentrations have been measured using a Jenway 970 Do meter. .Water depths above the vortex channel have been measured using a measuring scale. Inlet velocity (Vo) has been calculated as per inlet flow rate and inlet pipe cross section. Vertical shaft velocity values (Vs) has been calculated according to the typical shaft velocity (V*) as per equations 1, 2 and 3 by [11].

$$(Vs/V*)^2 = (\tanh(z/z*)) \qquad (1)$$

$$V^{*}=(1/n)^{\wedge}(3/5)(Q/\pi Ds)^{(2/5)} \qquad (2)$$

$$Z^{*}=(V^{*2})/2g \qquad (3)$$

Where Z: shaft length, Z*: scaling depth, V*: typical end velocity.

Available equations which can be used to calculate or predict the vortex chamber height such as equations (4) and (5) by literature [11] & [15] don't include the entrance angle among their variables, therefore a dimensionless analysis technique have been used to develop equations that better estimate the water height inside the vortex chamber and hence the chamber depth can be more precisely designed.

$$\frac{hM}{R1}=\left[\frac{2^{0.5}Q}{(gbhoR1^{3})0.5}-\frac{1}{2}soe\right](1.1+0.15Fo) \qquad (4)$$

Where

R1: Radius of the first curvature of vortex chamber

, Soe : channel bottom slope

$$Q=\frac{\pi D^{2}}{4}\sqrt{\frac{1}{1+\beta+\xi}}\,.\sqrt{2g.(h+L)} \qquad (5)$$

Where: β and ξ are factors depends on flow rate, shaft length, shaft radius and friction factor.

Two bench scale models for both centric and eccentric shaft consists of four parts (inlet pipe, vortex chamber, vertical shaft, outlet structure) have been constructed in the laboratory of Environmental Engineering Department, Faculty of Engineering, Zagazig university. A schematic diagram of the models is shown in fig (1).

The models were constructed from UPVC pipes and the water is fed into the models through a diesel water pump with discharge varying from (1-8) L/s. Detailed description of each unit of both centric and eccentric model are presented here after and shown in fig. (2).

*Inlet pipe*, inlet pipe convey the flow from source of water to the vortex chamber .The diameter of inlet pipe (Di) was 75mm and its slope ($S_{oo}$) 2%.

*Vortex chamber*, vortex chamber receives flow from inlet pipe and directs it tangentially to the vertical shaft through special top cut. The vortex chamber made of UPVC pipe , its diameter (Dc) 200 mm and its height (hc) 300 mm, the slope of vortex channel bottom ($S_{oe}$) was 8%, the shaft eccentricity (e=1.25 cm) and the enlargement angle (ɵ) ranged from (270º-220º). Fig.3 shows the geometry of both centric and eccentric vortex chamber models. The geometry of circular vortex chamber is the same as the eccentric one except that the center of the vertical shaft is the same of the vortex chamber for the centric one and shifted by e=12.5 mm for the eccentric model.

*Vertical shaft*, vertical shaft diameter of vertical shaft (Ds) was the same with the inlet pipe Di (75mm); (DS/Di =1 as recommended by, Hager (1985)).The shaft length (Ls) was 4000 mm.

*Outlet structure*, outlet structure was located at the end of the vertical shaft, it was (250 liter) capacity made of PVC tank which act as a small dissipation pool.

## 4. RESULTS AND DISCUSSION

Tables (1) and (2) presented the geometric and hydraulic characteristics for both centric and eccentric model. {For each flow rate (Q), water depths above vortex channel (initial, ho, maximum, hm, and exit, he), inlet Froude number (Fo), dissolved oxygen (Do), inlet velocities (Vo), and efficiency of total energy dissipation inside the vertical shaft (η) were investigated}.

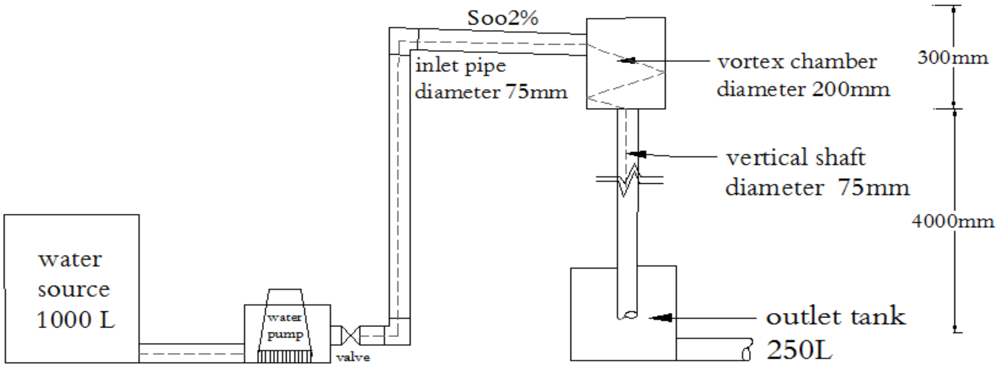
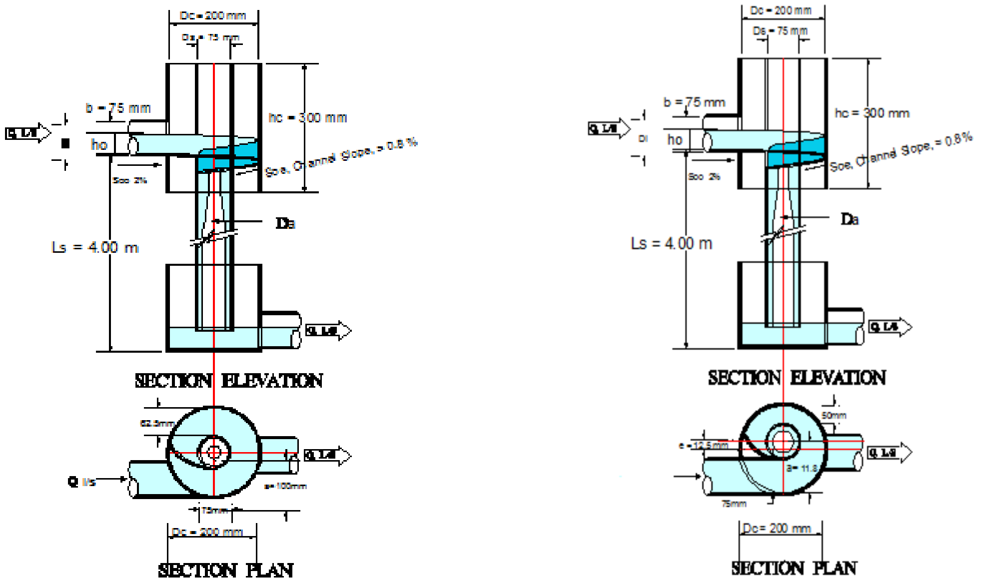


Figure (1) Schematic Diagram of the Model



a) Centric chamber

b. Eccentric Chamber

Figure (2) Vortex Chamber Configuration

Table1. Geometric and Hydraulic Characteristics of Centric Vortex Model

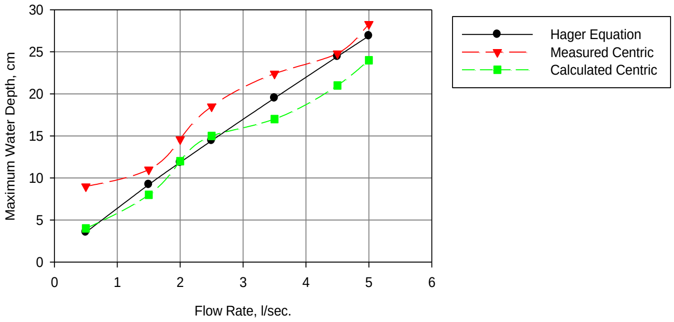
| Discharge (Q) L/s | Velocity (Vo) m/s | Froude number (Fo) | Circular vortex shaft | | | Efficiency (η) % | Do mg/l |
|---|---|---|---|---|---|---|---|
| | | | (ho) cm | (hm) cm | (he) cm | | |
| 0.5 | 0.1 | 0.2 | 4.5 | 9.0 | 9.0 | 70.6 | 0.54 |
| 1.5 | 0.3 | 0.4 | 8.0 | 11.0 | 11.0 | 73.8 | 0.71 |
| 2.0 | 0.5 | 0.4 | 11.0 | 14.6 | 14.0 | 78.7 | 0.84 |
| 2.5 | 0.6 | 0.5 | 14.0 | 18.5 | 18.0 | 82 | 0.98 |
| 3.5 | 0.8 | 0.6 | 18.0 | 22.4 | 22.0 | 85 | 1.39 |
| 4.5 | 1.0 | 0.7 | 21.0 | 24.8 | 24.0 | 86.3 | 1.73 |
| 5.0 | 1.1 | 0.7 | 25.0 | 28.3 | 28.0 | 88 | 1.84 |

Table2. Geometric and Hydraulic Characteristics of Eccentric Vortex Model

| Discharge (Q) L/s | Velocity (Vo) m/s | Froude number (Fo) | Spiralvortex shaft | | | Efficiency (η) % | Do mg/l |
|---|---|---|---|---|---|---|---|
| | | | (ho) cm | (hm) cm | (he) cm | | |
| 0.5 | 0.1 | 0.4 | 1.0 | 4.0 | 4.0` | 53 | 0.71 |
| 1.5 | 0.3 | 0.4 | 6.0 | 8.0 | 7.0 | 67.6 | 0.88 |
| 2.0 | 0.5 | 0.5 | 9.0 | 12.0 | 10.5 | 75.5 | 0.97 |
| 2.5 | 0.6 | 0.5 | 12.0 | 15.0 | 13.0 | 79 | 1.12 |
| 3.5 | 0.8 | 0.7 | 15.0 | 17.0 | 15.5 | 81 | 1.52 |
| 4.5 | 1.0 | 0.8 | 18.4 | 21.0 | 19.0 | 84 | 1.97 |
| 5.0 | 1.1 | 0.8 | 21.3 | 24.0 | 22.0 | 86 | 2.1 |

Literature [10] presented an equation in order to predict initial and maximum water depth above vortex channel as a function of flow rate, inlet and vortex chamber dimensions, Froude number and gravity acceleration. Measured values of initial water depths are close to the results calculated by Hager's equation. For the maximum water depths (hm) the results showed that the measured values of maximum water depths for both centric and eccentric model were differed than the results calculated by Hager theoretical equations by about 20%. In addition, the maximum water depths for eccentric chamber were lower than that of the centric chamber by about 25% and that's allowed to pass more flow rates more than that of the centric chamber by about 19%.

Fig (3) presented comparison between measured and calculated maximum water depth for both models according to literature [10] .This results agreed with the previous literatures [1], [6], [8] and [14] who stated that the centric vortex drop shaft needs to undesirable requirements of water depths inside the vortex chamber to pass the design discharges than the other types of vortex shaft.



Figures (3) Water Height in Vortex Chamber

In order to identify the optimum closure of the entrance angle of the special top cut at the vertical shaft, experimental runs have been carried out for 270°, 250°, 230° and 220° open cut entrance angles (ɵ) and then a dimensionless analysis technique was carried out to get equations that correlate the relationships between different parameters and variables which affected the maximum water depth using Buckingham's theorem. Different variables that may affect the maximum water depths above the vortex channel (hM) for the vortex models that have been considered are:

Flow rate (Q), initial, maximum and exit water depths above vortex channel (ho, hm, and he), inlet Froude number (Fo), inlet velocities (Vo), angle of open (θ ) and the gravity acceleration (g). Buckingham theorem depends on simplifying a physical problem by appealing to dimensional homogeneity to reduce the number of relevant variables, for these models:-

Number of considered relevant variables: n=7
Number of independent dimensions: m=2
Number of dimensional groups (πs): n-m=5

From the previous equations, the non-dimensional relationship between the maximum water level and the other variables is:-

$$\pi_1 = f\,(\pi_2, \pi_3, \pi_4, \pi_5,)$$

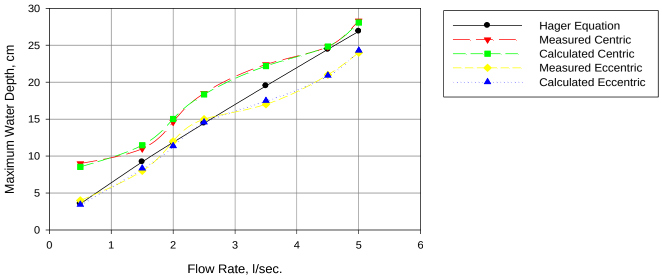
$$hM/ho = f\,\left(\frac{b}{ho}, \frac{ho^5 * g}{Q^2}, F_o, \theta, S_{oe}\right)$$

By using regression the coefficients for each non-dimensional group and residuals have been calculated as per the measured values. Results of the linear regression analysis as relative risks and 98% confidence intervals are presented in equations (6) and (7). Equations (6) and (7) represent the maximum water depth for centric and eccentric chambers.

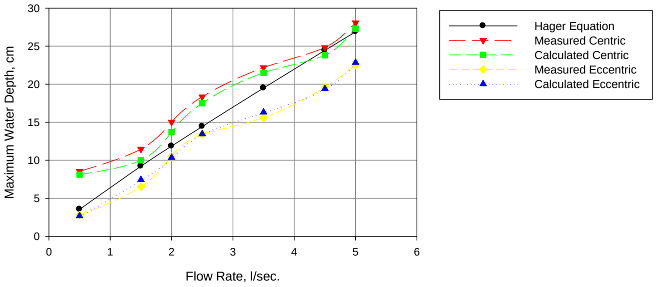
$$h_m = \left[\frac{2.0811\, h_o}{b} - 1.883\, F_0 - \frac{0.00256\, h_o^5 g}{Q^2} - 0.00335\,(360 - \theta)\right] \quad (6)$$

$$h_m = \left[\frac{0.9543\, h_o}{b} - 0.398\, F_0 - \frac{0.00104\, h_o^5 g}{Q^2} - 0.00532\,(360 - \theta)\right] \quad (7)$$

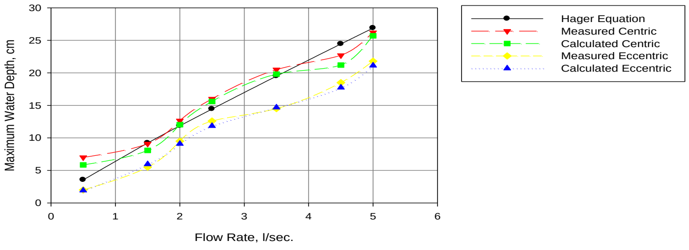
Figures (4, 5, 6 and 7) show comparison between measured maximum water depths, calculated depth as according to literature [10] and calculated according to equations (5) and (6). From results it's found that the decreasing of enlargement angle from 270° to 220° decrease the water level above vortex channel by (11-29) % for centric chamber and (13-30) % for eccentric chamber that's allow eccentric chamber to receive more flow rate by about 18% and in the same time it helps the air nucleus diameter to enlarge with the angle. These results agreed with the results by literature [7] that studied closer angle ranged from (180°-260°) and concluded that the optimum closer is 220°.



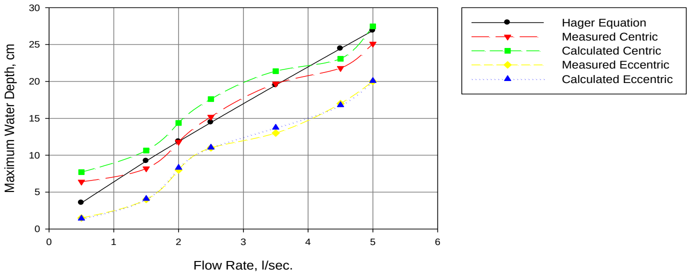
Figures (4) Measured and Calculated Water Depth for Ө 270°



Figures (5) Measured and Calculated Water Depth for Ө 250°



Figures (6) Measured and Calculated Water Depth for Ө 230°



Figures (7) Measured and Calculated Water Depth for Ө 220°

To investigate the effect of both centric and eccentric vortex chamber on dissolved oxygen concentration, a deoxygenated tap water have been passed through the two models and the dissolved oxygen readings were taken using a Do meter, followed by temperature readings and results presented in tables (1) and (2). For both eccentric and centric model varying with discharge is presented in figure (8).

From results it's found that the dissolved oxygen concentration at the downstream of the eccentric shaft model raised by (10% - 28%) than the upstream concentration and it's raised by (7% - 24.3%) for the centric shaft, this value according to the saturation level (7.4 mg/l) at 33ºC and discharge ranged from (0.5 to 5) l/s. It's noticed that the dissolved oxygen concentration for eccentric vortex model is larger than that in centric one by about 12% at the maximum discharge and this may attributed to the more turbulence in the flow.

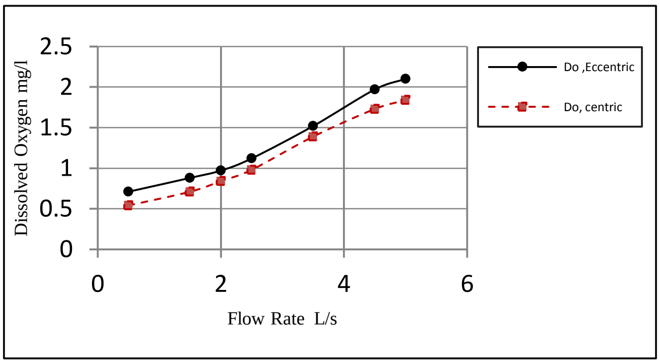


Figure (8) Dissolved oxygen increasing value with the increasing of flow rate

The efficiency of the vertical shaft depends relatively on the vortex chamber configurations which effect on water levels above vortex channel and it also depends on shaft diameter and the total drop length. Figure (9) shows the energy dissipation efficiency inside the vertical shaft for both centric and eccentric vortex drop shaft versus the water discharge values. The dissipation efficiency was calculated according to equations recommended by [11] for vortex drop shaft.

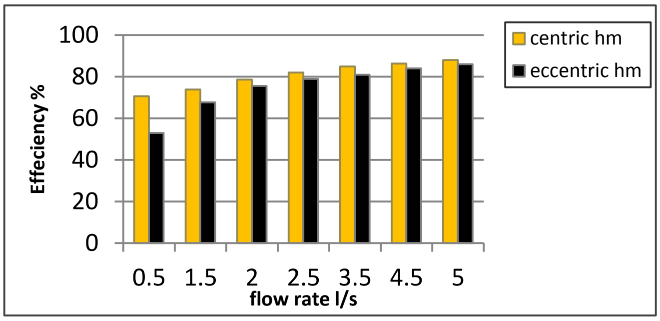


Figure (9) Energy Dissipation efficiency with the flow rate

It's obtained that the efficiency of the total energy dissipation inside the vertical shaft increasing with the increasing of water discharge value due to the increasing friction between the water flow and shaft's walls along the vertical shaft, and it's not less than (86% - 88%) at the maximum discharge for both centric and eccentric model.

## CONCLUSIONS

In the presented study it can be shown that the model tests were performed to verify the design, size, shape of vortex chamber and the water levels above it which are to be expected under operation conditions for this simplified geometry.

- The results showed that the eccentric vortex shaft model reduces the required vortex chamber depth by about 25% than that of the centric model.

- Results also have shown that with the decreasing of the enlargement angle from 270º to 220º the depth of the water above vortex channel is decreased by about 30% and increasing the amount of flow rate by about 18% than the maximum value.
- The results also showed that the efficiency of the vertical shaft for both centric and eccentric vertical shaft not less than 86% for eccentric shaft and 88% for centric shaft at the maximum discharge.
- Eccentric chamber rises the percent of dissolved oxygen by 28% at maximum discharge, while the centric chamber raises the DO by about 24%.

## Conflicts of Interest

The authors declare no conflict of interest.

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