

基于 CFD 的网格絮凝池栅间距特性研究

李国强, 邴 帅, 刘鹏亮, 王卫东
(青岛市市政工程设计研究院, 山东青岛 266071)

摘 要:以广东中山某镇给水厂单体竖井建立分析模型,借助 CFD 软件对网格絮凝池单个竖井内湍流进行数值模拟。通过对图形曲线及模拟变量 -- 湍动能 k 分析探讨,确定了单层栅条板栅间距 $D=4\text{cm}$ 或 5cm 的栅条布置方式,其具备较高湍动能级、较强速度差异优点,对现有网格絮凝池网格分布改造具有重要意义。

关键词:计算流体力学;网格絮凝池;湍动能 k

中图分类号: TU991.22

文献标识码: A

文章编号: 1009-7716(2014)11-0193-03

0 前言

强化絮凝技术的关键环节之一是高效的絮凝池的研究。目前常规及新型池子所取得的实验数据及其分析结果尚处于实验阶段,同时混凝理论分析方法对于絮凝池的研究大多处于初级的指导性阶段。因此基于中山市某镇给水厂网格絮凝池基本参数,分析絮凝池的水力特性指导反应条件的优化,使得絮凝剂在最佳工况条件达到强化絮凝的效果是本文研究的内容。

1 CFD 概述

计算流体力学(Computational Fluid Dynamics, 简称 CFD),是通过计算机数值计算和图像显示技术,对包括有流体运动和热传导等相关的物理现象系统所作分析的一门新兴学科。

CFD 的基本原理:把原来在时间域及空间域上连续的物理量的场,用一系列有限个离散点上的变量值的集合来代替,通过一定的原则和方式建立起关于这些离散点上场变量之间关系的代数方程组,然后求解代数方程组获得场变量的近似值^[1]。

2 网格絮凝池建模及单栅条数值模拟研究

2.1 网格絮凝池数学模型的建立

中山某镇 5 万 t/d 的给水厂,单个竖井尺寸为 $1\,000\text{ mm} \times 1\,000\text{ mm} \times 4\,000\text{ mm}$,采用理想液态流模拟絮凝池单井内部流场,顶进底出,水流方向垂直向下。

网格絮凝池的单个竖井结构属于中心对称结构,同时本文主要考虑垂直截面速度、能量耗散对

流场的影响,因此可以将竖井简化成二维模型进行计算。模型参数见表 1。

表 1 网格絮凝池二维模型参数(单位: mm)

模型长度	模型高度	栅条厚度	栅条宽度	栅条间距	网格划分尺度
1 000	4 000	10	50	30、50、80、120	10

沿切线方向切取尺度为 $4\,000\text{ mm} \times 1\,000\text{ mm}$ 平面,见图 1。

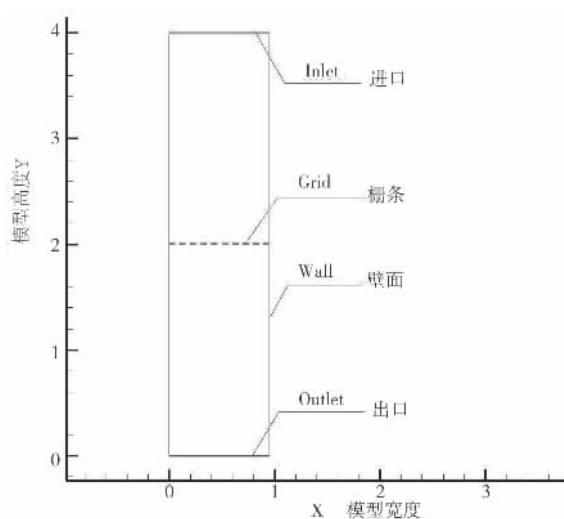


图 1 单层网格絮凝池二维模型示意图

2.2 网格絮凝池模型的边界条件的确定

(1)进口边界条件

本文对网格絮凝池单体竖井的模拟为不可压缩流,采用速度进口。速度的选取参照中国工程建设标准化协会标准定制的《栅条、网格絮凝池设计标准》中关于前段栅条流速的选取: $0.12\sim 0.14\text{ m/s}$,因此速度选取为 0.13 m/s ,采用 $k-\varepsilon$ 模型进行的数值模拟计算。

(2)出口边界条件

本文采用自由出流(outflow),它适用于不可压

收稿日期: 2014-07-07

作者简介:李国强(1984-),男,山东青岛人,工程师,从事水动力学及排水管网研究工作。

缩流及出口处的流动时完全发展的情况。

(3)设置收敛判断依据:本文数值模拟采用定常流计算,采用简化后整个流场绝对累积误差来判定收敛情况。变量残差值达到 $1e-4$,即可以认为计算收敛。同时,收敛后验证 Mass Flow Rate 出口质量稳定性。

3 网格絮凝池单层栅条板过栅紊流特性的数值模拟研究

3.1 不同栅间距下端动能及湍动耗散的影响分析

随着栅条个数的增加,栅条出流的湍动能和湍动能耗散率也随之变化。从水体的紊动结构来分析,栅条所产生的整流作用对反应效率的增加具有重要意义。

根据中国工程建设标准化协会标准《栅条、网格絮凝池设计标准》中对网格絮凝池设计中,见表 2。

表 2 网格絮凝池速度梯度设计参数

池型	絮凝池分段	速度梯度	孔眼
网格絮凝池	前段 (安放密栅条)	70 ~ 100	50 mm
	中段(安放疏栅条)	40 ~ 60	80 mm
	末段 (不安放栅条)	10 ~ 20	-

在网格絮凝池的实际设计中,一般的研究设计人员采用该标准进行设计参数的选定。然而这种传统的经验设计参数选取方式很容易造成设计人员选取参数的随意性和普遍性,不能够根据工程实际来确定参数,造成分格数增多、栅条孔径增大使得池体复杂、庞大。利用计算流体软件模拟不同间距栅条的流场对絮凝的作用机理,为实际工程的优化提供一条新方法。

为了考察栅间距对竖井内部流态的影响,选取了五种栅条布置形式进行模拟。布置方式见表 3。

表 3 网格絮凝池栅条布置方式

栅条编号(宽-距)	栅条数	栅条宽度	备注
5-3(cm×cm)	13	50 mm	横向均布
5-4(cm×cm)	12	50 mm	
5-5(cm×cm)	10	50 mm	
5-8(cm×cm)	8	50 mm	
5-12(cm×cm)	6	50 mm	

依据单栅条数值模拟方法进行模拟,即在速度进口流速选取 0.13 m/s,水体通过单体竖井栅条迭代收敛后的数值模拟图像见图 2、图 3。

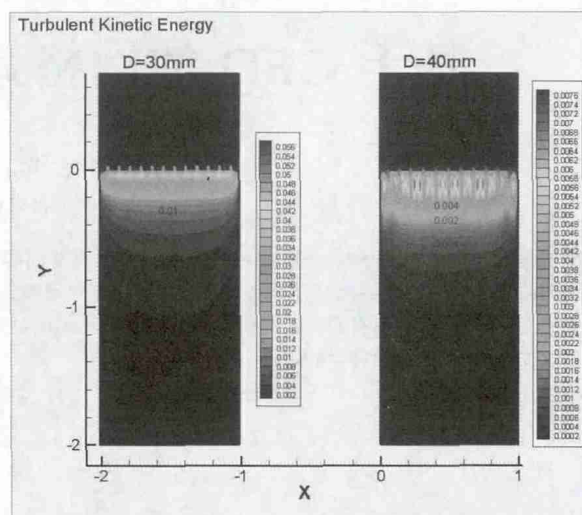


图 3 栅条间距 D=50 mm、80 mm 湍动能分布图

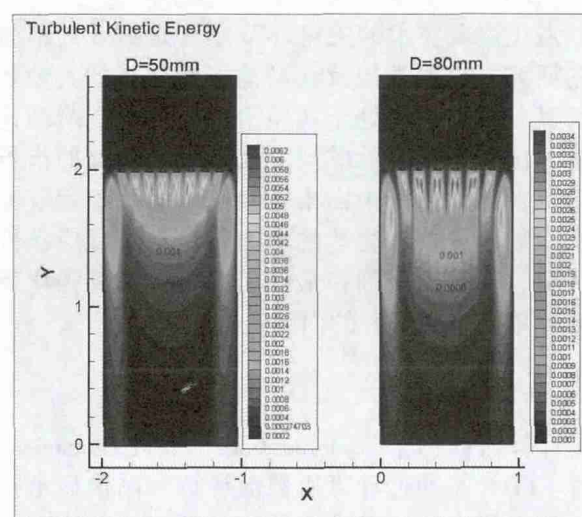


图 2 栅条间距 D=30 mm、40 mm 湍动能分布图

从图 2、图 3 可知,湍动能的核心区和多股出流之间的混合点随着栅间距的减小而向上游紧缩,这与各出流(絮体)间的相互混合是紧密相关的。在混合点和核心区域,出流之间,出流与环境流体间,出流与絮体间发生强烈的掺混,引起强烈的紊动。这些湍动能最终通过粘性应力对湍动变形的做功,即湍动耗散率项转化为其他能量耗散殆尽。

从动能分布图中反映出,流体经过栅条板后速度衰减,流体迅速与周围流体剧烈掺混卷吸,这是由于栅条板后附近的湍动能较大,湍动掺混作用较强所致。同时图形反映出竖井中的速度并非逐次衰减,而是有一段明显的加速区,然后衰减伴随着流动向下游发展,流核区逐渐消失,各断面流速分布趋于一致(或有 consistency 趋向)。在这一过程中,板后负压流体能将能量传递给附近流体,形成低压流体边界层,它随着流动的发展变得越来越厚,直至扩展到壁面或至出口处。因此在相同因素影响下,多栅条出流具有更大的影响区域。

同时流体中的速度梯度和紊流切应力是非恒定的,都具有由壁面(wall)向流场中心区沿程降低的变化规律。对于絮凝过程中大部分阶段,絮体颗粒较小,水中颗粒跟随性好,颗粒速度与水流流速接近。由于水流速度梯度的存在,相邻流层的颗粒也具有速度梯度,从而为相互碰撞创造了条件。如果是在均匀切变场中,颗粒就会平稳的聚集成团,但是实际工程中的非均匀切变场,不同的流层具有不同的剪切强度,而且变化较大,颗粒的成长就会受到影响。在靠近壁面的区域速度梯度大,颗粒相互碰撞的机率高,但切应力大,水流对颗粒的揉搓作用强烈。在水流中心处,颗粒之间相碰撞之后更容易结合。

3.2 不同栅间距数值模拟湍动能 k 、湍动能耗散率 ε 面平均值评价

采用 CFD 软件中 Mass-Weighted Average 计算,其更接近于高速度区域的值,即有更多质量流通过面上的变量值,见图 4。

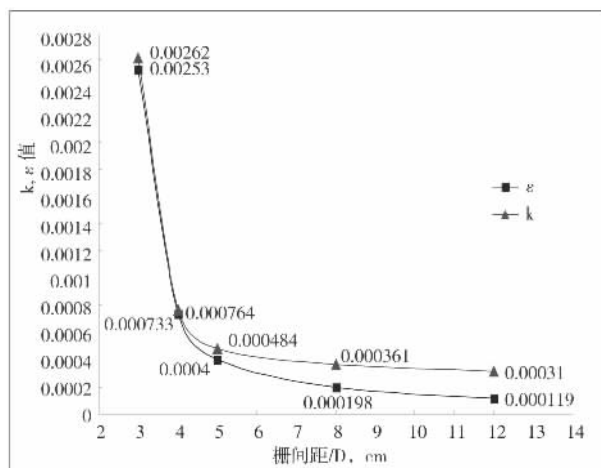


图 4 不同栅间距湍动能 k 、湍动能耗散率 ε 面平均值变化曲线图

根据紊流微涡旋动力学理论,湍动能 k 及湍动能耗散率 ε 越大,池内絮凝效果越好得到的絮体越密实。根据以上各变化曲线可知,随着栅条间距从 $D=120$ mm 向 $D=40$ mm 逐级缩减中,湍动能、湍动耗散率及涡旋速度梯度呈现增加的趋势。当 $D=30$ mm 时,曲线出现一个突跃,是 40 mm 栅距

的各指标的 3~4 倍。经过分析,这种突跃是栅条处的流体大部分呈现出射流状态,湍动能及剪切力急剧增加紊动十分强烈。

根据絮凝体破碎理论,絮凝池前置阶段絮凝体形成粒径大而多孔的结构,此时在水流剪切力作用下容易发生破碎。具有较高能级的栅间距 $D=30$ mm 容易使絮体颗粒因强剪切作用及高湍动度造成破碎。因此栅间距 $D=40$ mm 和 50 mm 的栅条布置方式是较优的。

4 结论

网格絮凝池竖井的内部紊流流动问题是一种相对复杂的流动问题,它对工程设计及现有给水厂的更新改造具有很重要的指导意义。本文得到如下研究结论:

(1) 本文主要运用 CFD 计算流体力学软件对网格絮凝池竖井进行了数值模拟。采用 Realizable $k-\varepsilon$ 模型,对网格絮凝池这类高雷诺数并流动中包含有射流和混合流的模型具有很好的可操作性,计算消耗时间少。

(2) 对速度进口流速为 0.13 m/s,通过在竖井内流动中加入栅条方法可以改变整个流场流态;通过改变栅条密度,增加栅条个数可以降低负压对絮凝过程的影响,限制湍流剪切梯度,控制水中涡旋的大小和强度。

(3) 新的水质标准对中山市某镇给水厂改造升级提出了要求,栅间距 $D=40$ mm 或 50 mm 的栅条布置方式具备较高湍动能级、较强速度差异,以其作为网格絮凝池前段栅条布置间距,可以保证网格絮凝池改造后形成密实的絮体,降低出水 NTU。

参考文献

- [1] 王绍文,姜安玺,孙喆.混凝动力学的涡旋理论探讨[J].中国给水排水,1991,7(1):4.
- [2] 单立志,施汉昌,王锐.网格反应、斜板反应沉淀水处理实验设备的设计制作[J].实验技术与管理,2006,23(10):55-57.
- [3] 王启山.水工业工程常用数据速查手册[M].北京:机械工业出版社,2005.
- [4] 周自坚.网格式机械搅拌絮凝技术的实验及理论研究[D].黑龙江哈尔滨:哈尔滨工业大学.

geometric proportion 1:10 continuous beam bridge scale model. The result shows that the traveling wave effect will influence the displacement at an end of sliding support. Therefore, it is very important to consider the traveling wave effect for the study of earthquake response of viaduct.

Keywords: viaduct, traveling wave effect, dynamic response

Research on Section Topology Optimization of Steel Corrugated Web Box Girder Bridge Based on Evolutionary Structural Optimization (ESO) Algorithm Wang Jun (179)

Abstract: On the basis of a steel corrugated web bridge, the secondary development and expansion of topology optimization module built in ANSYS is realized with the help of the APDL. Meanwhile, ESO topology optimization program is written on the basis of the displacement sensitivity and stress sensitivity. In addition, the rationally arranged topology optimization form of steel corrugated web combined section is achieved by several times of model iterative computation. The result of the optimization shows that sensitivity can accurately reflect the contribution of unit to structure performance. Furthermore, error deleting of unit can be reduced by the analysis of sensitivity. Therefore, the credibility of the optimization realized by ESO is enhanced.

Keywords: ESO, steel corrugated web, topology optimization

Comment on Calculation Method for Ultimate Bearing Capacity of Compression Stiffened Plate

..... Liu Shujie(184)

Abstract: Based on the conclusion of domestic and foreign standards, this paper has a study on the setup requirements of stiffened ribs and its calculation method of ultimate bearing capacity of compression stiffened plates, and briefly compares and illustrates it by the practical cases. The study result can be referred for the structural design of steel bridges.

Keywords: compression stiffened plate, setup of stiffened rib, calculation method of ultimate bearing capacity

Study of FRP Bridge Deck for Steel Assembled Highway Bridges - - - Ma Wengang, Sun Dong, Shen Nangong (187)

Abstract: Fiber reinforced polymer (FRP) material has many advantages of light weight, high strength and corrosion resistance, and is widely used in bridge deck. Based on the development situations of FRP bridge deck in recent years, the paper studies and puts forward the FRP bridge deck scheme of steel assembled highway bridges, and describes the finite element analysis calculation, which provides the theoretical basis for the manufacture of FRP bridge deck.

Keywords: assembled, steel highway bridges, FRP bridge deck

Design of Production Mixing Ratio of Superpave Asphalt Mixture Chen Wei (190)

Abstract: Based on the design conclusion of target mixing ratio, the article describes the design of production mixing ratio of Superpave20 asphalt mixture, defines the feeding speed of cold materials, proportion of hot feed bin and amount of asphalt, and analyzes the key technologies in the construction process of test section.

Keywords: asphalt mixture, Superpave, production mixing ratio, test section

Study on Grid Spacing Characteristics of Grid Flocculation Tank Based on CFD

..... Li Guoqiang, Bing Shuai, Liu Pengliang, Wang Weidong (193)

Abstract: A analysis model is established for a single shaft of a town waterworks in Zhongshan City of Guangdong Province. The turbulent flow field within a single shaft of grid flocculation tank is numerically simulated by means of CFD software. Through the analysis and discussion of graphic curve and simulating variable - turbulent kinetic energy k , the layout mode of single layer grid plate with grid spacing $D = 40\text{mm}$ or 50mm is determined. It has the advantages of higher turbulent kinetic energy level and stronger speed

differences, which has the important meaning for the grid layout and reconstruction of grid flocculation tank.

Keywords: computational fluid dynamics, grid flocculation tank, turbulent kinetic energy k

APPLICATION OF ACHIEVEMENTS

Application of Foamed Light-weight Soil in Retaining Wall of Channel

..... Qin Yaqiong, Wu Lipeng, Zhou Wenfang, Ji Shan (196)

Abstract: Taking the Sixin Avenue (Longyang Lake Road (S) ~ Longyang Avenue) Project as an example, by comparing the advantages and disadvantages of the foamed light-weight soil retaining wall with the cantilever retaining wall, the article better verifies the superiority of the cast-in-situ foamed light-weight soil retaining wall in the soft soil subgrade of Lingang Channel without the excavation conditions, and discusses the calculation method of the water retaining wall and the matters for attention in construction of foamed light-weight soil. The valuable experience is accumulated for the application of the foamed light-weight soil in the similar projects.

Keywords: water retaining wall, anti-sliding stability of the whole, foamed light-weight soil

Study on Application of Ecological Fish Tank Brick Song Rui, Gao Lihong (200)

Abstract: Aiming at Lishui Oujiang River Water Ecological System Protection and Restoration Demonstrating Section Construction Project, the article studies an introduced river revetment component - the ecological fish tank brick, and focuses introduction on its conception, main function, advantages and construction matters for attention. Its study result shows that the ecological fish tank brick can provide a safe refuge for the aquatic organism of fish and etc., is conducive to protect the biodiversities of river, is favorable for recovery of the natural environment and ecological environment in the areas of South Mountain of Oujiang River, also provides the experience of fish tank brick referring for the similar river ecological bank restoration projects and provides the demonstrating role for the surrounding mountainous areas, counties and cities in order to realize the whole river water ecological system of Oujiang River

Keywords: Oujiang River, ecological revetment, ecological fish tank brick, study, application

THE RELATIVE SPECIALITIES

Design of Three-gorge Reservoir District Riparian Zone Ecological Bank Harnessing Project

..... Duan Fei, Yin Wenfeng, You Ling (203)

Abstract: Based on the riparian zone ecological bank harnessing project from Changjiang River Bridge II to Mixi Valley of Wanzhou District, and according to the landform and geological conditions of the project, the article sets forth the riparian zone ecological environmental harnessing measures in the combination of road and embankment, which can be referred for the riparian zone harnessing and utilization of the other areas.

Keywords: riparian zone, combination of road and embankment, ecological environmental harnessing

Linear Regression Analysis of Initial Geostress Field of Zhifang Tunnel Wei Mingqiang, Zhang Leting(205)

Abstract: The main factors of influencing the initial geostress field are the self weight stress field and tectonic stress field. Firstly the lithology of the studied area is assumed as the elasticity, and then the hydraulic fracturing in-situ stress measured data every test point and three-dimensional finite element calculation results of four imitated tectonic stress fields are used, the least squares multiple regression analysis is carried out. The regression coefficients L1, L2, L3 and L4 correspondent to four independent variables (separately correspondent to the self weight stress, the tunnel axis direction of tectonic stress, the