ISSN: 2414-1895 DOI: 10.6919/ICJE.202108_7(8).0021

Research on Design Method of Industrial Pipeline Based on FLUENT Technology

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Abstract

Drainage pipeline system is a facility for collecting and transporting sewage, which transports the sewage from production to sewage plant or water outlet. In order to utilize the sewage treatment function of drainage pipeline, it is particularly important to explore the formation and growth mechanism of bio-film in drainage pipeline. Therefore, this paper introduces FLUENT software to analyze the hydraulic parameters of the drainage network, and improves ant colony algorithm to optimize the drainage network. The flow pattern of drainage pipes with diameter of 100mm, slope of 0.005 and fullness of 0.5, 0.4, 0.3 and 0.2 were tested by PIV test platform, and the corresponding flow field information was obtained. The specific distribution law is that the flow velocity of the same vertical section pipe gradually increases with the increase of water depth, and the flow velocity of the same water depth pipe increases along the way. Taking the final investment quota of drainage pipe network as the optimization target, the optimization result of saving engineering cost can be directly reflected.

Keywords

FLUENT; Ant Colony Algorithm; Drainage Pipe Network.

1. Introduction

The design of building drainage system has developed into a relatively perfect professional system from the initial simple sanitary ware pipeline design [1]. With the development of social modernization and the demand for use, the design concept of buildings has gradually developed to the space height. While striving to maximize the effective utilization rate of land, high-rise buildings all over the country have sprung up, and high-rise buildings have become the symbol of modern metropolises. Landmark high-rise buildings and towers are gradually in line with international standards and heading for the whole world [2]. With the construction of more and more high-rise buildings, complicated building layout and more humanized design requirements, higher requirements are put forward for building drainage system, including the continuous emergence of new building drainage materials and special drainage pipe fittings. Domestic enterprises must require relevant measured data and design parameters for product promotion, while China lacks test towers.

FLUENT software can simulate the complex flow from in-compressible to highly compressible. It can deduce a variety of optimized physical models. With the continuous development of computational fluid dynamics, FLUENT software has been widely used in hydraulics [3-4]. In addition, after ant colony algorithm was put forward in 1990s, it was quickly applied in the optimal design of drainage network because of its good optimization. Because ant colony algorithm needs to build an optimization matrix of hydraulic parameters, FLUENT software can just deal with hydraulic

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parameters and provide an optimal matrix, which are just complementary. Therefore, it is meaningful to combine the advantages of both in improving the optimal design ability of drainage network, and it is worth studying.

2. Optimal model design of drainage pipe network

The mathematical model of optimal design of drainage network is mainly composed of decision variables, constraints and objective functions. In the optimal design of drainage network with fixed layout, the traditional research method is to select various optimization algorithms to deal with the relationship between hydraulic parameters of drainage network after selecting decision variables. None of these research methods can meet the actual needs of optimal design of drainage network. In this study, considering the constraints of hydraulic parameters and the relationship between hydraulic parameters, the monotonic of hydraulic parameters and the physical state of flow in pipeline are analyzed by FLUENT software, and the pipe diameter set whose parameters meet the design specification requirements is screened out before the optimization program is written in MATLAB according to ant colony algorithm.

2.1 Determination of design flow

Under the condition that the plane layout has been determined, the first step to optimize the design of drainage network is to determine the design flow. The maximum flow of sewage and rainwater that can be guaranteed to pass through the drainage pipeline and its ancillary structures is called the design flow (the pipeline studied in this paper is a rainwater-sewage confluence pipeline). When optimizing the design of pipeline parameters under the determined plane layout, the calculation formulas of the intermediate parameters involved in calculating the design flow Q are as follows:

Design flow of domestic sewage:

$$Q_1 = \frac{q \cdot N \cdot K_z}{24 \times 3600} \tag{1}$$

In which, q——Domestic sewage quota in residential areas;

N——Design population;

K_z——Total variation coefficient of domestic sewage quantity. $K_z = \frac{2.7}{Q^{0.11}}$.

Design maximum flow of industrial waste water in industrial enterprises:

$$Q_2 = \frac{mMK_g}{3600T} \tag{2}$$

In which, m——Waste water quota per unit product in the production process;

M——The number of products per day;

K_g——Total variation coefficient, determined according to process or experience;

T——Working hours per day in industrial enterprises.

Rainwater flow:

$$Q_3 = \phi q_3 F \tag{3}$$

In which, ϕ——Design runoff coefficient;

q_3——Design rainfall intensity;

F——Design catchment area.

Total design flow:

$$Q = Q_1 + Q_2 + Q_3 \tag{4}$$

2.2 Boundary conditions and initial conditions

Boundary condition refers to the law that the variable or its first derivative on the boundary of the solution domain changes with time and place. Only when the problem of reasonable boundary condition is given, the solution of the flow field can be calculated [5]. For unsteady problems, besides

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boundary conditions, it is necessary to give the initial values of all flow variables at each calculation point in the flow area, which is the initial condition. Boundary conditions and initial conditions are called definite solution conditions. Only when the boundary conditions and initial conditions are determined, the solution of the flow field exists and is unique.

Considering that in the actual pipeline, the water flow inlet has a certain initial velocity, or the water level at the front end of the inlet is higher than the water surface in the pipeline, which is converted from potential energy to kinetic energy to form a certain initial velocity, so the water flow inlet is set as the velocity inlet, and the velocity value in PIV experiment is adopted. When the result is stable, calculate the average fullness value in the pipeline. If the fullness is higher than the required fullness, reduce the velocity inlet value, and if the fullness value is lower than the required fullness, increase the velocity inlet value [6]. Constantly carry out debugging until the fullness in the results meets the required working conditions. The turbulent intensity of water flow is taken as 4%, and the hydraulic diameter is taken as 0.1m The turbulent intensity is calculated as follows:

Saturation α (≤0.5), pipe radius R, wet cycle χ, water area S, hydraulic radius r, water viscosity coefficient v, turbulence intensity I, according to the mathematical formula and hydraulic calculation formula:

$$\begin{aligned} &S = \arccos\left(1-2\alpha\right)R^2 - 2\left(1-2\alpha\right)\sqrt{\alpha\left(1-\alpha\right)R^2} \\ &\chi = 2\arccos\left(1-2\alpha\right)R \\ &r = \frac{S}{\chi} = \frac{R}{2} - \frac{\left(1-2\alpha\right)\sqrt{\alpha\left(1-\alpha\right)}}{\arccos\left(1-2\alpha\right)} \\ &\mathrm{Re} = \frac{4vr}{v} \\ &I = 0.16\,\mathrm{Re}^{-0.125} \end{aligned} \tag{5}$$

The water flow viscosity coefficient v is taken as the water flow viscosity coefficient corresponding to the water temperature (10℃) in the experiment, which is $1.31 \times 10^{-6} m^2/s$. When the pipe diameter is 0.1m, the fullness is 0.1~0.5, and the initial velocity is 0.3m/s~1.8m/s, the calculated turbulence intensity I is 3.6%~4.6%, which is taken as 4% in this paper.

No matter whether it is standard k-ε model, RNGk-ε model or Realizable k-ε model, it is only effective for fully developed turbulence. These models are turbulence models with high Re number and can only be used to solve the flow in the turbulent core region [7]. However, the flow near the wall changes greatly. There are two ways to solve this problem, namely, the k-ε model with low Re number or the wall function method. In this paper, the standard function wall method is used to deal with the flow near the wall of the pipeline.

$$U^* = \frac{1}{k} ln(Ey^*),\quad y^* > 11.2,\ U^* = y^*,\qquad y^* \le 11.2 \tag{6}$$

Among them, $U^* \equiv \frac{U_p C_\mu^{1/4} k_p^{1/2}}{\tau_w/\rho}, y^* \equiv \frac{\rho C_\mu^{1/4} k_p^{1/2} y_p}{\mu}, k = 0.42, E = 8.955.$

U_p—— Average velocity of fluid at point p:

k_p——Turbulent kinetic energy at point p:

y_p—— Distance from p point to wall surface;

μ——Dynamic viscosity coefficient of fluid.

The boundary condition of turbulent kinetic energy at the wall is: $\frac{\partial k}{\partial n} = 0$, n is the local coordinate in the normal direction of the wall. The dissipation rate does not need to solve the transport equation, but can be directly calculated by the following formula:

$$\varepsilon_p = \frac{C_\mu^{3/4} k_p^{3/2}}{k y_p} \tag{7}$$

ISSN: 2414-1895 DOI: 10.6919/ICJE.202108_7(8).0021

3. Application and improvement of ant colony algorithm

Ant colony algorithm has strong global convergence, adaptability and robustness. Because the optimization object of ant colony algorithm is discrete and nonlinear, there will be no constraints and objective functions. It can well solve the problem of optimal design of drainage network with many constraints and complex hydraulic parameters. As an intelligent optimization algorithm with non-linearity, self-organization, positive feedback mechanism and parallel mechanism, ant colony algorithm's strong ability to search better solutions has been fully demonstrated in solving complex drainage network optimization design problems.

3.1 Setup parameter

Set up an m×n matrix composed of pipe diameter scale and market price, let the number of ants in the system correspond to the pipe diameter specification also be m, let S be the cost of various pipe diameters in the market. The $[D_1, S_1], [D_2, S_2]...[D_n, S_n]$ samples constitute n matrices. Combined with the initial pheromone value, the ant motion transition probability $P_{ij}^k(t)$ is calculated:

$$P_{ij}^k(t) = \begin{cases} \tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t) / \sum_{j \in N} \tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t) \\ 0 \end{cases} \tag{8}$$

In which, i——The number of ants;

j——Number of design pipe section;

N——Set of paths (pipe sections) allowed (selected) by ant k [meet the requirements of drainage pipeline design code;

η_{ij} ——The visibility of the i th ant in the j th pipe section:

τ_{ij}——The pheromone value of the i ant is used in the j pipe section (the number of ants is equal to the number of pipe diameters);

α, β ——They represent the relative importance of pheromone and visibility (both values are 1).

3.2 Advance of algorithm

When the ant colony algorithm is advanced in the programmed program, each ant in the ant colony (pipe section set) selects the route (pipe diameter) of the next generation according to the calculated transition probability $P_{ij}^k(t)$. With the continuous advancement and iteration of ant colony algorithm, the ant colony finally selects the pipe diameters of all designed pipe sections and finds out the contemporary optimal path (pipe diameter combination).

3.3 Update of pheromones

In the process of advancing ant colony algorithm, pheromones on the path (pipe diameter) need to be updated:

$$\tau_{ij}(t+1) = \rho\tau_{ij}(t) + \Delta\tau_{ij}, \rho \in (0,1) \tag{9}$$

In the formula, the persistence of pheromone track of ρ ants on the path is 0.7.

3.4 Iterate

According to the above steps, the ant colony algorithm is iteratively calculated in the MATLAB program. The algorithm iterates once until convergence is satisfied after the set number of iterations.

4. Verification of simulation results

Set an inlet speed value preliminarily, and analyze its fullness after FLUENT runs. If the calculated fullness is greater than the required fullness, the initial inlet speed should be reduced; otherwise, if the calculated fullness is less than the required fullness, the initial inlet speed should be increased, and then the operation can be adjusted according to the results, and finally the simulation results under the specified working conditions can be obtained.

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Under the slope of 0.005, the final fullness under different fullness conditions is as follows in Table 1:

Table 1. Final simulated fullness value at 0.005 slope

Working condition fullness value	Simulate final fullness value	Relative error
0.1	0.183	1%
0.3	0.297	-0.63%
0.5	0.467	-0.81%

Increase the pipe diameter, analyze the hydraulic model with FLUENT software, and observe that when the pipe diameter is 300mm, the fluid pressure field and velocity field are shown in Figure 1 below:

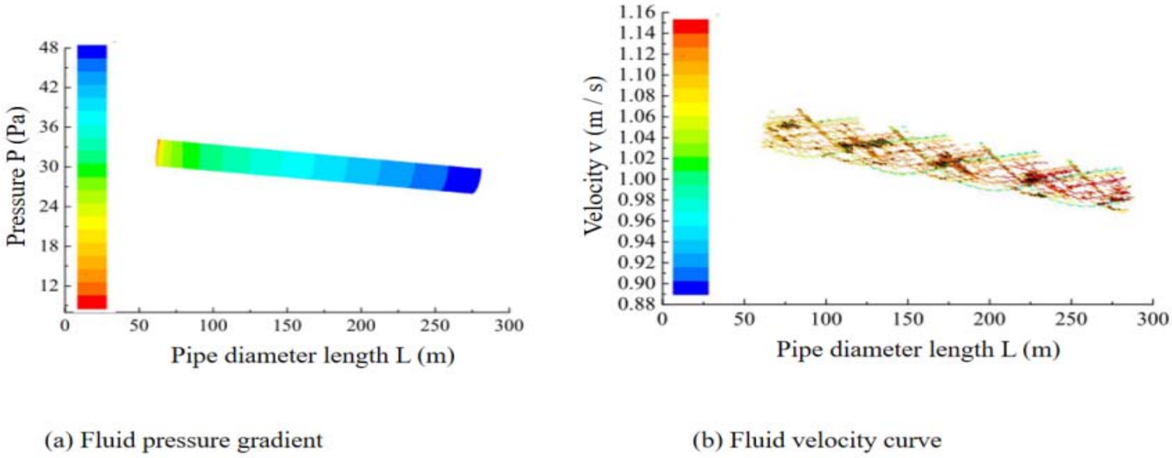

Figure 1. Curve of fluid pressure gradient and fluid velocity

By observing the pressure diagram, it is found that the water pressure gradually increases from 16Pa at the inlet to 46Pa, with a steady growth rate and a small change gradient. It is proved that under the design flow rate, with the pipe diameter of 300mm and the fullness of 0.55, the fluid can normally pass through the pipeline without siltation. The velocity field ranges from 0.90m/s to 1.12m/s, and most of the fluid velocity tends to be about 1.08, which is because the cohesion of the pipe wall causes the fluid velocity to decrease, and the contact between the fluid surface and the air causes the fluid velocity to increase appropriately. Therefore, under the condition of this pipe diameter specification, it meets the requirements.

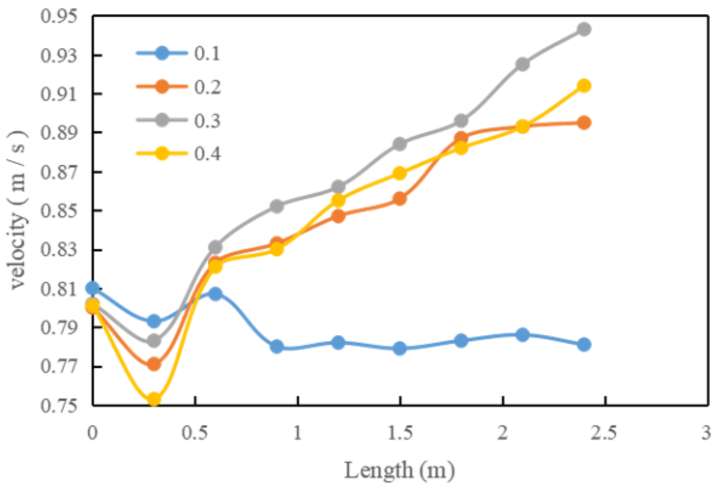

Figure 2. Flow velocity distribution along the road

4.1 Analysis of section velocity along water flow

Use z to express the distance from the bottom of the pipe along the axial direction, and set four sections: Z=0.01m, Z=0.02m, Z=0.03m and z = 0.04m. See Figure 2 below for the velocity distribution of the sections.

At Z=0.01m section, the flow velocity gradually decreases and then tends to be stable. This is because Z=0.01 section is at the bottom of the fluid, which is greatly squeezed by the upper fluid, so that the viscous resistance is greater than the component force of gravity in the velocity direction, and the flow velocity gradually decreases. With the flow, the viscous resistance and the component force of gravity in the velocity direction reach equilibrium, and the velocity gradually becomes stable. At the exit, due to the change of boundary conditions, turbulence is strong, resulting in rapid increase and instability of water flow. In Z=0.02 and Z=0.03m sections, the change trend of flow velocity is basically the same, and the flow velocity gradually rises and continues to increase after rapid decline, which is due to the inconsistency of fluid velocity on different sections, sliding each other and decreasing velocity under the action of viscous resistance. At Z=0.04m section, the velocity decreases first, then increases, and finally tends to be stable. The reason of velocity distribution in front is the same as that at Z=0.02m and Z=0.03m section. For the stable stage, it may be due to the balance between the resistance of upper water flow and gravity component.

4.2 Analysis of turbulent dissipation rate

See fig. 3 for the distribution of turbulent dissipation rate along the route.

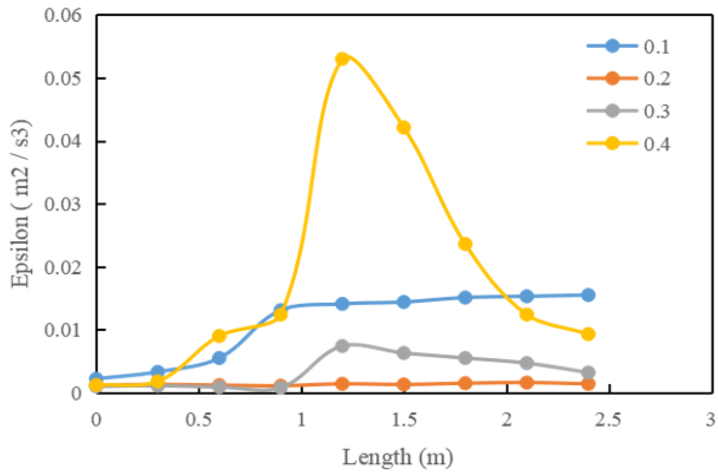

Figure 3. Distribution of turbulent dissipation rate along the route

It can be seen from Figure 3 that the turbulent kinetic energy of 0.1 section at the bottom of the pipeline is the largest as a whole, and the turbulent motion decreases slightly at the initial stage, and then increases steadily. At 0.1-0.3 section, turbulent kinetic energy decreases at first and then increases, and the higher the section position, the longer the process of decreasing. However, at 0.4 section, turbulent kinetic energy changes dramatically, and the upper part is greatly affected by boundary conditions. The law of turbulent dissipation rate is very similar to the distribution of turbulent kinetic energy along the way, that is, the turbulent dissipation rate is also large in areas with large turbulent kinetic energy, and vice verse.

Therefore, the increase of flow velocity in a certain range will bring more nutrients to the biofilm, and a certain turbulent effect can promote mass transfer and the growth of biofilm. Turbulent motion is characterized by mixing liquid particles with each other, making non-directional and irregular motion. Turbulence is time-averaged and pulsating. As a result of pulsation, the mass exchange, momentum exchange, heat exchange and concentration exchange between flow layers are intensified, so the head loss of turbulent flow is greater than that of laminar flow. The turbulent kinetic energy at

ISSN: 2414-1895 DOI: 10.6919/ICJE.202108_7(8).0021

the bottom of the pipe is great, which is beneficial to the growth of microorganisms attached to the pipe wall and the formation of bio-film.

5. Summary

In this paper, based on FLUENT software and ant colony algorithm, the optimal design of drainage network is studied, and the mathematical model and theoretical framework are constructed. Under the given plane layout, ant colony algorithm is feasible for the optimal design of drainage pipe network. By reducing the pheromone matrix, the optimization efficiency of ant colony algorithm is improved. And has the characteristics of effectiveness and high efficiency. The response surface method is used to study the shear stress of drainage pipe wall. By studying the relationship between shear stress of drainage pipe wall and initial flow velocity, initial fullness and slope, it is found that the degree of shear stress of pipe wall affected by the above three factors is in the order of initial flow velocity > slope > initial fullness. In the process of drainage network design, designers blindly use query charts and specifications, and use the upper limit of hydraulic parameters in design specifications as much as possible, resulting in great waste.

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