Accurate Calculation of Head Loss of Small Reservoir Based on PDMS 3D Model CAD

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Abstract. China has a limited share of water resources per capita and a severe water scarcity. It is one of the world's countries with the most limited water resources per capita. Water resource challenges in China also include a lack of understanding of water conservation and water conservation, as well as major waste, pollution, and over exploitation. In order to solve the problem of inconvenient accurate calculation of pipeline head loss with complex layout, research on computer-aided design (CAD) head loss calculation method based on Plant Design Management System (PDSM) three-dimensional model is proposed. Firstly, the pressure pipe model is taken as the research object, and the straight pipe and pipe components of the calculated pipeline are classified and summarized according to the identification code of the three-dimensional model component library; Secondly, the head loss calculation formula is compiled and the corresponding logic between the calculation formula parameters and the PDSM three-dimensional model is established; Finally, the head loss of the same type of straight pipe and pipe components is calculated respectively. This calculation approach overcomes the drawbacks of the standard penstock head loss calculation method, such as the vast number of calculations required, erroneous calculation outputs, and lack of automation. Compared with the traditional calculation technology, the calculation accuracy is improved by 20%. It can calculate the pipeline head loss and local head loss synchronously, which is more accurate and simpler than the traditional calculation method.

Keywords: PDSM 3D model; Head Loss; Accurate Calculation; Small Reservoir
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1 INTRODUCTION

China has a small per capita share of water resources and serious water shortage. It is one of the countries with the scarcest per capita water resources in the world. China's total annual water resources is 2800 billion m3, accounting for about 6% of the total global water resources. However, at present, the total amount of water resources that can be effectively utilized in China is only about 1100 billion m3, and the total per capita water resources is 2018m3, only 0.26% of the world average. China's land area accounts for only 7% of the total surface area of the earth, while freshwater resources supply more than 21% of the world's total population. At the same time, the distribution of water resources in China has typical asymmetric characteristics: uneven distribution of time and space, uncoordinated distribution of productivity and water resources, and mismatch of water and soil resources. Taking the Qinling Huaihe River line as the boundary between the South and the North: the land area of the northern region (Huaihe River Basin and its north) accounts for 63.5% of the total land area of the country, while its water resources account for only 19% of the total water resources of the country; The land area of the southern region (the Yangtze River Basin and its south) accounts for only 36.5% of the total land area of the country, while its water resources account for 81% of the total water resources of the country. The inter annual distribution of water resources is uneven, drought and flood disasters occur frequently, the annual rainfall distribution in most areas is too concentrated, and the phenomenon of continuous high water or continuous low water is very common. A physical disruption of the land occurs whenever large numbers of people congregate in one compact region. The use of detergents, chemicals, and exhaust emissions in the construction of new roads, residences, and factories has an impact on the water's purity.

Furthermore, among China's water resource issues include a lack of understanding of water conservation and water conservation, as well as major waste, pollution, and overexploitation of water resources. The multi decadal distribution of water resources is uneven, drought and flood catastrophes are prevalent, annual rainfall distribution with most places is overly intense, and the phenomena of continuous high or low water is quite common. As a result, in order to avoid additional waste of water resources in tiny reservoirs, a precise estimate of small reservoir head loss based on PDMS 3D model CAD is used to establish a sound basis for energy conservation, as illustrated in Figure 1.

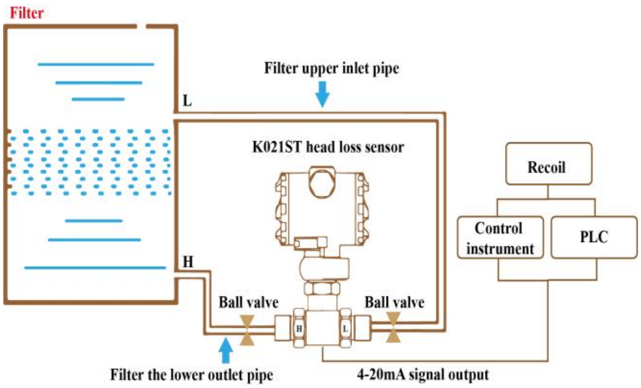

Figure 1: Small reservoir of PDMS 3D model CAD.

2 LITERATURE REVIEW

In recent years, the design of large projects at home and abroad clearly requires the use of three-dimensional design, and the three-dimensional design application system has been formed and is becoming more and more mature. As a powerful functional module in the plant three-dimensional layout design management system (PDSM), pipeline three-dimensional layout design has been widely used in the engineering design of large projects. The advantages brought by the collaborative design concept of pipeline three-dimensional layout have long formed a consensus in the industry. The calculation of head loss of penstock is an important work involved in the three-dimensional layout of pipeline. The calculation based on the three-dimensional digital model can realize the integration and coordination of the actual layout path and the theoretical calculation of the model.

When fluid flows at a low velocity and in tiny diameter pipes, laminar flow develops. The fluid flow is particularly ordered, in that neighboring layers of the fluid do not mix and travel parallel to each other as well as the pipe walls. The fluid layers in turbulent flow do not travel in a straight line. They move in a zigzag pattern at random. When the fluid's velocity is high and it runs through bigger diameter pipes, the result is turbulent flow. Garmendia, I. revealed an important fluid flow mechanism through experiments. In laminar flow, the head loss along the way is proportional to the 1 power of the average velocity of the section, and in turbulent flow, the head loss along the way is proportional to the 1.75 ~ 2 power of the average velocity of the section [1]. The turbulent flow which causes random fluctuations and mixing in the fluid, laminar flow is a type of fluid (gas or liquid) flow in which the fluid moves smoothly or in regular patterns [2, 3]. In laminar flow, also known as streamline flow, the speed, pressure, and other flow characteristics remain constant at each location in the fluid. Laminar flow across a horizontal plane is composed of microscopic parallel layers, called laminar [4, 5]. The fluid remains in contact with the horizontal remains stationary as the other layers glide over each other. Laminar flow occurs only when the flow channel is small, the fluid flows slowly, and the fluid's viscosity is relatively high [6, 7]. Jo, B.H. published in the Journal of civil engineering society, and then more and more scholars at home and abroad studied the friction coefficient of rough and smooth circular tubes [8].

Anderson, J.R. systematically studied the resistance coefficient of water flow in the circular pipe, and solved the problem of determining the flow zoning in the circular pipe and the head loss coefficient in each area [9]. More precisely, flow resistance is defined as the process of dissipating downstream mean flow energy. Turbulence generation converts mean flow energy to tumultuous flow energy, results in this dissipative kind of flow resistance [10, 11]. Flow resistance coefficients, which specify the number and velocity components associated with a loss in each element of a pipeline, may be used to calculate pressure losses caused by valves, fittings, expansions, and contraction [12, 13]. The Moody diagram (also known as the Moody chart) is a non-dimensional graph that shows the relationship between the Darcy friction factor, Reynolds number, and relative roughness in a circular pipe. Zhou, J. proposed that moody diagram can be applied to the analysis of the resistance characteristics of incompressible fluid in conventional circular section straight pipe [14]. Chambon studied the variation of head loss coefficient along the rectangular open channel by artificially roughening the bottom and wall of the rectangular open channel with uniform sand with different particle sizes, and reached a conclusion similar to that of Nicholas test [15]. Bhattacharya has established the neural network (ANN) model of the influencing factors of the head loss coefficient along the way based on the results of Nicholas test, and studied and analyzed the influencing factors of the resistance loss coefficient along the way [16]. The conversion of potential energy to kinetic energy is known as head loss. Head losses are caused by the pipe system's frictional resistance [17, 18]. In contrast to velocity head, friction head cannot be neglected in system equations. The values are determined by the square of the flow rate. A considerable portion of the head may be lost. The size of the entire head determines the impact of head losses [19, 20]. Toepke, M.W. based on the basic principle of hydraulics, the calculation formula of water head loss in circular section FRP straight pipe found that Haizeng William formula is suitable for the calculation of water head loss in pipe with diameter less than 2000mm [21]. Wu,

H. according to Darcy's Derivation and research, it is found that there are some differences in the calculation formula of head loss between non-circular section pipeline and circular section pipeline [22].

Zheng, B. through the numerical simulation method, in the study of the local head loss of water flow in the sudden expansion and sudden reduction part of the circular pipe with Reynolds number greater than 4400, it is found that the local head loss coefficient changes linearly with the logarithm of Reynolds number re [23]. Wong, I. through the turbulence model in fluent software, the local head loss coefficient obtained by numerical simulation of 90 ° circular section elbow when Reynolds number is 60000 is basically consistent with the test value of 0.257 [24]. Selecting the perfect printing settings for maintaining greater durability during the 3D-printing procedure is challenging, if not impossible, and involves a lot of trial and error (especially for a highly viscous prepolymer material such as PDMS) [25, 26]. Apart from the time taken to dry each layer (because to PDMS's long curing time at room temperature), the base polymer and curing agent may not be evenly mixed during the printing process [27]. When placed into a 3D printer, it can potentially block the nozzle channels. To prevent blocking the nozzles, they must be put through distinct nozzles throughout the printing process (which may adversely affect the curing process as well) [28]. The precision of direct PDMS printing is still poor. As a result, current 3D-printing procedures for creating complicated shape/porous PDMS structures must still be adapted [29].

Based on the current research, research on the calculation method of CAD head loss based on PDSM three-dimensional model is proposed. It can realize the accurate calculation of head loss based on PDSM pipeline three-dimensional model, which will greatly simplify the mechanical calculation of pipeline three-dimensional layout design, improve the efficiency of pipeline layout, guide the pipeline layout design, provide parameters for pump selection and check the pump head [30]. For the design scenario with high accuracy of local head loss calculation, the calculation method taking the actual model as the research object has obvious advantages. This calculation method solves the shortcomings of the traditional calculation method of penstock head loss, such as large amount of calculation, inaccurate calculation results and low degree of automation. Compared with the traditional calculation technology, the calculation accuracy is improved by 20%. It can calculate the head loss along the pipeline and local head loss synchronously, which is more accurate and simpler than the traditional calculation method.

3 ACCURATE CALCULATION OF HEAD LOSS OF SMALL RESERVOIR BASED ON PDMS 3D MODEL CAD

3.1 Calculation Method of Head Loss

3.1.1 Traditional head loss calculation method

The frictional loss in the hydro pipeline, given as a proportion of the available head, is known as pipe head loss. Friction causes a loss of pressure in water (or other viscous fluid) passing through a pipe. The head loss of pipeline includes the head loss along the pipeline and the local head loss. At present, most design engineers of the design institute use the following three methods to calculate the head loss of pressure pipe.

3.1.1.1 Traditional estimation

This method calculates the water loss along the pipeline according to the length of the calculated pipeline. The local head loss is estimated as 5% ~ 10% of the head loss along the way. This calculation method ignores the actual calculation of pipe components on the pipeline, and the calculation result has a great error.

3.1.1.2 Calculate with the help of Excel table

In this method, the calculation formula of head loss is compiled by using Excel table, and then the pipeline length and the number of pipe parts are counted according to the layout information of two-dimensional drawings, which are input into the table to calculate the along-road and local head loss respectively. The statistical process of pipe parts in this way is quite complex, the workload of manual data input is large, and there is still a large deviation between the calculation results and the actual project [31].

3.1.1.3 Designers use computer-aided drawing software

This is secondary development technology for calculation. Although this calculation method can make good use of two-dimensional pipeline graphics to automatically input and output data, and the error of calculation results is small, the input link of graphic parameters is cumbersome, the analyzability of calculation result data is poor, and the requirements for two-dimensional drawing are very high [32]. The above calculation methods have the problems of large amount of manual work and large deviation of calculation results, which is not conducive to pipeline hydraulic calculation in design scenarios with high design accuracy requirements.

3.1.2 Calculation formula and application conditions of traditional head loss

The head loss along the pipeline is the energy consumed by the work done by the flow friction. Different flow patterns follow different laws, and the calculation methods are also different. The flow pattern of water transmission and distribution pipeline is basically in the turbulent area, and the flow resistance in the turbulent area is related to the viscous force of water, flow velocity and roughness of pipe wall. The turbulent flow area is divided into hydraulic smooth area, transition area and rough area according to the resistance characteristics. The calculation formulas of head loss along the pipeline have applicable scope and conditions, which are generally divided by the characteristic area of flow resistance. In theory, the ratio of Δ to δ (laminar bottom layer thickness) can be used to determine the characteristic area of turbulent flow resistance, but the specific operation is difficult due to the complexity and difficulty of the determination method. Therefore, the value of $Re\Delta/d$ should be used as the discriminant in engineering design [33].

At present, the hydraulic calculation formula of head loss along the pipeline and the corresponding Darcy formula of friction coefficient commonly used in domestic pipelines are the basic formula of hydraulic calculation along the pipeline. It is a general formula of semi theoretical and semi empirical calculation. It is applicable to different sections of flow pattern. Among them, the friction coefficient can be calculated by klebrooke formula, which is different in different characteristic areas. Colebrook formula considers many factors and has a wide range of application. It is considered to be a comprehensive calculation formula for turbulent zone entry. The combination of Darcy formula and klebrooke formula is used to calculate the head loss along the pipeline, which has high accuracy, but the calculation method is troublesome, and it is often used in the resistance transition zone of turbulent flow. The Hazen William formula is applicable to the turbulent transition zone, where the head loss is proportional to the 1.852 power of the velocity. The calculation method of this formula is simple. As a standard formula for hydraulic calculation of water distribution pipeline in water supply system in the United States, it is also widely used in Europe and Japan. In recent years, it is also widely used in hydraulic calculation of water distribution network in China [34].

3.2 Calculation Method based on 3D Model

3.2.1 PDSM 3D pipe model

Since the promotion of the third-generation nuclear power design technology, CGN Engineering Design Co., Ltd. has fully implemented the three-dimensional design of nuclear power. Through various standards, management procedures and technical manuals, the three-dimensional design work has been standardized, and a complete and mature three-dimensional model has been formed. The pipe 3D model created based on PDSM design platform has the following characteristics:

1) The unified standard component library can provide accurate basic data.

2) Accurate layout path. Its pipe diameter, length, angle, size and parameter attributes provide accurate source data for calculation [35].
3) Independent pipe component classification standard. The unique mark of pipe parts shall be strictly in accordance with the pipe grade spref code, which is convenient for the program to classify and summarize the information of pipe parts.

The application of standardized model base database and standardized model naming provide basic conditions for software development. The relationship between components and grades is shown in Figure 2:

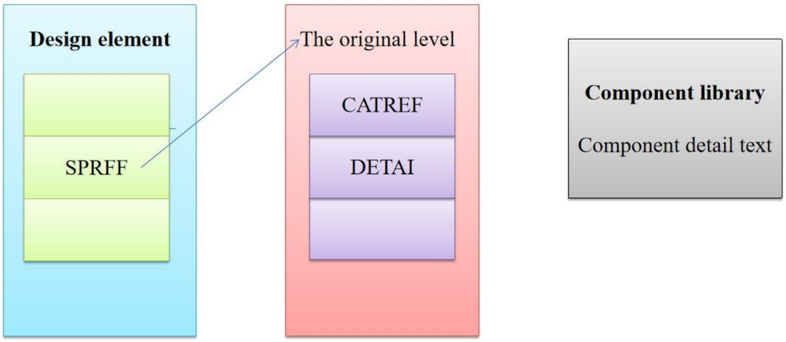

Figure 2: Relationship between components and grades.

3.2.2 Calculation formula of head loss

The research object of this technology is the pressurized pipeline, and the liquid transmitted and distributed by the pipeline is incompressible. The head loss consists of the head loss along the way and the local head loss. The calculation formula (1) adopted is as follows:
Calculation formula of head loss along the way (Haicheng - William formula):

$$i = 105 C_h^{-1.85} d_j^{-4.87} q_g^{1.85} \quad (3.1)$$

Where: i is the head loss per unit length of the pipeline, kPa / m is the calculated inner diameter of the pipeline, q is the design flow, and C is the Haicheng - William coefficient.

When the pipe material is plastic pipe, composite pipe and lined plastic pipe, C = 140; When the pipe material is copper pipe and stainless-steel pipe, C = 130; When the pipe material is cast iron pipe lined with cement and resin, C = 140; When the management material is ordinary steel pipe and cast iron pipe, C = 100.

Sevilev formula (3.2) is:

$$i = \lambda \frac{1}{d_j} \times \frac{u^2}{2_g} \quad (3.2)$$

Where: i is hydraulic gradient; λ is the friction coefficient; D is the calculated inner diameter of the pipe; υ is the average flow velocity, M / S; G is the gravitational acceleration, which is 9.81m/s; V is the kinematic viscosity of the liquid, m / s.

3.2.3 Establish three-dimensional model and head loss calculation parameter logic

By analyzing the calculation formulas of Haicheng - William formula, sevilev formula and local head loss, it is concluded that q_g, v, t, L, d_j, C_h, λ, ξ are the parameters to be determined in the calculation of head loss. The logic of pipeline 3D model attributes and formula parameters is shown in Table 1.

Model properties	*Data type*	*Formula parameters*	*Describe*
Fitlength	Real number	L	Pipe and pipe length
Bore	Real number	L	Nominal diameter of pipe assembly
Ange	Real number	δ	Bending angle of elbow
Rtext	String	δ	Pipe assembly type description

Table 1: Logic of pipeline 3D model attributes and formula parameters.

Determine the value of corresponding local water loss coefficient according to the parameter attributes of various pipe components (such as reducer, elbow, elbow, check valve, gate valve, butterfly valve, stop valve, plug valve, ball valve, tee, expansion joint, Y-type filter, etc.) under the layout path of three-dimensional model; According to different design temperatures, the corresponding hydraulic viscosity coefficient relationship is established to determine the friction resistance coefficient; According to the pipe material and nominal diameter, determine the calculated inner diameter of the pipe, and determine the value of head loss calculation parameters of various three-dimensional model components, calculation principle and calculation process [36].

3.3 Concept of CAD

As a mature and popular technology, CAD technology has been widely used in enterprises and has become the real productivity of enterprises. However, the low level of intelligence and integration of CAD engineering database system has restricted the improvement of enterprise innovative design ability and the popularization of network computing environment. Mechanical CAD intelligent engineering database system mainly studies the standard data of mechanical design manual, analyzes the characteristics of engineering data and mechanical domain knowledge, and establishes an engineering database and knowledge base that is easy to expand and transplantable. The neutral mechanism provided is adopted to integrate PCAD and its management system, knowledge base and its expert system and anthropomorphic user interface management system, so as to construct a model that can give full play to all the talents of designers, improve the innovative design ability of enterprises and support the network computing environment [37].

3.4 Advantages of CAD in Mechanical Design

3.4.1 Intuitive

The two-dimensional function and three-dimensional function of CAD technology can provide many conveniences for designers, especially the intuition of three-dimensional function. The design of CAD three-dimensional model can set the material of each part, different materials have different displays, and the composition of the overall model in a deeper sense can be seen at a glance.

3.4.2 Parameterization, easy to adjust parts

The parameterization of CAD is the reason for designers to adjust conveniently and improve design efficiency. Mechanical design is generally designed manually by designers with drawing tools. Every modification must be completely redrawn, which increases a lot of meaningless workload and affects the smooth progress of design work. However, this modification is inevitable and frequent. When using CAD software, when individual parts need to be modified, the surrounding parts can be modified to allow them to naturally join the original design, which improves the accuracy and quality of the product model, avoids meaningless redrawing, and improves the efficiency of mechanical design. Combined with the model database, designers can assemble or disassemble relevant design graphics while following the design concept. By referring to the surrounding components of the part to be modified, the designer can easily change the parameters of the part directly. 3D CAD software can show the assembly forms of all parts in detail make the simulated assembly more reliable and reduce the risk of errors in the actual assembly. By viewing the model, you can easily find problems and modify them. The assembly modification history system allows the designer to investigate the modification process of each part at any time.

3.4.3 Improve design efficiency and shorten design cycle

CAD technology can improve the working mode of mechanical design, replace manual operation with mechanical operation, reduce the working pressure of designers and improve work efficiency. Once, manual hand drawing was based on the spatial imagination of the human brain, which was difficult. It needed to consider the repeated verification and modification of the structure, the operation was cumbersome, and it was easy to become irreparable due to small mistakes. In this process, a lot of time and human resources will be wasted. CAD software can generate mechanical design drawings as long as data is input. While ensuring the accuracy of data, CAD can modify and retain relevant data, and emphasize the display of important designs for easy viewing and modification. CAD software can save historical data samples, allowing designers to mobilize and reuse. Only some parts that need to be redesigned and manufactured can improve the design efficiency by more than three times. According to the survey, the time required for mechanical design today is only 60% of that in the past.

The material of each part may be adjusted in the CAD three-dimensional model, and various materials have varied displays. When utilizing CAD software, when individual components need to be adjusted, the surrounding parts may be modified to allow them to organically connect the original design, improving the accuracy and quality of the product model, avoiding unnecessary redrawing, and increasing mechanical design efficiency. As long as data is entered, CAD software can create mechanical design drawings. CAD may alter and maintain key data while assuring data correctness, and highlight the display of critical designs for simple viewing and modification.

4 EXPERIMENT AND RESEARCH

4.1 Calculation Principle and Process

According to the three-dimensional model determined above and the parameter calculation logic of the head loss calculation formula, the layout information of the pipeline is calculated. Carry out the head loss calculation of similar straight pipes and pipe parts respectively, and summarize various calculation data. This data is used to calculate the total head loss of the pipeline. The specific calculation process is as follows.

1) Based on the three-dimensional model of calculation pipeline, relevant programs are developed, and spref code is used to classify and summarize the length, diameter and other parameters of the same type of straight pipe section; The friction coefficient is determined according to the design flow, design temperature, design material, etc., and the head loss formula along the way is compiled to complete the calculation of head loss along all straight pipe sections [38].
2) Based on the three-dimensional model of calculation pipeline, relevant programs are developed, and spref code is used to classify and summarize the parameters of the same type of pipe parts, such as quantity, centerline length, pipe diameter and so on; Determine the friction coefficient according to the design flow, design temperature, design material, etc., compile the formula of head loss along the way, and complete the calculation of head loss along the way of all pipe components.

3) Based on the three-dimensional model of calculation pipeline, relevant programs are developed, and spref code is used to classify and summarize the type, quantity, pipe diameter, angle and other parameters of the same type of pipe components; Determine the local head loss coefficient according to the design flow, design temperature and design material, compile the local head loss formula, and complete the local head loss calculation of all pipe components.
4) The summary of the calculation results of the above three steps is to calculate the head loss on the pipeline.

4.2 Determination of Model Parameters

The differential evolution algorithm (DE) is used to identify the undetermined parameters K, a, b and d in the total head loss model shown. Differential evolution algorithm is an intelligent optimization algorithm that uses floating-point vector coding and heuristic random search in continuous space. It has obvious effect in optimizing some functions with large scale, high dimension, nonlinearity and non-differentiability. Like genetic algorithm, DE algorithm first generates a population randomly, and then performs mutation, crossover and selection operations on the individuals in the population, so as to generate a new generation. In this way, it iterates repeatedly and finally converges to the optimal individual. For the fitting parameters of exponential function, the function can be described as the optimization problem min (fx). Under the condition of full load experiment, the head loss h of filter layer with different thickness and the clean filter layer H0 with the filtration time are obtained by using formula (1), and then the sample space is established together with the change data of turbidity and speed of water to be filtered in the actual production and operation of the water plant at the corresponding time. 1296 groups of data were obtained from the data actually produced by a water plant from February to April 2010 after past outliers and smoothing. They were divided into six data tables, five of which were used for parameter identification, and the remaining one was used for model test. Due to the space relationship, 10 groups of data are randomly selected from the data sample space. The data samples are shown in Table 2.

Number	*Time*	*Turbidity Of Water To Be Filtered*	*Filtration Rate*	*Filter Thickness*	*Blockage Meter Reading*
1	1	2.345	6	0.66	1.456
2	3	2.544	6	0.66	1.654
3	5	2.756	6	0.70	1.688
4	7	2.398	6	0.76	1.986
5	12	2.178	6	0.66	1.436

Table 2: Sample data of filter rate and filter thickness.

For the initial state of filter layer with different thickness, its H0 is different. According to table 2, the head loss of the clean filter layer of the filter layer with thickness of 0.55, 0.8 and 1.09M can be substituted into the equation, and the model can be tested with the data in the remaining data table. It is obtained that the relative error square sum mean error of the sample data is 0.0852. Figure 3 depicts the model's anticipated value and the actual head loss of filter layers of various thicknesses. Figure 3 indicates that the model structure based on this technique is right, and the head loss fitting curve under three thicknesses is near to the real curve, suggesting that the differential identification parameters are valid and dependable.

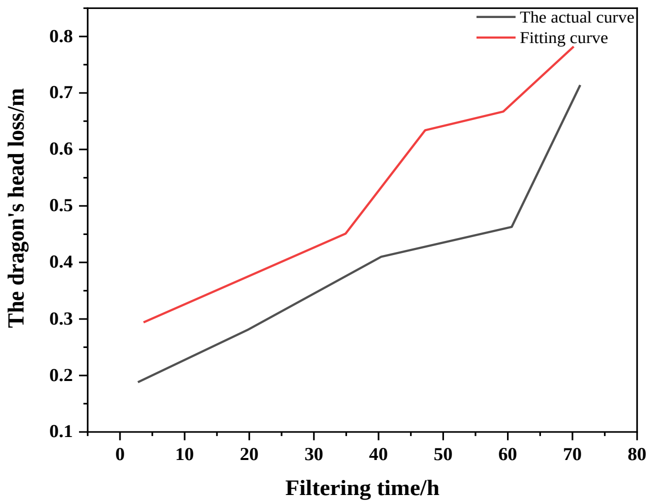

Figure 3: Prediction results of head loss of filter layers at different depths.

4.3 Calculation Software Design

4.3.1 Process calculation

The research is divided into three steps: the definition of calculation pipeline, the calculation of head loss and the export of result report, determines the design of software calculation process, and finally completes the head loss calculation of pressure pipeline based on three-dimensional model. The calculation process is shown in Figure 4.

4.3.2 Man-machine interface

According to the calculation habit and calculation process, the man-machine tool interface design is carried out in PDMS 3D software. First of all, the design button supports engineers to easily and quickly define the calculation pipeline. Then, the setting window supports the input of engineering design parameters, and the corresponding logic between formula parameters and 3D model is established by the background compiler in the engineering calculation part; Based on the model identification code, extract and calculate the pipeline model data, classify and summarize them, and automatically calculate the along-line head loss and local head loss of straight pipe and pipe components [39]. Finally, the head loss calculation results are displayed, and the excel calculation report is exported. The interface function conforms to the engineering calculation logic, which is convenient for engineers to carry out mechanical calculation.

4.3.3 Advantages of calculation software

The calculation software has the following advantages.

1) It is completely carried out by relying on the model consistent with the actual pipeline. Compared with the traditional calculation method, the calculation result has high precision and is more in line with the reality.
2) The excel header information data meeting the requirements of head loss calculation is derived to facilitate the design engineer to trace and analyze the calculation results.
3) The tool interface is simple and clear, easy to use, one click results can be obtained, and the degree of automation is high.

4) This method is a new way of head loss calculation based on three-dimensional pipeline model, and has broad application prospects.

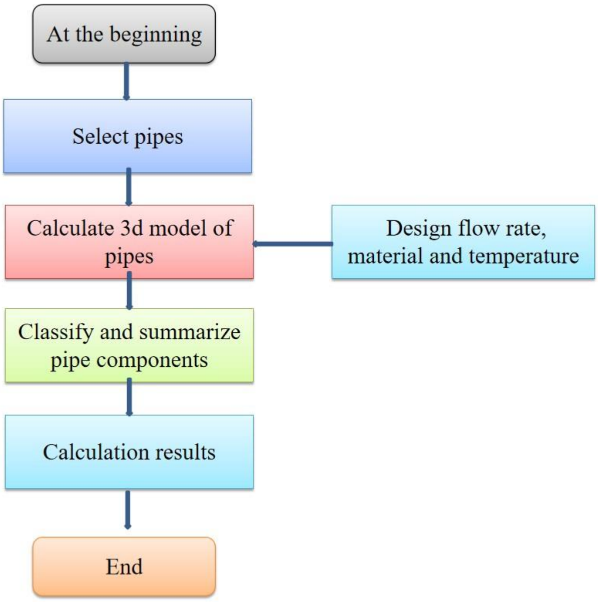

Figure 4: Calculation of pressure pipeline based on three-dimensional model.

4.4 Head Loss in Turbulent Flow

In laminar flow, each particle moves regularly along the axial direction without transverse movement. One of the important characteristics of turbulence is that each particle of liquid no longer moves regularly in the axial direction, but infiltrates and pulsates with each other in the process of movement. This extremely irregular movement causes collisions between particles and forms vortices, which make the turbulent energy loss much greater than that of laminar flow. In turbulent flow, e represents the absolute coarseness of the pipe and is the average height of the convex and concave part of the pipe wall, so the pressure loss in the pipe can be written in the form of power function, i.e., formula (3.3):

$$(x+a)^n = a^2 = c^2 \tag{3.3}$$

According to the principle of dimensional consistency: for all physical quantity equations derived according to the basic physical laws, the dimensions of each item must be the same.

4.5 Discussion on Friction Coefficient

4.5.1 Properties and application conditions of friction coefficient

Each hydraulic calculation formula along the pipeline has corresponding friction coefficient and determination method, and the expression form is also different. The friction coefficient is an unknown number and should be determined by test. However, in practical application, it is generally selected by designers according to different pipes and their different inner wall smoothness, referring to the existing data. This value is very important, but it is very arbitrary, and the result of value directly affects the accuracy of hydraulic calculation results. Therefore, understanding and being familiar with the attributes of friction coefficient and mastering the methods and skills of value selection are also the key to doing well the hydraulic calculation along the pipeline.

1) Equivalent roughness Δ equivalent roughness is the theoretical value calculated by Darcy formula and Nicholas formula according to the results of hydraulic test of natural (also known as industrial) pipeline. Each kind of pipe has a certain equivalent roughness and does not change due to different flow patterns. The equivalent roughness is often used when judging the flow pattern and selecting other calculation formula parameters [40].
2) Friction coefficient λ. The friction coefficient λ can be applied to different resistance characteristic areas, and the values of λ in different intervals are different. In the smooth region of turbulent flow, the value of λ is only related to Reynolds number (RE) and decreases with the increase of Reynolds number (RE); In the transition region, Reynolds number (Δ/ d) and roughness (λ / d) change with the relative change of flow roughness; In the turbulent rough area, it is only related to the relative roughness (Δ / d). As long as the pipe and pipe diameter are determined (i.e., the relative roughness Δ / d is determined), the value of B in this area should be the fixed value [41].
3) Roughness coefficient n, roughness coefficient n is the parameter when using Pavlov formula and Manning formula to calculate Xie Cai formula C (Manning formula should be used for 0.5mm ≤ Δ ≤ 4mm and Pavlov formula should be used for 1mm ≤ Δ ≤ 5mm). It is applicable to the rough area of turbulent flow. In this area, the corresponding value of N can be selected according to the smoothness of the inner wall of the pipe, but generally, the value range of n should be greater than 0.01, otherwise the calculation result error is large. As shown in Figure 5:

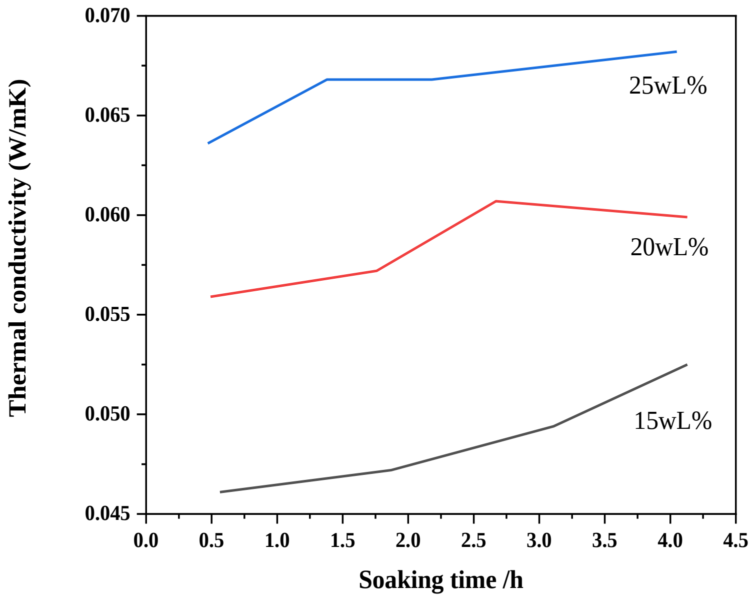

Figure 5: Relationship between friction coefficient and turbulence.

5 CONCLUSION

The automatic calculation of water head loss based on PDMS and CAD pipeline three-dimensional model is realized, which can make the calculation of water head loss of pipeline with more pipe components and local water head loss dominant more accurate and convenient. The tool calculation forms a statistical report, which is convenient for the design engineer to process and review the process data, and also provides a reference basis for the layout design. It has a broad application prospect in the three-dimensional layout design of pipeline by using PDMS and CAD. The calculation method proposed in this paper can greatly simplify the calculation workload of design engineers, improve work efficiency and calculation accuracy, and will effectively promote the application of PDMS and CAD 3D layout design to a deeper level. This study is an innovation in the calculation method of head loss of penstock. The calculation results are not only accurate and practical, but also convenient and simple to use. It has been used in the three-dimensional pipeline design of Zhongguang nuclear power plant project and has high application value. In future we provide a new option for PDMS casting/micro molding procedures that uses molding shapes created by a commercially available novel acrylic photopolymer-based 3D printing process.

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REFERENCES

[1] Garmendia, I.; Anglada, E.; Vallejo, H.; Seco, M.: Accurate calculation of conductive conductances in complex geometries for spacecrafts thermal models, Advances in Space Research, 57(4), 2016, 1087-1097. https://doi.org/10.1016/j.asr.2015.12.027
[2] Sun, Y.; Sharma, A.: Research and Design of High Efficiency Superfine Crusher using CAD Technology, Computer-Aided Design & Applications, 19(S2), 2022, 26-38. https://doi.org/10.14733/cadaps.2022.S2.26-38
[3] Garcia-Tenorio, C.; Mojica-Nava, E.; Sbarciog, M.; Wouwer, A: Analysis of the ROA of an anaerobic digestion process via data-driven Koopman operator, Nonlinear Engineering, 10(1), 2021, 109-131. https://doi.org/10.1515/nleng-2021-0009
[4] Asogwa, K.; Bilal, S.; Animasaun, I.; Mebarek-Oudina, F.: Insight into the significance of ramped wall temperature and ramped surface concentration: The case of Casson fluid flow on an inclined Riga plate with heat absorption and chemical reaction, Nonlinear Engineering, 10(1), 2021, 213-230. https://doi.org/10.1515/nleng-2021-0016
[5] Yousef, F.; Semmar, B.; Al Nasr, K.: Dynamics and simulations of discretized Caputo-conformable fractional-order Lotka–Volterra models, Nonlinear Engineering, 11(1), 2022, 100-111. https://doi.org/10.1515/nleng-2022-0013
[6] Tao, Y.; Yafeng, W.; Yan, L.; Sharma, A.: An Efficient CAD based Design System for Spatial Cam Reducer. Computer-Aided Design & Applications, 19(S2), 2022, 134-143. https://doi.org/10.14733/cadaps.2022.S2.134-143
[7] Zhan, X.; Mu, Z. H.; Kumar, R.; Shabaz, M.: Research on speed sensor fusion of urban rail transit train speed ranging based on deep learning, Nonlinear Engineering, 10(1), 2021, 363-373. https://doi.org/10.1515/nleng-2021-0028
[8] Jo, B. H.; Van Lerberghe, L. M.: Three-dimensional micro-channel fabrication in polydimethylsiloxane (pdms) elastomer, Journal of Microelectromechanical Systems, 9(1), 2020, 76-81. https://doi.org/10.1109/84.825780
[9] Anderson, J. R.; Chiu, D. T.; Jackman, R. J.; Cherniavskaya, O.; Whitesides, G. M.: Fabrication of topologically complex three-dimensional microfluidic systems in pdms by rapid

prototyping, Analytical Chemistry, 72(14), 2000, 3158-3164. https://doi.org/10.1021/ac9912294
[10] Awan, A.; Riaz, S.; Abro, K.; Siddiqa, A.; Ali, Q.: The role of relaxation and retardation phenomenon of Oldroyd-B fluid flow through Stehfest's and Tzou's algorithms, Nonlinear Engineering, 11(1), 2022, 35-46. https://doi.org/10.1515/nleng-2022-0006
[11] Guo, E.; Jagota, V.; Makhatha, ME.; Kumar, P.: Study on fault identification of mechanical dynamic nonlinear transmission system, Nonlinear Engineering 10 (1), 2021, 518-525. https://doi.org/10.1515/nleng-2021-0042
[12] Balyan, V.: New OZCZ Using OVSF Codes for CDMA-VLC Systems, Advances in Intelligent Systems and Computing, 1235,2022, 363-374. https://doi.org/10.1007/978-981-16-4641-6_30
[13] Zhou, J.; Ellis, A. V.; Voelcker, N. H.: Recent developments in pdms surface modification for microfluidic devices, Electrophoresis, 31(1), 2010, 2-16. https://doi.org/10.1002/elps.200900475
[14] Chambon, F.; Winter, H.H.: Linear viscoelasticity at the gel point of a crosslinking pdms with imbalanced stoichiometry, Journal of Rheology, 31(8), 2019, 683-697.
[15] Bhattacharya, S.; Datta, A.; Berg, J. M.; Gangopadhyay, S.: Studies on surface wettability of poly(dimethyl) siloxane (pdms) and glass under oxygen-plasma treatment and correlation, Journal of microelectromechanical systems, 14(3), 2015, 590-597. https://doi.org/10.1109/JMEMS.2005.844746
[16] Wang, H.; Sharma, A.; Shabaz, M.: Research on digital media animation control technology based on recurrent neural network using speech technology, International Journal of System Assurance Engineering and Management, 13(1), 2022, 564-575. https://doi.org/10.1007/s13198-021-01540-x
[17] Balyan, V.:Cooperative relay to relay communication using NOMA for energy efficient wireless communication, Telecommunication systems, 76 (2), 2021, 271-281. https://doi.org/10.1007/s11235-021-00756-3
[18] Balyan, V.: Channel Allocation with MIMO in Cognitive Radio Network, Wireless Personal Communication, 116, 2021, 45–60. https://doi.org/10.1007/s11277-020-07704-5
[19] Rathee, G.; Sharma, A.; Saini, H.; Kumar, R.; Iqbal, R.: A hybrid framework for multimedia data processing in IoT-healthcare using blockchain technology, Multimedia Tools and Applications, 79(15), 2020, 9711-9733. https://doi.org/10.1007/s11042-019-07835-3
[20] Toepke, M. W.; Beebe, D. J.: Pdms absorption of small molecules and consequences in microfluidic applications, Lab on A Chip, 6(12), 2016, 1484-1486. https://doi.org/10.1039/b612140c
[21] Wu, H.; Odom, T. W.; Chiu, D. T.; Whitesides, G. M.: Fabrication of complex three-dimensional microchannel systems in pdms, Journal of the American Chemical Society, 125(2), 2013, 554-559. https://doi.org/10.1021/ja021045y
[22] Zheng, B.: A droplet-based, composite pdms/glass capillary microfluidic system for evaluating protein crystallization conditions by microbatch and vapor-diffusion methods with on-chip x-ray diffraction, Angewandte Chemie International Edition, 43(19), 2016, 2508-2511. https://doi.org/10.1002/anie.200453974
[23] Postiglione, G.; Alberini, M.; Leigh, S.; Levi, M.; Turri S.: Effect of 3D-printed microvascular network design on the self-healing behavior of cross-linked polymers, ACS Appl. Mater. Interfaces, 9 (16), 2017, 14371-14378. https://doi.org/10.1021/acsami.7b01830
[24] Dahlberg, T.; Stangner, T.; Zhang, H.; Wiklund, K.; Lundberg, P.; Edman, L.; Andersson, M.: 3D printed water-soluble scaffolds for rapid production of PDMS micro-fluidic flow chambers, Scientific reports., 8 (1), 2018, 1-10. https://doi.org/10.1038/s41598-018-21638-w
[25] Femmer, T.; Kuehne, A.J.; Wessling M.: Print your own membrane: direct rapid prototyping of polydimethylsiloxane, Lab on Chip, 14 (15), 2014, 2610-2613. https://doi.org/10.1039/c4lc00320a

[26] Hillier, C. ; Balyan, V.: Error Detection and Correction On-Board Nanosatellites Using Hamming Codes, Journal of Electrical and Computer Engineering, 2019(6), 2019, 1-15. https://doi.org/10.1155/2019/3905094

[27] Jiang, Y.; Wang Q.: Highly-stretchable 3D-architected mechanical metamaterials, Scientific reports, 6, 2016, 1-11. https://doi.org/10.1038/srep34147

[28] Wong, I.; Ho, C. M.: Surface molecular property modifications for poly(dimethylsiloxane) (pdms) based microfluidic devices, Microfluid Nanofluidics, 7(3), 2019, 291-306. https://doi.org/10.1007/s10404-009-0443-4

[29] Eteshola, E.; Leckband, D.: Development and characterization of an elisa assay in pdms microfluidic channels, Sensors & Actuators B Chemical, 72(2), 2001, 129-133. https://doi.org/10.1016/S0925-4005(00)00640-7

[30] Niu, X. Z.; Peng, S. L.; Liu, L. Y.; Wen, W. J.; Ping, S.: Characterizing and patterning of pdms-based conducting composites, Advanced Materials, 19(18), 2016, 2682-2686. https://doi.org/10.1002/adma.200602515

[31] Berthier, E.; Young, E.; Beebe, D.: Engineers are from pdms-land, biologists are from polystyrenia, Lab on A Chip, 12(7), 2012, 1224-1237. https://doi.org/10.1039/c2lc20982a

[32] Junger, A.; Boettger, S.; Engel, J.; Benson, M.; Michel, A.; Roehrig, R.: Automatic calculation of a modified apache ii score using a patient data management system (pdms), International Journal of Medical Informatics, 65(2), 2018, 145-157. https://doi.org/10.1016/S1386-5056(02)00014-X

[33] Singh, A.; Freeman, B. D.; Pinnau, I.: Pure and mixed gas acetone/nitrogen permeation properties of polydimethylsiloxane [pdms], Journal of Polymer Science Part B Polymer Physics, 36(2), 2015, 289-301. https://doi.org/10.1002/(SICI)1099-0488(19980130)36:2<289::AID-POLB8>3.0.CO;2-M

[34] Chan, H. N.; Chen, Y.; Shu, Y.; Chen, Y.; Tian, Q.; Wu, H.: Direct, one-step molding of 3d-printed structures for convenient fabrication of truly 3d pdms microfluidic chips, Microfluidics & Nanofluidics, 19(1), 2015, 9-18. https://doi.org/10.1007/s10404-014-1542-4

[35] Femmer, T.; Kuehne, A.; Torres-Rendon, J.; Walther, A.; Wessling, M.: Print your membrane: rapid prototyping of complex 3d-pdms membranes via a sacrificial resist, Journal of Membrane Science, 478, 2015, 12-18. https://doi.org/10.1016/j.memsci.2014.12.040

[36] Chen, J.; Guo, H.; He, X.; Liu, G.; Xi, Y.; Shi, H.; Hu, C.: Enhancing performance of triboelectric nanogenerator by filling high dielectric nanoparticles into sponge pdms film, ACS applied materials & interfaces, 8(1), 2016, 736-44. https://doi.org/10.1021/acsami.5b09907

[37] Wu, S.; Ladani, R. B.; Zhang, J.; Ghorbani, K.; Zhang, X.; Mouritz, A. P.; Kinloch, A.J.; Wang, C.H.: Strain sensors with adjustable sensitivity by tailoring the microstructure of graphene aerogel/pdms nanocomposites, ACS Applied Materials & Interfaces, 8(37), 2016, 24853-24861. https://doi.org/10.1021/acsami.6b06012

[38] Chiang, C. L.; Koh, K. S.; Chin, J.; Chia, J.: Quantitative studies on pdms-pdms interface bonding with piranha solution and its swelling effect, Micromachines, 3(2), 2018, 427-441. https://doi.org/10.3390/mi3020427

[39] Novara, C.; Dalla Marta, S.; Virga, A.; Lamberti, A.; Angelini, A.; Chiadò, A.; Rivolo, P.; Geobaldo, F.; Sergo, V.; Bonifacio, A.; Giorgis, F.: Sers-active ag nanoparticles on porous silicon and pdms substrates: a comparative study of uniformity and raman efficiency, The journal of physical chemistry, C., Nanomaterials and interfaces, 120(30), 2016, 16946-16953. https://doi.org/10.1021/acs.jpcc.6b03852

[40] Rezakazemi, M. R. M.; Vatani, A.; Mohammadi, T.: Synergistic interaction between poss and fumed silica on the properties of crosslinked pdms nanocomposite membranes, RSC Advances, 5(100), 2015, 82460-82470. https://doi.org/10.1039/C5RA13609A

[41] Mishima, S.; Nakagawa, T.: Plasma-grafting of fluoroalkyl methacrylate onto pdms membranes and their voc separation properties for pervaporation, Journal of Applied Polymer Science, 73(10), 2015, 1835-1844. https://doi.org/10.1002/(SICI)1097-4628(19990906)73:10<1835::AID-APP2>3.0.CO;2-Y