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A quantitative analysis on the influence of temperature on head loss along PVC pipe and the choice of pipe diameter

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A quantitative analysis on the influence of temperature on head loss along PVC pipe and the choice of pipe diameter

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Abstract. PVC pipe is widely used in engineering. For instance, it can be used to transport hot water. However, in the process of transmission, a certain head loss will be produced, and the cost problem will be considered in the choice of pipe diameter [1]. Through the controlling of variable, this paper introduces and deduces the formula used to calculate the influence of temperature on head loss. By listing the results and making a graph after calculation, the influence of temperature parameter change on the head loss of PVC pipe is explored, and a reasonable pipe diameter selection scheme is discussed. The formulas and parameters used in this paper are all from the research of other scholars and experts. The results show that the head loss in PVC pipe decreases gradually and stably with the increase of temperature. In addition, with the increase of pipe diameter, the head loss will be reduced, the power consumption of the pump will be reduced, but the material cost will be increased. In conclusion, the water temperature can be increased in a certain range to reduce the head loss. When the distance of pipe distribution is short, a larger pipe diameter can be selected to reduce the power consumption cost. For longer distances, smaller pipe diameters can be selected to reduce material costs.

Keywords: PVC pipe, effect of head loss on temperature, control variables, pipe diameter selection, cost.

1. Introduction

PVC pipe is a kind of hot-pressed plastic pipe that is made from PVC resin, stabilizer, and lubricant. It is generally used for the transportation of waste water, chemical liquid, heating and cooling agent, food, super pure liquid, slurry, gases, compressed air, and vacuum system. It especially has a wide range of application in water supply and drainage [2], as well as hot water transportation. When conveying hot water, it is inevitable to produce head loss. At the same time, the pump will generate a lot of redundant power consumption, and then increase the economic cost. Compared with the ordinary metal water pipe, the head loss of PVC water pipe is more easily affected by the temperature. In this paper, a series of formulas will be applied and the numerical results will be illustrated by a line graph. The author analyzes the cause of the head loss of hot water in PVC pipe by focusing on the influence of temperature parameter on the head loss, and them puts forward a scheme for pipe diameter selection. Although the research on the hydraulic head loss in pipelines has been very mature now, this paper can still provide some help and reference for the layout of hot water conveying pipelines.

2. Causes and types of head loss

Head loss is the loss of mechanical energy per unit weight of liquid during as water flows. Internal and external causes are the two causes of head loss. The internal cause is the viscosity of the liquid, which is the fundamental cause. The external cause is the external resistance to the flow [3]. However, in PVC pipe, the change of temperature will also have a certain impact on the result of head loss. PVC pipe is made of a type of plastic called polyvinyl chloride, a kind of versatile material that has a very wide range of use, especially in engineering applications [4]. All materials expand when the temperature increases. On the contrary, all materials shrink when the temperature drops, and the PVC pipe is no exception. The size of a PVC pipe changes with the temperature, so do the stiffness and the ability to hold pressure. For example, temperature changes can cause small changes in the size of PVC pipes, and the change in pipe length is the most obvious. Generally, for every 12 °C increase in temperature, the change in a pipe length of 30 meters is about 3.8 inches. This series of changes will lead to the changes in the head loss value in a pipeline. Head losses come in two forms. One is the frictional head loss and the other is the local head loss.

3. Methodology

3.1. Frictional head loss of PVC pipe and its calculation method

In the process of liquid flow, the flow resistance generated in the uniform flow section where the direction of flow, the roughness of the wall, the shape of the flow section and the area are unchanged is called frictional drag. The influence of flow resistance causes the loss of energy or head loss in the process of fluid flow. The resistance along the path is uniformly distributed on the entire uniform flow segment, which is proportional to the length of the pipe segment and is generally expressed as Hf. The classic Darcy formula is generally used to calculate the head loss along the path, and its specific expression can be expressed as

$$h_f = \lambda \frac{L}{D} \frac{v^2}{2g} \tag{1}$$

Where, λ is the head loss coefficient along the path; L is the distance along the path; V is the average velocity of the section; D is the pipe radius; g is the local gravitational acceleration [5]. In addition to the pipe radius, the calculation of head loss along the path also needs to determine the head loss coefficient λ, which is generally related to the flow pattern and boundary conditions of the water flow. Considering in the general flow rate conditions, commonly used thermoplastic water pipe PVC is generally in the hydraulic smooth area, because the impact of the absolute equivalent roughness of the pipe wall on the results is so small that it can be ignored. Therefore, the hydraulic friction coefficient λ can be calculated according to the following formula:

$$\lambda = \frac{0.304}{R_e^{0.239}} \tag{2}$$

Where Re is the Reynolds number. It should be calculated as follows:

$$R_e = \frac{vD}{\gamma} \tag{3}$$

In the formula (3), γ is the viscosity of water, which can be used at different temperatures according to Table 1.

Table 1. The value of γ at different temperatures [1].

water temperature (°C)	0	5	10	15	20	25	30	40
γ (m^3/s)$\times 10^{-6}$	1.78	1.52	1.31	1.14	1.00	0.89	0.80	0.66

As can be seen from the equation (1), to calculate the head loss, it is necessary to substitute the data in Table 1 and calculate it step by step. At least three formulas are needed and the calculation is pretty complex. In order to simplify the formula and calculation and reduce the workload, the derivation is as follows. Due to the large fluctuation of water temperature in a specific project, the calculation of head loss is usually based on the base temperature, and then whether to modify is decided according to the specific situation. The reference temperature of the cold water pipe is generally 10 °C. When the water temperature is 10 °C, γ=1.31×10-6m3/s. Based on the equation (3), equation (4) can be obtained below:

$$R_e = \frac{vD}{\gamma} = \frac{vD}{1.31\times10^{-6}} \tag{4}$$

Put the equation (4) into the equation (2), and the equation (5) is obtained:

$$\lambda = 0.304 \times \frac{1.31^{0.239}}{v^{0.239}D^{0.239}(10^6)^{0.239}} \tag{5}$$

Put the equation (5) into the equation (1), and the equation (6) is obtained:

$$h_f = 6.08 \times 10^{-4} \times \frac{Lv^{1.761}}{D^{1.239}} \tag{6}$$

Take the head loss $h_f = i$ when L=1m, and

$$i = 0.000608\frac{v^{1.761}}{D^{1.239}} \tag{7}$$

$$q = \frac{\pi D^2}{4}v \tag{8}$$

The the equation (9) can be obtained based on the equation (8):

$$v = \frac{4q}{\pi D^2} \tag{9}$$

In combination with the equation (7), the equation (10) can be obtained:

$$i = 0.000608\frac{v^{1.761}}{D^{1.239}} = 0.00093\frac{q^{1.761}}{D^{4.761}} \tag{10}$$

where q is the volume flow rate per unit time through the section of the pipe in m3/s. Now the equation (1), (2) and (3) can be replaced with (7) and (10). Equation (7) is used when the flow velocity is known, and equation (10) is used when the flow rate is specified. Through this series of simplified formulas, the amount of calculation is reduced a lot [6].

It should be noted that the i values of the above formulas are all the head loss when the water temperature is 10 °C. If it is not 10 °C, the i values need to be multiplied by the correction coefficient K, as shown in Table 2.

Table 2. The water temperature correction coefficients [1].

Water temperature (°C)	0	4	5	10	15	20	25	30	40
K	1.08	1.05	1.03	1.00	0.96	0.93	0.91	0.89	0.85

3.2. Local head loss of PVC pipe and its calculation method

The local head loss is mainly caused by the obvious change of the flow boundary, which is caused by the large change of the flow state. The energy loss only appears in the local flow segment before and after the boundary change. It has three characteristics: large energy consumption, concentrated energy consumption, and vortex loss [7]. Theoretical and experimental results show that the local head loss is mainly related to the flow velocity and the boundary change form, which can be calculated by the following formula:

$$h = \xi\frac{v^2}{2g} \tag{11}$$

where V is the average velocity of the section; ξ is the local head loss coefficient [8]. The local head loss coefficient ξ can be found on the website.

4. Result and analysis

4.1. Influence of temperature on the frictional head loss

Assuming there is such a horizontal PVC pipe, the total distance along the straight pipe is 10m, the pipe radius D is 0.02m, the local gravity acceleration g is 9.82m/S2, and the average velocity of the water in the section is 0.8m/s. Besides, there is a 90-degree curved pipe between the two 5m straight pipes. Now assume that the temperature of the water flowing through the pipe is 0 °C, 4 °C, 5 °C, 10 °C, 15 °C, 20 °C, 25 °C, 30 °C, and 40 °C, respectively.

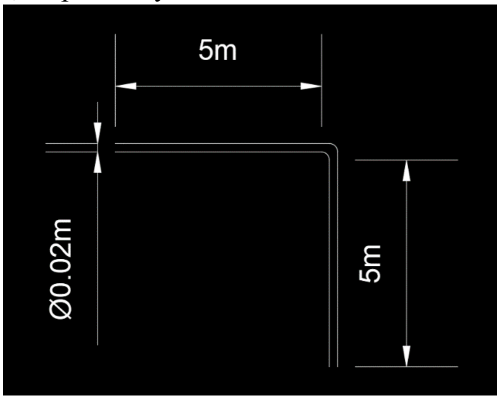

Figure 1. A common pipeline situation in engineering.

The calculation results of the frictional head loss will be shown in Table 3, and a two-dimensional curve with the head loss Hf as the Y-axis and the temperature T as the X-axis will be presented in Figure 2 to observe the change. Since the length of pipelines used for water supply and drainage is relatively long, the frictional head loss is generally far greater than the local head loss. Therefore, the local head loss is generally ignored in the pipeline hydraulic calculation. The local head loss is also ignored in this paper.

Table 3. The change of parameters with the change of temperature.

Water temperature °C\ Various parameters	Correction factor K	Take the head loss I when L=1m	Ki	Hf (m)
0	1.08	0.052	0.056	0.56
4	1.05	0.052	0.055	0.55
5	1.03	0.052	0.054	0.54
10	1.00	0.052	0.052	0.52
15	0.96	0.052	0.05	0.5
20	0.93	0.052	0.048	0.48
25	0.91	0.052	0.047	0.47
30	0.89	0.052	0.046	0.46
40	0.85	0.052	0.044	0.44

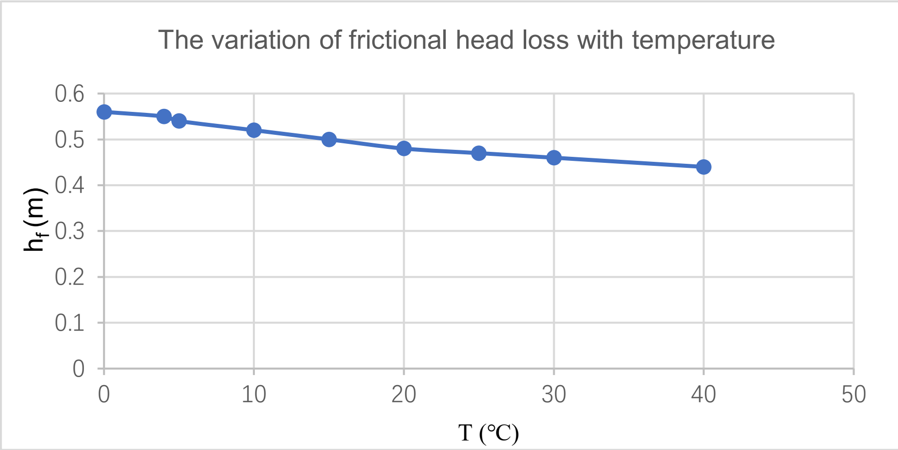

Figure 2. Variation of frictional head loss with temperature.

In Figure 2, it can be seen that the frictional head loss decreases with the increase of temperature, and the curve does not fluctuate much. So in order to reduce the frictional head loss along the PVC pipe, it is necessary to appropriately increase the water temperature during the transportation.

4.2. Selection of pipeline economic velocity and pipe diameter

Pipeline economic velocity is the velocity that minimizes the total cost of water supply when designing the pipe diameter. In the case that the pipeline flow has been determined, the selection of pipe diameter has a great influence on the investment cost and operation cost of pipeline network. As can be seen from the equation (1), for the pressure water distribution pipeline, when the pipe diameter increases, the pipeline velocity decreases, then the head loss decreases, the energy consumption of the pump decreases, and the energy consumption cost decreases, but the cost of the coffin increases. When the diameter of the selected pipe decreases, the flow rate of the pipeline increases, the head loss will increase accordingly, the energy consumption will increase, and the energy consumption cost will increase, but the cost of the coffin can be reduced. Table 4 shows the pipe diameter and the flow rate for hot water transmission.

Table 4. Selection of pipe diameter corresponding to different flow rates [9].

nominal diameter (mm)	15-20	25-40	≥50
flow velocity (m/s)	≤0.8	≤1.0	≤1.2

To solve the above problems, a solution can be put forward as follows. If the total construction length of the pipeline is relatively short, the pipe diameter can be increased appropriately according to the actual situation. Increasing the pipe diameter will increase the construction cost, but because the layout length of the pipe is not particularly long, the investment cost is only reflected in the unit length, which is not too much on the whole. The advantage brought by the increase of pipe diameter is that the head loss will be reduced in the later stage of water transportation, and the energy consumption of the pump will not be too large. On the contrary, if the total construction length of the pipeline is relatively long, the pipe diameter can be appropriately reduced according to the actual situation, which will reduce the construction cost. Although reducing the pipe diameter will increase the head loss in the pipe, it will reduce the construction cost, and considering that the pipe will be replaced later, a smaller pipe diameter can be appropriately selected when the distance is long.

The cost is calculated in the following two ways. First, the total material cost of arranging the required pipe length and using the pipe with the current selected diameter is calculated, and then the electricity cost of pumping water by the selected pump in a pipeline replacement cycle is also calculated. By adding up the cost of electricity and the cost of materials, the total cost of a pipe replacement cycle can be found. With a variety of pipe diameters, the pump in the cycle of electricity consumption is also different. What needs to be done is to find the minimum value of the material cost and power cost within the cycle. This method can effectively reduce the expenditure cost of the enterprise.

5. Conclusion

In conclusion, with the increase of temperature, the frictional head loss along the PVC pipeline will decrease stably. Therefore, the head loss in this type of pipe can be reduced by increasing the temperature appropriately. The head loss of PVC pipe can be easily calculated be multiplying the equation (10) by the corresponding correction coefficients. When choosing the pipe diameter, if the total construction length of the pipeline is relatively short, the pipe with a larger diameter can be selected to reduce the power consumption of the water pump. If the total construction length of the pipeline is longer, smaller pipes can be selected to reduce the cost of materials. Additionally, improvements still need to be made in this paper. For example, more in-depth discussion can be made and more mathematical analyses on the cost of investment in the layout of pipelines, the energy consumption of water pumps, and the capital consumed by replacing pipelines can be conducted. Future research can focus on more methods, such as statistics and measurement, to obtain the formula which can be used to calculate the amount of capital consumed under different pipe lengths and figure out the most economical pipe diameter selection scheme under the corresponding construction length.

References

[1] Wang Z X and Feng J 2020 An Innovative Method for Conventional Triaxial Tests of Concrete: Applications of PVC Pipes as a Mould and Sealing Membrane *Advances in Civil Engineering* pp 1–14 https://doi.org/10.1155/2020/4125428
[2] Carvajal Z W, Gómez N and Saldarriaga J 2020 Turbulent flow in PVC pipes in water distribution systems *Urban Water Journal* 17(6) pp 503–511 https://doi.org/10.1080/1573062X.2020.1786137
[3] Zhao Y S and Chen J 2004 hydromechanics 1(M)
[4] Liu Z Z, Dan B, Lian T and Jiang R F 2003 Calculating method of head loss of hot water pipeline for water temperature change *Journal of Xi 'an University of Technology* 19(4) PP 360-362
[5] Wang and Dawdy D R 2014 Flow resistance of gravel bed channels *International Journal of Sediment Research* 29(1) pp 126–132 https://doi.org/10.1016/S1001-6279(14)60028-7
[6] Ma Y L and Ma C 2019 Simple calculation of hydraulic loss of plastic pipe *Modern plastics* pp 29-30
[7] Wang Y L, Delan Z and Zhan L 2015 Research on head loss of inner cylindrical capillary tube based on dimensional analysis *Journal of hydraulic engineering* 46(5) pp 602-611
[8] Zuo B J, Wang W and Cao S 2020 Analysis on the head loss calculation of pressure pipeline in rural hydropower station *Jiangsu Water Resources* 3(R) pp 30-33
[9] Organized by China Engineering Construction Standardization Association *Code for design of building water supply and sewerage* 1(M) 2007