Optimization study on laying and installation of conjugated directly-buried heating pipes

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Abstract: The total cost of life cycle for district heating pipes can be significantly reduced by combinatorial optimization of laying and installation parameters. The objective function was established by Life Cycle Cost Analysis method and solved by Genetic Algorithm method of MATLAB in this study. The results show that the total cost, heat loss cost, construction cost and insulation material cost increase with the increases of pipe nominal diameter. The optimal combination of buried depth and insulation thickness were obtained for different pipe diameters.

1. Introduction
The total life cycle cost can be saved by adopting the reasonable laying and installation parameters of district heating pipe system. It includes the heat loss cost, power consumption cost and investment cost. It is necessary to obtain optimal combination of laying and installation parameters to achieve the minimal total life cycle cost.

The studies on the optimal combination of district heating pipe system are very few. Most of them focus on the optimal insulation thickness, while the effect of buried depth was neglected. Keçebaş[1, 2] calculated the pipe optimum insulation thickness, energy saving and payback periods by the thermo-economic analysis and exergy analysis method, respectively. The optimum insulation thickness of exergoeconomic optimization is higher than that of energoeconomic optimization. Başoğul[3, 4] investigated the energy and environmental assessments of thermal insulation by the life cycle assessment method (LCA) and life cycle cost method (LCC), respectively. The LCC analysis was suggested to calculate the optimum insulation thickness, while the LCA analysis was recommended for environmental impact evaluation. Kayfeci[5, 6] calculated the insulation thickness of heating pipe for different insulation materials. The artificial neural networks (ANNs) was used to predict the insulation
thickness and life cycle costs. Ertürk[7] calculated the optimum insulation thickness of heating pipes for different insulation materials, fuels and climate zones in Turkey. Zhang[8] investigated the optimal insulation thickness of direct-buried laying heating pipeline, payback periods and energy savings for different pipe diameter, buried depth and fuel types at the city of Xi’an.

The total cost of life cycle was affected by many factors such as buried depth, pipe space and insulation thickness et al. However, there is little research on the optimal combination of laying and installation parameters of district heat pipe system. So it is necessary to study the combinatorial optimization of laying and installation parameters. The main work is to obtain the optimal buried depth, pipe space and insulation thickness for different nominal pipe diameter, which lead to the minimal total cost of life cycle. The objective function was established by life cycle cost analysis method and solved by Genetic Algorithm method with MATLAB software.

2. Model description

Based on the design code of heating piping systems(CJJ34-2010), the heating pipes are composed of steel pipe, thermal insulation layer and protection layer. In practical engineering, the water supply pipeline and return pipeline are laid in the same trench. The diagram of heating pipes is shown in Fig. 1. In this study, the material of insulation and protection layer are polyurethane foam and high density polyethylene respectively.

Based on the thermal engineering design manual, the heat loss of water supply pipe and return pipe are calculated by the following formula:

\[
q_{\text{supply}} = \frac{(T_{\text{supply}}-T_{\text{soil}})R_{\text{return}}-(T_{\text{return}}-T_{\text{soil}})R_{\text{addition}}}{R_{\text{supply}}R_{\text{return}}-R_{\text{addition}}^2} \\
q_{\text{return}} = \frac{(T_{\text{return}}-T_{\text{soil}})R_{\text{supply}}-(T_{\text{supply}}-T_{\text{soil}})R_{\text{addition}}}{R_{\text{supply}}R_{\text{return}}-R_{\text{addition}}^2}
\]

In this study, the structure of the water supply pipe and return pipe are same. The total thermal resistance of insulated pipe is as follows:
The convection heat transfer coefficient of the inside surface can be calculated by Dittus-Boelter equation:

$$h_{in} = 0.023Re^{0.8}Pr^{0.3} \left( \frac{\lambda_{water}}{D_{equivalent}} \right)$$

(4)

The convection heat transfer coefficient of the outside surface is calculated as follows:

$$h_{out} = 11.58 \left( \frac{1}{\lambda_{insulation}} \right)^{0.2} \left( \frac{2}{T_{outsurface,mean} + T_{air,mean}} \right)^{0.181} (T_{outsurface,mean} - T_{air,mean})^{0.266} (1 + 2.86v_{air})^{0.5}$$

(5)

The heating pipe heat loss is the sum of water supply pipe and return pipe heat loss. While considering the heat loss caused by accessory equipment, the heat loss is determined by following equation:

$$q_{pipe} = (1 + \alpha_{heatloss})(q_{supply} + q_{return})$$

(6)

The annual heat loss cost for heating pipe is as followed:

$$C_{heatloss} = 0.024q_{pipe}ld_{g}e$$

(7)

The investment cost is the sum of construction and installation cost. According to *Indices for National Municipal Engineering Investment Estimate*, the construction cost is linear with pipe diameter and can be calculated by following equation:

$$C_{construction} = 1.03^{\frac{h_{pipe}^{-1.2}}{0.1}} (8.13 + 631.24D_{nominal})l$$

(8)

The installation cost includes labor cost, mechanical cost and material cost. The labor cost and mechanical cost are constant for the heating pipe with same diameter, which can be neglected. So the installation cost is as followed:

$$C_{installation} = C_{material} = \rho_{material}V_{material}c_{material}$$

(9)

The total cost of life cycle includes heat loss cost, power consumption cost and investment cost. As the invariants are neglected, the total cost of life cycle can be calculated by the following equation:

$$C_{total} = P_{1}C_{heatloss} + P_{2}(C_{construction} + C_{material})$$

(10)

The optimal combination of laying and installation parameters of heating pipes can be determined by minimizing Eq. (10). In this study, the Genetic Algorithm method is used to solve the minimum value of the objective function, and then the corresponding variable values are obtained.
3. Results and discussion

3.1 Analysis of influence factor

Fig. 2 shows the annual heat loss cost versus buried depth, pipes space and insulation thickness. It can be seen from Fig. 2(a) that the annual heat loss cost decreases with the increase of buried depth for different pipe nominal diameter. This is principally because the increase of buried depth can increase soil thermal resistance, and then enhance the soil thermal insulation performance. Fig. 2(b) shows that the annual heat loss cost increases with the increasing pipes space for different pipe nominal diameter.

It is mainly because the increase of pipes space can decrease the addition thermal resistance between the water supply pipe and return pipe. Fig. 2(c) shows that the annual heat loss cost decreases with increasing the insulation thickness for different pipe nominal diameter. This mainly because of the increasing of insulation thickness can increase the insulation layer thermal resistance.

It also can be seen from Fig. 2 that the annual heat loss cost increases with increasing the pipe nominal diameter. This is mainly because the heat transfer area increases with increasing the pipe nominal diameter, which leads to the more heat transfer from the inside to outside surface of the pipe.
Fig. 3 shows the investment cost versus the buried depth for different pipe nominal diameter. It indicates that the investment cost increases with the increase of buried depth. It is mainly because the construction cost and installation cost increase with the increase of pipe diameter.

![Investment cost versus buried depth](image1)

**Figure 3.** Investment cost versus buried depth.

3.2 Optimal combination of laying and installation parameters

The parameters of design stage include the pipe nominal diameter, pipes space, buried depth and insulation thickness. In order to reduce the heat loss cost and investment cost, the pipes space should be selected the minimum value under actual conditions. The optimal combination of buried depth and insulation thickness for different pipe nominal diameter were obtained by Genetic Algorithm method. The optimization results were shown in Fig. 4. Fig. 4(a) shows that the optimal buried depth firstly increases then decreases with the increase of pipe nominal diameter. The optimal insulation thickness decreases with the increase of pipe nominal diameter generally. It also indicates that the smaller buried depth and larger insulation thickness for smaller size heating pipe should be adopted; The larger buried depth and smaller insulation thickness for larger size heating pipe should be adopted. Fig. 4(b) shows that the total cost, heat loss cost and construction cost and insulation material cost increase with

![Optimization results for different pipe nominal diameter](image2)

**Figure 4.** Optimization results for different pipe nominal diameter.
the increases of pipe nominal diameter, which indicates that the pipe nominal diameter is an important parameter affecting the total cost of life cycle.

4. Conclusion
In this study, the optimal combination of laying and installation parameters of conjugated directly-buried heating pipes have been investigated. The objective function was established by LCCA method and solved by Genetic Algorithm method of MATLAB software. The results indicate that the optimal buried depth firstly increases then decreases with increasing the pipe nominal diameter. The optimal insulation thickness decreases with increasing the pipe nominal diameter generally. It reveals that the smaller buried depth and larger insulation thickness should be adopted for smaller size heating pipe. The larger buried depth and smaller insulation thickness should be adopted for larger size heating pipe. The pipe space should be chosen the minimum value corresponding to the pipe diameter.

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