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Optimisation of tree path pipe network with nonlinear optimisation method

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ABSTRACT

In this paper, the optimisation of pipe network with hot water is presented. The mathematical model, consisting of the nonlinear objective function and system of nonlinear equations for the hydraulics limitations is developed. On its basis, the computer program for determination optimal tree path with the use of simplex method was solved. For economic estimation the capitalised value method, which consider all costs of investment and operation was used. The results are presented for real case study network with 24 nodes and 33 pipe sectors.

1. Introduction

Nowadays, efforts connected to energy savings demand the search for new technical scientific expertise in the field of heating techniques [1–4]. The focus of research is on better and more efficient use of primary energy [5].

If we limit ourselves to district heating energy systems, we may state that these systems ensure savings in the process of use of primary energy and are acceptable from the ecological point of view.

The whole system is represented as a nonlinear target function by nonlinear equations of hydraulic limitations and by minimizing the nonlinear function the optimal design and dimensions of the pipe network are defined [6,7].

One method for modelling pipe networks is by linear programming, consisting of optimisation with limitations [8], meaning the search for the best possible, optimal solution of the stated problem within given conditions.

Nowadays, two methods for solving linear programmes are used, both of them interactive, searching for a gradually better solution, until the optimum value is achieved. Mostly, simplex methods focused on searching for permissible solutions within the monotonous defined extreme point of the convex polyhedron of possible solutions and a defined base of the vector space, are used.

2. District heating systems

District heating systems are intended for the distribution of heat energy by a fluid from a heating source to different users [9–11]. The pressure losses of the system are defined by the nonlinear Darcy–Weisbach equation [12]

$$p_i - p_j = 0.81\frac{\rho q_{vij}^2}{d^4}\left(\frac{\lambda L}{d} + \sum\zeta\right) = K_{ij}q_{vij}^2. \quad (1)$$

The Darcy friction coefficient (λ) is a function of the Reynolds number. In the range of the laminar flow, the pressure losses depend only on the fluid viscosity, but in the range of turbulent flow the decisive factor is the relative pipe roughness coefficient, which depends upon age, corrosion and pipe material.

The relative pipe roughness coefficient (k/d) is a relation between absolute roughness of the inner pipe wall and the inner pipe diameter.

The heat losses through the pipes are negligible. Optimal thickness of insulation was calculated with the help of developed computer program [13]. The program flow diagram is presented in Fig. 1, and the difference between the static and dynamic economic methods in Fig. 2.

3. The linear programming method

At the beginning, the optimisation problem has to be designed. The common configuration of the mathematical model of the linear optimisation problem with m limitations and n variables is [14,15]

objective function $\min(c_1x_1 + c_2x_2 + s + c_nx_n)$ limitation

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Nomenclature

A, B, C, D, E, F	constants
AC	annuity costs
B_0	investment costs
CC	capitalised costs
C_0	operating and maintenance costs
C_1	pipe network expenditure
C_2	pump investment expenditure
C_3	pumping costs
C_4	construction expenditure
C_e	electric price
$C(q_v)$	objective function
C_p	pump price
d	pipe diameter
i	interest rate
k	pipe roughness
K	coefficient of Darcy–Weisbach equation
L	pipe length
L_0	salvage value
n	device lifetime
N_v	number of nodes
N_c	number of pipes
p	pressure
P	power
Re	Reynolds number
t	operating time of pipe network
v	velocity
q_v	flow volume
Greeks	
ρ	density
λ	friction factor
ζ	coefficient of local losses
η	pump efficiency

$$\begin{aligned} &a_{11}x_1 + a_{12}x_2 + \cdots + a_n x_n (\leqslant, \geqslant, =) b_1 \\ &a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n} x_n (\leqslant, \geqslant, =) b_2 \\ &\vdots \\ &a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn} x_n (\leqslant, \geqslant, =) b_m \\ &x_1, x_2, \ldots, x_m \geqslant 0 \end{aligned} \tag{2}$$

The mathematical model (2) is soluble with a simplex algorithm [16].

The conditions in the form of non-equations are transferred into equations by introducing additional variables.

$$a_{11}x_1 + a_{12}x_2 + \cdots + a_n x_n \geqslant b_1. \tag{3}$$

The possible surplus is subtracted and the non-equation becomes an equation

$$a_{11}x_1 + \cdots + a_n x_n - x_{n+1} = b_1. \tag{4}$$

The additional variable (x_{n+1}) was added and we now have to consider this with conditions, but it has no influence on the objective function due to the fact that its coefficient (c_{n+1}) is zero.

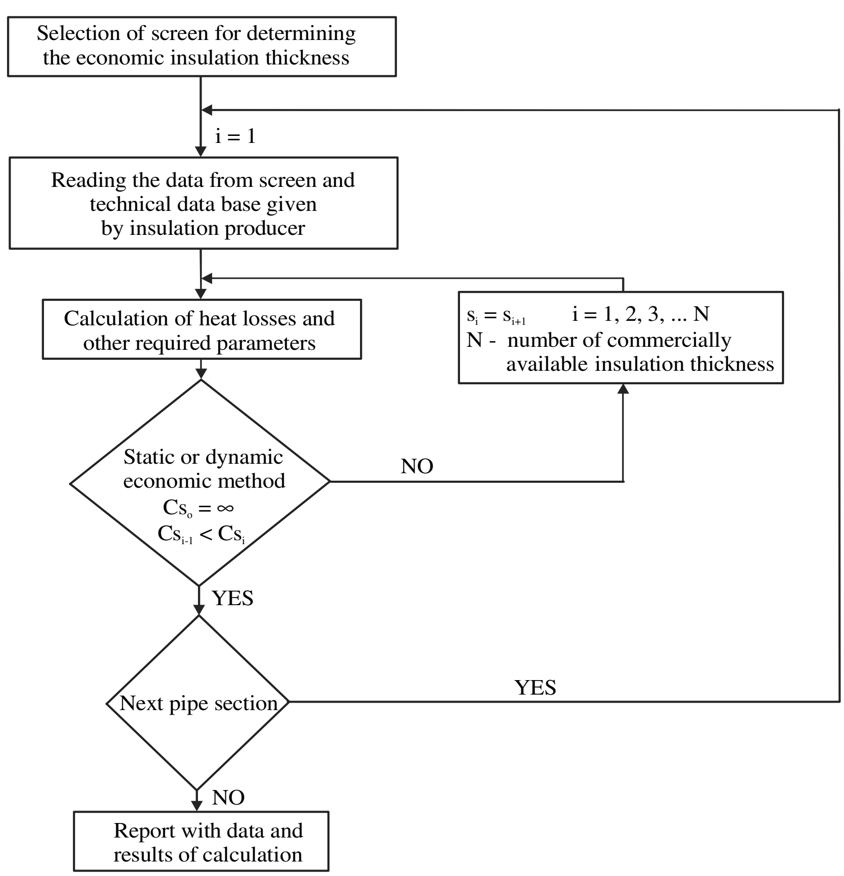

Fig. 1. Simplified flow diagram for optimal thermal insulation thickness (c_s – insulation costs).