ARTICLE IN PRESS

Applied Thermal Engineering ■■ (2016) ■■–■■

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Energy saving analyses on the reconstruction project in district heating system with distributed variable speed pumps

Xianjie Sheng *, Duanmu Lin **

School of Civil Engineering, Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian 116024, Liaoning Province, China

HIGHLIGHTS

- The mathematical model of economic frictional factor based on DVFSP DHS is established.
- Influence factors of economic frictional factor are analyzed.
- Energy saving in a DVFSP district heating system is presented and analyzed.

ARTICLE INFO

Article history:
Received 1 October 2015
Accepted 10 January 2016
Available online

Keywords:
District heating system
Distributed variable frequency speed pump
Economic frictional factor
Branched network
Energy saving

ABSTRACT

Optimization of the district heating (DH) piping network is of vital importance to the economics of the whole DH system. The application of distributed variable frequency speed pump (DVFSP) in the district heating network has been considered as a technology improvement that has a potential in saving energy compared to the conventional central circulating pump (CCCP) district heating system (DHS). Economic frictional factor is a common design parameter used in DH pipe network design. In this paper, the mathematical model of economic frictional factor based on DVFSP DHS is established, and influence factors are analyzed, providing a reference for engineering designs for the system. According to the analysis results, it is studied that the energy efficiency in the DH system with the DVFSP is compared with the one in the DH system with conventional central circulating pump (CCCP) using a case based on a district heating network in Dalian, China. The results of the study on the case show that the average electrical energy saved is 49.41% of the one saved by the DH system with conventional central circulating pump in the primary network.

1. Introduction

The world is facing a serious challenge of energy, climate change and environmental issues with the development of economy and urbanization. With increasing energy demands worldwide, improving the efficiency of energy systems and the environment quality are becoming an important problem. District heating system (DHS) has many advantages of energy efficiency, environmental protection, and good-quality heating. It is an integral part of the infrastructure and an important element of the economy in many countries, such as China, Russia, Denmark, Finland, Sweden and Switzerland. District heating (DH) is a significant technology for improving the energy efficiency of heating systems in communities [1]. In a general way, district heating networks incorporate a system of piping from one or more heat sources to heat users. Having such a production and distribution system for district heating not only provides hot water for the community with reduced energy consumption but also reduces greenhouse gas emissions. On the cost of delivering heat from the generation station to heat users, factors such as heat source efficiency, temperatures of supply and return water, and heat losses affect prices. Persson and Werner [2] had comprehensively studied heat delivery costs, explaining that heat distribution cost includes annual payback of original network investment cost plus operational costs to cover temperature and pressure losses during heat delivery. They found that district heating was profitable when the total costs were lower than those for other means of local heat production, suggesting that, when the distribution cost was high, a lower cost of recycled heat could compensate for the total cost of the DH. According to Persson and Werner [2], the capital costs for DH heat delivery in dense areas like cities are low, and in such low density areas the local heat producer may operate a DH system. Persson and Werner also claim, in examining possible future applications of DH and future competitors in the DH market, which the future architecture of cities should be carefully planned.

The most commonly used dimensioning methods limit the maximum pressure gradient and/or the maximum velocity to specific values derived from practice and calculate the diameters

* Corresponding author. Tel.: +8615041120978; fax: +86-411-84674141.
E-mail address: shengxianjie@yeah.net (X. Sheng).
** Corresponding author. Tel.: +8613898602850; fax: +86 411 84674141.
E-mail address: duanmu@dult.edu.cn (D. Lin).

http://dx.doi.org/10.1016/j.applthermaleng.2016.01.059

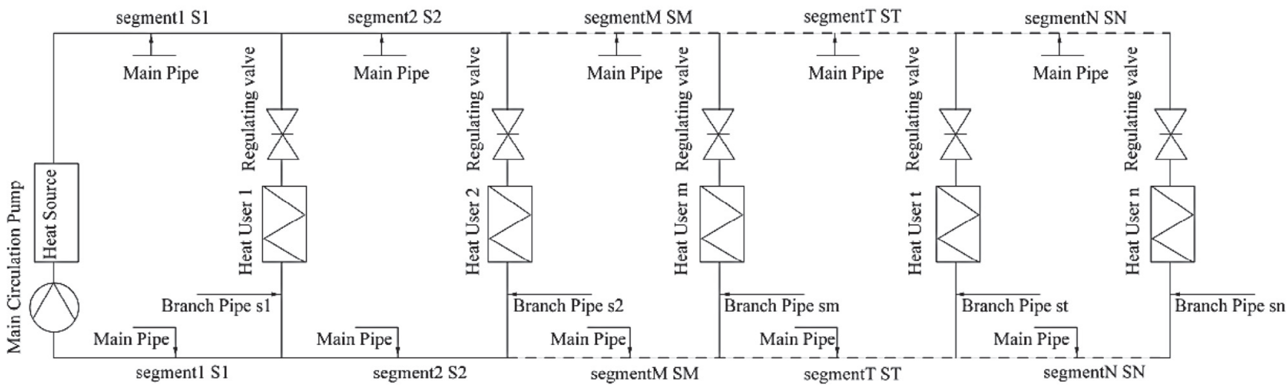

Fig. 1. Traditional-type district heating network.

of each media pipe segment. Such dimensioning approaches are very reliable, but often lead to over-dimensioned DH networks, resulting in more expensive installation costs and in energy inefficiency. The new optimization method is based on the consideration that the next generation of DH networks will ensure better cost-effectiveness if lower heat losses are guaranteed through reduced media pipe sizes, despite the consequent increase of the required pumping power. The economic optimization has often been the sole objective, even in the most comprehensive studies [3]. In the past twenty years. the optimization of district heating systems, such as improving the system performance, minimizing the investment and operational costs, [4] etc., is drawing more and more attention of researchers, and some methods have been developed, such as a lot of researches on the optimization of district heating systems with the mathematical programming method were presented [5–10]. Bojic et al. [5] used the mixed 0–1 linear programming method to solve the optimization problem of a district heating system. Dobersek et al. [6] optimized a tree path pipe network with the mathematical model consisting of nonlinear objective functions. Henning [7] proposed the MODEST (Model for Optimization of Dynamic Energy Systems with Time-Dependent Components and Boundary Conditions) to minimize the capital and operation costs of energy supply and demand-side management by linear programming method. Kecebas et al. [8] take advantage of the artificial neural network to optimizing the geothermal district heating systems. Wright et al. [9] optimized the pay-off between the energy cost of a building and the occupant thermal discomfort with the multi-criterion genetic algorithm search method successfully. Adamo et al. [10] put forward a procedure to optimize district heating networks on the basis of the second law analysis. However, these methods require large amounts of actual engineering data and the calculation of the mathematical programming method for district heating systems are very large. Meanwhile, these studies are based on a CCCP heating system, which could not come to fundamentally deal with the throttling loss of pipe network. During the past decades, the costs of frequency conversion pumps have come down significantly due to the advances in technology, which allowed widespread applications of variable speed pumps in DH systems. In order to increase the efficiency of distribution system, many scholars pointed out some improvements that could be made. It is possible to use distributed variable speed pumps as control valves to save energy; and therefore, this attracts more and more attentions. Gamberi et al simulated a heating system with multi-pumps using Newton–Raphson algorithm [11]. Wang and Li studied the optimal configuration of a DH system with distributed variable speed pumps [12]. Deng and Fu theoretically proved the possibility of using variable speed fans and variable speed pump to adjust wind valve and water valve. They pointed out that the hydraulic stability and controllability of the new system was greatly improved in addition to the obvious energy saving effect [13]. Nowadays, efforts connected to energy savings demand the search for new technical and scientific expertise in the field of heating techniques [14–21]. But in these literatures, the research of pipe diameter size in the two systems is not a detailed analysis.

1.1. CCC DH pipe network

Traditionally, district heating (DH) systems are built as branched networks whose circulating pump is designed in the heat source (Fig. 1).

A branched network layout is widely used in the distribution networks of DHS as well as the draining and irrigation systems. Such layouts are also observable in natural objects such as blood vessels and trees [22,23]. Branched (also known as tree-like) DH networks are formed in layouts permitting a unidirectional flow from the heat source to the end-consumers (Fig. 1). In a layout of this type, there are only two pipe segments connected to each interior node and a unidirectional flow from the root node (the node without any preceding nodes – i.e., the heat source) toward the leaf nodes (the nodes without any successor nodes – i.e. the end-consumers) [24,25]. The traditional way of determining the heat load on each pipe segment is to sum all of the heat loads of the successor nodes [26]. In the present study, the use of a simultaneity factor which is a function of the cumulative number of consumers for each pipe segment was considered. This enables the descending succession of pipe diameters from the heat source to the end-consumers, hence, larger diameters being followed by smaller diameters [27]. In such a branched network layout, thermostatic bypass units were to be inserted at the leaf-nodes in each route of the DH network. The supply heat carrier medium, when cooled down, was directed through the bypass units to the return line to be sent back to the heat source. But some drawbacks exist in this topology. The control system is slow, which reduces the energy efficiency of the system. Besides, the pipe lengths vary between the heating plant and different consumers, which creates some special needs for the network. The water flow has a tendency to flow through the shortest routes, where the pipes have the lowest flow resistance, and this is why the valves of the closest consumers are throttled most in the network when compared to those of the other consumers. This causes large local pressure differences and losses, and it complicates the use of the network. Additionally, the main pump in the network is dimensioned according to the pressure difference needed for the most distant consumer. In the conventional central circulating pump (CCCP) district heating system (DHS), reducing the cost of district heating (DH) pipe infrastructure along with decreasing heat losses and pump electrical energy consumption would reduce the capital costs and increase the economic competitiveness of DH compared

Please cite this article in press as: Xianjie Sheng, Lin Duanmu**<<new line>>duanmu@dult.edu.cn, Energy saving analyses on the reconstruction project in district heating system with distributed variable speed pumps, Applied Thermal Engineering (2016), doi: 10.1016/j.applthermaleng.2016.01.059