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A method for the simulation and optimization of district heating systems with meshed networks

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ABSTRACT

There are two main methods nowadays for modeling district heating systems, but a key disadvantage of both is that a real network containing loops cannot be described without artificial simplifications in order to eliminate those distinguishing features. However, loops are very common in mature networks that have developed a meshed structure, and make the distribution of mass and heat flows quite characteristic. For this reason, a new process integration method for modeling complex district heating systems containing loops is described in this paper. This method makes it possible to analyze how loops and bottlenecks affect the behavior of the network, as well as the distribution path of the thermal energy in it. The district heating system in the town of Kiruna (located in the north of Sweden) has a complex design with several loops and part of it is used in the paper as an example of application.

1. Introduction

Iron ore has been mined for over 120 years in the town of Kiruna, in northern Sweden, at the local mining company LKAB. The mine, located close to the town, is currently the largest underground iron ore mine in the world. As a result of the vast mining operation, a deformation zone has developed at ground level and is currently approaching the town. The town, with a population of about 20,000 people, is going through an urban transformation and parts of it are about to be relocated as shown in Fig. 1 [1].

The relocation of the town affects all its main infrastructures, the district heating system (DHS) being among the affected ones.

DH technology is well established in Sweden and its share of the total heat demand for housing and business premises was 50% in 2005 [2], among the highest in Europe. Swedish municipalities traditionally operate their own DHS [3]. In Kiruna, the DHS is operated by TVAB (the local energy company), which also owns the DHS and the related heat production plants, as is shown in Fig. 2.

In order to study how the DHS will be affected by the urban transformation, a model of the current DHS has to be created. Nowadays there are two commonly used methods to create such a model: the Danish method [4] and the German method [5]. Both these methods use the principle of merging smaller branches into bigger branches, incorporating the heat loads of the removed branches into the preserved ones.

An example of how these methods work is shown in Fig. 3. In the center of the figure the complete DHS for a town in Denmark is shown, whereas the left and right sides of the figure show the simplifications introduced according to the rules defined in the Danish and German methods, respectively, in order to reduce the numbers of network nodes.

A more detailed analysis of the two methods makes it apparent that the Danish method is not capable of handling DHS loops at all, while the German method requires to modify the loop structure into a series of pipes [6]. As can be seen in Fig. 2, the structure of Kiruna DHS mainly consists of a number of loops so that neither the Danish nor the German method could be applied without causing significant issues in the subsequent analysis of network flow distribution. In fact, for a given set of user demands the heat and mass flow distribution in the branches of a network with multiple loops is mainly determined by the local pressure at the nodes that are at the ends of the branches. The information about the pressure is therefore critical and any simplification method reducing the topology of a network with multiple loops to one with a tree or linear structure will unavoidably lose it, making it impossible to understand the real distribution of the flows in the network.

It is worth noting that there is a lack of published papers in the literature regarding DHSs featuring loops and the related bottleneck issues that characterize them. Furthermore, only a few papers are published about the analysis of multi-source production plants

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Nomenclature

Abbreviation

DH district heating
DHS district heating system
TVAB tekniska verken i kiruna AB
LKAB luossavaara kirunavaara AB
CHP combined Heat and Power
MILP mixed integer linear programming

or DHSs and the problem of expanding or redesigning a DHS to connect new consumers [7–10].

The aim of this paper is to illustrate a new method, developed with process integration techniques, that:

- Allows the modeling of DHSs with loops, without introducing any simplification or modification to their physical structure.
- Allow the modeling of DHSs containing of multiple sources of thermal energy production.
- Allows the redesign of the DHS structure, in particular to add or remove consumers.
- Gives the possibility to study DHS flow distribution and find bottlenecks in DHSs with loops.

Kiruna DHS will be used in the following as an example of application to better show the procedure for building the model and the results that can be obtained.

2. Method description

2.1. Process integration techniques

Process integration is often used to study the links among different parts within the control volume of complex systems. For instance, it is commonly applied to sectors like pulp and paper, steel and mining industries, where a typical control volume can be a product unit, a set of material flows or an entire production site for specific reference periods such as weeks or a steady state single time step [11–13]. In this work the spatial boundaries of the control volume include an entire city with ancillary facilities, as shown in Fig. 4, and the considered time period is one complete year subdivided in daily time steps.

Basically, there are three main methodologies that can be applied in process integration: Pinch Analysis, Exergy Analysis and Mathematical Programming [10,13–16]. Pinch Analysis focuses on the

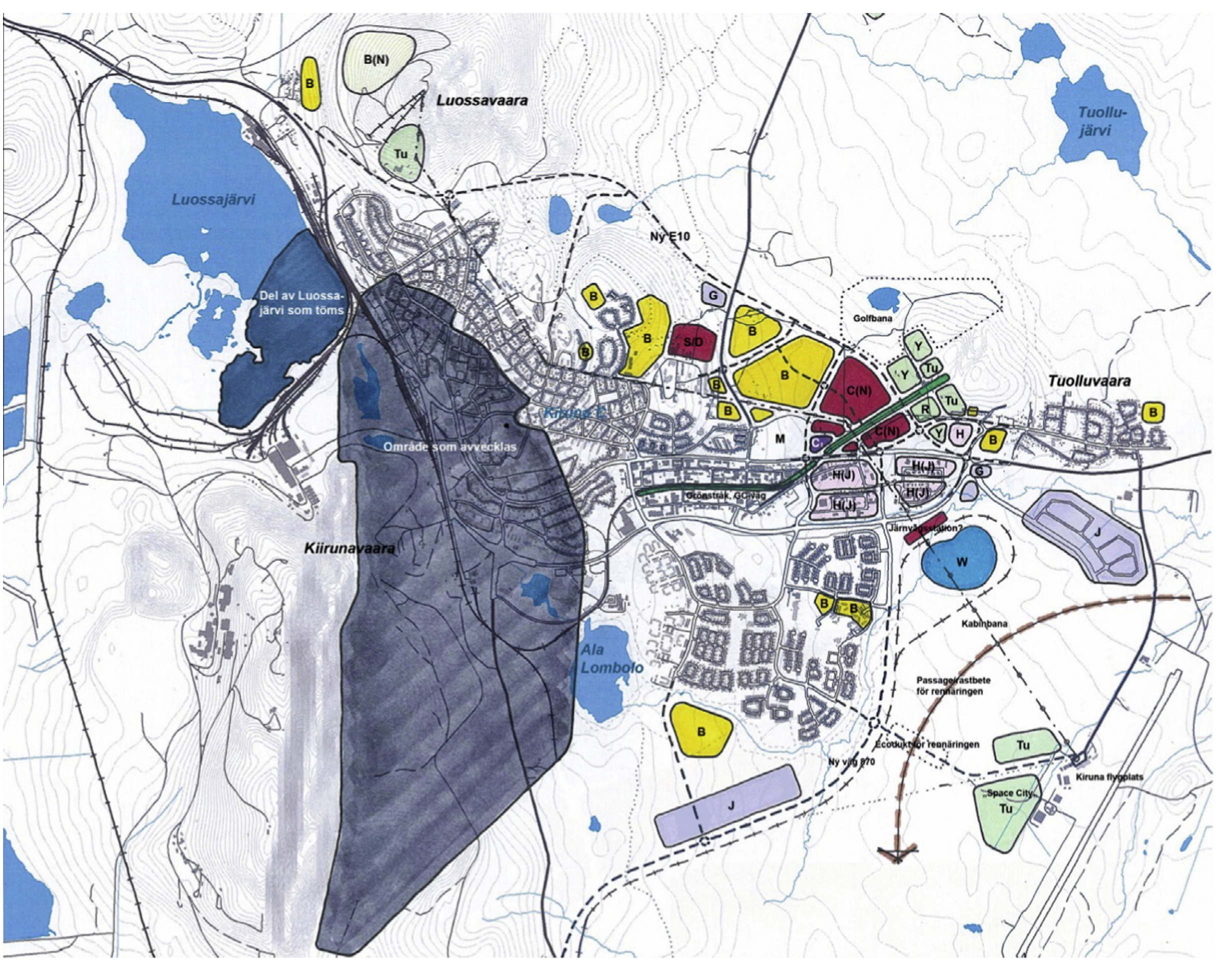

Fig. 1. The map of the town of Kiruna showing the locations of the mine deformation zone and the terrain chosen for building relocation [1].