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Hybrid thermo-chemical district networks – Principles and technology

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HIGHLIGHTS

- Open absorption processes are considered for energy potential transport in district networks.
- Use cases heating, cooling and drying are presented with requirements and exemplary model cases.
- Current state of the development of technology components with experimental data is shown.

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ABSTRACT

Low-temperature residual heat and heat potentials of renewables below 70 °C often stay unused as either the distance between source and demand is too large or the heat does not occur at demand times. Hybrid thermo-chemical networks have a high potential to improve this situation, to transport thermal energy potential over long distances and to bridge short to medium time differences between demand and supply. The storage and transport potential of thermo-chemical substances has been identified and examined comprehensively. However, none of the studies addressed the replacement of water by thermo-chemical fluids (TCF) in district networks. Therefore this paper elaborates the use of TCF in such networks. First, it elaborates technological application cases showing the theoretical potential to reduce primary energy consumption up to 85%. Second, it presents technological components that have been developed for thermo-chemical systems.

1. Introduction

A growing demand for secure sustainable energy supply with low resource consumption and low emissions requires the exploitation of previously unused sources of residual heat and residual renewables, especially at low levels of temperatures. Whereas low energy-demand of buildings allows the use of heating systems working with low supply temperatures, the problems associated with transport of low-temperature heat persist. Heat losses during transport are limiting the usage of low-temperature heat to near distance heat networks with a radius of only a few hundred metres. This restricts the use of low temperature heat to specific cases, in which heat source and heat consumers are located close together and schedules of available heat and demand match. Under these conditions, in most cases, the large potential of residual heat remains unused.

The aim of the ongoing research presented in this paper is to examine technology and business cases for district energy system based on thermo-chemical fluids (TCF). This new technology will contribute to the optimal use of energy resources, particularly low-grade residual heat and thermal renewables. By making these energy sources available, which are not exploitable by conventional district heating technology, thermo-chemical energy networks contribute to sustainable energy systems. Rather than on focusing on thermo-chemical processes that are known from fundamental research the paper focusses on the integration of the technology in the context of the built environment and the given waste heat sources.

This novel type of district energy network uses a liquid desiccant as thermo-chemical fluid (TCF) for the purpose of energy potential transport. Low-grade heat is used for TCF regeneration, a process in that water is evaporated out of the TCF, providing a concentrate. This concentrate can be used as an energy potential carrier for transport and storage. The benefits for a sustainable energy system that will be substantiated in the paper are:

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- Exploitation of unused low-grade residual heat,
- Loss-free long-distance transport and medium-term storage and
- Higher economic value by extended services.

The novelty of the paper is that it presents a scenario for the use of thermo-chemical is district networks. Whereas the potential of thermo-chemical substances in energy storage and transport has been recognized, thermo-chemical networks have not been examined in terms of their technological and economic application potential up to now. Most research, which is compiled in the next section, focuses on the storage aspect and only adds the remark that also transport of the storage is possible. Furthermore, transport of residual heat has been realized only at a small prototypical scale with PCM fluids or solid thermo-chemical storage on a container-and-truck basis. None of the studies tackles the modelling, analysis and realization of a multi-functional pipe-based network similar to water-based district heating and cooling networks based on a TCF. The paper starts to explore potential by developing and modelling a multi-functional application scenario, examining the energetic advantage with respect to reduction of primary energy demand and the technological and economic feasibility.

Section 2 provides a survey of existing technology approaches to thermo-chemical technology as it is relevant for district energy networks. Section 3 introduces the principles of the thermo-chemical network technology. Section 4 applies a systems engineering and modelling approach to develop technological application cases and Section 5 carries out fundamental engineering of operation. Section 6 tackles the realization with respect to developed network components.

2. Background

Residual heat and renewables have high volume especially at low and very low temperatures (Fig. 1)a. A study [1] identifies an industry volume of around 20 TW h per year in Norway from that 64% are below 140 °C and 47% are below 60 °C. Pehnt et al. [2] state that economic use of current thermal technology for residual heat recovery can come up for 6–12% of the energy demand in German industry depending on the temperature level. Among such technologies, Walsh and Thornley [3] determine a favourable payback period of between 3 and 6 years for organic Rankine cycle (ORC) and condensing boiler technology. However, the currently tapped potentials of residual heat recovery are mainly based on local reuse within the industry and on the utilization based on thermal district networks. For instance, Law et al. [4] review technologies for local reuse of low-grade heat in food industry. For thermal district networks bridging longer distances, the temperature level is often too low and the energy losses and costs are too high to allow transport to further distant consumers, such as residential buildings that form a large portion of the thermal energy demand.

Due to these reasons, different studies examine the use of absorption processes and other thermo-chemical processes for the transport of residual heat. In a study of different transport processes for heat energy over long distances, Ma et al. [5] highlight adsorption and absorption besides phase-change materials as main mechanisms.

On the basis of ammonia, Kang et al. [6] describe and analyse a spatially distributed absorption heat pump process focussing on cooling with desorption temperature higher than 100 °C. Lin et al. [7] lay out an ammonia-based transport system scenario based on experiments. Their economic analysis results in a payback period within 4 years. Kiani et al. [8,9] and Ammar et al. [10] develop, examine and optimize this technology for residual heat transport. Ammar et al. recommend distances up to 30–40 km and determines for heating and cooling based on an ammonia-water system a coefficient of performance (COP) of approximately 0.5 (running closed absorption heat pumps). However, the ammonia-based network is not compatible with district technology as it uses a highly hazardous fluid and requires a closed refrigeration process.

Fluids for thermal energy storage using absorption or reversible chemical reactions driven by low-grade heat are of interest for thermo-chemical networks. However, most of the literature, deals with thermo-chemical storage materials focussing on local thermo-chemical storage application. Reviews N'Tsoukpoe et al. [11], Yan et al. [12] and Kalaiselvam and Parameshwaran [13] well reflect the current state-of-the-art of thermo-chemical storage with some additional research worth noting [14–18]. Furthermore, there exists coupling of thermo-chemical storage with district heating systems for buffering [19]. Open sorption systems based on magnesium chloride $MgCl_2$, which is a cheap well-suited TCF, by [20–24]; examples of other salt solutions are also present [25,26]. Transport is only marginally mentioned and specific long-distance transport related aspects, such as toxicity, play a subordinate role. Furthermore, N'Tsoukpoe et al. [27] examine possible salt hydrates for low-temperature heat storage from micro CHPs. Basciotti and Pol [28] propose and theoretically examine the coupling of a thermo-chemical storage to a district heating network for cooling purposes. However, also these studies do not examine a thermo-chemical district network but focus on the local storage aspect.

Container-based transport is taken into account and realized in a prototypical way. Mazet et al. [29] and Storch and Hauer [30] examine solid desiccants and PCMs for transport. Container solu-

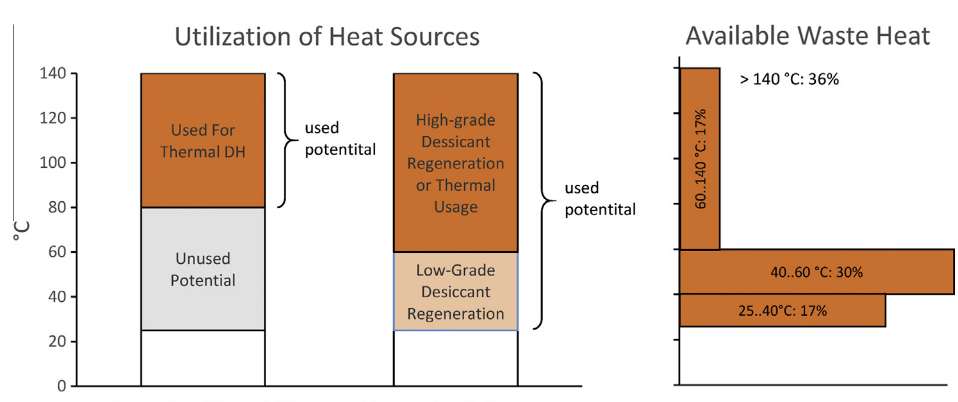

Fig. 1. Estimated low-grade residual heat volume based on data from [1] and its aimed exploitation by thermo-chemical technology.

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