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Assessment of absorption cooling as a district heating system strategy – A case study

Elsa Fahlén [a,*], Louise Trygg [b], Erik O. Ahlgren [a]

[a] Energy Systems Technology, Division of Energy Technology, Department of Energy and Environment, Chalmers University of Technology, SE-412 96 Göteborg, Sweden
[b] Division of Energy Systems, Department of Mechanical Engineering, Linköping Institute of Technology, SE-581 83 Linköping, Sweden

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ABSTRACT

Heat load variations, daily as well as seasonal, are constraining co-generation of high-value energy products as well as excess heat utilisation. Integration of heat-driven absorption cooling (AC) technology in a district heating and cooling (DHC) system raises the district heat (DH) demand during low-demand periods and may thus contribute to a more efficient resource utilisation. In Sweden, AC expansion is a potentially interesting option since the cooling demand is rapidly increasing, albeit from low levels, and DH systems cover most of the areas with potential cooling demand. This study aims to assess the potential for cost and CO_2 emission reduction due to expansion of DH-driven AC instead of electricity-driven compression cooling in the DHC system of Göteborg, characterised by a high share of low-cost excess heat sources. The DHC production is simulated on an hourly basis using the least-cost model MARTES. Despite recent advances of compression chillers, the results show potential for cost-effective CO_2 emission reduction by AC expansion, which is robust with regards to the different scenarios applied of energy market prices and policies. While the effects on annual DHC system results are minor, the study illustrates that an increased cooling demand may be met by generation associated with low or even negative net CO_2 emissions – as long as there is high availability of industrial excess heat in the DHC system, or if e.g. new biomass-based combined heat and power capacity is installed, due to the avoided and replaced marginal power generation.

1. Introduction

In temperate countries like Sweden, strong seasonal and daily load variations in district-heating (DH) systems limit the utilisation of base load technologies and increase the need for part load and peak load generation associated with lower efficiencies and higher emissions and operation costs. Many larger Swedish DH systems are characterised by a high share of the heat supply coming from waste-fuelled plants, industries and combined heat and power (CHP) plants and, in some of these DH systems, heat is wasted during low demand periods [1]. The strong load variations do not only contribute to an inefficient resource utilisation; they may also constitute a hindrance for the penetration of new advanced technologies which need many operation hours to justify the higher investment costs for the more complex equipment needed [5]. Thus, there is need for strategies for increasing the resource efficiency of DH systems on a system level, such as load levelling and management as well as other types of strategies, hereafter referred to as system strategies.

One system strategy for decreasing the seasonal DH load variations is simply to integrate heat loads during low demand periods, e.g. by utilisation of heat-driven absorption cooling (AC) technology [2,3] in a district heating and cooling (DHC) system [4,7–11,30,31]. Another system strategy for decreasing seasonal DH load variations is to combine and allow operational optimisation of heat-demanding and heat-generating processes dependent on varying demands (and prices) in e.g. a biomass energy combine [14,15]. One option is to install a fuel storage in combination with time-delaying of the drying of moist fuels to periods with a low heat demand [16]. Alternatively, seasonal thermal storages can be used, which has also shown to be economically interesting in certain DH systems with a high dependence of oil for peak load heat generation [1]. However, seasonal thermal storages require large volumes to store considerable amounts of heated water and thermal storage is associated with high heat losses if not equipped with expensive insulation.

Thermal storage of heat is more common for short-term load levelling; typically, daily or weekly variations in the DH demand are managed by thermal storage in pressurised or non-pressurised steel tanks. This system strategy has potential for not only

Abbreviations: AC, absorption cooling; CC, compression cooling; CCHP, combined cooling, heating and power; CHP, combined heat and power; COP, coefficient of performance (cooling produced per unit of heat or electricity used); DC, district cooling; DH, district heating; DHC, district heating and cooling; TEP, tradable emission permits.

* Corresponding author. Tel.: +46 (0)31 772 14 38.
E-mail addresses: elsaf@chalmers.se (E. Fahlén), louise.trygg@liu.se (L. Trygg), erik.ahlgren@chalmers.se (E.O. Ahlgren).

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reducing the need for peak capacity and the use of expensive fuel, but also for increasing CHP generation [17,19]. Moreover, thermal storage in combination with heat pumps has potential for balancing the electricity supply and demand in energy systems which are characterised by a high share of wind power and CHP plants, as in Denmark [18]. Another system strategy for short-term load levelling is by utilising the inherent inertia in the DH network [19] as well as in the building masses and radiator circuit piping systems [20].

Another kind of system strategy is to construct regional DH networks which enables interconnection of existing DH networks and connection of new customers in less populated areas as well as of new excess heat deliverers. Interconnection of DH systems and co-operation between industries and energy utilities have potential for a more cost-effective and energy efficient DH supply by regional optimisation [21,22] and have also been realised in several Swedish regions [23–25].

The aim of the present study is to assess one of the system strategies, namely integration of DH-driven AC chillers in a DHC system. More specifically, the purpose is to evaluate the potential of the AC system strategy to improve the economic and environmental performance of a Swedish DHC system in terms of reducing costs and CO_2 emissions. The robustness is tested with regards to available base load capacity in the DH system and given different assumptions of marginal power generation and of future energy market prices and economic policies.

1.1. AC systems

The demand for cooling is steadily increasing, not only in tropical areas and subtropical areas, like southern Europe, but also in the Nordic countries [26]. Apart from the cooling demand due to climatic conditions, growing population and higher living standards, increased numbers of technical appliances such as lighting, printers and computers also increase the need for cooling. In warmer countries, the peeks in the power demand are partly due to the use of electricity-driven cooling facilities [27]. However, also in European countries, the increasing number of cooling facilities increases the already strong daily variations in electricity demand and thereby also the need for peak load power generation [26] which is associated with high operating costs and CO_2 emissions. At the same time, there are large excess heat resources in Europe which are not utilised today [26]. The utilisation of heat-driven AC machines instead of electricity-driven compression cooling (CC) machines is decreasing the power used for cooling. Higher resource efficiency may be achieved if combining cooling, heating and power (CCHP) generation in so-called CCHP systems [13] or trigeneration plants [28] instead of producing these energy services separately, and if enabling cascade utilisation of thermal energy from multiple energy resources [13].

Substitution of conventional electricity-driven CC chillers by heat-driven AC chillers can be an interesting option also in Sweden where DH systems cover most of the areas with potential cooling demand and where an increasing share of the DH is supplied by low-cost heat from industries, waste incineration and CHP plants. For example, it has been estimated that it is possible to almost double the deliveries of excess heat from the Swedish industries, compared to today's 4 TWh [29]. There is potential for CO_2 emission reduction if a part of this excess heat would be used to produce AC instead of as today being wasted.

Case studies of Swedish DHC systems [8,11,30,31] and of industries connected to a DH system [4,7,9,10] have shown that substitution of conventional CC by AC capacity can contribute to cost-effective CO_2 emission reduction due to increased net power generation in CHP plants replacing marginal coal condensing power. The occurrence and the amount of CO_2 emission savings were found to be strongly affected by the assumption of replaced marginal power generation [8,31] and of future energy market prices and policies [7]. It is complex to identify the technologies and fuels used for marginal power generation in the current and future Nordic power system, as discussed in e.g. [32,33], also given the uncertainties regarding climate agreements [34]. Therefore, it is of great importance to assess the robustness of the AC technology's potential for cost-effective CO_2 reduction in Nordic DHC systems given different assumptions of marginal power generation, energy market prices and CO_2-related policies.

The Swedish case studies previously mentioned apply a coefficient of performance[1] (COP, which refers to the cooling produced per unit of electricity/heat used) of electricity-driven CC chillers between 2 and 5 while the COP of the latest centrifugal chillers has proven to be more than 6 for specifications according to Japanese Industry Standard (not including power for cooling towers) [35] and well above the requirement set by the ASHRAE Standard 90.1-2004 (COP of 6.1) [36]. Performance tests of advanced centrifugal chillers made for temperature specifications representative for Swedish climate conditions show a COP of approximately 7 in full load operation for both the latest fixed- and variable-speed centrifugal chillers [35]. For lower outdoor temperatures, the variable-speed centrifugal chiller reaches a COP of 22 in part load operation. Thus, the highlighted potential for cost-effective CO_2 emission reduction by AC utilisation in the previously mentioned studies may be overestimated due to the considerably higher efficiency of the latest CC chillers.

Hondeman [37] illustrates that for electricity-optimised CHP-systems based on coal and natural gas, CC technology is more favourable than AC technology from an energy perspective if the COP of the CC chillers is higher than 6, as achievable today; however, Poredos and Kitanovski [6] claim that from an exergy perspective, hot water AC chillers are almost 10% more efficient than CC chillers considering a COP of 6.6. Nevertheless, if low-cost excess heat from industries or from a CHP plant fuelled by waste or biomass is available, as in many Swedish DH systems today, DH-driven AC technology may still lead to cost-effective CO_2 reduction despite the recent advances of CC chillers.

2. Method

In this section, the methodological considerations regarding scientific approach and studied cases and scenarios are presented.

2.1. Case study

Swedish DH systems are highly diversified with regards to production mix solutions [38]. Instead of modelling several DHC systems on a highly aggregated level which may lead to ambiguous results for the specific system, one system is modelled in detail for which the base load capacity is altered in order to better reflect also other DHC systems (with less excess heat available). The study is based on the DHC system of Göteborg, where the cooling demand is expected to increase, and in which approximately 80% of the DH is supplied by industrial excess heat and CHP plants fuelled by municipal solid waste and natural gas.

The AC technology's potential for cost-effective CO_2 reduction in the studied DHC system is investigated given an assumed cooling demand around the years 2020–2025 and by simulating the DHC system's operation to meet the heating and cooling demand when increasing the share of installed AC capacity. Due to the strong seasonal, daily as well as hourly variations in the cooling and heating demand, the DHC system's operation is simulated on an hourly

[1] Also referred to as energy efficiency ratio (EER).