POTENTIAL INTEGRATION OF SOLAR THERMAL ENERGY AND THERMALLY DRIVEN ABSORPTION CHILLER TO GENERATE RENEWABLE AND CLEAN COOLING FOR INDUSTRIAL PROCESSES

Summary

The paper presents a study investigating a concept for renewable cooling in industrial application by combining solar thermal energy with an absorption chiller and an optimized thermal energy storage system (TES), to minimise the dependency on reused industrial waste heat. The study follows the context of the EU Net-Zero policy ambitions and the technical challenge of decarbonizing industrial cooling demand. In the context of the EU-funded project RE-WITCH the study targets synergies between solar thermal heat generation and thermally driven absorption chillers to supply industrial cooling demand. Therefore, dynamic simulations in TRNSYS18 with hourly weather data and realistic industrial load profiles to represent time-dependent solar heat supply and cooling demand are used. The study analyses coincidence and mismatches of solar heat availability and heat demand for the absorption chiller, and what this means for the sizing of the system and TES. Overall, the technical feasibility is summarized through demand coverage metrics, including comparisons across different climates and implications for back-up needs, to evaluate the concept of solar thermally-driven industrial cooling systems.

Keywords: Industrial application, process cold, synergies, solar thermal heat, absorption chiller

Field of application for the findings: Industrial processes

Addressed audience: Industrial stakeholders, energy auditors, researchers

1. Introduction

The current European industrial policy framework puts focus particularly on accelerating the manufacturing scale-up and market deployment of net-zero technologies in Europe. A key instrument in this context is the EU Net-Zero Industry Act (NZIA) stemming from the Green Deal Industrial Plan. It aims to strengthen domestic production capacities for strategic clean technologies, facilitate investment, and improve regulatory and market conditions for their uptake. The aim is not only to increase European competitiveness, but also to accelerate the practical implementation of the energy transition ("Net-Zero Industry Act - European Commission," 2026). Especially the decarbonisation of industrial cooling and air-conditioning demand remains a technical challenge. In many industrial sectors, untapped potential of waste heat is available while cooling demand exists simultaneously. Thermally driven absorption chillers are a perfect match for such a circumstance, coupling because they can convert heat into cold as driving energy, especially when waste heat is available and electrical load peaks need to be reduced. Absorption chillers are an important and promising technology in systems that can generate cooling from recovered heat (Deng et al., 2011). At the same time, the commercial roll-out of absorption chillers is limited compared to electrically driven compression systems; applications typically focus on use-cases where heat sources are available at relatively low prices (Herold et al., 2016). A major bottleneck of the technology lies not so much in the existence of individual technologies as in their actual integration into real-world processes. In the case of absorption chillers, technical and economic feasibility depend heavily on the combination of available heat source temperature and the desired chilled water temperature. The required temperature lift in the significantly determines the design and performance of the unit. For this very reason, research and reviews regularly discuss couplings that buffer heat sources (e.g. solar thermal energy) using thermal energy storage (TES) in order to stabilise operating points and enable control strategies (Ibrahim et al., 2024a). This is the background for the EU-funded project RE-WITCH with 27 partners across Europe ("Renewable and Waste Heat Valorisation in Industries via Technologies for Cooling Production and Energy Harvesting"), under which thermally driven and next-generation adsorption technologies and advanced absorption chiller concepts are developed and demonstrated. The driving heat source is built on a combination of renewable solar thermal heat and industrial waste heat. The project also explicitly addresses the actual integration and demonstrations at four demo sites in industrial applications (Vasta et al., 2024). Most solutions rely on the availability of waste heat. But how can cooling demand be covered by sustainable thermally driven cooling systems when there is no potential to reuse waste heat?

Solar thermal is a great heat source, since the heat generation is free of GHG emission, sufficient temperature of more than 100°C can be easily achieved. However, the fluctuation of solar radiation and the dependency on those are a critical drawback for solar thermal heat to serve as a reliable energy source in the industrial process field. Integrating TES is a crucial step to overcome these barriers. This combination is identified as a relevant field of integration and optimisation and is being investigated as an option for more sustainable cooling supply (Ibrahim et al., 2024b). Overall, the concept targets synergies between solar thermal heat generation, thermal energy storage and thermally driven absorption chiller to supply process cold in an industrial application without relying on reused waste heat. This study delivers an added value to highlight solar cooling solutions in the industrial process and its opportunities and challenges.

2. Method

The target is to develop a thermally driven concept which is not dependent to the availability of reused waste heat and still ensures the cooling supply of industrial applications. The methodology focuses on analysing a fully solar-thermally driven cooling supply concept for an industrial process. Key technology will be an optimised TES to bypass dependency on waste heat. Instead of analysis of a process at steady state, the work investigates the dynamic characteristics of solar availability and industrial process patterns.

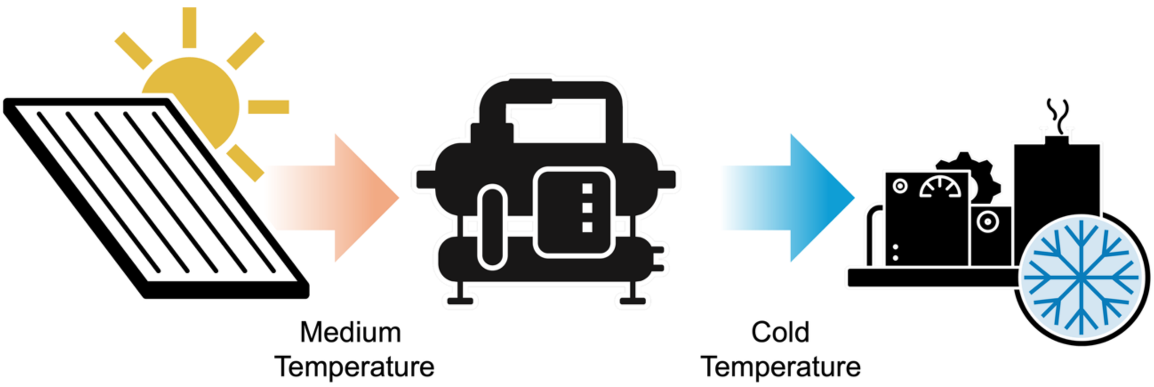

Figure 1: Graphical presentation of the study concept, lifting solar thermal heat via absorption chiller to supply cold to industrial processes.

To capture the strongly time-dependent behaviour of solar heat supply, storage charging/discharging, and process cooling demand, the system is modelled in a dynamic simulation in TRNSYS18. TRNSYS is a transient system simulation environment designed to represent energy systems as interconnected component models, which makes it suitable for investigating operation varying in time, control logic, and part-load effects in coupled thermal systems. The industrial process represents a real-life process, such as product cooling in the food industry and is modelled as a time-dependent cooling demand schedule. This schedule is implemented in the demand profile of the chilled-water loop. The required cold at the product is given at 10°C, while the absorption chiller provides chilled water at 12°C. The solar heat supply given at a temperature of 80°C supply the absorption chiller.

The model is built of essentially three different loops: (i) solar hot water loop to supply heat from the solar thermal collector field to the absorption chiller, (ii) the heat rejection loop to dispatch excess heat from the absorption chiller to the ambient and finally (iii) the chilled water loop supplying cold from the absorption to the industrial process unit. The role and performance of the TES is modelled and analysed for 2 different locations: within the (i) solar hot water loop or within (iii) the chilled water loop. This will allow a distinct investigation on the system performance for different configurations.

Local ambient temperature and solar irradiation are location-dependant and have great influence on the system performance. The system is modelled and investigated in three different climates across Europe to analyse its potential in replication and its potential limitations by climate. In different climates the parameters to successfully run the solar thermally-driven system may change. With this dynamic simulation, it can be assumed through sensitivity studies what are the most important boundary conditions to run a solar-thermal driven cooling system and to ensure cooling supply of industrial applications.

3. Results

The analysis is performed for a whole year to investigate the influence both daily and seasonal fluctuation in the three investigated locations. The results show different operation modes, such as (I) solar heat is available to drive the chiller at same time, (II) energy can be stored in TES, (III) energy from TES is extracted and (i) hours of lacking cold supply. This includes the number of hours (and share of the year) of each mode as well as the amount of energy each. The results highlight the different impact of the location of the TES (hot loop or chilled loop) on the total system performance. It becomes clear how large thermal storage systems would need to be in order to guarantee operation, which also answers the question of technical feasibility. Second, the results evaluate the charging and discharging behaviour of TES, including the frequency of full and empty states, and the duration heat/ cold supply covered by the TES. The results are further used to make the synergies within the coupled system explicit, for example how the interaction of solar thermal field, TES and absorption chiller shapes the match between available driving heat and required process cold. The study compares annual and seasonal sums of generated solar heat, heat delivered to the absorption chiller, rejected heat, and useful cooling supplied. So, the study provides indicators if the concept of solar-driven industrial cooling is potentially practical in terms of footprint and delivered output. Through this it can be also compared for the different climate sections how advantageous back-up technology would be or if it’s technically needed.

Rather than assessing the absorption chiller as a standalone component, the results quantify how effectively the available driving heat, from collected and stored solar thermal energy, is converted into process cooling. This is expressed through the chiller’s thermal COP as well as the resulting annual and seasonal cooling energy yield per unit of driving heat. The analysis shows how this conversion varies over time due to changing temperature levels and part-load operation, and it also shows how often the system runs under conditions that deliver useful cooling, and how often operation is limited or not possible because the available driving temperature is too low. In this way, absorption chiller performance is linked directly to overall technical feasibility of the fully solar-driven concept.

Finally, the results summarise feasibility in terms of demand coverage. Total cooling energy supplied to the process, fraction of annual demand met, and the timing of unmet cooling demand or times when a technically not practical dimension of the systems is necessary. These indicators directly answer whether a fully solar-thermal driven configuration can meet the process requirements and where the dominant limitations are located.

4. References

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