Annex 58

High-Temperature Heat Pumps

Executive Summary

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or “Annexes”, in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex.

The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Disclaimer
The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Heat Pump Centre
A central role within the HPT TCP is played by the Heat Pump Centre (HPC).

Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology, including researchers, engineers, manufacturers, installers, equipment users, and energy policymakers in utilities, government offices, and other organizations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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Operating Agent

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The Annex is being operated from 01/2020 to 12/2023. The main information can be found on the Annex 58 homepage: https://heatpumpingtechnologies.org/annex58/

Participating countries of Annex 58

There is a high number of countries participating in Annex 58, while each country is represented by a national team consisting of a number of organizations. The following countries are formally participating in the Annex:

- Austria
- Belgium
- Canada
- China
- Denmark
- Finland
- France
- Germany
- Japan
- Netherlands
- Norway
- South Korea
- Switzerland
- USA

A presentation of all national teams can be found on the Annex 58 homepage.

Authors of the report

The Annex 58 reports is the result of a collaborative effort with contributions from various authors that are listed in the table below. The final report was prepared and edited by Benjamin Zühlsdorf (DTI), Virginia Amato (DTI), Jonas Lundsted Poulsen (DTI), Cordin Arpagaus (OST), Florian Schlosser (Paderborn University), and Sabrina Dusek (AIT).

Table 0-1: Overview of authors of the report, sorted by organization and country.

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Foreword

This report has been compiled as part of the IEA HPT Annex 58 about High-Temperature Heat Pumps (HTHP). The Annex is structured into the following 5 tasks:

- Task 1: Technologies – State of the art and ongoing developments for systems and components
- Task 2: Integration Concepts – Development of best practice integration concepts for promising application cases
- Task 3: Applications and Transition – Strategies for the conversion to HTHP-based process heat supply
- Task 4: Definition and testing of HP specifications – Recommendations for defining and testing of specifications for high-temperature heat pumps in commercial projects
- Task 5: Dissemination

The overall objective of the Annex is to provide an overview of the technological possibilities and applications as well as to develop best practice recommendations and strategies for the transition towards heat pump-based process heat supply. The intention is to improve the understanding of the technology's potential among various stakeholders, such as manufacturers, potential end-users, consultants, energy planners, and policy makers. In addition, the Annex aims to provide supporting material to facilitate and enhance the transition to a heat pump-based process heat supply for industrial applications.

This will be achieved by the following sub-objectives:

- Provide an overview of the technology, including the most relevant systems and components that are commercially available and under development (Task 1).
- Identify technological bottlenecks and clarify the need for technical developments regarding components, working fluids, and system design (Task 1).
- Present best practice system solutions for a range of applications to underline the potential of HTHPs (Task 2).
- Present strategies for the transition to heat-pump-based process heat supply (Task 3).
- Enhance the information basis about industrial heat pumps, potential applications, and potential contribution to the decarbonization of the industry (Task 1, 2 & 3).
- Develop guidelines for handling industrial heat pump projects with a focus on the HP specifications and the testing of these specifications (Task 4).
- Disseminate the findings to various stakeholders and add to the knowledge base for energy planners and policy makers (Task 5).

Annex 58 focuses on HTHPs, which are heat pumps that supply a relevant share of their main product at temperatures above 100 °C. In this context, the focus is on developing, summarizing, and communicating information about the most relevant technologies and applications rather than covering all technologies. The relevance was mainly determined by the various participants and indirectly given by the technologies' application potential and market perspectives. Therefore, the Annex is primarily focused on applications for industrial heat supply but will not specifically be limited to these applications.

Executive Summary

The decarbonization of industrial process heating is a top priority to achieve climate goals as process heating accounts for a considerable share of the final energy consumption and greenhouse gas emissions of industries. High-temperature heat pumps are a promising alternative to fossil fuels to provide process heating at the highest efficiency using potentially emissions-free electricity. However, the deployment of heat pumps for temperatures above 100 °C is still limited. Enabling a large variety of industries to convert their process heat supply to high-temperature heat pumps requires a common understanding of the technology, its potentials, and its perspectives.

The overall objective of the Annex is to provide an overview of the technological possibilities and applications as well as to develop concepts and strategies for the transition towards heat pump-based process heat supply. The intention is to improve the understanding of the technology's potential among various stakeholders, such as manufacturers, potential end-users, consultants, energy planners and policy makers. In addition, the Annex aims to provide supporting material to facilitate and enhance the role of high-temperature heat pump-based process heating for industrial applications. The work was structured in five tasks: Task 1 - Technologies, Task 2 - Integration Concepts, Task 3 - Applications and Transitions, Task 4 - Definition and Testing of Heat Pump Specifications, and Task 5 - Communication.

Task 1 provided an overview of the state of the art and future perspectives. The first part of the report is a technology review covering high-temperature heat pump technologies with supply temperatures above 100 °C that are available in the market or under development. The review was based on a systematic description that includes information on the layout, development status, expected performance, capacity and temperature range, compressor type, working fluid, investment cost, footprint and weight. The reviewed solutions included 34 technologies with a technology readiness level between 4 to 9, specific investment cost between 200 €/kW to 1500 €/kW, capacities between 30 kW to 70 MW and maximum supply temperature between 100 °C and 280 °C. The second part is a review of realized demonstration cases described by sector, application, process integration, technology type, manufacturer, operating experiences. The demonstration review highlighted 15 demonstration cases in various industrial sectors (food, refinery, electronics, chemicals). Lastly, an overview of the high-temperature heat pump industries, markets, application potentials and development perspectives were given on a national basis for 13 countries. The national reviews indicate a generally large application potential with differences on a national and local level depending on the composition of the industrial sector. The work from Task 1 showed that some high-temperature heat pump solutions are already available and implemented. However, it also highlighted the need for further efforts for a transition towards heat pump-based process heat supply. The high-temperature heat pump technology is currently under development and therefore the technology and demonstration cases review database is continuously updated on the Annex 58 homepage always conveying the state of development

Task 2 focused on developing guidelines for the integration of high-temperature heat pumps in the most promising application areas. The first part of the report included a description and analysis of integration concepts for selected industrial processes and heat pump concepts for selected heat pump applications. A standardized template was used for a more structured collection of information about the concepts. The study included 12 industrial processes described by their temperatures, heating and cooling demands, mass flows and production patterns. 27 different integration concepts were identified, and it was found that the optimal integration practices vary depending on the case-specific process requirements, but processes using the same heat pump application share similar process requirements. The second part of the study described technology concepts that can be developed for three heat pump applications: steam generation, hot water/oil production and heating with large temperature glides such as heating air for drying. Information about 15 heat pump concepts was collected using another template and described their functioning principle, layout, refrigerant, compressor type and expected performance. Based on these data material, it was found that processes with similar characteristics typically benefit from the implementation of the same heat pump technologies, allowing for the development of blueprint solution for selecting heat pump concepts for specific applications, thereby reducing developmental efforts. Nonetheless, the prevailing regulatory and economic conditions, such as electricity prices and available subsidy schemes continues to play a crucial role.

In Task 3, instructions for creating decarbonization strategies for industries were developed. The aim of the task was to develop a long-term strategy that includes both technologies available today and in the near future and that takes a holistic view of all the measures that can be implemented. The first part of the development of a decarbonization strategy addressed the definition of overarching goals, the timeline in which the goals must be achieved and the factors influencing targets and timelines. The second aspect is the collection of data about the status of the site in order to develop the decarbonization strategy and the reference scenario for its evaluation. The required data includes cooling and heating demand of the individual processes, medium, temperature and mass flow, existing waste heat flows, and site-specific aspects. Third, Task 3 investigated how to develop and evaluate concept solutions for decarbonization. The report gives an overview of the possible technologies, with a focus on heat pump technology. The possible integration levels for heat pump technologies in industrial processes and the methods for the development of integration concepts were explained. The evaluation criteria for evaluating the solutions were also discussed. The last aspect addressed in the Task 3 report was the development of an implementation roadmap for the transition, which includes a definition of milestones, targets, and required expertise.

Task 4 investigated many aspects important to consider during a large-scale high-temperature heat pump project with the aim of supporting both contractors and end-users in heat pump projects. The main outcomes are three sets of guidelines for defining heat pump specifications, testing and validating heat pump performance in large-scale projects. The first guideline is for the definition of heat pump specifications, in which the parameters, performance metrics, safety, and testing procedures are discussed. The second guideline is for laboratory testing conditions, including recommendations for the type of tests, and methodology for performing tests, assessing deviations and uncertainties, and presenting results. The third guideline for site testing outlines similar recommendations as for the guideline for laboratory testing, in addition to the use of simulation models in combination with site testing. Besides the three guidelines, the task 4 report also includes a review of existing heat pump standards, examples and lessons learned from heat pump projects for process heating and district heating, together with descriptions of the phases from a typical heat pump project from idea to heat production.

Task 5 revolves around the dissemination activities conducted to report valuable information about high-temperature heat pumps. The activities include the reports of Task 1, 2, 3, and 4, workshops and presentations at international conferences, articles, and webinars. The task reports are published on the homepage https://heatpumpingtechnologies.org/annex58/. Several “Deep Dives”, webinars of around 2 hours about selected topics, were organized within Annex 58. Selected speakers were invited, and the “Deep Dives” sessions were open to all interested participants. The topics covered included process integration, application potential for high-temperature heat pumps, heat-driven heat pump technologies, working fluid and cycle optimization, steam generation and mechanical vapor recompression. Finally, the outcomes from the activities of the Annex were disseminated in a final webinar and the webinar slides are published on the homepage.

Looking ahead, the development and deployment of HTHPs are expected to accelerate significantly, driven by technological advancements, increasing industrial demand for sustainable energy solutions, and supportive regulatory environments. Technology developments, end-user adoption, and boundary conditions are mutually dependent with one increasing with the other. By 2030, HTHPs are projected to be a key technology in industrial process heating, with advancements leading to increased efficiencies, reduced costs, and broader industry adoption. Collaboration among technology providers, end-users, policymakers, and R&D organizations will be crucial in overcoming existing barriers and ensuring the successful integration and operation of HTHPs across various industrial sectors. Thus, there is an ever-increasing potential in gathering, coordinating, and disseminating information between the different groups of stakeholders to support increased installations consequently accelerating decarbonization of industry.

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