Application of Industrial Heat Pumps

IEA Industrial Energy-related Systems and Technologies Annex 13
IEA Heat Pump Programme Annex 35

Executive Summary

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Contents

1 Introduction

Securing a reliable, economic and sustainable energy supply as well as environmental and climate protection are important global challenges of the 21st century. Renewable energy and improving energy efficiency are the most important steps to achieve these goals of energy policy.

While impressive efficiency gains have already been achieved in the past two decades, energy use and CO_2 emissions in manufacturing industries could be reduced further, if best available technologies were to be applied worldwide.

Heat pumps have become increasingly important in the world as a technology to improve energy efficiency and reduce CO_2 emissions. In particular industrial heat pumps (IHPs) offer various opportunities to all types of manufacturing processes and operations. IHPs are using waste process heat as the heat source, deliver heat at higher temperature for use in industrial processes, heating or preheating, or for space heating and cooling in industry. They can significantly reduce fossil fuel consumption and greenhouse gas emissions in drying, washing, evaporation and distillation processes in a variety of applications. Industries that can benefit from this technology include food and beverage processing, forest products, textiles, and chemicals.

The introduction of heat pumps with operating temperature below 100 °C is in many cases considered to be easy, however, higher temperature application still require additional R&D activities for the development of high temperature heat pumps, integration of heat pumps into industrial processes and development of high temperature, environmentally sound refrigerants.

In this context, the IEA HPP-IETS Annex 35/13 "Application of industrial Heat Pumps", a joint venture of the International Energy Agency (IEA) Implementing Agreements "Industrial Energy-Related Technologies and Systems" (IETS) and "Heat Pump Programme" (HPP) has been initiated in order to actively contribute to the reduction of energy consumption and emissions of greenhouse gases by the increased implementation of heat pumps in industry

The Annex 35/13 started on 01. April 2010 and expired on 30. April 2014 with 15 participating organisations from Austria, Canada, Denmark, France, Germany (Operating Agent) Japan, The Netherlands, South Korea and Sweden.

The Annex comprised an overview in the participating countries of the industrial energy situation and use, the state of the art and R&D projects in heat pumping and process technologies and its applications, as well as analysing business cases on the decision-making process in existing and new applications and in the wider application of industrial heat pumping technologies. The annex has been subdivided in the following tasks:

- Task 1: Market overview, barriers for application
- Task 2: Modeling calculation and economic models
- Task 3: Technology
- Task 4: Application and monitoring
- Task 5: Communication.

2 Market overview, barriers for applications

The Task 1 Report summarized the present energy situation in general and the industrial energy use and related heat pump market subdivided into participating countries. Based upon these findings focus will be given to further work to meet the challenges for the wider application of industrial heat pumping technologies.
Although heat pumps for the industrial use became available on the markets in the participating countries in recent years, just very few carried out applications can be found. To distinguish the reasons for this situation, application barriers were also a part of the survey in Task 1:

- Lack of knowledge:

  The integration of heat pumps into industrial processes requires knowledge of the capabilities of industrial heat pumps, as well as knowledge about the process itself. Only few installers and decision makers in the industry have this combined knowledge, which enables them to integrate a heat pump in the most suitable way.

- Low awareness of heat consumption in companies:
  In most companies knowledge about heating and cooling demands of their processes is quite rare. This requires expensive and time consuming measurements to find an integration opportunity for an industrial heat pump.

- Long payback periods:

  Compared to oil and gas burners, heat pumps have relatively high investment costs. At the same time companies expect very low payback periods of less than 2 or 3 years. Some companies were willing to accept payback periods up to 5 years, when it comes to investments into their energy infrastructure. To meet these expectations heat pumps need to have long running periods and good COPs to become economical feasible.

- High temperature application
  From the technical point of view one barrier can be identified regarding to the temperature limits of most commercially available heat pumping units. Many applications are limited to heat sink temperatures below 65°C the theoretical potential for the application range of IHP increases significantly by developing energy efficient heat pumps including refrigerants for heat sink temperatures up to and higher than 100°C.

  The barriers can be solved, as shown in the results of the Annex: short payback periods are possible (less than 2 years), high reduction of CO_2-emissionen (in some cases more than 50 %), temperatures higher than 100°°C are possible, supply temperatures < 100 °C are standard.

3 Modelling calculations and economic models

The Task 2 Report intended to outline how the integration of IHP in processes is supported by computer software, i.e. by modeling.

In order to 'update' the Annex 21 screening program in the sense of a 'modern' development taking the original goals into account a proposal has been made that allows a consistent integration of a heat pump into a process based on pinch analysis. The basic elements of this concept are:

- Substitution of the problem table algorithm by an extended transshipment model which allows a simultaneous optimization of utilities and heat pump.
- Approximation of the heat exchanger network as in the standard pinch analysis.
- Development of an algorithm for selecting of a hot and cold stream (may be of several hot and cold streams) to which the heat pump could be connected.
- Development of a heat pump data base to be used within the simultaneous optimization. Since this optimization is nonlinear a special algorithm needs to be developed that enables convergence.

This concept of integrating a heat pump into a process is 'below' the sophisticated methods given by H.E. Becker [Methodology and Thermo-Economic Optimization For Integration of Industrial Heat Pumps, THÈSE NO 5341 (2012), ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, Suisse, 2012]. Presently it is impossible to state whether such a development is unprecedented, relevant and needed.

The scoping analysis of existing models shows that the difference between 'pure' pinch models and sophisticated mathematical optimization models has been bridged in modern software tools. Regarding the integration of heat pumps into a process, codes like OSMOSE or CERES (amongst may be others) look promising.

Independent of any software tools, approaches and optimizations, a general heat pump data base should come more into the focus. Such a data base is needed for many purposes. Typical information to the database are not only source and sink temperature as well as size of heat pump etc. but also further details of the selected hot and cold streams to which the heat pump is selected, because this would allow to select a specific heat pump type.

The goals of Task 2 should be carefully reconsidered if a "new Task 2" team should be constituted. The State of the Art as well as industrial needs of research organizations, large companies as well as of energy consultants should be critically reviewed. We conclude that the application of general optimization methods is limited to a fairly small number of research groups and highly specialized groups within large companies. Energy consultants probably will prefer pinch analysis type models. In the whole context we consider the thesis of H.C. Becker (directed by F. Maréchal) as key reference due to the systematic methodology, based on pinch analysis and process integration techniques, to integrate heat pumps into industrial processes

4 Technology

The scope of the Task 3 Report was to identify in the industrial sector appropriate heat pumps as a technology of using waste heat effectively and for meeting future industrial and environmental requirements.

Commercially available heat pumps can supply heat only up to 100 °C. As industrial waste heat, available at low-temperatures, represents about 25 % of the total energy used by the manufacturing industry, R&D work has to be focused on high-temperature heat pumps able to recover heat at relatively low temperatures, generally between 5°C and 35°C for hot water supply, hot air supply, heating of circulating hot water and steam generation at temperatures up and higher than 100 °C.

Some development of the industrial heat pump using R-134a, R-245fa, R-717, R-744, hydro carbons, etc. has been made recently. However, except for R-744 and the flammables R-717 and HCs which are natural refrigerants with extremely low global warming potential (GWP), HFCs such as R-134a and R-245fa have high GWP values, and the use of HFCs are likely to be regulated in the viewpoint of global warming prevention in the foreseeable future. Therefore, development of alternative refrigerants with low GWP has been required.

At present, as substitutes of R-134a, R-1234yf and R-1234ze (E) are considered to be promising, and R-1234ze (Z) is attractive as a substitute of R-245fa. R-365mfc is considered to be suitable as a refrigerant of heat pump for vapor generation using waste heat, but its GWP value is high. Therefore, it seems that development of a substitute of R-365mfc should be furthered. The table below shows basic characteristics of the present and future refrigerants for IHPs.

Refrigerant	Chemical formula	GWP	Flammability	T_c °C	p_c M Pa	NBP °C
R-290	CH3CH2CH3	~20	yes	96.7	4.25	-42.1
R-601	CH3CH2CH2CH2CH3	~20	yes	196.6	3.37	36.1
R-717	NH3	0	yes	132.25	11.33	-33.33
R-744	CO2	1	none	30.98	7.3773	-78.40
R-1234yf	CF3CF=CH2	<1	weak	94.7	3.382	-29,48
R-134a	CF3CH2F	1,430	none	101.06	4.0593	-26.07
R-1234ze(E)	CFH=CHCF3	6	weak	109.37	3.636	-18.96
R-1234ze(Z)	CFH=CHCF3	<10	weak	153.7	3.97	9.76
R-245fa	CF3CH2CHF2	1,030	none	154.01	3.651	15.14
R-1233zd		6	none	165.6	3.5709	n. a.
R-1336mzz		9	none	171	n. a.	n. a.
R-365mfc	CF3CH2CF2CH3	794	weak	186,85	3.266	40.19

5 Applications and monitoring

The **Task 4 Report** focused on operating experiences and energy effects of representative industrial heat pump implementations, in particular field tests and case studies.

Industrial heat pumps are a class of active heat-recovery equipment that allows the temperature of a waste-heat stream to be increased to a higher, more useful temperature. Consequently, heat pumps can facilitate energy savings when conventional passive-heat recovery is not possible

The economics of an installation depends on how the heat pump is applied in the process. Identification of feasible installation alternatives for the heat pump is therefore of crucial importance. Consideration of fundamental criteria taking into account both heat pump and process characteristics, are useful. The initial procedure should identify a few possible installation alternatives, so the detailed project calculations can concentrate on a limited number of options.

The commercially available heat pump types each have different operating characteristics and different possible operating temperature ranges. These ranges overlap for some types. Thus, for a particular application, several possible heat pump types often exist. Technical, economic, ecological and practical process criteria determine the best suited type. For all types, the payback period is directly proportional to installation costs, so it is important to investigate possibilities for decreasing these costs for any heat pump installation.

The survey with a total of 150 projects and case studies has tried to present good examples of heat-pump technology and its application in industrial processes, field tests and commercial applications along with an analysis of operating data, when available, in accordance with the annex definition of industrial heat pumps, used for heating, ventilation, air-conditioning, hot water supply, heating, drying, dehumidification and other purposes.

6 Final Conclusions and future actions

The IEA HPP-IETS Annex 35/13 "Application of industrial Heat Pumps", a joint venture of the International Energy Agency (IEA) Implementing Agreements "Industrial Energy-Related Technologies and Systems" (IETS) and "Heat Pump Programme" (HPP) has been initiated in order to actively contribute to the reduction of energy consumption and emissions of greenhouse gases by the increased implementation of heat pumps in industry.

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The programme and work has been mainly concentrated on the collection of statistical energy and environmental data and information related to industry as well as the present status of R&D and the application of heat pumps in industry. In total **39 R&D projects and 115 applications** of heat pumps in industry, in particular the use of waste process heat as the heat source, have been presented and analyzed by the participating countries.

It has been shown that in many companies and especially in SMEs, only very little and aggregated information on the actual thermal energy consumption is available and disaggregated data such as consumption of individual processes and subprocesses therefore has either to be estimated or determined by costly and time-consuming measurements, which often requires the integration of several processes at different temperature levels and with different operating time schedules. The exploitation of existing heat recovery potentials often requires the integration of several processes at different temperature levels and with different operating time schedules. Different technologies available for heat supply have to be combined in order to obtain optimum solutions.

Basis for the modeling calculation and economic models activities (Task 2) has been the update of the IHP screening program, to determine how industrial heat pumps could be used in different applications, developed and presented in "Annex 21 - Global Environmental Benefits of Industrial Heat Pumps (1992 -1996)".

The IHP screening program has been analyzed and converted from an outdated Visual Basic version to the latest Visual Basic version employing the .NET framework. This new, converted version would in principle be ready for any modifications, updates of data and models as well as for extensions. However, during the execution of Task 2 it became obvious that the authors consider this approach as a dead-end and the screening program as obsolete. Since 1997 no further work on this program has been done and the authors decline any further developments. We simply noticed that the formulation of the corresponding item in the legal text did not take this situation into account. However, parts of the screening program, for instance the database, could be easily extracted and modernized for other purposes.

Although the Annex has been prolonged by one year, mainly because of missing results from Task 2, nearly none of the deliveries could be finished as foreseen,

due to the fact that most participants are not concerned directly with modeling and software aspects and a large underestimation of the wide range of software tools with their very different scopes.

Taking into account the results of the annex with detailed information on statistical data, R&D results and case studies, a possible follow-up annex should be concentrated on a consistent integration of a heat pump into a process based on pinch analysis. The basic elements of this concept should be:

- Substitution of the problem table algorithm by an extended transshipment model which allows a simultaneous optimization of utilities and heat pump.
- Approximation of the heat exchanger network as in the standard pinch analysis.
- Development of an algorithm for selecting of a hot and cold stream, to which the heat pump could be connected.
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