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Unlocking waste heat potentials in manufacturing

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Abstract

Industry releases vast amounts of heat energy as dissipative waste heat to the atmosphere. It is therefore necessary to acquire a better understanding of the waste heat potentials in manufacturing. The paper presents an integrated approach for identifying and quantifying waste heat potentials of different production processes. The identification is based on an estimation procedure followed by a simulative assessment of production processes to quantify and allocate waste heat over time. The approach further elaborates on a potential source and demand matching of heat streams. A case study from the automotive industry demonstrates the applicability of the approach.

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Keywords: Energy Efficiency; Waste Heat; Simulation; Manufacturing Processes; Integrated Approach

1. Introduction

In December 2015 the world has agreed to undertake action reducing carbon emissions aiming to keep global average temperature well below 2°C above pre-industrial levels. For Europe the target is to cut greenhouse gas emissions (from 1990 levels) at least by 40% until 2030.

Heating and cooling account for 46% of the overall energy demand worldwide. A significant amount of this demand (66%) is met supplying fossil fuels [1]. Industry can make a major contribution to that since 34% of the overall heat demand is accounted for as industrial heat in Europe [2]. Here it should be noted that vast amounts of that heat energy as well as conversion related heat e.g. from electricity are lost as waste heat. With respect to industry, many efforts have been made to contribute to the reduction of CO_2 emissions by focusing on energy efficiency improvements, e.g. efficient use of electrical energy and/or auxiliary media such as compressed air [3]. However, despite having different approaches and methods for energy efficiency improvements available, only limited effort has been made to increase the usage of waste heat [4]. As a starting point in manufacturing, many technical processes emit waste heat which originates from thermal or mechanical processes. Depending on the respective temperature level, waste heat can either be directly used as an energy source or indirectly for other processes, e.g. to convert it into electricity. Direct use might bear the highest potential for low-temperature waste heat whereas indirect use through conversion might be most appropriate for temperature levels above 150°C. Depending on the temperature level the overall potential of waste heat recovery is estimated to range from 32% up to 80% [5]. To capture this potential different methodological and technological approaches have been proposed. Yet, the majority of these approaches remains on a conceptual basis and do not provide direct decision support.

Therefore, an integrated approach to assess waste heat potentials considering different manufacturing levels is proposed. To go beyond conceptual descriptions, the approach employs different methods ranging from static calculations, to simulations and mathematical optimization. Each step of the approach is supported by an easy-to-handle tool to facilitate the identification and quantification of waste heat potentials. The approach is demonstrated using a case study from the automotive industry.

2. Waste Heat in Manufacturing

2.1. Description and forms of waste heat

Waste heat can be described as a stream within a machine

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system resulting in energy losses [6]. Such streams transmit or radiate the waste heat via the machine surface, cooling streams or via exhausts to the environment. Both forms of waste heat can be considered for waste heat reuse [6]. To quantify the waste heat, the energy content of the waste heat stream is described as follows:

$$\dot{Q} = \dot{m} \cdot h(T) \tag{1}$$

The quantity of the waste heat stream $\dot{Q}$ [W] is a function of the waste heat stream mass flow rate [kg/h] and the waste heat stream specific enthalpy h(T) as a function of the temperature of the heat source to the heat sink [5]. The quality of waste heat is defined by the waste heat temperature with regards to the applicability of recovery technologies.

2.2. Examples of waste heat in manufacturing

Waste heat can occur in multiple forms e.g. as hot combustion gas in an oven, warm waste water from washing processes or absorbed heat in cooling fluids [6]. In the U.S., two third of the industrial heat demand corresponds to high-temperature heat (above 500°C) e.g. from metal furnaces and ovens. The waste heat can be recovered for high-quality energy, available for diverse uses. Medium-temperature waste heat (230°C-650°C) originates from process exhausts or drying ovens [6]. Practically, it is used for combustion or process preheating or steam generation. Particularly in manufacturing, waste heat with lower temperature can occur with large quantities contained in numerous exhaust streams e.g. cooling water, washing machine exhausts and air compressors. Typical recovery methods are space and domestic water heating or temperature upgrading via heat pumps [6].

One of the most efficient waste heat recovery options is local reuse in the same process to minimize the local energy demand [6]. If the waste heat cannot be used in the same process, the transfer of the waste heat to other processes and systems can be considered as an option. Another option regards the direct use of low-grade waste heat services (<100°C) to support building and space heating [7]. Hence, it is beneficial to check for suitable waste heat cascading options or storing alternatives e.g. warm water tanks to gain the most of the energy used.

2.3. Barriers/obstacles to waste heat utilization

Even so the potential is there, waste heat recovery has been rarely implemented due to numerous economic, technological and organizational obstacles. These obstacles are often interrelated to each other leading to different tradeoffs regarding either the profitability or efficiency of waste heat recovery options, e.g. including [5,6,7]:

- Economic obstacles, e.g. long payback periods and costs for operation and maintenance or material constrains.
- Temperature restrictions, e.g. the lack of end-use of waste heat, especially low-temperature waste heat recovery technologies are less developed and costlier.
- Information restrictions, personal and time effort for the identification of waste heat sources as well as a lack of communication.
- Knowledge limitations, due to a lack of experts and missing methodological and planning support.
- Administrative restrictions e.g. lack of infrastructure and bureaucratic effort for realization.
- Differences in temporal and local existence of heat sources and sinks

3. State of Research and Research Objectives

3.1. Focus of waste heat concepts and approaches

The need for understanding the potential of waste heat has been recognized by many governmental agencies and researchers [5,8,9]. Besides the distinction of different industry sectors, existing approaches can be classified with regard to system levels, namely a factory (F), process chains (PC), TBS and process/machine (P/M) level [3]. On these levels, approaches address waste heat aspects either deliberately or indirectly.

On the process/machine level, Neugebauer et al. incorporate convective heat transmission to time-variable thermal simulation to improve FEM results [10]. In addition to that, Zuest et al. propose a numerical simulation model to quantify heat release of machine tool subsystems such as the internal cooling system of a lathe [11]. Another approach from Schrems considers both resulting heat from machine tool subsystems and components to predict the energy demand of single machine types as well as possibly resulting process chains thereof [12]. With respect to the TBS level some authors present numerical simulations for specific processes/technologies (e.g. heat pumps) with a particular focus on recovering low grade waste heat [13]. While Brückner and colleagues compare different waste heat recovery technologies regarding their economical benefit subject to different consumer types and operating hours [14]. A more technical perspective on waste heat recovery technologies is proposed by Oluleye et al. by presenting four simplified mathematical models which are incorporated into a methodology for assessing the recovery potential of useful energy from waste heat by using preliminary heat recovery temperatures for process sites [15].

Besides single machine simulations, a new simulation paradigm known as coupled or co-simulation approaches evolved, which enable an analysis of various systems and their interrelations to each other [16,17]. In that context, Loebner and colleagues propose a generic description of a system comprising different system components including heat related component and its relations to each other to identify potential leverages for improving the overall energy demand [18]. Bleicher et al. base their work on [18] and present a planning approach for production facilities that couples simulation models for machines, energy systems and the building [19]. Thiede et al. propose in that context a multi-level simulation framework and recommendations for selecting appropriate coupling concepts [20].

With regard to the overall factory level several approaches originate in the domain of process engineering and commonly