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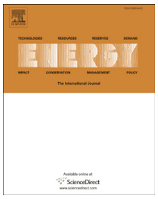

Recovering energy from flue gas by using a utilities grid technique

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ABSTRACT

The effect of industrial activity on the environment has attracted increasing attention over recent decades. Industry has therefore started looking at methods of reducing the mass flow rates of utilities. This has resulted in extensive research into developing various recovery methods for in-plant utilities, thereby reducing the overall mass flow rates of utilities.

This paper focuses on an effective application regarding utilities and available heat flow rate for recovering energy by using a utilities grid technique, which

- minimises the amount of heat flow rate loss
- searches for more appropriate allocations of heating non-process streams.

The research idea, which is presented using a utilities grid technique, is founded on the heat flow rate of the flue gas and the available heat flow rate being produced for steam generation and air heating regarding combustion along a furnace-channel without changing the basic process operation. The goal of the utilities grid technique is to search for more appropriate allocations of heating non-process streams by using the mathematical method.

This technique has been tested on an existing methanol process that allows for efficient air heating and an additional 4.4% of steam production.

1. Introduction

Minimising the consumption of steam reduces energy and utilities usages, as well as increasing process efficiency by using pinch analysis and/or mathematical methods.

Pinch analysis, along with other principles of process integration, has established itself as one of the more important tools for analysing and optimising the energy systems of process plants. The principles of pinch analysis were formulated by Linnhoff and co-workers, as presented in book [1]. The second edition as presented in 1994 [2], included HEN (heat exchanger networks) synthesis, heat recovery targeting and selecting multiple utilities. The second edition [2] was elaborated on by Kemp [3] in a book that includes optimisation of energy use, and energy saving using practical applications. Forty years of heat integration by using pinch analysis and mathematical programming has been described by Klemeš and Kravanja [4].

Shenoy presented energy optimisation methodologies based on pinch analysis and mathematical programming for the synthesis of optimal heat exchanger networks [5]. These methodologies involve three-steps: targeting, network synthesis, and detailed design. They have been used for identifying energy savings in grassroots designs,

El-Halwagi researched into the comprehensive and authoritative treatments of the concepts, tools and applications of process Integration [6]. Emphasis was given to systematic ways of analysing process performance. The graphical, algebraic and mathematical procedures are presented in detail.

A targeting methodology is proposed for determining optimum loads for multiple utilities by considering the cost trade-offs in energy and capital for HENs (heat exchanger networks) [7]. This method is based on a newly-developed CUP (Cheapest Utility Principle), that simply states that it is optimal to increase the load of the cheapest utility and maintain the loads of the relatively expensive utilities as constants, whilst increasing the total utility consumption.

Mass-exchange operations are highly impacted by heating and cooling [8]. Therefore, there is a natural coupling between the problems of synthesising MENs (mass exchange networks) and

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HENs (heat exchange networks). The objective of this paper was to introduce a systematic method for the simultaneous synthesis of CM&HEN (combined mass- and heat-exchange networks).

Wang and Smith researched the minimisation of wastewater within process industries [9]. Targets are first set that maximise water re-use. The approach used allows individual process constraints relating to minimum mass transfer driving force, fouling, corrosion limitations, etc.

Waste reduction through source reduction and on-site recycling is an important aspect of pollution prevention [10]. Techniques of process integration may be used for pollution prevention. In this paper an algorithmic procedure is presented for reducing waste generation through maximising on-site reuse/recycling. The proposed methodology is based on pinch principles and establishes a minimum waste generation target prior to detailed network design.

Tan and Foo presented a new application for pinch analysis [11]. A scenario is assumed wherein energy sector planning takes place using carbon emission constraints arising from an effort to reduce climate change effects. This is a procedure for identifying the minimum amount of zero-carbon energy resource required to achieve the overall emissions target for a country or region, given that the amount of fossil energy resources available are already known.

Heat integration is a key tool for energy saving achieved by heat recovery within process industries [12]. Energy saving plays an important role in achieving sustainable future development. Heat recovery at the Total Site level can provide a considerable potential for energy saving, as presented in Ref. [13].

Dhole and Linnhoff [14] introduced a simple exergetic model for estimating cogenerational potential for a total site based on the site source and the site sink profiles. Based on the total site source and sink profiles, as proposed by Dhole and Linnhoff [14], Raissi [15] proposed site utility composite curves for given steam levels. Raissi [15] proposed a temperature-enthalpy (T–H) model based on Salisbury [16] approximation and on the observation that the specific power produced by the turbine is approximately proportional to the differences in saturation temperatures. Klemeš et al. [17] proposed a site utility grand composite curve for providing designers with a tool for determining the potential for cogeneration.

Bandyopadhyay et al. [18] presented a new concept for total site integration by generating a SGCC (site level grand composite curve). The proposed SGCC targeted the maximum possible indirect integration as it incorporated assisted heat transfer. A methodology was proposed for estimating the co-generational potential at the total site level, utilising the concept of multiple utility targeting on the SGCC. The proposed methodology for estimating the co-generational potential was simple and linear, as well as utilising rigorous energy balance at each steam header.

Vargas [19] described the optimum thermodynamic match between two streams at different temperatures as being determined by maximising the power generation (or minimising the entropy generation) associated solely with stream-to-stream interaction. Each stream experiences a change in phase. They showed that the optimum is marked by an optimal ratio between the stream mass flow rates, and an optimal ratio between the two heat exchanger sizes when the total heat transfer area is fixed. The sensitivity of the optimum relative to the various physical parameters of the two-stream arrangement is documented systematically. This study shows that the optimum is ‘robust’ relative to changes in several parameters such as the distribution of a heat transfer coefficient along the hot-end heat exchanger, and the model used for the thermodynamic behaviour of steam.

Bejan and co-authors stated that thermodynamic optimisation may be used by itself (without cost minimisation) within the preliminary stages of design, in order to identify trends and the existence of optimisation opportunities [20]. The optima and structural characteristics (materials, configuration) identified, based on thermodynamic optimisation, can be made more realistic through subsequent refinements to the model. Ultimately, the design based on the most realistic model is optimised from the start entirely based on cost minimisation. The integrative design philosophy that emerges from such applications can be summarised as follows: an entire system can be conceived from the beginning as a system designed for optimally performing certain global objectives, and not as an ensemble of already existing parts. The thermodynamic imperfection of the system is due to a variety of currents that must overcome resistances. Global system performance is maximised when the imperfection is distributed optimally, i.e. when the flow resistances are minimised together. Optimal spatial distribution endows the system with architecture (structure, configuration, geometry).

If available heat from different processes is integrated within another process this can reduce energy usage. Hui and Ahmad introduced the potential for transferring energy between processes by a common steam system, that yielded near-minimum cost designs [21]. Steam generated in one process can be used in others. This provides indirect heat transfer between processes.

Bandyopadhyay and co-authors presented total site integration offering energy conservation opportunities across different individual processes and also when designing, as well as for optimising the central utility system [22]. During total site integration of the overall process, indirect integration with intermediate fluids or through a central utility system is preferred as it offers greater advantages for flexibility and process control but with reduced energy conservation opportunities [22].

Mallikarjun and Lewis presented a novel two-stage strategic DER technology-policy framework for determining the optimal energy technology allocation [23]. The methodology simultaneously considers economic, technical, and environmental objectives.

Sedighizadeh and co-authors presented a multi-objective framework by proposing simultaneous optimal network reconfiguration and DG (distributed generation) power allocation [24]. The proposed method encompasses objective functions of power losses, voltage stability, DG cost, and greenhouse gas emissions and is optimised subject to power system operational and technical constraints.

Methods for reducing energy have been developed for several years. These methods are supplemented for use within industry and include multi-criteria optimisation [25], steam generation [26], and wastewater collection for steam generation [27]. The energy saving was effective on the lower CO_2 emissions [28]. This paper currently presents the effective applications of utilities and available heat flow rate by using the utilities grid technique.

2. Utilities grid technique

The heat flow rate of the flue gas and available heat flow rate would be targeted regarding options for heat recovery and optimal energy conversion in order to reduce carbon emissions and the usages of fossil fuels within industrial processes. The goal of the utilities grid technique is to minimise the amount of heat flow rate loss and search for more appropriate allocations of heating non-process streams. This technique is very useful regarding energy recovery without changing the basic process operation.

The utilities grid technique, as a simple method of energy modification, is based on utility saving targets using pinch analysis and/or MINLP (mixed integer nonlinear programming). Pinch analysis is a methodology for minimising the energy consumptions