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Heat recovery and power targeting in utility systems

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ABSTRACT

New heat recovery and power targeting models have been developed to evaluate and improve site-wide heat recovery and distribution, and cogeneration systematically. Previous graphical methods for utility system targeting have been proposed based on the assumption of only steam latent heat in the utility system. In this work, a practical graphical approach based on extended site composite curves to quantify site steam targeting has been proposed to provide realistic utility targeting methods, allowing for BFW (boiler feedwater) preheating and steam superheating in steam generation, and steam desuperheating for process heating. Condensate heat recovery from steam usage has also included in the graphical method. A new cogeneration targeting model has been developed including practical limits such as steam mains superheat and turbine exhaust dryness. These new realistic energy and power targeting methods improve the accuracy of the targeting, and overcome the shortcomings of previous targets.

1. Introduction

Systematic analysis is necessary to evaluate site-wide power and heat generation, distribution, utilization, and cogeneration improvements. Targets for utility system design and operation require prediction of the utility boiler steam demand, fuel consumption for power and heat generation, site steam cascade, and potential shaft power generation by steam expansion.

Cogeneration [1] is widely analyzed by both graphical approaches and mathematical programming methodologies. Graphical approaches as visualization tools have been developed to capture the overall characteristics of a site system [2]. The process composite curve was proposed as a tool to address individual process heat recovery [3]. Process Pinch can be used to identify the bottleneck in the process direct heat integration.

Site source–sink profiles [4] of the overall site utility system represent processes and utility system integration and provide the process quantified heating and cooling targets graphically. Site composite curves [4,5] address process heat recovery through steam mains and utility boiler steam demand target from fuel consumption. Other graphical methods have been developed based on the principle of pinch analysis, such as Time slices [6] and stream temperature and enthalpy plot technique [7]. Process minimum temperature differences were specified to obtain more realistic utility and heat recovery targets [8].

The graphical methods had been extended to site-wide heat and power integration. Shaft power potential by steam expansion in steam turbines can be calculated based on the T-H model [9] in the site composite curves. A site level grand composite curve [10] has been proposed to estimate the cogeneration potential. These graphical methods have been applied in hybrid renewable energy system [11], carbon footprint reduction [12], waste heat recovery on a site [13], and graphical generation analysis and improvements in the site systems [14].

However, these graphical methods are based on the assumption of steam heat input and output as latent heat only. These targets are unrealistic excluding many practical considerations, such as BFW (boiler feedwater) preheating and steam superheating for steam generation, and steam desuperheating for process heating.

Power potential by steam expansion is another important issue for the utility system. Raissi [9] investigated the T-H (temperature-enthalpy) model to provide a graphical representation for power estimation with the assumption of saturated inlet and outlet steam of a steam turbine. Other models for power estimation were developed principally based on exergy models [15], and these models essentially were used as a reference of an ideal thermal engine performance expressed by a Carnot cycle. Varbanov [16] and Aguilar et al. [17] developed an improved turbine hardware model, but coefficients in the model determined only by steam saturation temperature drop across the steam turbine. Mavromatis and

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Kokossis [18] developed a thermodynamic model based on the energy balance, but some import effects such as inlet steam superheat temperature were not included in the model.

More realistic steam properties with steam superheating instead of the saturated steam should be considered in the system analysis. Manassaldi et al. [19] examined the effect of steam, including both latent heat and superheat on the HRSG (heat recovery steam generation) design. Botros et al. [10] designed steam power islands allowing for steam reheating before turbine expansion. Mitra et al. [20] proposed mathematical model on a component basis for the operational optimization of industrial combined heat and power plants. However, the calculation complex limits their practical application.

In this paper, site composite curves relating to new design situations and retrofit situations will be examined. Site composite curves are extended to include BFW (boiler feedwater) preheating and steam superheating during steam generation, steam desuperheating for process heating, condensate heat recovery to provide more accurate and realistic steam targeting. Cogeneration implications by steam turbines on a total site have been quantified by introducing a new cogeneration targeting model. Practical constraints can be included in the model to predict realistic power generation potential by turbine expansion. The application of these energy and power targeting methods in process integration with utility systems can achieve thermodynamically possible and practical targets, and give quantitative insights of their interaction.

2. Site composite curves

Just as it is useful to have energy targets for individual processes on a site, it is also useful to have energy targets for the total site. This requires a thermodynamic analysis for the site to develop site composite curves. Site composite curves provide a temperature-enthalpy picture for the whole site, analogous to those for individual processes. There are two ways in which such curves can be developed.

The first relates to a new design situation. It would start from the grand composite curves of each of the processes on the site and would combine them together to obtain a picture of the overall site utility system [4]. Processes have their heat sink and heat source profiles extracted from their grand composite curves and combined to obtain a site hot composite curve and a site cold composite curve. The temperatures are shifted over and above the shift included in the construction of the grand composite curve. If the original hot and cold streams were shifted by $\Delta T_{min}/2$ to produce the grand composite curve, then site composite curves require an additional shift of $\Delta T_{min}/2$ to give a total shift of ΔT_{min} [9]. If different values of ΔT_{min} apply to different processes, then data for each grand composite curve are given their individual shift in ΔT_{min} before the steams are combined in the construction of the site composite curves. Even further, within a grand composite curve for an individual process, different streams have different shifts in ΔT_{min} in the construction of the grand composite curve. Each stream must ultimately be shifted by the ΔT_{min} for that stream before the construction of the site composite curves.

The other way to construct the site composite curves relates more to a retrofit situation. If the existing amount of heat recovery is assumed to be fixed (whether maximized or not), the site profiles can be constructed from the individual process duties within each of the utility heat exchangers on the site. The temperature – enthalpy profiles of the process streams within each of the utility heat exchangers are used to construct the site composite curves. Again, the temperature needs to be shifted for the site composite curves. Starting from the individual process stream data, this needs to have a shift of ΔT_{min}.

Data for a case study are given in the following tables. Table 1 shows steam data. For a 5-process flowsheet on a site, individual process data are listed in Table 2–6. They are on-site data. The data collection includes hot or cold stream initial temperature T_S, target temperature T_T, and the heat load for the stream heating or cooling ΔH. Normally, stream special heat capacity CP is also included in the data table to illustrate the relationship between stream heating or cooling load and the temperature drop. Steam is generated at very high pressure and distributed around the site at three lower pressures. ΔT_{min} is 10 °C for all processes.

Fig. 1 shows the individual composite curves, after the ΔT_{min} shift. The composite curves for the individual processes are combined to give a site source–sink profiles. Fig. 2 shows the steam generation and steam use profiles matched against the site sink–sink profiles. The curves address an ideal match between the steam generation and steam use based on the assumption of saturation steam. For the site, cooling the targets are set by starting with the highest temperature cooling utility, and each lower temperature cooling utility maximized in turn. For the site heating, the targets are set by starting with the lowest temperature cooling utility, and each higher temperature heating utility maximized in turn.

Heat recovery for the site can be targeted by overlapping the site profiles [5,9]. The amount of overlap between the profiles is a degree of freedom available to the designer. Fig. 3 shows the maximum overlap between the site steam profiles. This minimizes the steam generation in the utility boilers and the site heat rejection. The limit is set by the site pinch [5,9].

3. Extended site composite curves

Previous site composite curves have assumed only the latent heat part of the steam generation and use profiles for the ideal targets of steam generation and steam use. So far, a number of issues have not been addressed for the steam profiles:

1) BFW (boiler feedwater) preheating. BFW is fed to process steam generation at the deaeration temperature, which will be below saturation temperature. Preheating of the BFW prior to vaporisation can be carried out by recovery from the site hot composite curve.
2) Steam superheating. Steam fed to the steam mains from process steam generation should be superheated and this can also be carried out by heat recovery from the site hot composite curve.
3) Steam desuperheating. Steam fed to process steam heaters, if superheated, involves a poor heat transfer coefficient until saturation conditions are attained. The design of steam heaters benefits from the desuperheating of steam prior to use. If this is carried out, BFW from the deaerator is injected into the steam under temperature control to typically bring it within 3 °C of saturation. The benefit is smaller and cheaper heat exchangers and in some cases less damage to sensitive process fluids. However, for the same process heating load, the mass flowrate of steam increases and additional boiler fuel is required to compensate for the desuperheating.

Table 1
Steam data on a site.

Main	T_S (°C)	T_T (°C)	T_{SAT} (°C)	Pressure (bar)
VHP	111	550	310.9	100
HP	105	270	250.3	40
MP	105	232	212.4	20
LP	105	172	157.8	5
CW	20	30		