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A novel approach to hot oil system design for energy conservation

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HIGHLIGHTS

- A new design method was developed for hot oil system by changing arrangement of HEN.
- Hot oil is supplied to a network of heater with a parallel/series configuration.
- Better hot oil generator performance and increased heating capacity was achieved.
- Debottlenecking procedures for the design of hot oil systems was developed.

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ABSTRACT

In this paper, a new systematic design methodology was developed for hot oil system by changing arrangement of heat exchanger network from parallel to mixed series/parallel. In re-circulating hot oil systems, hot oil from the hot oil generator is supplied to a network of heaters that usually has a parallel configuration. However, re-use of hot oil between different heating duties enables hot oil networks to be designed with series arrangements. This allows better hot oil generator performance and increased heating capacity, both in the context of new design and retrofit. First, the hot oil generator and the hot oil network were examined separately, in order to discuss the nature of hot oil system design. A model of hot oil systems was then developed to examine the performance of the hot oil generator to recirculation flow rate and return temperature, as well as to predict heating efficiency. In second step, the design of the overall hot oil system was developed by investigating the interactions between the hot oil network design and the hot oil generator performance. Debottlenecking procedures for the design of hot oil systems was also developed.

1. Introduction

Hot water heaters, steam heaters, and recirculating hot oil systems are all used to supply the required heat to a process [1]. Of these methods, recirculating hot oil systems are by far the most common today, as they do not have a drum to supply latent heat, and they are able not only to conserve process water and steam, but also to reduce energy and capital cost, compared to hot water and steam heater systems [2–4].

Hot oil heating is a type of indirect heating in which a liquid phase heat transfer medium is heated and circulated to one or more heat energy users within a closed loop system. Mineral oil, pressure-less synthetic oil and pressurized synthetic oil are common heat transfer mediums [4]. Main suppliers of hot oil packages and plants such as Sigma Thermal [4], Gaumer Process [5], Chromalox [6], Thermal Fluid Systems [7] and GTS Energy [8] offer those systems at up to 420 °C to be used to heat revolving rolls, platens, molds, jacketed tanks and autoclaves in petrochemical, chemical and pulp-and-paper plants. The general specifications of hot oil systems offered by Chromalox® are given in Table 1 [6].

However, no attention has been placed on the interactions between hot oil generator and heat exchanger networks [9,10], even though changes to operating conditions of hot oil systems

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Table 1
General specifications of hot oil systems offered by Chromalox® [6].

Model	System type	Application	Operating temperature (°C)	Mbh[a]
CMXO	Heat transfer non-pressurized	Synthetic oil	10–290	20.4–81.9
COS	Heat transfer non-pressurized	Synthetic oil	10–330	30.7–1365
PFC	Heat transfer non-pressurized	Synthetic oil	10–315	30.7–2047
CLD	Heat transfer pressurized	Synthetic oil	10–400	30.7–2047
CLS	Heat transfer pressurized	Syltherm® 800	40–400	30.7–2047
OMHTS	Heat transfer multiple zone	Synthetic oil	10–400	30.7–4094
CHTV	Heat transfer vaporizer	Dowtherm® Therminol®	−30 to 400	51.2–1024

[a] Mbh is the ASME & ANSI standard for one thousand British Thermal Units per hour.

frequently occur in industrial sites. Design and operating problems of hot oil generators have been the focus of attention on the part of manufacturers and process engineers. Mitra [10] represented the design considerations of hot oil systems and sizing of equipment. Mukherjee [11] addressed some techniques for improving the performance of the individual components in hot oil systems. Arnold [12] developed a differential equation model to do a detailed thermal analysis for a hot oil system in different temperature ranges. Ennis [13] discussed some of the key safety design and operational aspects of hot oil systems. Probert [14] presented a method for designing and rating of hot oil storage tanks. Halttunen [15] addressed a method to analysis energy costs of hot oil pumping systems. Wallace et al. [16] designed a new method for hot oil integration with a heat recovery system generator. Policastro [17] suggested an advanced, flexible control system for hot oil plants. Colaco and Floyd [18] developed a computerized method to do control and analysis of conditions of a hot oil system on a dynamic basis. Gu and Liu [19] presented an analysis on the flow process of hot oil in the organic heat transfer material heater based on finite time thermodynamics. Hlozek and Bardov [20] designed a hot oil system to do waste heat recovery from reciprocating gas engines. Nasir et al. [21] designed a hot oil system to utilize the turbine waste heat to generate electric power in a Neptune plant. Mostajeran Goortani et al. [22] introduced a hot oil system to recover the heat from stack gases and distribute it to the appropriate cold streams in a Kraft mill plant. Ohm et al. [23] described a drying technique for the upgrading of crushed low-rank coal utilizing a hot oil system. Singhmaneeskulchai et al. [24] studied on dynamic data reconciliation of a utility heat exchanger using hot oil from a waste heat recovery unit as a hot stream to heat up ethane product as a cold process stream from a natural gas separation plant.

However, to date, research on heating systems have focused on the individual components [10], and not on the system as a whole. Because of the interactions between hot oil networks and hot oil generator performance, all of the heating system components should be considered when designing and operating these systems. Process integration method can be applied to address the interactions between the components of hot oil systems. Process Integration is a family of methodologies for combining several parts of processes or whole processes to reduce the consumption of resources [25]. This methodology examines the potential for improving and optimizing the heat exchange between heat sources and sinks in order to conserve energy, reduce costs and emissions [25,26]. Klemes et al. [25] represented the recent developments in process integration.

Various process integration approaches have been developed over the past two decades to study energy systems with the goal of identifying energy recovery opportunities in process industries. Thermal pinch analysis, which was developed for the analysis and optimization of heat exchanger networks, seems to be the most commonly used heat integration method [27]. Thermal pinch analysis was introduced by Linnhoff and Flower [28]. This analysis was expanded and widely publicized by Linnhoff and Hindmarsh [29], Smith [30,31], Kemp [32] and Gundersen [33].The mass pinch analysis was introduced by El-Halwagi and Manousiouthakis [34]. This analysis was applied in the area of wastewater minimization by Wang and Smith [35,36]. This method was widely expanded by Mann and Liu [37], Prakash and Shenoy [38] and Wan Alwi and Manan [39]. The mass and thermal pinch analyses were combined together by Savulescu et al. [40], Panjeshahi et al. [41,42], Ahmetovíc and Kravanja [43,44] to identify opportunities to simultaneously reduce the water and energy consumption in industrial facilities.

Consider some of the possible changes to an existing hot oil system. A new heat exchanger might be introduced into the heat exchanger network, or the heat duty of heaters changed, or process changes might change the operating conditions. These process changes influence the conditions of the hot oil return and, consequently, affect the performance of the hot oil generator. In such situations, it is often not clear how the system will be affected by the new conditions or how the hot oil network design will affect the heating system. As such, a combined thermal and mass pinch analysis should be used to investigate the interactions for the overall system.

In this paper, we present a systematic method for the design of hot oil systems that accounts for these interactions and process constraints, based on a combination of thermal and mass pinch analyses. First, the hot oil generator and the hot oil network will be examined separately, in order to discuss the nature of hot oil system design. A model of hot oil systems will be developed to examine the performance of the hot oil generator to recirculation flow rate and return temperature, as well as to predict heating efficiency. A methodology for hot oil network design will then be developed, assuming fixed inlet and outlet conditions for the hot oil. Finally, the design of the overall hot oil system will be developed by investigating the interactions between the hot oil network design and the hot oil generator performance [45]. Debottlenecking procedures for the design of hot oil systems will also be developed. In summary, moving from parallel to series arrangements for hot oil networks:

- Increases the efficiency of the hot oil system,
- Decreases the temperature differences in the hot oil heat exchangers.

2. Design of hot oil networks

The current practice for hot oil network design most often uses parallel configurations [4,10,46], whereby hot oil is supplied directly to individual heat exchangers. After the hot oil has been used in each heat exchanger, the cold oil returns to the hot oil generator (Fig. 1a). The minimum hot oil demand is determined by minimizing the flow rate to the individual heat exchangers (Fig. 1b). Under a parallel arrangement [47], return hot oil flow rate and temperature become maximized, leading to poor generator performance [45].

Thus far, no systematic methods have been suggested for dealing with the design of hot oil networks, and the traditional parallel design is not flexible when dealing with various process