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AN INTEGRATED APPROACH TO DRYING TECHNOLOGIES

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Key words and phrases: onion model; optimization; pinch technology; process integration.

Abstract: The "onion model" approach is proposed to optimize drying and associated processes that form an integrated drying system. The approach consists of optimizing the dryer as the core of the system and then extending the optimization for the shell comprising both downstream and upstream operations. Application of pinch technology to drying is presented, and illustrated by the case study on optimization of the dryer with heat pumping by mechanical vapor recompression.

Introduction

An analysis of numerous process flow diagrams for industrial plants comprising a drying stage indicates that drying is closely integrated with other operations by heat and mass streams. Rarely, however, particularities of a drying technology are considered in the contexts of the processing plant during plant design. More frequently, the dryer is selected on a stand-alone basis to perform the required task, and then the external heat source (e.g., steam or natural gas) is specified as to secure the required dryer duty. Although the dryer is assumed to be designed for optimum operation, it may set off the plant global optimum, as the heat streams of the stand-alone dryer are not integrated into heat network of the plant. In contrast, the dryer may require adjustment to set a new optimum when heat necessary for drying is recovered from elsewhere in the plant. Clearly, the dryer cannot be optimized in isolation from other processes though optimization of the complex systems may include a systematic decomposition of the system with iterative optimization of these subsystems followed by process synthesis.

The “onion” model

Accepting that a drying technology is composed of a dryer, ancillary equipment, down- and up-stream processes and utilities, the “onion model” can adequately represent the hierarchical structure of all components of the drying system in the form suitable for optimization. As shown in Figure 1, the dryer forms a core of the onion and the adjacent layer No I encompasses ancillary equipment necessary to run the dryer. The subsequent layer No II could comprise complementary processes such as heat recovery, process control, treatment of volatiles, etc. The peripheral layers No III and No IV are composed of down- and upstream processes such as dewatering, preheating, pre-forming, grinding, screening, blending, granulations and others. Each of these layers includes utilities that may form a network of heat streams to be further optimized if the objective is to minimize energy use.

The onion model indicates that optimization should start with the dryer along with the layer No I. Any tool could be applied, such as multi-objective optimization, for example [1, 2]. Further, downstream and upstream processes can be included, and a pinch technology approach could be applied to optimize this integrated drying technology.

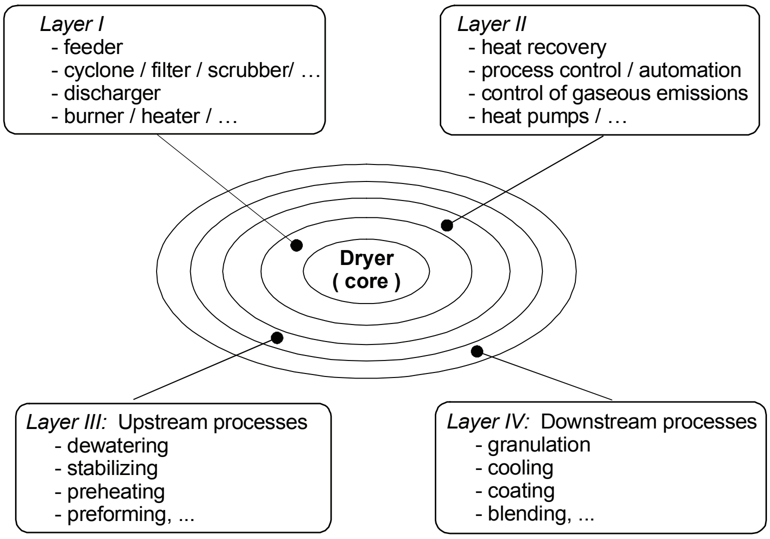


Fig. 1 Onion model for drying technology

Pinch analysis

Pinch technology is an advanced technique in process integration used to optimize a well-defined and organized structure formed of individual unit operations [3]. An analysis of the structure of heat streams in a network of heat exchangers and utilities is one of possible engineering applications of pinch technology to minimize energy consumption, reduce capital and operating costs, overcome problems with utilities, redesign the process flow diagram, and others. Because of similarity of heat and mass transfer phenomena, pinch technique originally developed for heat transfer analysis has been adopted to mass transfer processes. The recent example of such application is a fresh and wastewater minimization problem [4, 5]. In such a case, water purity and flow rate are used as the process parameters instead of temperature and enthalpy, which are used when dealing with heat streams. More recently, the process integration includes economical aspects in terms of running and investment costs.

The available information on the application of pinch analysis for drying systems is very limited. Besides conceptual considerations indicating that low-temperature dispersion dryers and superheated steam dryers offer best opportunities for heat integration [6], only few case studies on drying are provided. Smith and Linnhoff [7] evaluated energy savings in heat pump-assisted drying of spent grain regarding a drying system as a heat exchanger network. Such approach is justified because in convective dryers the primary heat input is first to a drying agent from whom it is transported to the material being dried. Although the heat input to the dryer takes place over a wide range of temperatures to ensure sufficient drying rate, the material temperature at any point in the dryer is lower than the gas temperature at this point to secure temperature difference as a driving force for heat transfer. Therefore, the dryer can be analyzed as a heat exchanger with a hot stream (drying agent) and a cold stream (material) assuming constant heat capacities of both streams. Evaporation of moisture from wet material, however, results in humidification of the drying agent. This affects not only thermal properties of the solid and gaseous phase such a specific heat but also the mass flow rate which means that heat capacity of respective heat streams is not constant. Therefore, detailed analysis should account for variations in enthalpy associated with gas and material streams. Another case study involved feedstock production in a continuously operated plant composed of multiple-effect evaporators, a conveyor dryer with seven temperature zones, and a dehumidifier [8]. As a result of process integration, several modifications to the plant were proposed with a payback of about 12 months. Keey [9] reports briefly on results of heat integration for spray drying of detergents but the original paper is not easily accessible [10].

Our own analysis indicates that the pinch technique in drying process integration can be used in either heat or mass transfer approach. Thus, temperature and enthalpy are the process parameters when integrating thermal processes in a drying system. When integrating mass transfer processes, the moisture concentration and mass flow rate can be selected as process parameters because water content in the wet material is higher than that in a drying agent and both change with drying time for batch drying, or dryer length for continuous dryers (Fig. 2).

The application of pinch technique for minimizing energy consumption using heat transfer approach is well illustrated by the example given by Smith and Linnhoff [7]. Figure 3a shows a schematic of animal feed production from spent grains in a whisky distillery. The plant has two feeds: of low- and high-concentration solids, and one discharge of a dry product. Water is removed from the high-concentration feed by centrifuging followed by two stages of drying in rotary dryers. Water from the low-concentration feed is removed by evaporation followed by drying in a second stage of rotary dryer. Because of heat recovery, a mechanical vapor recompression is incorporated into the low-concentration feed line. As it is usual with this type of a plant, the basic components such as evaporators and dryers have been designed on a stand-alone basis without consideration of the process context. Also, optimization of the evaporator-heat pumping system on a stand-alone basis has been found economical. The grand composite curve for evaporation, heat pumping and second-stage drying (the first drying stage is not shown because of too high temperature to allow integration with other processes) indicates the heat pump to be appropriately placed across the pinch. However, the cold side below the pinch encroaches into a pocket in the grand composite curve. By simply rearrangement of the steam streams to avoid encroaching into the pocket (Fig. 4), the global streams are unchanged, but the load on the heat pump is lower which translates into a reduction in electricity consumption and thus lower energy costs.

In the case presented here the drying segment of the plant has not been altered. In general, however, pinch technique can indicate the need for modifications to the dryer design and operating parameters. Although thermal characteristics of dryers are rather design-specific, in many dryer types such as drying in a fixed bed, falling bed, etc, the designer has certain degree of the freedom to manipulate drying temperature, material feed or gas flow rates. Then these can be changed in accordance with the plus/minus principle in order to follow the results of pinch analysis. Even in the case of fluid bed drying, where gas flow rate is constrained by hydrodynamic conditions yet gas temperature can be changed if required by pinch rules.

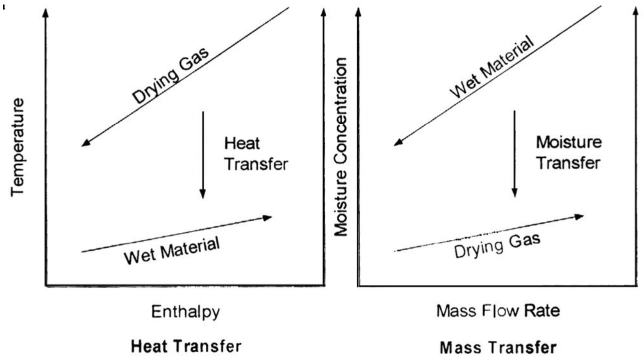
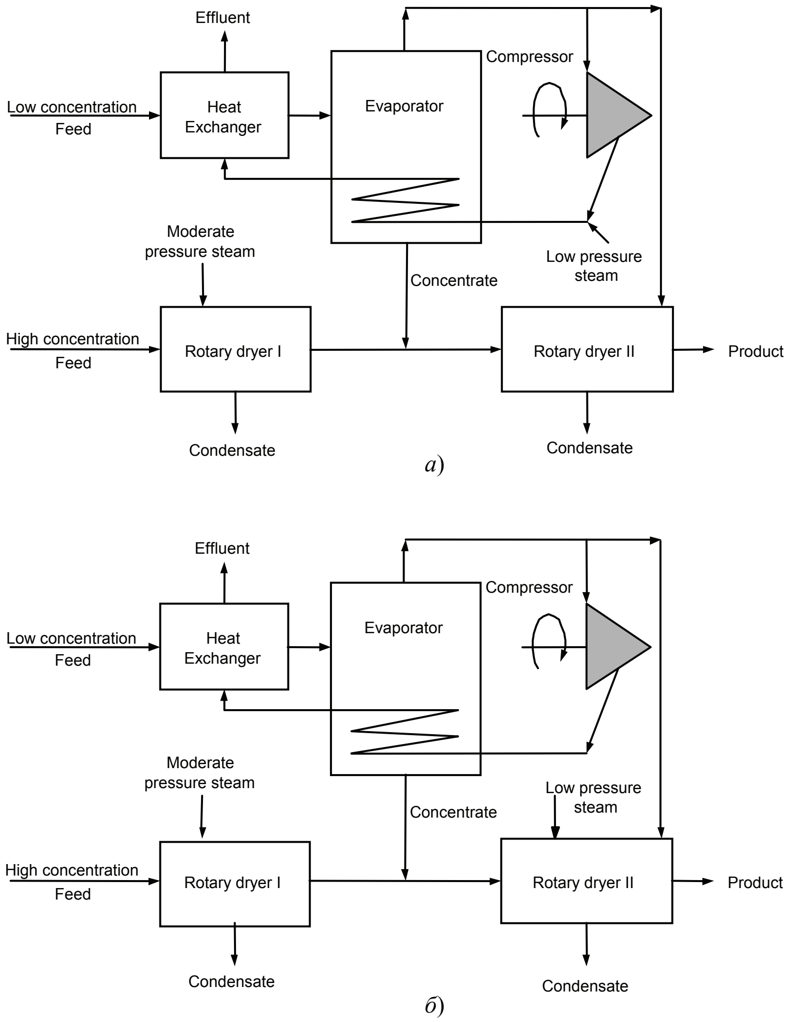


Fig. 2 Heat and mass transfer approach in pinch technique for drying



a)

б)

Fig. 3 Production of animal feed before (*a*) and after (*b*) modifications according to results of pinch analysis

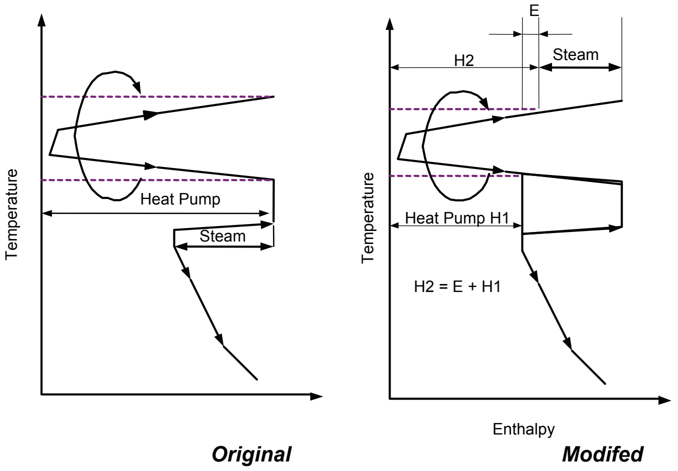


Fig. 4 Grand composite curves for the plant before and after modifications

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Интегрированный подход к технологии сушки

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Ключевые слова и фразы: интеграция процессов; пини-технологии; оптимизация; послойная модель.

Аннотация: Подход «модель луковицы» (послойная модель) предложен для оптимизации сушки и сопутствующих процессов, составляющих комплексную сушильную систему. Подход включает сушку как ядро системы и далее распространение оптимизации по оболочкам, включающим предшествующие и последующие операции. Показано применение пини-технологий к сушке, которое иллюстрируется оптимизацией сушилки с тепловым насосом при механической компрессии паров.

Integriertes Herangehen zur Trocknungstechnologie

Zusammenfassung: Das Herangehen “Zwibelmodell” (Schichtenmodell) ist für die Optimisierung der Trocknung und der Begleitprozesse als komplexes Trocknungssystem vorgeschlagen. Bei diesem Herangehen wird die Trocknung als

Systemkern und als Verbreitung der Optimisierung nach den Hüllen einschließlich Vor- und Nachoperationen betrachtet. Es ist die Benutzung der Pinch-Technologien zur Trocknung gezeigt. Sie wird durch Optimisierung der Trockenanlage mit der Wärmepumpe bei der mechanischen Dämpfenkompression illustriert.

Approche intégrée des technologies de séchage

Résume : Le principe du modèle de l'oignon est proposé pour optimiser les procédés de séchage et les procédés associés qui forment un système intégré. L'approche consiste à optimiser le séchoir en le considérant comme étant le coeur du système, et ensuite à optimiser les opérations en amont et en aval. L'application de la technique du pincement thermique au séchage, ainsi qu'un cas d'étude montrant l'optimisation d'un séchoir avec pompage de chaleur par recompression mécanique de vapeur, sont présentés.