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A review: Energy recovery in batch processes

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ABSTRACT

The implementation of batch processing has increased due to its intrinsic flexibility and adaptability. These are essential characteristics when it comes to producing high-value added materials such as agrochemicals, pharmaceuticals, specialty chemicals...the demand for which has grown in recent decades.

Although industrial processes are highly diverse, a common feature to all is that they utilize fossil fuels as the energy source. The reliance on fossil fuels as a primary source of energy generates a negative impact on the environment. The implantation of renewable energies and efficient usage of energy has thus become crucial. Improving energy use could be achieved through advancements in plant machinery and the use of methodologies such as 'process integration'.

Process integration can be described as system oriented methods that could be used during the design and retrofit of industrial processes in order to obtain an optimal utilization of resources. The methods have traditionally focused on an efficient energy use, although recently process integration techniques cover other areas such as efficient use of raw materials, emission reduction and process operations. Energy integration tries to reach the optimization of heat, power, fuel and utilities.

The consideration of energy integration complicates the process design and the generation of batch process design alternatives, so what is now required is the proposal and development of different approaches and methods oriented towards recovering energy in this kind of industrial process. Improving energy end-use efficiency will make it possible to reduce dependence on energy imports and bring about innovation and competitiveness.

The aim of this work is report the main contributions that have been carried out in order to attain energy integration in batch processes, as well as different examples of applications that have shown the possibilities offered by the developed tools.

Contents

1. Introduction

The process industries usually require enormous quantities of mass and energy [1] and there has been a trend towards an increase in global raw materials and energy consumption. This makes the environment more vulnerable in terms of environmental problems [2]. Thus the use of energy and raw materials in process industries urgently requires both a more efficient management

Abbreviations: GA, genetic algorithm; GCC, grand composite curves; HEN, heat exchanger network; HSUs, heat storage units; HTM, heat transfer medium; MILP, mixed integer linear programming; MINLP, mixed integer nonlinear programming; PCM, phase change material; RTN, resource-task network; SSN, state sequence network; TAM, time average model; TSM, time slice model.

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and a minimization of waste in order to fulfil environmental regulations [3,4]. These environmental regulations are the result of public awareness about resource shortages and sustainable development. The current trend shows that the industries are working on waste reduction and an improvement in processes sustainability. This is because the efficient use of resources is recognised as a key element of sustainable development and an effective strategy to reduce negative environmental impacts and production costs.

Industrial plants have continuous and/or batch processing. The implementation of the latter has increased over the last few decades due to its intrinsic flexibility and adaptability. Batch processes consist of a set of operations which are carried out over a period of time on a separate, identifiable item or parcel of material [5]. The flexibility and adaptability of batch processes are essential to produce high-value added materials such as agrochemicals, pharmaceuticals, foods and fine and specialty chemicals, the demand for which has risen in recent decades [6–9].

Industrial activity accounts for around one third of global energy consumption. Although industrial processes are highly diverse, a common feature to them all is that they utilize fossil fuels as an energy source. The reliance on fossil fuels as a primary source of energy generates a negative impact on the environment. Different studies have proved that the main cause of global warming is the emission of greenhouse gases, which are emitted during the burning of fossil fuel [7]. Thus, in order to lessen the impact on the environment and attain economic performance. The implantation of alternative energy sources and efficient usage and transformation of energy is needed. Improving energy use could be achieved through advancements in plant machinery and the use of methodologies such as 'process integration' [10].

Process integration could be described as system oriented methods that can be used during the design and retrofit of industrial process in order to obtain an optimal use of resources. The methods have traditionally focused on an efficient energy use, but recently process integration techniques cover other areas such as efficient use of raw materials, emission reduction and process operations. Process integration has developed different tools and methods, the objective of which is to help in decision making [10,11]. Energy integration focuses on the optimization of heat, power, fuel and utilities [12,13].

The increase in environmental concern and energy cost has enabled industry to reduce energy consumption. In the past, batch industries could tolerate these high inefficiencies due to the high value of final products. However, the emphasis on process sustainability, global price competition and escalating energy costs have incentivized batch industries to consider different measures (raw material and energy reduction, switching to renewable feedstock, waste minimization, recycling. . .) [14].

Considering heat integration in early design stages of batch processing can lead to more efficient designs. Therefore, efficient models could be decision-making tools which make design easier [15]. However, energy savings in batch plants were neglected in the past because it was believed that they were not as large in magnitude as in continuous cases [16]. This thought was the result of considering batch plants less energy-intensive compared to their continuous production counterparts, which is untrue for some batch operations (dairy products, brewing, and biochemical) [17]. Fortunately, nowadays, new strategies, characterized by the detailed description of the discontinuous process have been proposed to incorporate heat integration considerations in multiproduct and multipurpose plants [18].

Furthermore, heat integration is sometimes far more likely to be carried out to save energy in batch processes because of the lack of heat recovery in them. Simultaneous consideration of production scheduling and heat recovery opportunity becomes an attractive subject in batch plants [9].

The flexibility of batch processes leads to extra complexity in the design and operation of the plant. As multiple tasks can be performed by the same equipment, optimal task scheduling becomes absolutely crucial for meeting production in a cost-effective manner.

In the simplest form, the aim of heat integration is to establish matches between streams that require cooling and those that require heating in order to minimize the use of external utilities (cooling water and steam).

Heat integration is an essential aspect of all industrial processes due to its ability to reduce the amount of hot and cold utilities consumed and, consequently, lower the operating costs. While conventional pinch analysis has been successful in providing solutions for continuous processes, a different method is required to highlight the optimal design for non-continuous and variable rate processes because heat recovery in a batch process is constrained by temperature and time [19,20]. For this reason, different methods, tools, and mathematical models have been developed since the 80's. The aim of this paper is to review the main works that have been done in order to achieve energy integration in batch processes as well as different examples that show the results obtained once developed tools have been implemented in real situations. Section 2 describes some of the more specific features of batch processing and the main ways that could be implemented in heat recovery. The following section draws together different approaches which have been developed to achieve heat recovery in recent decades. The final section focuses on conclusions.

2. Batch process

Batch plants could be used to produce a variety of products by sharing resources (equipment, raw materials, manpower, utilities. . .) over time. This offers an operational flexibility, which makes this kind of process attractive when product demands change quickly, or when small productions are needed [21].

Batch processing works in a discontinuous mode and is used by the pharmaceutical, polymer, food, speciality chemical industries. . .on account of its suitability and flexibility when it comes to producing small quantities of high-value products [22]. This kind of process enables a process to be modified without there being any significant equipment changes, which is essential in the current market. Batch processes are characterized by the following [5]:

- Manufacturing operations are executed independently in batches.
- Resource sharing (steam, electricity, auxiliary equipment. . .).
- Multipurpose equipment (e.g., a piece of equipment could be used as a storage unit or as a processing unit).
- Flexibility (equipment may be connected in different ways).

Batch processing flexibility is highly complex when these plants have to be designed because it is necessary to take into account the requirements and constraints of the corresponding production facilities (safety considerations, technical limitations, short-term availability of units. . .) [23]. Thus, it is essential the development of tools that make easier their design and optimization [21].

There are a great number of works that have proposed different methodologies aimed at increasing batch process efficiency. These approaches include: make-span reduction and annual throughput maximization [24–27]; process measurements [28,29]; freshwater and wastewater minimization through the exploitation of inter- and intra-process water reuse, batch schedules optimization and/or wastewater treatment [30–35]; reduction of waste generation [36,37]; decreasing the necessity of resources [38,39];