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Applied Thermal Engineering 26 (2006) 374–381
APPLIED THERMAL ENGINEERING
www.elsevier.com/locate/apthermeng

Global energy targets and optimal operating conditions for waste energy recovery in Bisphenol-A plant

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Received 24 December 2004; accepted 23 June 2005
Available online 19 August 2005

Abstract

The worldwide increase in energy demands and the uncertainty of future energy costs make energy conservation a major element in controlling operating costs of any chemical process. This paper presents new opportunities for energy saving inside Bisphenol-A (BPA) plant through the optimal selection of process operating temperatures that enhance plant's energy recovery system. These optimal operational modifications are systematically selected from a set of allowable process operating conditions without enumeration using novel interval constraint satisfaction model-based software called TEM_icons™. The paper shows that simple in-process modifications for the sake of energy utilities saving in an actual BPA industrial facility can result in more than 17% saving in hot utility consumption.

Keywords: Operational optimization; Heat integration; Bisphenol-A; TEM_icons™; Interval constraint satisfaction; Constraint logic propagation

1. Introduction

BPA is a very important raw material for plastic industry. Its production is an energy intensive process. Keeping the BPA energy consumption bill under control needs more aggressive energy recovery schemes than just straightforward heat integration via in-process modifications that enhance the waste energy recovery. Many methods and tools for analyzing the energy dimension in industrial chemical plants have been developed during the last two decades. These methods used mainly mathematical programming and pinch technology to determine the optimal process conditions that result in efficient use of energy in chemical process industries. Two main challenges face the industrial community in adopting these methods. The first challenge is related to the plant-wide model development time and cost as well as the combinatorial nature of the customized full-scale model of a real industrial facility. The second one is the need to search the space of all possibilities in process operating conditions modifications without exhaustive enumeration and without using heuristics that render sub-optimal solution. Furthermore the lack of a systematic technique to rigorously quantify the potential benefits, in energy saving due to in-process modifications, does not help justify the decision for very involved energy study.

This paper addresses these two challenges systematically using new interval constraint satisfaction-based technology known as TEM_icons™. It also demonstrates that significant energy saving can be realized in BPA plants through optimal in-process modifications.

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1359-4311/$ - see front matter
doi:10.1016/j.applthermaleng.2005.06.017

2. Background of energy efficiency optimization methods and tools

2.1. State-of-the-art in energy integration

State-of-the-art energy integration research through the late 1980s has been reviewed [1]. Much work has been done on energy integration since then, but it has lacked the ''break through'' influence of research done in the late seventies and the eighties [2–4]. This is especially true for commercial software development, where pinch technology is still the technique most widely used for energy integration applications.

Mixed-integer linear and non-linear programming (MILP and MINLP) have been extensively used in academic software packages [5–9]. These MILP and MINLP are now being incorporated in some commercial packages. Such widely used energy integration software packages include HX-NET by Hyprotech (recently acquired by AspenTech), SUPERTARGET by Linnhoff March (recently acquired by KBC) and HEXTRAN by Simulation Science Inc. (acquired by Foxboro, Inc.). In general, these packages lack an embedded user-friendly systematic tool to automatically include all possible process parametric and structural modifications. They also lack the ability to automatically include the energy system's operability requirements, which are necessary to define optimal design and operation of any energy system during the targeting phase [10,11].

2.2. Pinch technology and the optimization of process operating conditions

Linnhoff and Vredeveld introduced the term Pinch Technology in the early eighties of the last century [12]. A number of basic principles and tools were then added and have become the foundation of Pinch technology.

A general strategy for process modifications was established by Linnhoff and Vredeveld [12]. It was referred to as the *Plus/Minus* principle. That means to increase ''plus'' heat available above Pinch and/or heat demand below Pinch or to reduce ''minus'' heat demand above Pinch and/or heat available below Pinch. It has also been proposed to change temperatures across the pinch that will shift heat duties from one part of the process to the other that is often possible. This principle is simply treated, as the ultimate tool that provides a definite reference for any adjustment in process heat duties and indicates which process modification would be beneficial or detrimental. The problem with this principle is that it fails in some specific cases as shown by the author in another paper [13] due to the change in pinch location upon process modifications. Besides, it needs enumeration to select best set of operating conditions that can be beneficial to the plant's energy problem. This task can become impossible in huge chemical complex where the number of alternatives is enormous.

2.3. TEM_ICONS^{TM} software at a glance

TEM_icons^{TM} is an interval constraint satisfaction-based software. It contains unique capability for optimal energy systems targeting and design. It is the first user-friendly software and up to our knowledge is the only one that can globally calculate, without exhaustive enumeration, energy utility targets under all possible combinations of process parametric and structural modifications. It can also: (1) rigorously calculate these targets under all known possible combinations of process disturbances and uncertainties, and (2) define the optimal process conditions so that optimal utility consumption can be specified. It globally solves the minmin and maxmax energy problems for industrial applications [14]. Solving these two problems gives the global minimum and maximum heating and cooling utilities for any plant. These global energy targets often are not attained together due to the fact that the process conditions that lead to the global minimum in heating utility are not the same one that lead to the global minimum cooling utilities. TEM_icons^{TM} like any other modern window-based software uses the main bar of the opening window to select the task to be implemented. Double clicking the flow task in the main bar leads to the software main window. This window consists of four sub-templates named flow, network variables, ROMC (region of minimum choice) and utilities with and without integration. The first two of these four sub-templates are used for process conditions input data display and the second two are used for the calculated data display.

The flow sub-template is used to display the process data entered through an interactive window named flow. After the fill-in-the-space task of such input template, the flow sub-template displays all the process streams associated with its names, types, lower values of the supply and target temperatures and the upper values of the supply and target temperatures, status of the streams (active or in-active) and the streams flow-specific heat values. The network variables sub-template displays the desired minimum temperature difference between the hot streams to be cooled and the cold streams to be heated and the desired level of accuracy in temperature. The calculated values of global minimum heating and cooling utilities and the lower and upper values of pinch temperature region are displayed respectively in the two sub-templates named utilities with and without integration and the ROMC. Upon entering all the process conditions, in form of intervals, and specifying the desired temperature accuracy as well as the hot and cold streams minimum temperature difference, the global energy consumption values will be calculated