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Electricity cogeneration in an exothermic reactor circuit system using an open gas turbine

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HIGHLIGHTS

- The drop of pressure and temperatures in chemical processes give the available energy.
- This temperature and pressure drops could be exploited for electricity cogeneration using turbine.
- The NLP model is formulated as an optimum energy target of process integration.

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ABSTRACT

Efficient energy usage, sometimes simply called energy efficiency, is the goal of efforts to reduce the amount of energy within industries. More energy-efficient industries could reduce the problems of pollution, global warming, energy security, and fossil fuel depletion. Many chemicals are produced under high-pressure and at high temperatures and later the product cleaned under lower pressure and temperature, this energy could be exploited for electricity cogeneration using an open gas turbine within an exothermic reactor circuit system.

In the presented work, an NLP model is formulated as an optimum energy target of process integration, steam production within an exothermic reactor, and electricity generation using an open gas turbine, into an exothermic reactor circuit system. This simultaneous NLP approach can accurately account for capital cost, the integration of combined heat and power, process modification, and additional production trade-offs, and can thus yield a better solution.

This approach is illustrated using an existing, complex methanol production process as different total-efficiency for electricity cogeneration. The objective function generates a possible increase in annual profit of 1.0 MEUR/a with 50% efficiency and 1.79 MEUR/a with 60% efficiency.

1. Introduction

There are several different motivations for improving energy-efficiency. Reducing energy usage reduces energy costs and may result in a financial cost-saving for consumers if the energy savings offset any additional costs of implementing an energy-efficient technology. Reducing energy usage is also seen as a key solution to the problem of reducing emissions.

The world's consumption has been increasing rapidly. It appears that an energy-gap, the difference between consumption and the naturally-growing production of non-renewable energy sources might develop. In order to bridge this energy-gap, and also consider the additional problems of atmospheric pollution, certain policies should be considered. From amongst several options, one of them is the use of heat for a power plant [1,2]. Recent advances in gas-turbine development have led to wider-usage of combined power plant systems for electrical power generation, and made it possible to achieve plant efficiency of 55–60%. This was, amongst other factor, the result of introducing high turbine inlet temperature (TIT). However, this temperature is restricted to about 800 °C by the metallurgical limit of turbine blades. Apparently, the key technology for achieving a higher gas-inlet temperature is to maintain the surface temperatures of the turbine blades below the allowable limit through the use of a coolant. This definitely penalizes the turbine's work but is more than compensated by the gains in power output from both topping and bottoming cycles.

The gas-turbine is known to feature low capital cost, high-flexibility, high-reliability without complexity, a short delivery time, early commissioning and commercial operations, and fast starting and loading.

Open-cycle gas-turbine engines emit higher-grade heat into the atmosphere than steam turbines eject to their condensers. The combined cycle uses the exhaust heat from the gas-turbine engine

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to increase the power plant output and boost the overall efficiency to more than 55% [3,4]. This is substantially above that of the simple cycle and even higher than that of supercritical-pressure reheated steam power plants. In places where high fuel costs prevail, this can yield outstanding rates of return [5].

Gas-turbines are increasingly being used in combination with steam-cycles, either to generate electricity alone, in combined cycles, or to cogenerate both electrical power and heat for industrial processes or district heating [6]. Natural gas-fired combustion turbines and combined-cycle plants are forecast to capture over 47% of the international and 80% of the US new-generation markets over the next decade.

These combined cycle-powered plants generate electrical power at lower costs than conventional steam plants of the same rating [7]. Short lead-time gas-turbines enable utilities to meet unexpected load growth at low cost, because the combined cycles can be built in small increments [8].

A step-wise methodology for gas turbine integration, combined with heat and power cogeneration, as developed by Axelsson et al. [9] is based on pinch analysis.

Lucas [10] analyzed a co-generation system on the basis of thermodynamic laws, and thermodynamic criteria, such as plant efficiency and power to heat ratio, were been defined.

Kalitventzeff and co-authors [11] described this application within an ammonia production plant, revisiting the major rules of energy integration from the perspective of overall energy efficiency, including the combined production of heat and mechanical power for an existing process.

This paper presents electricity generation using an open gas turbine within an exothermic reactor circuit system.

2. Gas turbine within an exothermic reactor circuit system

A gas turbine is a general rotary engine that extracts energy from a flow of combustion gas. Gas turbines operate on the principle that fuel and air will burn in a combustion chamber. The outlet gas serves as a working fluid (Fig. 1). The combustable products are then expanded within a turbine, which drives an electric generator.

Most exothermic chemical process are operated within a circular system, including reactors, heat-exchangers for cooling reactors' outlets, separators for product separation, and compressors for raising the pressure when it drops a little within the heat-exchangers' (Fig. 2). Lot of heat flow is released in an exothermic reactor, which could then be used for steam production. The pressure of the crude product is drops using a valve outside the circular system, after separating in order to continue purification of the product.

The main purpose is to use existing gases during chemical processes, in order to drive a turbine. Exothermic processes, which operate within reactor under high-pressures and temperature, followed by cleaning at low pressures, can be exploited for electricity cogeneration. The high operating pressure and temperature at a reactor's outlet can be exploited to produce electricity using the open gas-turbine system (Fig. 3). A higher pressure-drop is executed within turbine but is lower in the valve outside the circular system. The available heat is less in the system since it is used to produce electricity within a generator. The exothermic reactor cools to produce steam. The cooling of the reactor can be reduced, therefore, the outlet temperature may be higher and generate more heat flow rate in order to produce electricity. Cooling within the exothermic reactor is specific to each product, because high temperatures can affect the instabilities of components within the reactor (Fig. 4). The reactor's temperature profile does not reach a maximum temperature (T_{max}) within the reactor because of a counter-flow cools with demineralized water.

The reactor acts as the combustion chamber of a gas-turbine plant. Then, separation at lower pressure and temperature follows and this pressure change can be used to drive a turbine, coupled to an electricity generator.

The high operating pressure and temperature at the reactor's outlet can be exploited to produce electricity using an open gas turbine. The open gas turbine is a basic gas turbine unit. This turbine uses processed gas as a working fluid. The working fluid comes from the exothermic reactor (R), which is cooled with demineralized water to produce steam (Φ_{SP}) and circulates through the following units (Fig. 5):

- gas turbine (T) with electric generator
- heat-exchanger (H)
- separator (S), where the liquid product separates off and
- compressor (C).

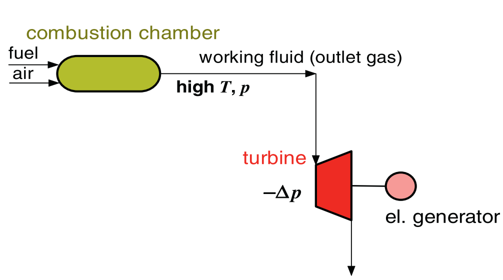

Fig. 1. Gas turbine.

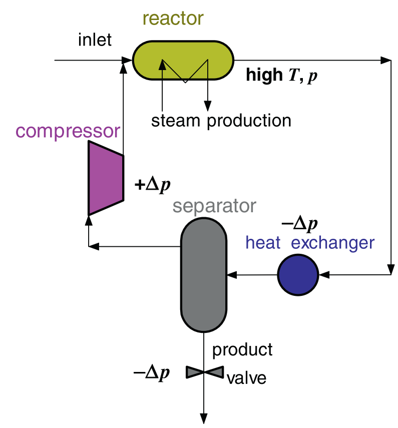

Fig. 2. Exothermic reactor circuit system.

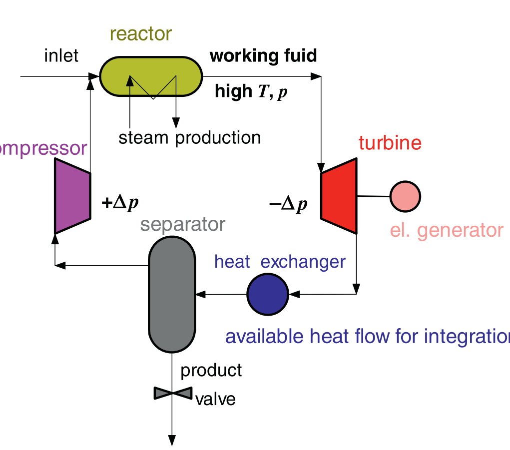

Fig. 3. Exothermic reactor circuit system including open gas turbine.