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Energy–exergy analysis and optimisation of a model sugar factory in Turkey

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ABSTRACT

This study is related to the energy and exergy analysis of a model sugar factory in Turkey. In this study, energy efficiency issue in food industries are investigated within a general context to provide energy saving by reducing energy – exergy losses in the sugar production process. The aim of this study is to determine the best energy and exergy efficiency with the mass and energy balances according to design parameters for a sugar factory. Energy savings that can be applied in food industries are examined. Appropriate scenarios are prepared, and optimization results are compared. As a result of thermodynamics calculations made according to the 1st and 2nd Laws of Thermodynamics, energy and exergy efficiencies of a factory were calculated. Factory total energy efficiency and exergy efficiency were found to be 72.2% and 37.4%, respectively, and according to these results, energy quality was found to be 0.64. In conclusion, the current turbine power process energy and exergy efficiencies were 46.4% and 27.7%, respectively, and the optimized turbine power process energy and exergy efficiencies were 48.7% and 31.7%, respectively. This study performs an attitude to the problem of exergy optimization of the turbine power plant. An overall assessment of the energy and exergy efficiency calculations is performed and is focused on how they should be.

1. Introduction

Maximum energy savings and minimal energy – exergy losses must be achieved for the profitability of enterprises. Engineering information should be used precisely for energy conservation in food industry processes. In particular, applications related to the principles of thermodynamics and heat transfer are very important for energy and exergy calculations. An inadequate understanding of energy and exergy analyses in the food industry and their low level of applicability lead to significant energy losses for enterprises. For this reason, energy losses should be minimized.

Food factories use an energy intensively. Energy must be efficiently used due to the energy being used in the food industry. It is also very important to save energy that is efficiently used. Due to the energy used in the food industry, both the protection of the environment and maximum utilization of energy used during the process are important issues. Energy analysis calculations must be performed to recover the energy lost due to the rejection of waste heat as well as energy by process in the food industry. Energy and exergy analyses of food processes make a major contribution to a business profitability. In the food industry, energy consumption is very high due to the extensive use of energy in the manufacturing process. Since, the production of the sugar process needs a steam energy. In this study, we analysed the energy and exergy of processes to get a high energy efficiency according to design parameters for the sugar factory. These hypothesis composes our study. Besides, this study can be a model for the similar studies and the food factories.

There are several similar studies in this research area. Wang [1] emphasized energy efficiency, which is very significant for the food industry. Taner [2] optimized the processes of energy efficiency for a drying plant in his studies. Çolpan [3] investigated energy, exergy and thermoeconomic analyses for a combined cycle cogeneration plant. Kotas [4] exposed the exergy method of a thermal plant through analysis. Szargut et al. [5] presented the exergy analysis of thermal, chemical and metallurgical processes. Büyükgüner [6] explored limestone-SO_2 reactivity in a circulating fluidized bed. Cengel and Boles [7] defined widespread exergy and energy terms. Dalsgard [8] determined the process integration for energy savings.

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Dincer and Rosen [9] highlighted the important aspects of energy, entropy and exergy. Genceli [10] denoted that heat exchangers are very significant in the thermodynamic area for industry. Onat et al. [11] showed a thermal calculation for steam boilers in their study. Taner [12] studied energy and exergy efficiency in his work. Yang et al. [13] presented exergy cost for waste treatment as the energy penalty for conventional exergy efficiency. Aghbashlo et al. [14] emphasized a review of the use of exergy analysis in drying operations. Ghosh and Dincer [15] introduced an energy and exergy evaluation of a new integrated system. Aviara et al. [16] studied energy and exergy analyses of native cassava starch drying in a tray dryer. Liu et al. [17] calculated the energy and exergy utilizations in the Chinese urban residential sector. Ersayin and Ozgener [18] presented the performance analysis of combined cycle power plants in their study.

A process of sugar factory is very complex process. It was applied the mass and energy balances to the process. So, this study presented exergy and exergy results of the sugar factory processes with the turbine power plant. Thermoeconomic analysis was also investigated. Previous similar studies were also explored for this study. Taner and Sivrioglu [19] analysed thermoeconomic analysis for a sugar factory. Ganjehkaviri et al. [20] studied on modelling and optimization of combined cycle power plant based on exergoeconomic. Karaali and Ozturk [21] described the thermoeconomic optimization procedure, which is a plain and influential procedure. Kim [22], Valero and Cuadra [23] researched thermoeconomic analysis for energy systems.

In this study, a detailed photo of the sugar factory under consideration is shown in Fig. 1. The left photo is a general view of the factory. The right photo is the turbine power plant.

In this study, it was executed a face to the problem of the exergy optimization of the turbine power plant. This evaluation was new for these similar researches. Kurata et al. [24] researched a micro gas turbine cogeneration system. Pellegrini and Oliviera Junior [25] presented an approach to the problem of exergy optimization of cogeneration systems in sugarcane mills. Casas et al. [26] studied the effect of the integration of Solid Oxide Fuel Cell (SOFC) technology in a sugar-ethanol factory. Deshmukh et al. [27] contrasted different cogeneration system scenarios for efficient energy production from bagasse fuel in an Indonesian sugar and ethanol factory. Vuckovic et al. [28] presented improved exergy analysis and exergoeconomic performance evaluation of thermal processes in an existing industrial plant. Palacios-Bereche et al. [29] applied thermal integration technique in their studies. Palacios-Bereche et al. [30] showed the impact on energy consumption and electricity surplus production in the cogeneration system. Arteaga-Perez et al. [31] approached to appraise the thermodynamic performance of the plant.

In this study, flue gas calculations are presented by also using the mass of fresh combustion air available in process (fresh combustion air), which is one of the input mass flows in advance of the flue gas output energy and exergy calculations (see in Appendix). These specific energy and exergy analyses were calculated as amount of actual specific combustion fresh air, mass quantity of actual specific combustion fresh air, amount of theoretical specific combustion fresh air for the fresh combustion air energy and exergy calculations. The amount of theoretical specific flue gas (fume), actual specific flue gas, mass flow of actual flue gas, ash mass flow, amount of unburned part to be burned for the flue gas output energy flow and exergy flow were calculated. In this study, sample calculations were made for the sugar factory under consideration, which is one of the leading establishments of the sugar industry of the Turkey food industry. It has been studied for some scenarios related to the process where most of the losses occurred by making separate energy and exergy analyses of the factory processes. Different scenarios were produced with respect to the steam power plant, which was the 7th process where most of the losses took place and for which it was discussed how to increase the efficiency. This was followed by the application of thermoeconomic analysis. Some calculations were carried out for the energy economy. Scenarios were designed according to these results and some proposals have been made. Improvements were applied according to the energy and exergy efficiency results, and the amount of energy that could be saved was investigated.

Statistical analysis demonstrated a precision of data. Thus, SPPSS 17.0 software programme was used for the precision of data. Aviara et al. [16] used regression equations for the relationship of energy and exergy parameters and process variables. Kalayci [32] suggested the SPSS software. Chen et al. [33] implemented statistical analysis of the parameters by using the SPSS software. Turhan et al. [34] used SPSS for assessment, approximation and prediction and developed regression models with good accuracy. Aranda et al. [35] presented regression analysis by using SPSS. In this study, all of these studies were analogized. Moreover, a techno-economic analysis of the energy efficiency and management of a sugar factory was performed.

2. Energy and exergy analysis in the food industry

Steam mass used in the food industry is used in the process stages of nearly all food industries. All issues related to energy become important where steam is present. A huge amount of energy is consumed during sugar production in the food industry. Thus, much consumption of energy puts exergy one step forward. In conclusion, the large amount of steam used in sugar production makes energy and exergy analysis important; moreover, these

Fig. 1. Photos of the sugar factory and turbine power plant.