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IMPROVING THE ECONOMIC PERFORMANCES OF THE BEET-SUGAR INDUSTRY

Bojana B. Prodanić, Aleksandar I. Jokić, Jelena Đ. Marković and Zoltan Z. Zavargo

General trend of free trade at the regional level as well as in the direction of European Union has motivated sugar factories located in Serbia to invest into technologies that are more efficient in order to make their products more competitive in the markets of Europe. Until 2005, the project of energy efficiency improvement in Serbian sugar factories was conducted in Crvenka and Žabalj. Now, they have energy consumption around 1 MJ/kg beet, in contrast to the previous consumption of 1.2 up to 1.5 MJ/kg beet. Further improvements are possible but investments would be high. A result of measurements taken during 2006, after the sugar factory „Donji Srem" - Pećinci was reconstructed showed that a considerable saving has been achieved. The first set of measurements showed that the energy consumption was 1.01 MJ/kg beet, which was 20% higher than intended, but at the same time energy savings were about 30% lower with respect to the values before the reconstruction.

KEYWORDS: Sugar factory, energy efficiency, retrofit design

INTRODUCTION

Great efforts have been made in the food production industry to minimize and, if possible, even to avoid pollution. The food and other process industries increasingly draw attention to the design of environmentally cleaner processes. In order to solve environmental problems and reach the zerowaste goal, much effort has been devoted to reuse, recycling, waste minimization, industrial ecology, eco-efficiency, corporate environmental management, sustainable production, life cycle deliberation, and other approaches. Besides the concern regarding pollution prevention, one of the issues of critical relevance in the context of sustainability, is the consumption of energy. A high amount of energy is needed to produce sugar. The excess of energy consumed in the sugar plant above the energy theoretically needed should be lowered as much as possible, in order to approach the zerowaste goal. The reduction of energy consumption in sugar production usually

Bojana B. Prodanić, B.Sc., Res. Assist., prodanic@tehnol.ns.ac.yu, Aleksandar I. Jokić, M.Sc., Assist., Jelena Đ. Marković, B.Sc., Assist., Dr. Zoltan Z. Zavargo, Prof., University of Novi Sad, Faculty of Technology, Bul. Cara Lazara 1, 21 000 Novi Sad, Serbia

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includes improvements in those energy systems comprising power plants, multiple-stage evaporators and process heating equipment. For economic and environmental reasons, there is a constant need for reconstructing sugar factories. The dominating trend is to increase the production rate and take advantage of advances in sugar technology and environment protection technologies (1). Energy efficiency is also an important issue in the factory reconstruction as the fuel cost is of the order of 10% of the overall cost of sugar production and fuel burning in the power house is responsible for a major part of atmospheric emissions.

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Evolution of multiple-stage evapoaration station

Evaporation is a unit operation in which a solution is concentrated by removing part of the solvent in the form of vapor. In 99% of the industrial cases, the solvent is water and the latent heat of evaporation is supplied by condensing steam, whose energy is transmitted to the solution by indirect heat transfer through metallic surfaces. The history of multistage evaporation is linked to the history of sugar technology. Implemented for the first time in the 19th century in a cane sugar factory in Louisiana, USA, this type of sucrose solution thickening were later adopted by the European beet–sugar industry (2). The evaporation station in sugar factory is a link between the initial process phase, characterized by low juice concentration, and crystallization of sugar from high concentration sugar syrups. A multiple-stage evaporator system is used in sugar processing in order to improve energy efficiency. The vapor needed to heat the first stage of evaporator is supplied from a boiler house, which typically incorporates a steam boiler and a steam turbine (cogeneration of heat and power), and the vapor from the first stage is used to heat the second one (and eventually other process units), and so forth. It can directly influence the energy demand through the energy loss in vapor. The requirements of sugar technology were essential in further development of evaporators. Multistage evaporator unit is one of the main heat consumers as well as the heat producers in sugar production, so it is necessary to have good performance of this part of the sugar factory in order to achieve minimal production costs. The energy demand in sugar processing is determined by four interlinked energy-intensive process stages: extraction, juice purification, evaporation, and crystallization. The energy system is composed of a boiler house, multiple-stage evaporator, and a process heating subsystem.

Owing to the surplus of sugar in the world market, new investments in beet-sugar factories are very rare. Economic factors stimulate however the concentration of sugar production and therefore retrofit investments are often necessary. Having identified the need for evaporator retrofit one has to consider the optimisation of investment for maximum use of the existing production facilities. Preferred are retrofit designs based on the use of existing evaporator units as well as their support structures. The elaboration of design details is difficult owing to the necessity of satisfying the geometric constraints of available space in which the new equipment and piping must be located. Additional difficulties may be caused by the need for simultaneous reconstruction of the heat exchanger network. Examples of evaporator retrofit are described in the literature (3). As a result, the specific energy consumption was reduced by 29% in the case of the sugar factory Krasnystaw, Poland. In the sugar factory Hohenau, Austria, a four-stage evaporator station, originally comprising four natural-circulation units and a tubular falling film unit, was reconstructed. The natural-circulation units were removed and replaced by four plate-type falling film units. Another new unit of the same type was installed on a new support structure. The reconstructed station is arranged in six stages including two pre-evaporation ones. The retrofit of the evaporator station and heat exchanger network resulted in a reduction of the specific energy consumption by 17% (2). It is known that the retrofit of evaporator station and the associated heat exchanger network can be optimised for minimum energy consumption or minimum annual cost (comprising investment and operation costs). The methodology of optimisation is based on Pinch Analysis and Network Pinch Method. Examples of optimal retrofit design can be found in the literature (1).

Process-related requirements on the evaporator station

The main structural properties of the evaporator station are the following: number of stages, flow arrangement and heat-transfer areas in the individual stages. There is a tendency to adapt the structural properties to the requirements of economic sugar production and high energy efficiency. A general requirement is that the concentration of juice in the evaporator outlet (thick juice) should be as high as possible, reaching 72-75% in most advanced factories. It is then possible to apply crystallization technologies that ensure a high sugar quality while also facilitating low energy consumption. The temperature range of evaporation is determined by the constraints of juice temperature. To avoid the deterioration of juice quality, and especially its pH and colour, the juice temperature at inlet should not exceed 128°C. To avoid uncontrolled crystal formation in thick juice (at the outlet), its temperature should be not lower than about 90°C. This relatively narrow range is to be divided into intervals corresponding to the individual evaporation stages. In an advanced evaporator station comprising six or seven stages, the average temperature interval is 6-7 K. However, as the boiling point elevation ranges from 0.5 K in the first stage to 7 K in the final one, the effective temperature interval is only 4-5 K. The natural-circulation evaporator units are insufficient for intensive heat transfer and therefore thin film units must be applied. Three types of thin film evaporator units are in use: falling film (heat transfer in tubes); falling film (heat transfer in plates) and climbing film (heat transfer in plates). Falling film units can operate at temperature differences as small as 3-4 K. When using such units in an evaporator station comprising five or six stages, a correct operation is possible at the initial juice temperature of about 121-122°C. This facilitates high quality of thick juice, making it possible to carry out sugar crystallization very efficiently.

The efficiency of energy transformation in the thermal system is influenced by the interaction between the evaporator station and crystallizers. It is essential that the vapour for crystallizer heating is supplied from an evaporation stage close to the last one. However, the saturation temperature of heating vapour must not be lower than the limiting temperature that is characteristic of crystallizer design. This effectively determines from which stage vapour can be supplied to the crystallizers. In this respect, forward-feed evaporator stations are ill suited for high concentrations of thick juice because the boiling point elevation in the final evaporation stages is large and therefore the saturation temperature of vapour is substantially lower than the juice temperature.

Numerous sugar factories have for many years operated four-stage, forward-feed evaporator stations. Owing to low energy efficiency, the simple four-stage arrangement is uneconomic at current energy prices. Where more up-to-date batch crystallizers, equipped with tubular heating chambers, are in use, the required heating-vapour temperature is 112-114^{o}C and one can apply the five-stage forward-feed arrangement. Owing to crystallizer heating with third vapour, the attainable energy efficiency is higher than in the case of four-stage evaporator stations.

However, in order to make it easier to maintain a favourable temperature distribution, the application of thin film units is desirable. In a sugar factory employing a four - or five-stage evaporator station, the energy efficiency can be improved by using fourth vapour for the crystallizer heating. However, the saturation temperature of fourth vapour in a forward-feed station is just above 100^{o}C and can be even lower in transient states. Although modern crystallizers, equipped with short heating tubes, stirrers and advanced controls, can be heated with vapours below 100^{o}C, the vapour pressure changing from above to below atmospheric pressure makes it difficult to operate the condensate recovery system. This difficulty can be avoided by combining forward and backward feed in the evaporator scheme, that is, applying the so-called pre-evaporation of incoming low-concentration juice in one or two final stages from which juice flows to the first and remaining stages. Such an arrangement facilitates higher saturation temperature of vapours in the final evaporation stages, thus improving the energy efficiency. This arrangement necessitates the use of thin - film evaporator units, and especially in the third and final stages where very large heat-transfer surfaces would be required if Robert evaporators are used.

RESULTS AND DISCUSSION

The aim of this work was to determine the difference between the planned energy consumption and energy consumption during the production of sugar after a reconstructtion of the factory. Mass and energy balances were calculated according to analytical data and the data from technological stations. Analytical data were acquired from the plant laboratory. Energy balances of some technological stations were calculated according to mass balances and temperatures correlated with tabulated data of enthalpies.

The sugar factory, located in Žabalj, Republic of Serbia, is a part of the Greek sugar concern EBZ. During 2004, multistage evaporator station was modernized by replacing old Robert evaporators with falling film plate evaporators (GEA-Ecoflex). Retrofit design was implemented on the second, third and fourth effect of this five - stage evaporation station. This means that, in the old vessels of the Robert evaporators, tube bundles were replaced by plate packets. In this way, it is possible to increase surface because plate packets are more compact. Before 2005 campaign, there were no further changes in the process of sugar production, so it was possible to evaluate the effects of falling film plate evaporators on the energy consumption, as well as to validate performance of this type of evaporators. During the reconstruction of Šajkaška sugar factory the aim was to achieve fuel consumption of 100 MJ per 100 kg of sugar beet (4).

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As was expected, the energy consumption had lowest value, about 6% higher than planned, during the first decade. In this period, *i. e.* at the beginning of the campaign, the evaporators surfaces were clean and the values of heat transfer coefficient were the highest. Changes of the coefficient of heat transmission (i.e. *k* values), for plate evaporators used in the evaporation process are shown in Figs. 1 - 3. It can be seen that these values for all stages had a decreasing trend from the start to the end of the campaign. During the second decade, an increase of the scale on the plate surfaces led to a decrease of the *k* values in all stages, and consequently the energy demand increased, which resulted in the 11% higher energy consumption than planned. Another reason for increased energy demand was the lower air temperatures during this period of sugar production that resulted in higher energy losses. Therefore, in the third decade the further scale deposition on the evaporator surfaces, as well as further temperature decline, led to the 16% increase in the energy consumption.

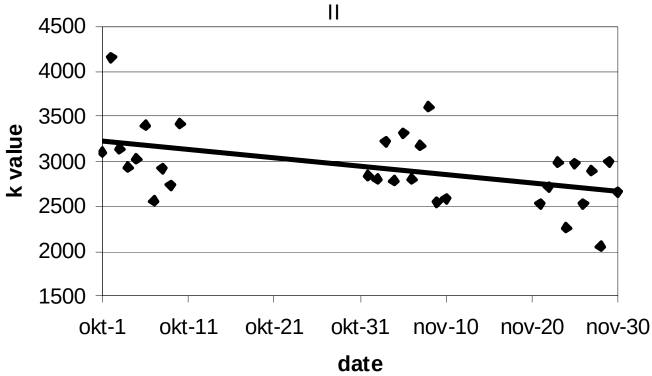

Figure 1. Changes of the coefficient of heat transmission for the second stage with falling film plate evaporators

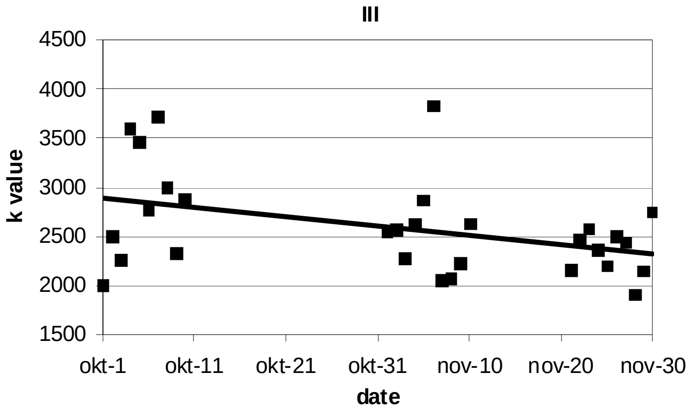

Figure 2. Changes of the coefficient of heat transmission for the third stage with falling film plate evaporators

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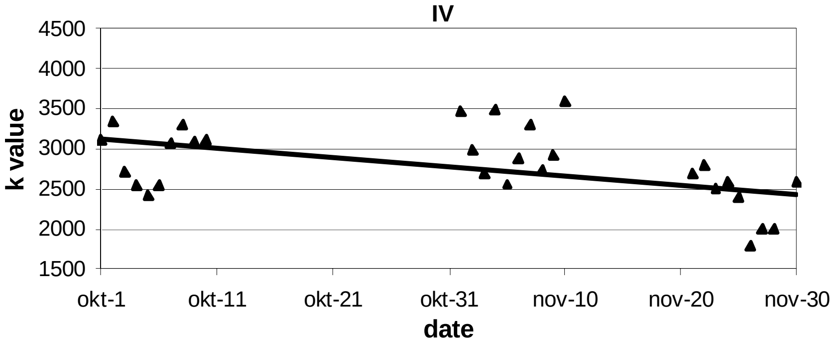

Figure 3. Changes of the coefficient of heat transmission for the fourth stage with falling film plate evaporators

The aim of the reconstruction of the Pećinci sugar factory was to reduce energy consumption to the level of 0.8 MJ/kg beet. Retrofit design was implemented on the evaporator stages where plate cassettes were inserted in the exsisting Robert evaporator vessels, while further improvement was achieved by implementing pre-evaporation in the fourth stage of the evaporation station. Measurements data taken in the 2006 campaign, point out to significant savings in the energy consumption. In the first series of measurements, average energy consumption was 1.01 MJ/kg of beat, which is 20% more than it was planned, but on the other hand the original fuel consumption was lowered by 30%. In the 2004 campaign, the factory had specific energy consumption in sugar production of 1.56 MJ/kg of beet, which is equivalent to 39 kg fuel/t of beet. Based on 3 series of measurements carried out, in the 2006 campaign, the energy consumption in sugar production was in average 1.03 MJ/kg of beet, which is equivalent to 26.6 kg of fuel/ t of beet. Saving in fuel consumption was 39-26.6=12.4 kg of fuel/t of beet. In the 2006 campaign, the Pećinci sugar factory refined 443,155 t of beet with 5495.1 t of fuel saving.

CONCLUSION

After retrofit design of the existing Robert evaporator vessels, they were used as vessels for new falling film evaporators (GEA-Ecoflex). In this way, the energy consumption in the Šajkaška sugar factory was reduced by about 20% in comparison with the previous consumption. Continuous monitoring of the factory performance carried out during the 2005 campaign showed good thermal performance of the falling film evaporators, which is in good agreement with the available literature data. At the same time, there are some possibilities for further decrease in energy demand through certain changes in the steam distribution. In the Pećinci sugar factory most of these shortcomings related to mechanical problems were eliminated during the campaign thanks to the newly installed equipment. Thus, it can be expected that the energy demand for sugar production, in the next campaign, will be lower since there will be not discontinuity in the process when all parts of the equipment function properly.

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ПОБОЉШАЊЕ ЕКОНОМСКИХ КАРАКТЕРИСТИКА (СМАЊЕЊЕ ПОТРОШЊЕ ЕНЕРГИЈЕ) У ИНДУСТРИЈИ ШЕЋЕРА

Бојана Б. Проданић, Александар И. Јокић, Јелена Ђ. Марковић и Золтан З. Заварго

Општи тренд слободне трговине на регионалном нивоу мотивисао је фабрике шећера у Србији да улажу у ефикаснију технологију, чинећи свој производ конкурентнијим на европском тржишту. До 2005. пројекат побољшања енергетске ефикасности фабрика шећера у Србији обухватио је шећеране у Црвенки и Жабљу. Ове шећеране су смањиле ниво потрошње енергије у производњи шећера од око 1 MJ/кг репе, у односу на раније стање када је потрошња била од 1,2 до 1,5 MJ/кг репе. Даља побољшања су могућа, али би инвестиције биле веома велике. Резултати мерења спроведени током кампање прераде репе 2006, после реконструкције фабрике „Доњи Срем“-Пећинци, показују значајну уштеду у потрошњи енергије. У првој серији мерења потрошња енергије је износила 1,01 MJ/кг репе, што представља за 20% веће вредности од планираних, али у исто време је остварена уштеда у потрошњи енергије од око 30% у односу на потрошњу пре реконструкције.

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