PERFORMANCE OF FALLING FILM PLATE EVAPORATORS IN RECONSTRUCTED MULTIPLE-EFFECT EVAPORATION STATION IN SUGAR FACTORY

by

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General trend of free trade in 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 at the markets in Europe. The aim of this work was to evaluate effects of falling film plate evaporators on the energy consumption of evaporation plant, as well as to validate performance of this type of evaporators. It was found that this type of evaporator decreased energy requirements and in the same time evaporation process was more effective due to high values of heat transfer coefficients.

Key words: *sugar industry, falling film plate evaporator, heat transfer coefficient*

Introduction

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 [1].

The history of multistage evaporation is linked to the history of sugar technology. Implemented for the first time in 1844 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 link between the initial process part characterized by low juice concentration and crystallization of sugar from high concentration sugar syrups. It can directly influence the energy demand through energy loss in vapour. The requirements of sugar technology were essential in further development of evaporators.

For economic and environmental reasons, there is a constant need of reconstruction of sugar factories. The dominating trend is to increase the production rate and take advantage of advances in sugar technology and environment protection technologies [3].

Energy efficiency is also an important issue in factory reconstruction as the fuel cost is of the order of 10% of the overall cost of sugar production and fuel burning in the powerhouse is responsible for major part of atmospheric emissions. Multistage evaporator unit is one of the main heat consumer as well as the heat producer in sugar production, so it is necessary to have good performance of this part of the sugar factory in order to achieve minimal production cost.

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Choice of evaporator for multistage evaporator station in sugar factory

For decades, the sugar technologist has been restricted in choice to variations of Roberts or tube bundle falling film evaporators, which were been introduced into sugar industry during 1960's [4]. In last 15 years, continued demand for increase in capacity and simultaneously decrease in steam demand has led to development of plate evaporators.

There are two different types of plate evaporators: falling film and raising film. Raising film evaporators utilize thermal energy to both transport and concentrate the sugar juice within the evaporator (Roberts, Alfa Laval and *etc*.), while falling film evaporators separate this functions; transport is achieved by electrical energy (through pumping) whilst utilizing thermal energy to concentrate the juice.

Figure 1 presents the characteristic values of heat transfer coefficient (*k*-value) of falling film tube and Robert evaporators compared with *k*-values obtained from the pi-

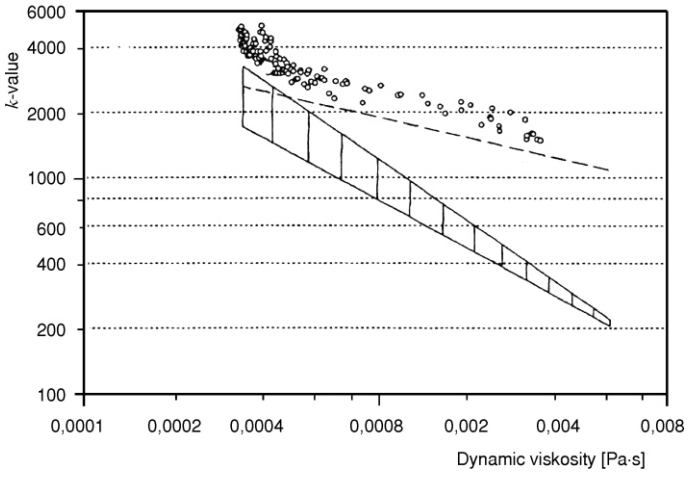

Figure 1. *k*-values of different evaporators [4]
○ *k-values pilot plant Berlin Technical University (falling film plate evaporator);*
- - *characteristic k-values of tube bundle falling film evaporator;*
— *characteristic k-values of Robert type evaporator*

lot plant falling film evaporator of the Berlin Technical University [4]. As it can be seen, the highest *k*-values are obtained for falling film plate evaporators.

The falling film plate evaporator permits evaporation at an effective temperature difference between saturated steam and juice, which is significantly lower than with conventional evaporators [5]. Besides better thermal performance of falling film plate evaporators their advantage is also better juice quality and in that way quality of final product, sugar, considering it's color.

Multistage evaporator station in sugar factory Sajkaska, Zabalj

Sugar factory located in Zabalj, Serbia, is part of 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. Advantages of the retrofit concept are:

- double heating surfaces in existing vessels,
- increasing the capacity without enlarging the factory's foundations,
- savings up to 50% on capital expenditure if compared to new units,
- conversation of energy, and
- improved product quality and higher product yield thanks to a shorter retention time.

Before 2005 campaign, there were no further changes in process of sugar production so it was possible to evaluate effects of falling film plate evaporators on the energy consumption, as well as to validate performance of this type of evaporators.

Necessary measurements were kindly obtained from sugar factory and it was processed using computer program developed at Institute for Sugar Technology in Novi Sad, Serbia. Parameters needed for calculation of sugar balance are measured in factory laboratory every hour, which implies that all parameters used for calculation are average values for 24 measurements during each day.

For performance evaluation of falling film plate evaporators three decades were selected: October 1-10, November 1-10, and November 21-30. In this way, the process was monitored during the whole campaign.

Results and discussion

Energy demand of reconstructed sugar factory

During reconstruction of Sajkaska sugar factory the aim was to achieve fuel consumption of 100 MJ per 100 kg of sugar beet. As it was said earlier, only the evaporator

station was reconstructed by the beginning of 2005 campaign so it is justified to assume that it is the main source of potential energy savings.

As it was expected, energy consumption had lowest value, about 6% higher than planned, during the first decade. At this period *i. e*. at the beginning of campaign, evaporator surfaces are clean and the values of heat transfer coefficient are the highest.

Change of *k*-values for plate evaporators used in evaporation process are shown in fig. 2. It can be seen that this values for all stages had decreasing trend from the start to the end of campaign. During second decade, increase of the scale on the plate surfaces led to decrease of *k*-values in all stages so consequently energy demand increases which resulted in 11% higher energy consumption than planned.

Another reason for increased energy demand lies in lower air temperatures during this period of sugar production that resulted in higher energy loss. Therefore, in third decade the further scale deposition on evaporator surfaces as well as further temperature decline led to 16% increase in energy consumption.

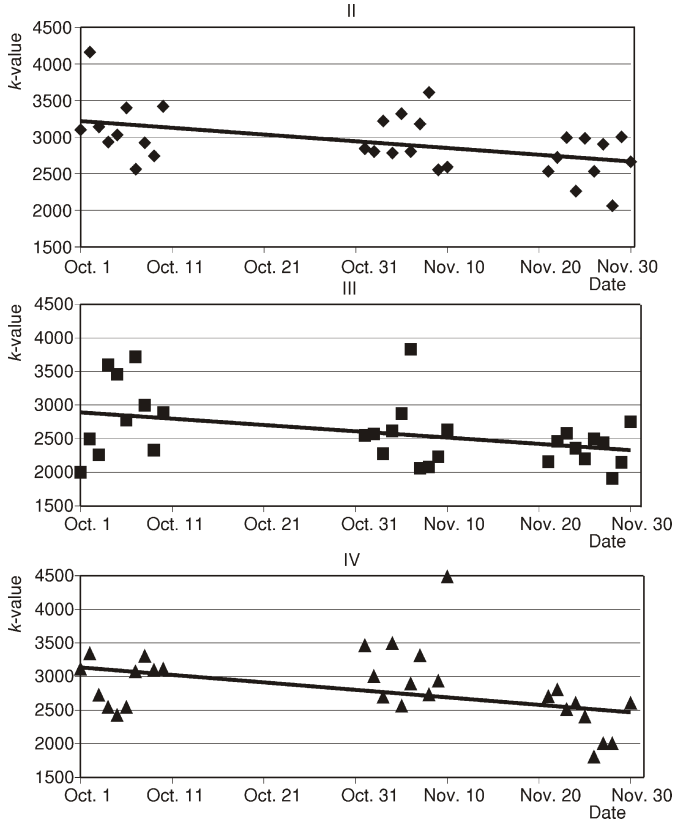

Figure 2. *k*-values of stages with falling film plate evaporators during 2005 campaign

Thermal performance of falling film plate evaporators

To carry out an objective comparison between different evaporator types from the aspect of thermal performance features of the juice like viscosity, wall thickness, effective temperature difference has to be considered [4]. Typical operating data of multi-stage evaporation station are shown in tab. 1.

Table 1. Typical operating data for falling film evaporators in Sajkaska sugar factory

Avrege values during II decade	II stage	III stage	IV stage
Heating surface [m^2]	2800	2800	1900
Juice flow in [kg/100 kg beet]	102.28	66.90	35.20
Juice flow out [kg/100 kg beet]	66.90	35.20	25.02
Water evaporated [kg/100 kg beet]	33.38	31.70	10.18
Juice inlet brix	14.33	21.48	40.83
Juice outlet brix	21.48	40.83	57.45
k-value [W/m^2K]	3041	2572	3154
T [K]	5.35	5.68	2.29

For all stages with falling film evaporators *k* values in function of dynamic viscosity are shown in fig. 3. As it can be seen from this figure *k*-values for monitored decreases with increase of dry mater content in juice. The only exception is the fourth stage was increase in *k*-value was registered. The reason for this may be in increased consumption of secondary steam from previous stage in order to achieve desired juice concentration, because of unfinished reconstruction of sugar factory during the 2005 campaign, which in fact runs as four-stage evaporation plant. That is also one more reason for increased energy consumption that can be avoided by corrections of stem distribution system.

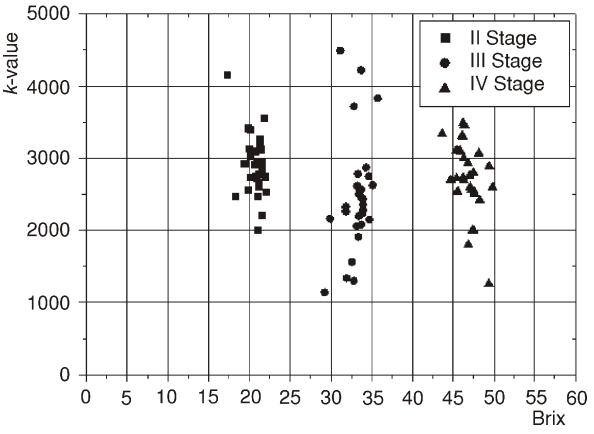

Figure 3. *k*-values of falling film plate evaporators

For all stages with falling film evaporators *k*-values in function of dynamic viscosity are shown in fig. 4. Although a number of falling film plate evaporators was installed throughout sugar industry

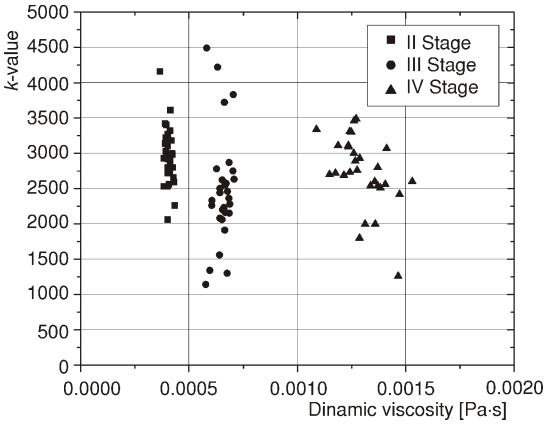

Figure 4. *k* values of falling film plate evaporators

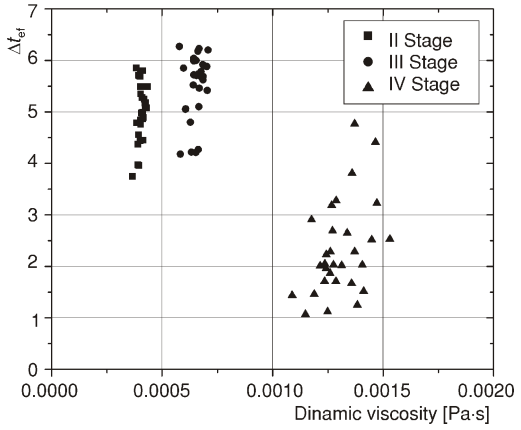

Figure 5. Values of effective temperature difference for falling film plate evaporators

there is not a lot of literature data about their *k*-values and hence limiting availability of practical data and because of that comparison of results with the help of this kind of diagrams is not yet exact [4, 5]. As it can be seen from fig. 4 experimental *k*-values are in good agreement with results obtained from the pilot plant falling film plate evaporator of the Berlin Technical University [4].

For the second stage average *k*--value for each decade was in range from 3140 W/m^{2}K for the start of campaign to 2600 W/m^{2}K at the end. During the campaign average *k*--values of third stage also had trend of decreasing values but not as significant as for the first stage. The fourth stage of evaporation process showed similar behavior, as the first stage and *k*-values are in range between 2900 W/m^{2}K at the beginning and 2300 W/m^{2}K at the end of the campaign.

For all stages with falling film evaporators values of effective temperature difference Δt_{ef} in function of dynamic viscosity are shown in fig. 5. One of the main advantages of falling film plate evaporators is their ability to work at low values of effective temperature difference and in that way, it is possible to reduce the turbine exhaust pressure [5]. However, as it can be seen from fig. 5 effective temperature difference could be lower for the second and the third stage (average values 5 K and 5.6 K, respectively).

Conclusions

By retrofit design of existing Robert evaporator vessels were used as vessels for new falling film evaporators (GEA-Ecoflex). In this way, energy consumption of Sajkaska sugar factory was reduced for about 20% in comparison with previous con-

sumption. A result of continues monitoring of factory performance done during 2005 campaign showed good thermal performance of falling film evaporators that are in good agreement with available literature data. At the same time, there are some possibilities for further decrease in energy demand through some changes in steam distribution.

Acknowledgments

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