Web-based application for analyzing the operation and optimising processing in sugar mills

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Abstract Increased competitive pressures and technological advances in computerisation have led to the development of simulation software in different industries. Sugars™ is the commercial software that has been mostly used in the sugar industry. These software products can have a fundamental role in the decision-making process for sugar-producing companies. Using modern simulation software, engineers can complete an accurate computer model of the sugar plant or its refinery to assess the process or equipment more efficiently than existing facilities have done. Assessments which previously took weeks can now be done in minutes, precisely and in more detail than previously possible. The results are more accurate decisions that can potentially save substantial investment costs and, at the same time, generate more revenue for the company lowest cost sugar production. The main objective of this research was to develop a web-based application that could simultaneously monitor, model, simulate, optimise and control. Solving this problem requires optimising more than 100 related linear and non-linear equations to reach optimum extraction and mass balance. Data are collected through a SQL Server database and then an application uses the input data to determine the optimum set points for control parameters of the plant. A case study of mill modelling is given to help determine better settings of the mills under different working condition. Finally, the practical model is used in a case study of a boiling system to evaluate the operational data.

Key words Modelling, optimisation, sugar process, business intelligence, visualisation

INTRODUCTION

In recent years, advances in computing technology have allowed the simulation of many industrial processes with high precision. Application of previous trial-and-error methods to achieve the best results can be very costly and sometimes dangerous during real-time operation, so process engineers have wanted to use lower cost methods. Process simulation is one of the best possible aids to fulfil this idea (Guthrie 1972). To date, the application of process simulation has been based on mass and energy balances, especially in the oil, gas and petrochemical industries (Radek 1995). Sugars™ is the only commercially available software package that is capable of performing mass and energy balance calculations specifically for the sugar industry (Stolz and Weiss 1997).

Engineers in the sugar industry are using either enterprise resource planning or computer process simulation software. Integration between different software means that modelling can be improved by applying process constraints to the actual daily data. Fortunately, new simulators have the ability to participate in these important activities because of the ease of communicating with the database and its open architecture (Banks 1997).

Today, the ability to connect management systems with accounting, planning, and operation controls will assist to develop strategic relations among operators, managers and stakeholders. In this way, it is possible to predict the production, allocation of production capacity and resource planning and scheduling. It can then connect to the management system for graphical reports that are required by managers. By using data obtained from simulation techniques, managers can make decisions and plan with greater certainty about the cost management, budget and allocation of human resources (Banks 1997).

Sugar Cane and By Products Development Company is the largest sugar producer in Iran, with an annual production of 700,000 t of white sugar, i.e. half of the country's sugar production. The mother company has seven agro-industrial companies that cover the cultivation area of 84,000 ha and produce 7,000,000 t of sugarcane each harvest. The Iranian Sugarcane Training and Research Institute is responsible for training and research in both agriculture and industry. The Institution initiated the idea of designing a comprehensive management platform using business intelligence (BI) to gather information for managers to make the best decisions.
BI is a set of techniques and tools for the acquisition and transformation of raw data into meaningful and useful information. The goal of BI is to allow the easy interpretation of large volumes of data (Chugh and Grandhi 2013). BI technologies provide historical, current and predictive views of process operations. BI is most effective when a company’s operations (external data) are combined with data from the company’s internal sources, process operational data (internal data), to create ‘intelligence’ (Rud 2009).

Such an application aims at three main objectives:

1. Processing and transmission of useful data to managers for planning, better process control and navigation by means of a web-based application that allows its use anytime and anyplace, without any restriction.
2. Performance analysis to compare the current result with the target and standard operating points and what the reasons are for deviations. Since large amounts of data need to be considered for the analysis, much time should be spent in the calculation of the necessary data. While in operation, there is not enough time to accurately calculate all parameters. By using this application, the analysis of the current and desired status can be reported. Then with the aid of simulation, solutions can be studied for improvement.
3. Optimisation is performed to determine the best operating set point. Selecting the best method depends on the type of optimisation problem. Since the restrictions in this case are functions of the parameters and equations are dependent, solving this kind of problem is very complex. Optimisation in this application has two different approaches, theoretical and practical optimisation. In theoretical, the optimisation determines the maximum possible achievement, whereas practical optimisation considers actual equipment and system behaviour. For example as for some problems, the efficiency of the B boiling in a factory has some limitations and it should be considered in practical optimisation to reach the best practical point.

MATERIALS AND METHODS

Mill modeling

To choose the best model, several mill models were studied and the Thaval and Kent (2012) model was chosen as the base model. In this model, five mills are linked together in the milling tandem. The relation between fibre extraction and separation parts is based on mass balance. The mill model uses four coefficients to determine how to divide the fibre, soluble solids (brix), pol and moisture entering the mill, between bagasse and juice. The coefficients are:

- Filling ratio;
- Reabsorption factor, which describes the separation of juice from bagasse;
- Imbibition coefficient to determine the separation of soluble solids from the juice brix trapped in the bagasse fibre; and
- Separation efficiency of the juice, which is used to evaluate the separation of fibre from juice.

The filling ratio and reabsorption factor are directly associated with the mill settings and simultaneously used for solving the optimisation equations. Constraints of the extraction are the maximum practical extraction of each mill, fibre separation, the purity of the last expressed juice and the quantity of imbibition. In addition, the targets are the moisture and pol of the final bagasse.

Clarification and evaporation

The main objective of clarification is to remove insoluble impurities by developing and settling mud flocs. According to the suspended solids content of the mixed juice, the amount of mud is calculated and compared with its actual value. In addition, inversion is calculated by using the process conditions from the heat exchangers through to syrup and compared with the ideal process inversion losses. The Vukov formula (Vukov 1965) is used to calculate the inversion rate of sucrose. There is no optimisation used in this section. The target is to reduce the amount of losses therefore equipment should be controlled by the ideal operating conditions to reduce the mud and inversion losses (Rein 2007).

Raw sugar boiling

Boiling is an important part of the sugar production process and responsible for crystallising sucrose from the syrup to produce crystal sugar. Sugar is processed in the three massecuite boiling scheme as shown in Figure 1. During the boiling of syrup, the intermediate products such as A massecuite and A molasses are produced. For each product there is a series
of characteristics such as volume, mass, brix, pol and purity that have standard equations relating these characteristics such as the relationship of purity with pol and brix. On the other hand, the mass balance between the combinations of these products has other more complicated equations that determine how materials are divided between different product streams. According to the three massecuite boiling scheme, the products of each massecuite will have an effect on the other massecuites.

Fig. 1. A three massecuite boiling scheme.

Solving these equations has two approaches, analysis and optimisation. In the detailed analysis, production and consumption of each product is evaluated and compared with the practical reports, such as A molasses usage in B and C massecuites. Solving the optimisation has recommendations for better utilisation of capacity and system to approach the theoretical efficiency according to the SJM formula. In other words, the main target is to optimise the parameters in the different massecuites in order to reach SJM efficiency as closely as possible. In addition, the storages and other boiling capacities, along with the elapsed time should be considered in boiling optimisation. Constraints, such as A/B massecuite ratio (i.e. A massecuite tonnage to B massecuite tonnage), each massecuite efficiency (sugar tonnage/massecuite tonnage), purity of final molasses are applied (Chen and Chou 1993).

Refinery

The refinery consists of two main processes, purification and crystallisation. In the refining of raw sugar, the dissolved impurities are reduced in the first stages and then crystallisation produces white crystal sugar. In the first stages of sugar refining, only pol loss is calculated and practical efficiency is compared with standard efficiency. White sugar boiling is the same as raw boiling, just by changing the boiling system to simple boiling in the series system. When the two boiling (raw and refinery) equations are solved simultaneously to calculate precisely the amount of final runoff that comes from refinery back to the raw house.

Energy

Reducing the energy consumption is an important role of energy management. In the production of sugar from cane with its high consumption of steam, energy is of particular importance. This application evaluates the interaction between
process parameters and steam consumption, based on calculating the optimal process parameters. Enhancing the syrup brix, reducing fluctuations in steam consumption and improving the boiling plan are cases that the application has considered. The brix in each evaporator body is adjusted so that the maximum energy recovery occurs. Solving simultaneous equations in boiling and steam consumption can lead to a sustainable system. Reducing the fluctuations in steam consumption can result in achieving the optimum steam flow.

Optimisation

The purpose of optimisation is to find the best acceptable solution, within the constraints. One problem may have different solutions for comparing them and to choose the optimal solution, the target function is defined. Selecting this function depends on the nature of the problem. However, the selection of the appropriate target function is one of the most important steps in optimisation. The optimisation problems that involve multiple target functions are called multi-objective problems. The goal of optimisation is to determine the design variables so that the target function is minimum or maximum and sometimes approaching the fixed target value. In the different sections of the application optimisation models described previously, it is important to solve the models according to the constraints. Constraint equations are as equal or unequal and also they may be a function of variables that make it difficult to solve. There are different optimisation methods to solve these complex equations; in this application we use mainly linear and quadratic methods. However, constraints determine and validate the acceptable range of optimised parameters. The application optimisation shows as follows:

Minimise or maximise (fixed target): $F(x)$
Subject to: $g_i(x)\leq 0$ $i = 1, 2, 3, \ldots, p$
$h_j(x)=0$ $j = 1, 2, 3, \ldots, q$
$X_{k^{\text{min}}}< X_k < X_{k^{\text{max}}}$ $k = 1, 2, 3, \ldots, n$

The function $F(x)$ is the target function. The design variables are bounded by $X_{k^{\text{min}}}$ and $X_{k^{\text{max}}}$. The constraints $g_i$ are called inequality constraints and $h_j$ are called equality constraints (Arora 2015).

Business intelligence and visualisation

The application structure consists of the following modules as can be seen in Figure 2:
- tools to extract, transform and load data (ETL) – they are mainly responsible for data transfer from transaction systems and the Internet to data warehouses;
- data warehouses – they provide some room for thematic storing of aggregated and already analysed data;
- analytical tools (OLAP, On-Line Analytical Processing) – they allow users access, analyse and model business problems and share information that is stored in data warehouses;
- tools for reporting and ad hoc inquiring – they allow for creating and utilising different synthetic reports;
- presentation layer – applications including graphic and multimedia interfaces whose task is to provide users with information in a comfortable and accessible form (Olszak 2006).

![Fig. 2. Business intelligence process.](image-url)
Application specification

Application with the ability to gather, store, process and report visually is essential for this work. There are many technologies (Table 1) that are involved from the beginning to the end of programming.

Table 1. Available technologies used in this web-based application.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTML5</td>
<td>HTML is a markup language for describing web documents (web pages).</td>
</tr>
<tr>
<td>CSS3</td>
<td>CSS3 is a Stylesheet language that describes the presentation of an HTML document.</td>
</tr>
<tr>
<td>Java Script</td>
<td>JavaScript is the programming language of HTML and the Web.</td>
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<tr>
<td>Jquery</td>
<td></td>
</tr>
<tr>
<td>Bootstrap3</td>
<td>HTML, CSS and java script framework for developing responsive website.</td>
</tr>
<tr>
<td>Ajax</td>
<td>For making asynchronous request using client side scripting</td>
</tr>
<tr>
<td>.Net Framework 4.6</td>
<td>Is a platform upon which developers can build software application.</td>
</tr>
<tr>
<td>ASP.Net MVC Using C#</td>
<td>A framework for building web application using a MVC design.</td>
</tr>
<tr>
<td>SQL Server</td>
<td>Relational Database Server</td>
</tr>
<tr>
<td>Microsoft Analysis Services</td>
<td>SQL Analysis Services(SSAS)</td>
</tr>
<tr>
<td>BIDS</td>
<td>Business Intelligence Development Studio</td>
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The main features of this web base application are:
- Accessibility: Unlike traditional applications, web systems are accessible anytime, anywhere
- Personalisation: The user has access to the history of his activities
- Responsive: the dashboard is available on many different devices
- BI: Data analysis and visualisation
- Performance: Using Technologies to make quick page loading
- Security: User authentication and authorisation
- User Friendly: Simplification, Readability & Contrast, interactive design
- User experience and usability:
  - Going where the action is: understanding users in context
  - Site structure and navigation: finding is the new doing
  - What next? Putting your knowledge into practice
  - Simple rules for designing simple pages

RESULTS AND DISCUSSION

Mill model

Filling ratio

Filling ratio is the non-dimensional representation of the delivery setting of the mill. It is defined as the no-void volume of fibre per unit escribed volume where the no-void volume is the volume without entrapped air. The filling ratio definition for a mill is based on bagasse occupying the escribed volume of the delivery roller. In practice, the filling ratio is a function of mechanical loading and control parameters of the milling unit. As can be seen in Figure 3, the filling ratio is increasing in the mill tandem as expected.

Reabsorption factor

If the no-void volume of bagasse leaving a mill in unit time is measured, it is found in most cases to be in excess of the escribed volume of the delivery nip. Hence, juice which ideally should be extracted must be passing the feed side of the delivery rollers through the work opening to the delivery side. Reabsorption factor is a term used to describe this
phenomenon. Reabsorption factor represents the volumetric juice extraction performance of the mill. Reabsorption factor increases from the first to the last mill.

**Imbibition coefficient**

The imbibition coefficient is defined as the ratio of the actual brix extraction to the theoretical brix extraction of the mill (assuming perfect mixing of the imbibition liquid and residual juice in bagasse from the previous mill). It is a measure of the performance of the mill in extracting brix. Measurements show that the imbibition coefficient decreases along the milling train, because the difference between the brix fraction of the juice in the bagasse, and the brix fraction in the imbibition applied to it increases for later mills in the train. This gradient occurs because, after initial cell breakage in the preparation devices, there is only a small increase in the proportion of broken cells along the train, and extraction of brix is mainly a washing process. Figure 3 as a case study, shows that imbibition coefficient is about 104 for the first mill and 97 for the second mill and decreasing to 77 for the final mill.

**Fig. 3.** Mill settings.
Mill extraction

The most important point in this section is the interaction between mill setting parameters and extraction of the mill (Fig. 3). The fibre has affected the filling ratio and the nip values can be determined. Finally, adjusting capacity and other process parameters by the mill settings and thereby optimising the extraction is the main purpose of this modeling (Fig. 4).

Pan boiling model

One of the major bottlenecks in the capacity of the sugar cane factory is boiling capacity. The art of boiling in this case is using the right strategy to maximise the available capacity and, therefore, a suitable boiling program that is done for this particular company. A and B massecuites are batch boilings and the C massecuite has the continuous boiling system. The capacity of the batch pans determines boiling capacity and, therefore, the capacity of syrup consumption. Applying the full capacity usage can achieve practical optimal values for this capacity. Three pans are for massecuite A with the volumetric capacity of 60 m$^3$ each. A single boiling of A massecuite is performed in 6 hours. Thus, A massecuite production capacity is about 30 m$^3$ per hour.

$$A_{mass(daily)} = 60 \text{ m}^3 (\text{pan vol. capacity}) \times 3 (\text{No. of A Pans}) \times \frac{24}{6 (\text{each batch time})} = 720 \text{ m}^3/\text{day}$$
B massecuite boiling with two cuts is carried out for 4 hours.

\[ B \text{ mass(daily)} = 60 \text{ m}^3(\text{pan vol. capacity}) \times 2(\text{No. of B Pans}) \times \frac{24}{4(\text{each batch time})} = 720 \text{ m}^3/\text{day} \]

The result of this application is the optimal use of capacity under different process conditions (Fig. 5). A syrup rate of 73.4 m\(^3\)/h at 65 brix is needed for boiling A and B massecuite. In optimum conditions approximately 40% of syrup goes to A massecuite and 60% to B massecuite as well as the input of 10,385 tcd sugarcane. According to the daily capacity of syrup and storage capacity of 275 m\(^3\), there are 3.75 hours for accumulation during a factory stoppage. For other process streams the capacities are 8.27 h for A molasses, 3.58 h for B molasses and 6.75 h of C melt.

Fig. 5. Boiling house results.
Business intelligence for managerial dashboards

As can be seen in the main chart of Figure 6, the basis of calculation is the sugar content in sugarcane. Then, step by step, the amount of sugar remaining in the output of each process stage such as mixed juice, syrup, etc are calculated, reported and compared with planning. For example in the pol chart in Figure 6, each factory can see the pol in the cane, mixed juice, syrup and in the sugar. The difference in bar height between the pol in cane and in the mixed juice represents the pol loss in bagasse at the milling tandem. Theoretical pol losses according to raw sugar quality in the refining of raw sugar are reported and compared in the right corner of Figure 6 for the seven factories. The amount of energy consumed compared to planned consumption can be observed in the middle right of Figure 6.

![Managerial homepage](image)

*Fig. 6. Managerial homepage.*

How to use different feeds in the different massecuites is easily visible at a glance in the left top of the Figure 7. This information is obtained from detailed calculations. Boiling efficiency in comparison with the optimal value can be seen in the other charts. Tonnes pol for the different massecuites have been reported. The quantities and purities of the different pan stage materials during production can be observed in Figure 7.
Fig. 7. Boiling house trends.
Quantitative parameter trends such as the preparation index, imbibition water, etc. can be seen in Figure 8. Changes in brix, fibre and water can be seen for each part of the mill tandem to highlight any problem at a mill as well as trends of different process parameters (Fig. 8).

**Fig. 8.** Milling house trends.

**CONCLUSIONS**

New technologies available on the web and database applications, along with the experience and expertise of sugar technologists can introduce a web-based application that clients can access universally and has availability everywhere. In summary, the main purpose of the application we developed is to help managers and sugar technologists to make decisions with respect to data processing and operating conditions by using optimisation and business intelligence modules. Future activities in order to connect the application to factory control systems are in progress.

**REFERENCES**


Aplicación basada en web para el análisis del funcionamiento y la optimización de procesamiento en los ingenios de azúcar

Resumen. El aumento de las presiones competitivas y los avances tecnológicos en la informatización han llevado al desarrollo de software de simulación en diferentes industrias. Sugars™ es el software comercial que se ha utilizado principalmente en la industria azucarera. Estos productos de software pueden tener un papel fundamental en el proceso de toma de decisiones para las empresas productoras de azúcar. El uso de software de simulación moderno, los ingenieros pueden completar un modelo de computadora exacto de la planta de azúcar o su refinería para evaluar el proceso o el equipo más eficientemente que las instalaciones existentes han hecho. Las evaluaciones, que antes tardaban semanas ahora se puede hacer en cuestión de minutos, de forma precisa y con mayor detalle que antes era posible. Los resultados son decisiones más precisas que potencialmente pueden ahorrar costos de inversión considerables y, al mismo tiempo, generar más ingresos para la compañía de producción de azúcar más bajo costo. El objetivo principal de esta investigación fue desarrollar una aplicación basada en la web que a la vez podría supervisar, modelar, simular, optimizar y controlar. La solución de este problema requiere la optimización de más de 100 ecuaciones lineales relacionados y no lineales para llegar a la extracción óptima y el equilibrio de masas. Los datos se recogen a través de una base de datos SQL Server y una aplicación utiliza los datos de entrada para determinar los puntos de ajuste óptimos para los parámetros de control de la planta. Un estudio de caso del modelado del molino se da para ayudar a determinar mejor la configuración de los molinos bajo diferentes condiciones de trabajo. Finalmente, el modelo práctico se utiliza en un estudio de caso de un sistema de ebullición para evaluar los datos de funcionamiento.

Palabras clave: Modelado, optimización, proceso de azúcar, inteligencia empresarial, visualización