How nonlinear models help operate a rosin distillation column more efficiently

Introduction

Economic conditions drive industries towards more efficient operation of their production processes. More efficient operation often means improvements in several variables which might conflict with each other, like quality sometimes comes at the cost of production rate and higher energy consumption. To determine the best operating conditions, it is necessary to have the knowledge of quantitative effects of several variables on consequences of interest. These relations tend to be complicated, and physical models do not usually describe industrial production processes accurately enough. Empirical and semi-empirical modeling approaches, on the other hand, do not necessitate any significant assumptions or simplifications.

Conventional techniques of empirical modeling are linear statistical techniques, which have severe limitations. New techniques of nonlinear modeling are capable of deriving knowledge about complicated nonlinear effects of variables from production data, taking nonlinearities into account. This article describes how nonlinear models of a tall oil distillation column implemented in Forchem Oy in Finland helps improve the operation of the process.

Tall oil distillation in Forchem

Tall oil or pine oil is a by product of pulping of pine wood with the Kraft process. Tall oil contains mostly acidic, but also some neutral components. A series of distillation columns are used to separate it into rosin, fatty acids, heavy oils and pitch. Rosin contains mostly rosin acids, particularly abietic and pimaric acids, and a smaller amount of impurities. These are also referred to as resin acids. For rosin production, water and turpentine are first removed from the raw tall oil as received from a pulp mill. In the rosin distillation column, tall oil is fed in, and raw fatty acids are taken out from the condenser at the top while a part of the heavy fraction containing mostly rosin is partly returned to the pitch column from the reboiler. Rosin is taken out somewhat above the bottom. Like most separation processes, this distillation is also energy intensive and affects the profitability of the production significantly.

Acid value of the tall oil indicates the total fraction of acidic components, while the rosin acid content is recorded separately. The acid value of tall oil is typically around 140, while the rosin acid content is around 30% for the raw material received in Forchem.
Rosin distilled from this oil will typically contain 90% rosin acids with a softening point around 60 to 65 °C.

Figure 1. The tall oil refinery of Forchem in Rauma

Why nonlinear modeling

Any process operation can be made more efficient with better quantitative knowledge of the effects of process variables and feed characteristics on the consequences of the process. These relations, however, tend to be complicated for most industrial processes in general, and distillation processes in particular. Mathematical modeling can be performed in various ways, and different ways are suitable in different situations. Attempts at physical modeling lead to modest accuracies in predicting most of the interesting consequences of distillation like product purity and energy consumption, partly because they require plenty of assumptions and simplifications, and partly because of the lack of sufficient knowledge of thermodynamics of each component in tall oil. Empirical and semi-empirical models, on the other hand, have neither of these limitations. All that is needed is sufficient amount of production data with a fair variation in the variables of interest.

Nonlinear modeling can be performed in many ways. The simpler ways include polynomial regression and linear regression with nonlinear terms. Nonlinear regression is useful in some situations. The form of the non-linearities, however, have to be specified in these older techniques. The new techniques of nonlinear modeling are based on free-form nonlinearities. They include series of basis functions, splines, kernel regression, feed-forward neural networks, etc.

So, to try to improve the tall oil distillation process, we chose an empirical approach based on feed-forward neural networks. Such networks are a set of efficient tools for nonlinear modeling, particularly because of their universal approximation capability. They can be applied to individual unit operations or entire trains, whether batch or continuous, and regardless of the type of chemical or other process.

Process models are developed from data on feed characteristics, process variables, as well as properties and flow rates of outgoing streams, to determine the best values of process variables to maintain operation within desired limits while also satisfying economic criteria (e.g., maximum yield, purity, production rate or energy efficiency and minimum raw material consumption or defects).

Development of nonlinear models for rosin distillation

For the development of nonlinear models, a number of variables were identified. Production data from January 2009 onwards was available for use. Production data tends to be dilute in information and often contains misleading observations. Therefore, only selected observations from this data were taken for model development. This work was done carefully which made it possible for us to make more progress in a shorter time period. Still, a few observations had to be excluded from that data set during model development work. Figure 2 shows the kind of variables which were included in the models. The nonlinear models were tested and found to be of good quality.

Figure 3 shows a comparison of the measured values of energy consumption of the distillation with values predicted by the nonlinear model. These nonlinear models were then implemented in a processMax+ system, a set of software components meant for facile use of the models by people not familiar with nonlinear modeling. The model development project started in February 2011 and was completed in June.

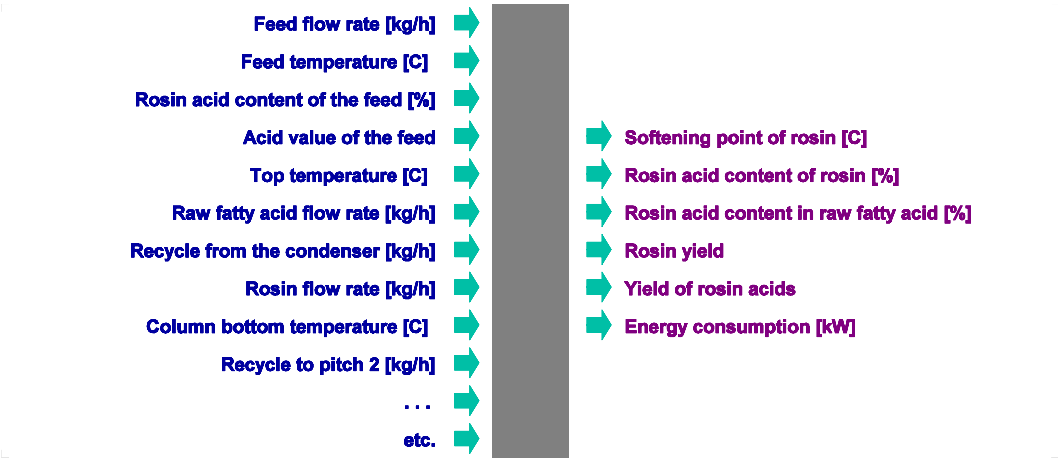

Figure 2. A schematic diagram of the set of nonlinear models

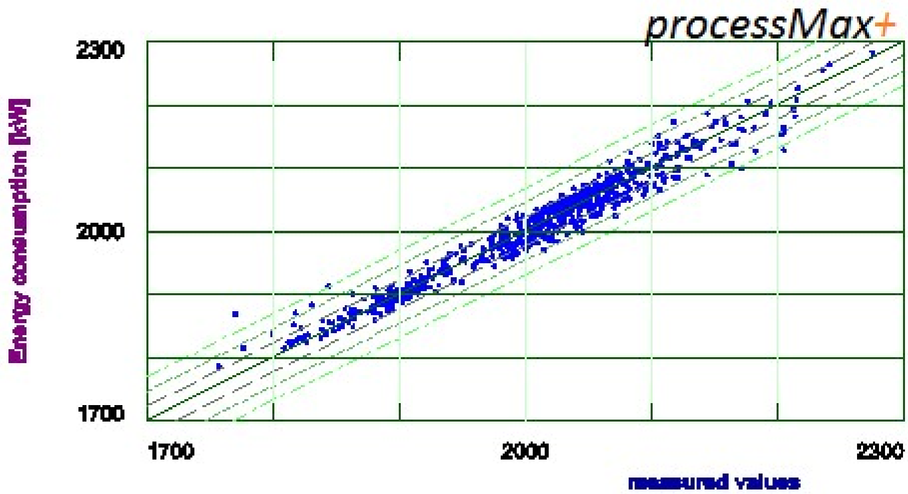

Figure 3. A comparison of the measured and predicted values of energy consumption of the column

The models allow us to see the individual and combined effects of the input variables on the outputs. Figure 4 shows the interesting cross-effect of feed flow rate and different rosin acid contents in the feed on rosin acid content in raw fatty acids. At low rosin contents in the feed, higher feed flow rates are preferable for a given production rate. When the feed has higher rosin contents, lower feed flow rates lead to smaller losses of rosin acids through the fatty acid stream. When there is a medium amount of rosin in the feed, which is typically the case, there is an optimum feed flow rates leading to a minimum loss of rosin acids in the raw fatty acid stream. Ideally one should strive to maximize rosin and raw fatty acid flow rates, while trying to get as much rosin acids as possible in the rosin and minimising the rosin acids in the raw fatty acid stream. Some input variables have desirable effects on some outputs while having undesirable effects on other outputs. These and such other conflicting objectives make it a challenging task to determine the best ways of operating the column.

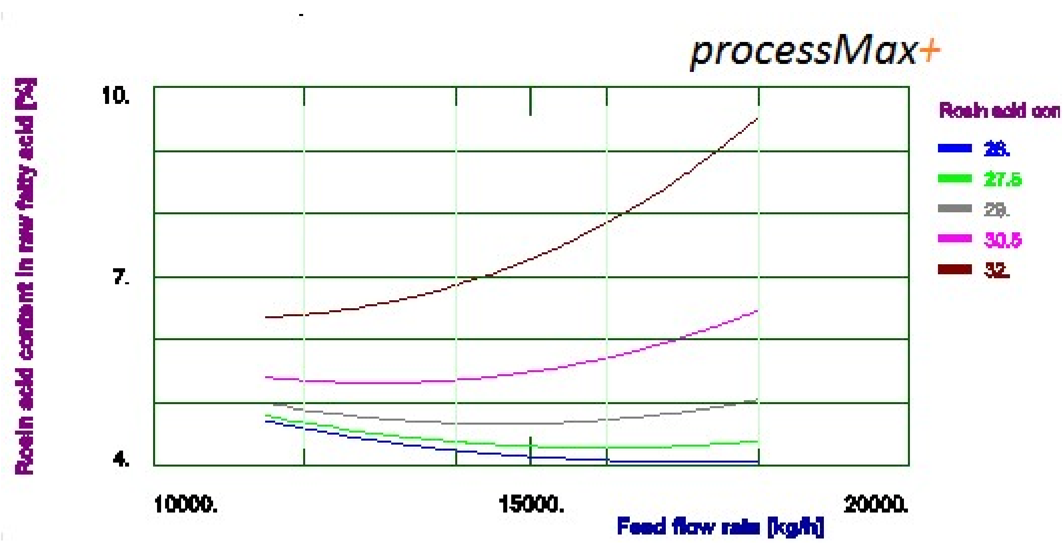

Figure 4. Effect of feed flow rate on rosin acid in raw fatty acids for different rosin acid in the feed

Benefits from efficient use of nonlinear models

Mathematical models can contain a lot of valuable quantitative knowledge in a concise and a precise manner. Concrete benefits, however, are achieved only if the models are used efficiently. processMax+ systems have therefore been developed over 15 years with several features which make it easier for the user to utilise the model for several kinds of calculations.

This will not only be a very useful tool for unexperienced operators, it will help experienced operators also operate the column better. She says that this will be particularly helpful in dealing with uncommon situations which occur sometimes. The production director, the second author, has asserted that if the operators use the models, it should lead to higher yields, lower energy consumption while ensuring the quality in terms of softening point and rosin acid content of the rosin.

The nonlinear models have helped improve the operation of the distillation column right from the first day. Seven and a half hours after the processMax+ system was taken into use, the rosin yield was increased by more than 8%, the energy consumption was lower by about 6% and the rosin acid loss through the raw fatty acid stream had reduced by around 0.3%. This was a very good improvement which could not be expected every time, but in the following days, it was noticed that a rosin yield increase of about 3% from their normal way of operation was usually possible with little effort, without much change in the energy consumption. Even at half that increase in yield, the benefit in terms of increased production is conservatively estimated to exceed € 500000 in a year. This has essentially increased the rosin production capacity as well as production efficiency.

Conclusions

Any process operation can be made more efficient with better quantitative knowledge of the effects of process variables and feed characteristics on the consequences of the process. These relations, however, tend to be complicated for most industrial processes. Nonlinear modeling is a new technology which helps production units derive more out of their equipment and raw materials while also improving their control over product properties. If used effectively, it can add to a company's competitiveness. Industries usually collect a lot of production data which is left unused or under-utilised. That data can contain valuable information which can be extracted by nonlinear modeling. Forchem expects to benefit substantially from the uptake of this technology. Only the increased production is conservatively estimated to be worth more than € 500000 in a year.