DOI: 10.5604/20830157.1130194

PROCESS AUTOMATION OF CONTINUOUS QUALITY CONTROL OF MIXTURE PREPARATION AT THE DISTILLERY

Sergiy Vorobyuk, Volodymyr Drevetskiy
National University of Water Management and Natural Resources Use, Rivne, Ukraine

Abstract. *The process of mixture preparation at the distilleries is considered. Optimal structure of artificial neural networks for the dry residue of the mixture definition has been substantiated and accuracy of such networks has been analyzed. The system of continuous quality control of mixture preparation is proposed using modern information technologies.*

Keywords: dry residue, mixture, automation system, automated workstation, artificial neural network, distillery

AUTOMATYZACJA PROCESU CIĄGŁEJ KONTROLI JAKOŚCI PRZYGOTOWYWANIA BRZECZKI W DESTYLARNI

Streszczenie: *Analizowany jest proces przygotowania brzeczki w destylarni. Opracowano optymalną strukturę sztucznych sieci neuronowych do oddzielania suchej pozostałości mieszaniny oraz przeanalizowano dokładność takich sieci. W oparciu o nowoczesny technologie informacyjne zaproponowany został system ciągłej kontroli jakości przygotowania brzeczki.*

Keywords: pozostałość stała, brzeczka, system sterowania, automatyczna stacja robocza, sztuczna sieć neuronowa , destylarnia

Introduction

Production of alcohol includes the following processes: preparation of raw materials for cooking; boiling raw materials with water for the destruction of cell structure and dissolution of starch; cooling boiled mass and saccharification starch using malt enzymes or microorganisms; fermentation of sugars by yeast into alcohol; selection of alcohol from mash and its rectification; preparing malt by germinating grains or cultivation of fungi and bacteria to produce enzymes.

Milled grain is mixed with water at a ratio of 2.5 ÷ 3.0 liters per 1 kg during the mixing preparation process. The amount of water changes according to the quantity of starch and moisture content of grain considering the fact that the concentration of the mash (measured by sugarmeter) should be within 18 ÷ 20% [3].

There are a lot of manual works in the process of determining the dry matter content: sampling, filtering, cooling and measuring the concentration by weight of dry matter. Temperature of the mixture is regulated depending on the dispersion of grinding of grain. To reduce the viscosity of the mixture bacterial preparations are used.

The technological values of the mash with a concentration of 16 – 18% of dry matter are standardized. It can be reached concentration of 19% and above using bacterial amylase (glucoamylase) to intensify the process of splitting starch molecules. Increasing the concentration to these limits will ensure increased productivity by 12 - 13% [2].

1. Problem

The purpose of raw materials mixture cooking at the distillery is the release of starch from plant cells and its conversion into a soluble state. In the process of cooking there is also a sterilization of mixture which is important in subsequent manufacturing processes of saccharification and fermentation. The main requirements for continuously operating plants of cooking are the preparation of starch that contains raw materials for saccharification with minimal thermal and electrical energy spending. Such plants should also be easy in maintaining and safe in operating [3].

2. The main material of the Article

Dry residue is the main parameter that controls the preparation of mixture. We have established a relation between the size of solid residue leachate mixture and its viscosity as a result of series of experiments carried out on state enterprise "Zirnenskyy Distillery" [1]. The viscosity of the filtrate was measured at 80 °C, and the concentration by weight of solids at 20 °C. Measurements of the viscosity at a given concentration were carried out 4 times using a glass viscometer type VPG.

We found empirically the concentration dry residue dependence on the mixture filtrate viscosity (Fig. 1). The mathematical description of this dependence is reflected in the form of second order polynomial. Accuracy approximation factor is $R^2 = 0.9893$ which indicates a high precision approximation.

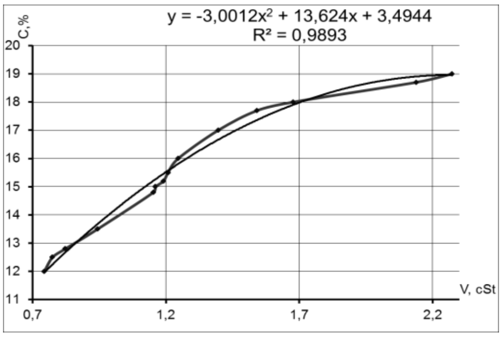

Fig. 1. Experimental curve and mathematical relationship of dry residue and kinematic viscosity

Calculating viscosity of unfiltered mixture provides a continuous gathering of measured information about the process and gives possibilities to automate it [4]. For solving this problem we suggested the usage of algorithms based on artificial neural networks. The possibility of learning is one of the main advantages of artificial neural networks over traditional algorithms. When trained on large amounts of data the neural network is able to handle incomplete, "noisy", partly distorted input parameters by issuing the output true result. Previously the possibility of using artificial neural networks was shown as information-measuring software capable to connect the measured parameters of mixture with quality controlled rate that is dry residue [5].

2.1. The structure of the control system

The main requirements for the structure of quality control system for cooking mixture at the distillery are continuous monitoring of quality indicators in real-time and high measuring accuracy of informative parameters. Also the designed system should be able to consider amendments to the calculated values of mixture viscosity for a range of operating temperatures. The system should consist of individual units of standard industrial equipment to ensure flexibility and interchangeability of its components. We have designed a block diagram of an automated system of continuous quality control of mixture cooking at the distillery (Fig. 2).

The sensitive element of the system is throttle 1. The inner diameter of the capillary is chosen from the condition of passing through it the mixture solids that are always present within the mixture. On both ends of the capillary by using the front chambers 2 and 3 the differential pressure gauge PDE was connected. Flow rate through throttle depends on opening angle of the manual valve 4.

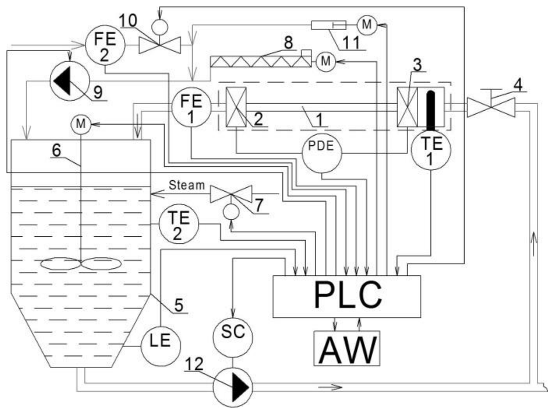

Fig. 2. Block diagram of the automated system for continuous monitoring of the mixture quality

Temperature of the mixture, which flows through the throttle, is measured using temperature sensor TE1. Also the entire capillary with input cameras and sensor TE1 are temperature-stabilized. This is done in order to reduce heat loss dissipation along the sensing element and to improve the reliability of the measured temperature.

Instantaneous volumetric flow of analyzed environment is measured by using flowmeter FE1. Type of the flowmeter was selected in accordance with the terms of two-component mixture taking into account a flow range and temperature of the mixture. After the measurement process of the mixture temperature, pressure drop on the sensitive element and instantaneous flow rate of mixture the analyzed environment is coming back into mixing tank 5. The mixing process by stirrer 6 takes place at the tank when analyzed environment is returned backward to the main part of the mixture.

The temperature in the tank is measured by temperature sensor TE2. Temperature control in the mixture tank is done by changing the steam flow, which depends on the degree of opening angle of valve 7. Grinding at the entrance of the mixture tank is served using screw 8. Then grind went to dismembrator 9. Also the grinding is supplied with heat water. Herewith flow range of warm water is measured using flowmeter FE2, and flow control is implemented using a control valve 10. The set mass ratio of water/grinding is being stabilized continuously in time. This ratio depends on the quality of raw materials, primarily from quantity of starch, depending on which is calculated the value of consumption of conditional starch. To split the molecules of starch enzymes are dozed into the warm water. The set point of enzymes flow rate is formed depending on the value of conditional starch. This task is fed to the dosing pump 11.

Mixture is continuously pumped by centrifugal pump 12 from a mixture tank. The value of the level in the mixture tank is controlled by changing the flow range at the exit, and the control signal goes to the frequency converter SC that is connected to the pump 12. Sampling point is located in such position that the pressure created by the pump 12 is enough for selecting, researching and returning mixture back to the mixture tank.

All measured parameters are submitted to a programmable logic controller (PLC). PLC is the basic unit for information acquisition, processing, calculation of control actions for the actuators. Also PLC continuously calculates the concentration of solids of the mixture and stabilizes it size in the presetting limits. PLC communicates with automated workplace (AW). AW is based on the integrated development environment - SCADA system Trace Mode. Differential pressure on the sensitive element and temperature of the test environment are shown on trends obtained by Trace Mode (Fig. 3).

On Figure 3 with coarse line are shown trends of pressure drop across the sensing element and with a thin line the temperature of the test environment. The axis of ordinates is signed to show the pressure drop across the throttle in Pa, temperature calibration herewith does not shown.

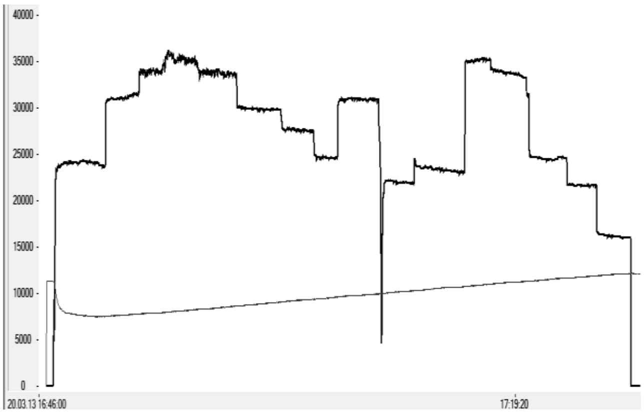

Fig. 3. Differential pressure and temperature trends

Hardware of PLC VIPA was chosen so that with the help of analog and discrete inputs/outputs it can collect information from the sensors, carry out the primary signal processing and issue control signals for actuators. All received data and actions of the operator are written to the archive. As parts of industrial automation equipment, which are used within the information-measuring and control system of dry residue mixture it was used: flowmeter, resistance thermometer, differential manometer and other industrial components made by different manufacturers.

3. The choice of the optimal structure of neural network

For processing the complex relationships between measured parameters and determine their impact on dry residue of the mixture we used artificial neural networks (ANN).

Training and testing networks was carried out with data obtained by the developed information-measuring system. In the experiments water was used as standard liquid to choose the optimal structure of neural network. Inputs of neural network were served pressure drop in the sensitive element, flow rate and water temperature, and the target output – dynamic viscosity. During the experiments, the water temperature varied within $15.2 \div 27.2\ ^0$C, the pressure drop was $8.8 \div 54$ kPa, flow through the throttle acquired values in the range $1.97 \cdot 10^{-5} \div 5.81 \cdot 10^{-5}$ m^3/s. In this case, the real value of dynamic viscosity were within $0.851 \cdot 10^{-3} \div 1.139 \cdot 10^{-3}$ Pa·s. Learning of the Network was carried out based on the results of 57 experiments during 10000 epochs.

Training and testing was carried out by means of Neural network toolbox of Matlab software application package. Taking into account that character of the relationship between the input parameters is unknown beforehand, it has been used various variations of the transfer functions of neurons (tansig, purelin, logsig) with different number of layers and neurons in layers.

As a result of checking the accuracy of simulation the data by designed neural networks it was selected the structure of neural network consisting of two layers of neurons (Fig. 4) with the number of 20 neurons in the hidden layer of the transfer function pureline-pureline.

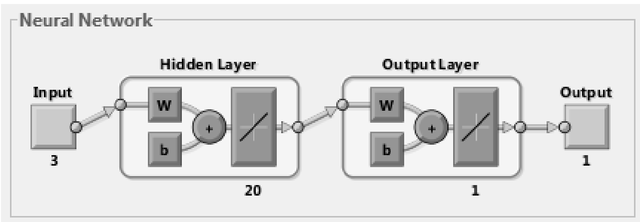

Fig. 4. Structure of ANN to determine the dynamic viscosity

The correlation coefficient of reproduced dynamic viscosity by neural network relative to the target for all the experimental data was R = 0.998 (Fig. 5).

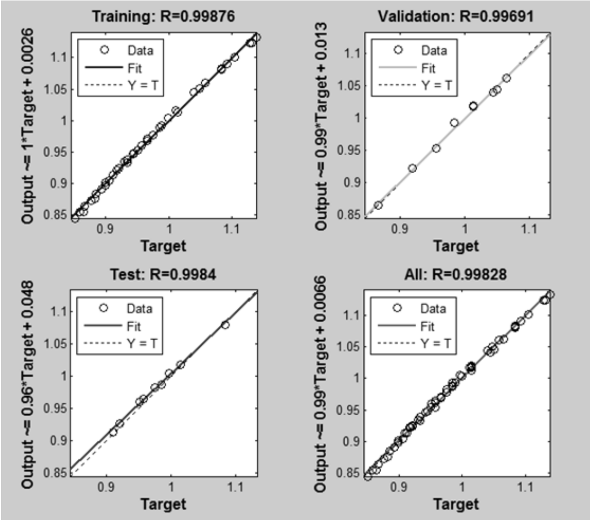

Fig. 5. Correlation coefficients of trained neural network

The accuracy of reproduction of dynamic viscosity of model fluid using ANN has correlation coefficients for all output not less than 0.99. During the application of ANN when determining the main controlled parameter for quality preparation control of mixture must take into account also time which the mixture spent in the tank, the dose and type of enzyme used. It is also necessary to control the temperature of the mixture in the tank which must differ from clustering temperature of the mixture. This temperature depends on the type of processed material. When reaching the temperature of clustering viscosity of the mixture abruptly increases, leading to failure of equipment and further stop the entire production cycle.

Fig. 6. A research prototype information-measuring systems for industrial execution

At this stage we conduct further experimental investigations of developed information-measuring system (Fig. 6) on "Zirnenskyy Distillery" in Rivne region of Ukraine.

4. Results

Artificial neural networks can be realized by means of software functions. It is also possible to realize ANN by means of SCADA systems, but this way is less reliable compared to the first.

To implement the human-machine interface we used ordinary laptop with installed free version of SCADA system. The SCADA system graphic user interface of measurement process is shown on Figure 7.

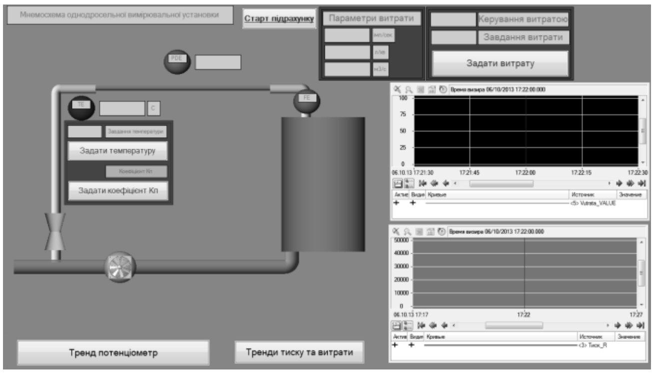

Fig. 7. Graphic user interface

5. Conclusions

The system of automatic quality control mixture was proposed basing on continuous measurement of viscosity mixture. Structural diagram of mixture quality control was designed. The possibility of integration the developed system to general plant management systems for alcohol production was taken into account. The fulfillment of all requirements is not possible without automation of technological processes that occur during the preparation of mixture and using calculation algorithms that are capable to find complex interactions between measured parameters in order to find their optimal values and increase the production productivity as a whole.

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M.Sc. Sergiy Vorobyuk
e-mail: sergiy.vorobyuk@gmail.com

Research engineer of computer systems and automation, postgraduate student, assistant of the Department of Automation, electrical engineering and computer integrated technologies.
The main scientific direction – automation of the process of continuous quality control, automation of distilleries, information-measuring systems based on supervisory control and data acquisition systems, information-processing and industrial automation systems; research and design of artificial neural networks models for industrial automation and measurement systems.

Prof. Volodymyr Drevetskiy
e-mail: Westra@rv.uar.net

Vice President of Engineering Academy of Ukraine, Head of Department of Automation, electrical engineering and computer integrated technologies.
The main scientific direction - development of methods and devices for continuous automatic monitoring of the physical and mechanical parameters of Newtonian and non-Newtonian fluids, as well as the quality of oil products. Author of over 200 scientific papers, including 51 patents, most of which are implemented in production.

otrzymano/received: 2014.05.04 *przyjęto do druku/accepted: 2014.10.30*