Controller design of the multivariable process control system

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Abstract - The paper focuses on the procedure of designing one of the most important elements of an automation control system in multivariable technological process - The controller of the main fermentation process (one of the most important process of the beer manufacturing). We focus on the justification of the choice of the type of controller, which provides the most effective solution to control problems, determine its optimal settings, and the regulatory law. The parameters of the SISO (Single-Input Single-Output) and MIMO (Multiple – Input, Multiple Output) technological processes were analyzed to select the controller. Furthermore, the interrelations and interdependencies of the parameters of the technical process were analyzed. The obtained transfer functions of the heating and cooling sub-processes have been simulated with P, PI, PID controllers. We compared the values of the controllers; the PID controller has been selected. It provides the most effective solution of the multivariable process control tasks. The algorithm for controlling the multivariable process of the main fermentation of beer has been developed. The simulation of the controller and the definition of its operating parameters implemented in an integrated development environment "MatLab".

Key-Words:- control of the process, controller, transient response process, parameters.

1 Introduction

The beer manufacturing in Burundi is composed by several processes. The most important process is the main fermentation. It is in this process where the quality of the product is defined. It requires a lot of financial and energy resources. This process is characterized by several parameters. The controllable parameter is the temperature, which influences the others. For controlling the temperature, an automated control system is needed. The main element of the automated control system is the controller. This will be designed in this paper.

2 Statement of the problem

The technological process of the main fermentation process in the manufacture of a beer product is characterized by basic dynamic and threshold changes of parameters such as the percentage of alcohol (A), the extract (E), temperature (T^o) and (pH) value. The main fermentation process continues 8 - 10 days, at a high cost [5]. The only parameter that can be controlled is temperature. This influences the other parameters. The problem of maintaining the temperature in a given interval is current. That is reason why the task will be solved in this paper.

3 General characteristics of the multifactorial technical processes

A technical process is defined as any technical, technological or structural means to perform an operation in the production of a product or service. This term covers the improvement of flows, the main fermentation of beer, the improvement of an existing system, the reduction of energy consumption…etc. This is a broad theme that affects all sectors today [1].

Technical processes are characterized by their parameters and properties, such as process duration, temperature, and the dynamic changes of the parameters.

There are mono-variable and multi-variable technological processes [2]. Mono - variable technological processes have only one input and output parameter (SISO-single input single output). The multi-variable processes (MIMO – Multiple Input Multiple - Output) are characterized by several parameters, and these are often correlated with each other, which forces us to consider this parametric interdependence during the automation of multivariate process control. The term "process" will be used in the broad sense of the term, and will include the process of producing a product, and its operation. This representation deals with the problem of the automated control of the technological process as a whole and the problem of controlling the units of the production process in particular.

The automation control of the multivariable technological process refers to the procedure for defining the relationships between the input and output data and parameters. Furthermore, the method must be created for controlling the input and output parameters of the technological process.

The goal of controlling the multivariable process is to achieve the required parameter values with the constraints who limit their dynamic changes.

The technological process of the main fermentation process in the manufacture of beer is characterized by basic dynamic and threshold changes of parameters such as:

- The percentage of alcohol (A),
- The extract (E),
- Temperature (To)
- The hydrogen potential (pH) [2, 3].

The uncontrolled dynamic changes of parameters of the main fermentation of beer (in base fermentation - where fermentation occurs at low temperature, initial temperature is 7 - 9^{o}C, while the maximum temperature is 13 - 15^{o}C) are shown in Fig.1. Based on the analysis of parameter changes using the least squares method is represented in equation (1) [2, 5].

Based on the analysis of experimental data [2], the equation of relationship between the values of parameters to the process time is shown on equation (1) and the graphs of these relationships shown in Fig.1.

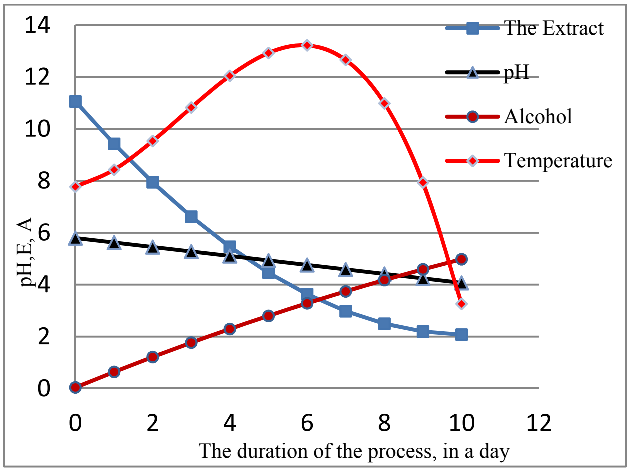

Fig.1.The changes in parameters of the main fermentation process of beer"Primus"

$$\begin{cases} 0,0137t^3-0,1t^2-1,675t+16,269 \leq 2,5 \\ -0,1725t+5,793 \leq 4,3 \\ -0,0116t^2+0,61t+0,04 = 4,5 \\ -0,043t^3+0,35t^2+0,34t+7,765 \leq 4 \end{cases} \quad (1)$$

where, $t \geq 0$

The control of the multivariable process is only possible by changing the temperature. In the course of the process others parameters should change in accordance with the relevant rules and by the completion of the process to achieve their critical values [5].

The goal of optimal control of the main fermentation process of beer is to minimize the duration of the process under the existing restrictions on its other parameters.

The optimal (minimal) duration of the main fermentation process of beer, based on the application of the Kalman filter, has been studied in the scientific article « Forecasting the optimal duration of the main fermentation process of beer using the Kalman filter »[5]. The automation control system of the multivariable technological process of the main fermentation of beer is shown in Fig.2.

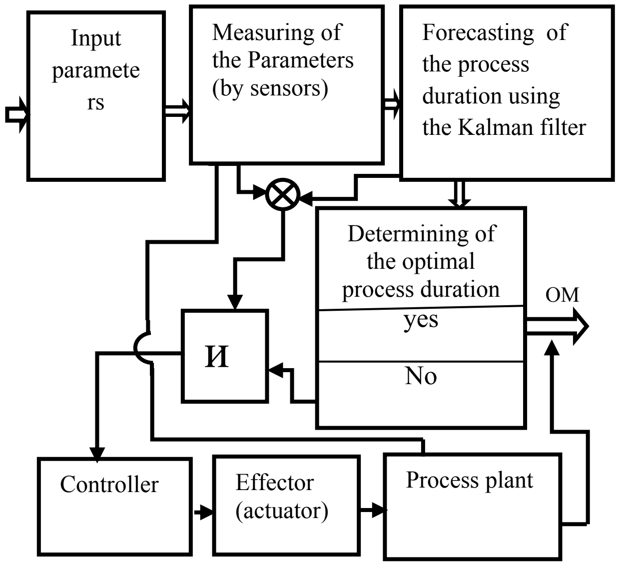

Fig.2.The automation control system of the multifactorial technological process of the main fermentation of beer.

Where, OM - Outgoing material.

The automation control system of the multivariable technological process is composed by elements such as:

- The sensors: are devices for measuring the physical size (temperature, densities…), they provide also the feedback information necessary to control the process.
- The controller: is a device, which acts with the effectors, if the temperature error is below the limit; the controller requires the effectors to heat the tank. The tank will be heated to the given temperature. Otherwise the tank will be cooled. It adjusts and maintains the desired process value or "set point" of the given parameter. The controller maintains the error signal close to zero;
- The effectors (actuator): are a devices for cooling or heating the tank, according to the value given by the sensors.
- Process plant: is the main fermentation of the wort mixed with the yeast in the cylindrical tank;
- The comparator compares the measured values of temperature by sensor with the wished temperature. According to the result of the comparison, the controller will determine the action for cancelling the error (deviation).

- The main known controllers are the following:
  - Controller P - Controller with proportional action,
  - Controller I- Controller with integral action,
  - Controller PI - Controller with proportional and integral action,
  - Controller - PID (Proportional-Integral-Derived.

3.1 Choice of the controller and the law of regulation

The multivariable technological process of the main fermentation of beer can be divided in two sub-processes: "heating" and "cooling". In the first sub-process the tank is heated under the effect of the surrounding temperature and the reproduction of the yeast seeded in the wort. The heating sub process continues 3-5 days and the tank heats to 5, 5 - 6 ^{o}C. Considering the transient mode of the system, there are stable (Fig.3) and unstable systems (Fig. 4)[6].

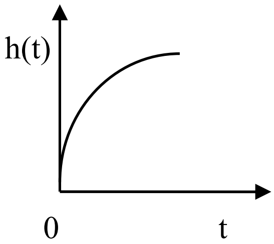

Fig.3. Stable system

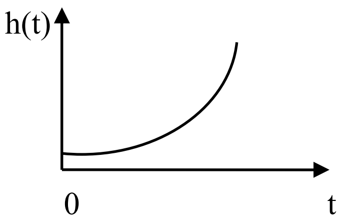

Fig.4.Unstable system

Fig.1 shows that the variation of the temperature as a function time is stable. In that case, the transfer function can be defined by using the Ziegler-Nichols method, Fig.5.

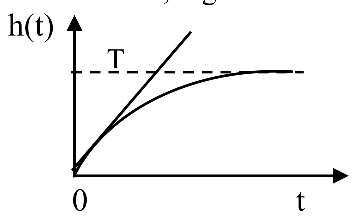

Fig.5.The transient mode of the heating sub process

The transfer function has the following form:

$$W(p) = \frac{k}{Tp + 1} \qquad (2)$$

The analysis of the Fig.1 and by applying formula (2), the transfer function of the sub - heating process is as follow:

$$W(p) = \frac{5,5}{4p + 1} \qquad (3)$$

The results of the simulation of the heating sub process using the controllers (I, P, PI, and PID) are shown in Fig. 6, 7, 8, 9.

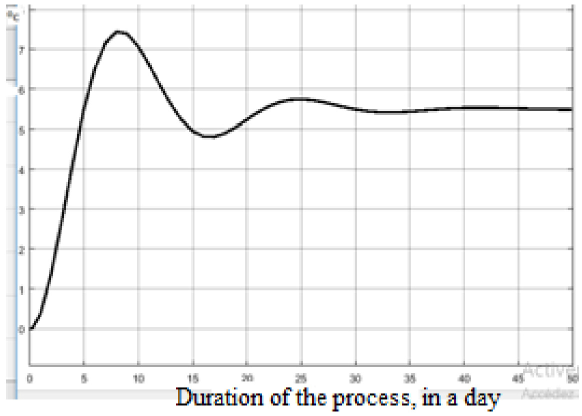

Fig.6. Result of the simulation using I controller

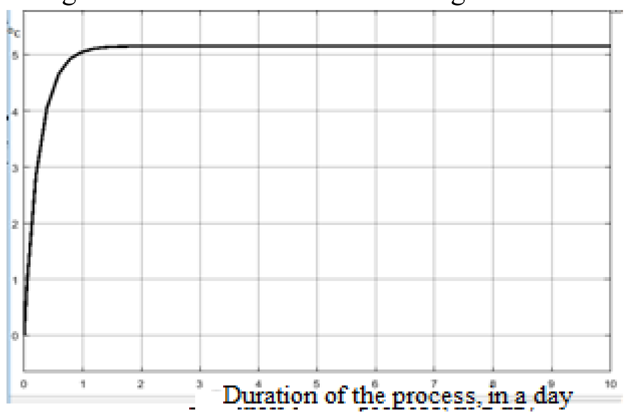

Fig.7. Result of the simulation using P controller

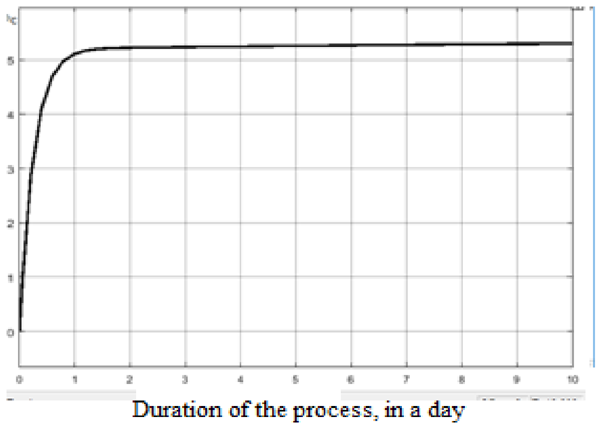

Fig.8. Result of the simulation using PI controller

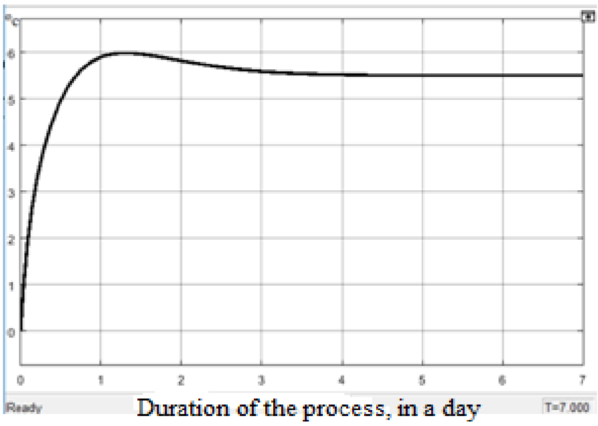

Fig.9. Result of the simulation using PID controller

The controller I is less dynamic, the process reaches a steady temperature value on the 35th day. By using the P-controller and PI- controller, the heating sub process starts quickly. This will damage the product. The steady value of the temperature is not reached (13,5° C).

The PID industrial controller allows reaching the steady - state temperature on the third day.

Then we can conclude that, in order to create automation control system of the heating sub-process, it is most expedient to use the PID controller. Fig .10 shows the simulation of the heating sub process. The result of this simulation is shown on Fig. 9.

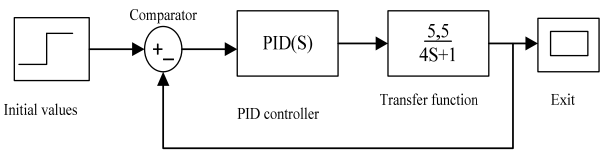

Fig.10. Simulation of the heating sub-process

The second sub-process consists in cooling the tank, from 13, 5 ° C to 4 ° C (9, 5 ° C) in 2 days. The transient mode of the cooling sub process has the following form.

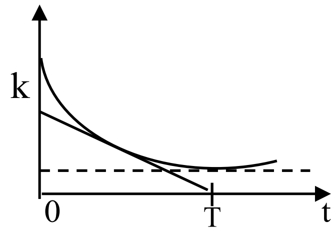

Fig.11.The transient mode of the cooling sub process

In accordance with formula (2), taking into account the results of the analysis of the Fig. 1, the transfer function of the cooling sub process will have the form:

$$W(p) = \frac{9,5}{2p+1} \qquad (4)$$

The results of the simulation of the cooling sub-process using the controllers (I, P, PI, and PID) are shown on Fig. 12, 13, 14.

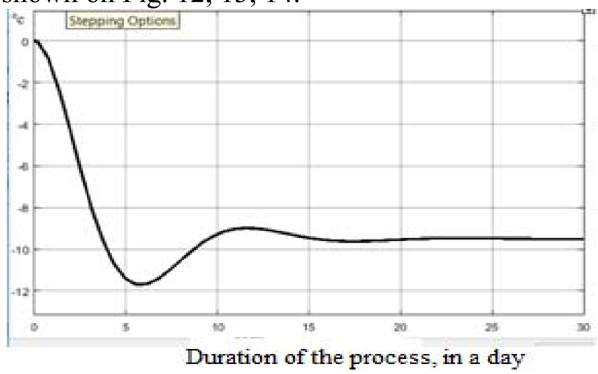

Fig.12. Result of the simulation using I controller

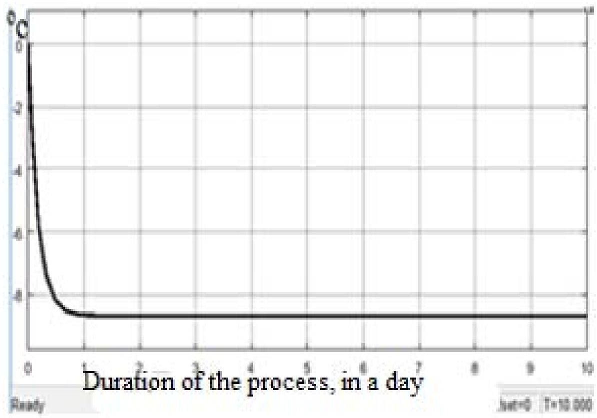

Fig.13. Result of the simulation using P controller

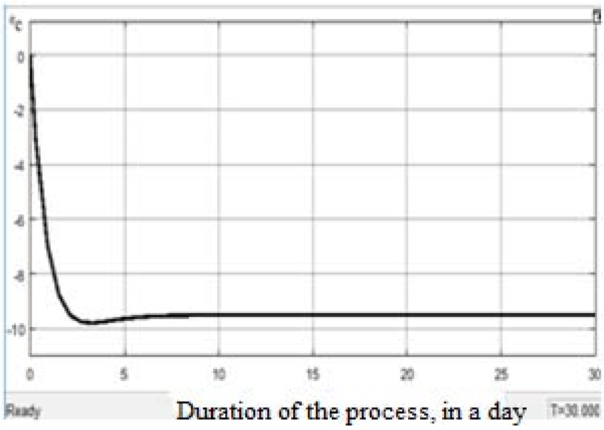

Fig.14. Result of the simulation using PI controller

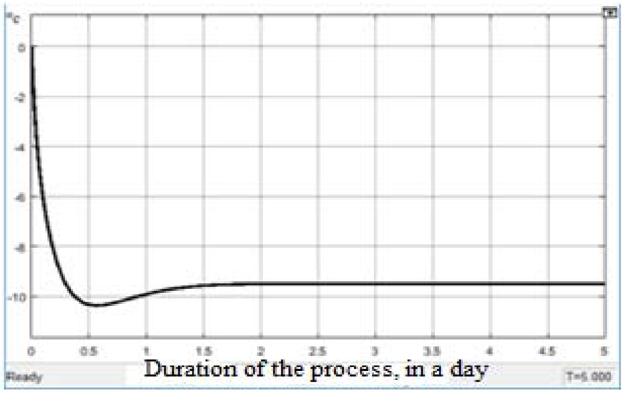

Fig.15. Result of the simulation using PID controller

By using the I-controller, the process later reaches a steady value of the temperature. With P controller, the process does not reach the minimum value (-9,5°C). If the PI controller is used, the sub process late reaches the minimum value on the third day. By using the PID controller, the steady-state temperature is reached in 1.5 days. We can conclude that for the automation control system of the cooling sub - process, the PID controller gives better results. Fig .16 shows the simulation of the heating sub process. The result of this simulation is shown on Fig. 15.

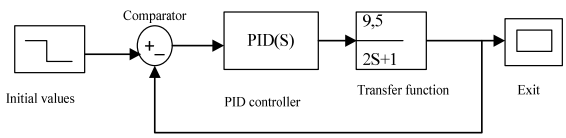

Fig.16. Simulation of the heating sub process

PID controllers are widespread and are the most widely used in industry (90 - 95% of controllers). This is due to its simple setting, operational reliability, relevance and low cost. Their transfer function has the following form:

$$F = K(N + \frac{1}{sTi} + sTd) \qquad (5)$$

The optimum values of the PID controller parameters were obtained, they represented on table 1.

The coefficients	The values of the coefficients for the heating sub-process	The values of the coefficients for the cooling sub-process
K	2, 2432	1, 75
T_i	0,12153	3,98
T_d	-0,03532	0,043
N	0,9452	24,1

Table1. The values of the PID controller parameters.

The performance and robustness of the automation control system of the multifactorial process of the main fermentation of beer Primus» are shown in Table 2 [7].

Performance and Robustness	Heating sub-process	Cooling sub-process
Rise time(in seconds)	0,319	0,314
Settling time(in seconds)	2,22	1,86
Overshoot	11,6%	8,56%
Peak	1,12	1,09
Closed-loop stability	stable	stable

Table2. The values of the PID controller performance and robustness

Algorithm for temperature regulation of the multivariable process of the main fermentation of beer is shown in Fig.17.

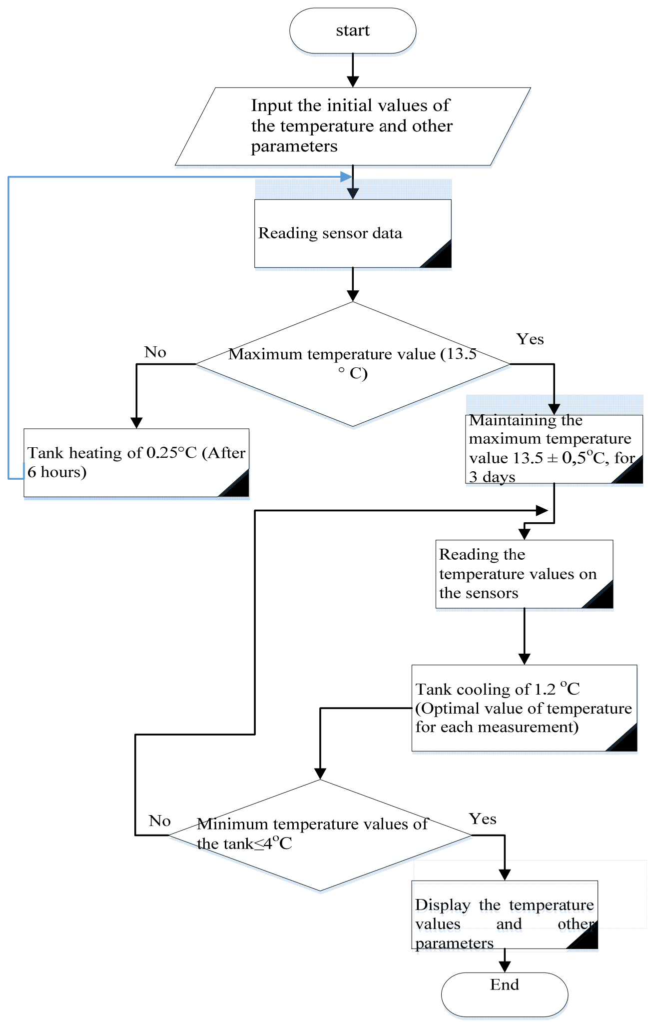

Fig.17. Algorithm for temperature regulation of the multivariable process of the main fermentation of beer

4 Conclusion

In this paper, we designed the PID Controller model of the functioning. The modeling was applied on the multivariable technical process of the main fermentation of beer. The PID controller provides the best results and allows us to maintain optimal temperature values.

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