УДК 664.9.047

Oleksii SYTNIKOV*, Denys SKLADANNYY, Sergii PLASHYKHIN, Kostiantyn SOKOLOV
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

COMPARISON THE MODERN CONTROLLERS' EFFICIENCY FOR THE SPRAY DRYER'S CONTROL SYSTEM

Spray drying is one of the widely used drying process in chemical, pharmaceutical, and food industry. This process allows removing water from the product, which is produced in the solution form, and turn the finished product into a flowing powder material. It is obvious that such a process requires a significant amount of thermal energy, which is spent on the water evaporation. In addition, as in any drying process, in spray drying there is a problem with possible material over-drying. Therefore, the task of qualitative regulation of the spray drying process remains relevant.
In this article, we attempt to compare the efficiency of two modern controllers for controlling the spray drying process. This is known in the theory of control of dynamic objects using predictive models model predictive controller and a fuzzy controller based on linguistic variables. The regulators choice due to both their popularity and high control quality indicators, which are given in published scientific works. The study was performed on based on spray drying process models, which were obtained in the previous work of the authors.
In the research we used the software package MATLAB Simulink for control systems simulation. The research result show, that using the MPC-controller in the spray dryer's control system allow to reduce the transient processes time. However, in case of a fuzzy controller, the control system partially levelling the mathematical model's inaccuracy.

Keywords: *energy efficient technology, spray dryer, simulation model, MPC controller, fuzzy controller*

DOI: 10.20535/2617-9741.1.2024.300982

* Corresponding author: o.sitnikov@kpi.ua
Received 21 February 2024; Accepted 01 March 2024

Introduction. The spray drying process is widely used in the pharmaceutical, chemical, food, and some other industries. Such process allows turning the liquid products into flowing powders. Strengthening requirements for processes environmental safety and growth the competition in industries requires the development and implementation the modern drying process control methods. Traditionally, spray dryers are operated using control systems with proportional (P) and proportional-integral (PI) controllers. Both P and PI control systems are based on fixed single-input – single-output strategy. In this paper we would like to present the theoretical result of our research of spray dryer control systems using modern controllers. The use of such controllers, in our opinion, should significantly improve the technical and economic characteristics drying process.

Literature analysis and problem statement. In recent years, a significant number of scientific publications have been published, devoted to the work of modern controllers in systems of automated control of technological processes. Using the MPC controller [1,2] and fuzzy controller [3,4] to solve such problems is gaining considerable popularity. In the paper [3] authors investigated and compared two control algorithms: fuzzy control and model predictive control. The authors investigated the implementation of both algorithms in real time on low-cost embedded devices, such as microcontrollers. This makes them accessible for a wide range of applications, such as robotics, industrial control etc. It is shown that fuzzy control is simple to implement and does not require an accurate model of the system, but it may not be as precise as MPC. MPC can be more accurate, but it requires more complex implementation and an accurate model of the system. Authors concluded, that neither algorithm has no significant advantages over the other and the choice of the best algorithm depends on the specific application. Another result of investigation and comparison the fuzzy controller and model predictive controller is shown it work [4]. In the paper studies fuzzy logic based and MPC based DC-DC converters, which are used to regulate the output voltage in DC power systems. The authors come to similar results regarding the models' accuracy and complexity necessary for the specified controllers' high-quality operation. The paper concludes that MPC converters are better choice for systems where high accuracy regulation is required. However, fuzzy logic-based converters may be a better choice for systems where simplicity of implementation is important.

The three controllers: proportional-integral controller, a linear model predictive controller with real-time optimization and an economically optimizing nonlinear model predictive controller are investigated is work [5] for a four-stage spray dryer. The key performance indicators such as the profit of operation, the product flow rate, the specific energy consumption, the energy efficiency, and the residual moisture content of the produced powder are computed and compared for the three controllers. The MPC controller showed the best result in that research according to the optimal operation. The authors of the work [6] used a more traditional approach to solving the problem of automated control. In this research the method for controlling the outlet air temperature from the spray dryer chamber using a PID controller to adjust the liquid feed or inlet air temperature to maintain a set outlet air temperature. The authors assert that the proposed method can be effectively used to control the spray drying process because of it is simple to implement, and provides stable outlet air temperature, and improves product quality. Also, the idea of comparing different regulators for controlling spray drying is developed in the work [7]. The authors developed a dynamic model of the spray drying process that takes into account suspension properties, drying conditions, spray chamber hydrodynamics and heat and mass transfer. Two methods of optimal controller synthesis are proposed in the research: linear quadratic controller (LQC) and MPC. Author concluded, that both proposed control methods can be effectively used to optimize the spray drying process and both LQC and MPC provide better product quality, disturbance rejection and economy.

In previous authors' work [8], using the methods, described in [9], two mathematical models of spray dryer are built. The first one takes into account the heat loss to the environment, but the second one not. Obviously, that the accuracy of the first model is significantly exceed the accuracy of the second one. The transfer functions for control channels, taking into account heat loss to the environment, such function is:

$$W_{Cc\mathrm{D}} = \frac{\left|\Delta_{T_{g.1}D}\right|}{\left|\Delta D\right|} \tag{1}$$

Without taking into account heat loss to the environment is:

$$W_{Cc} = \frac{\left|\Delta_{T_{g.1}}\right|}{\left|\Delta\right|} \tag{2}$$

where:

$$\left|\Delta\right| = \left(T_{w_{c.2}}p+1\right)\left[\left(T_{w_{g.2}}p+1\right)\left(\left(\left(T_{T_{c.2}}p+1\right)\cdot\left(T_{T_{g.2}}p+1\right)\right)-\left(K_{T_{g.2}/T_{c.2}}\cdot K_{T_{c.2}/T_{g.2}}\right)\right)\right]$$

$$\left|\Delta_{T_{g.1}}\right| = -\left(K_{T_{g.1}/T_{g.2}}-T_{T_{g.2}}p\right)\left[-\left(T_{w_{g.2}}p+1\right)\left(\left(K_{T_{c.2}/w_{c.2}}\cdot K_{T_{g.2}/T_{c.2}}\right)-\left(K_{T_{g.2}/w_{c.2}}\cdot\left(T_{T_{c.2}}p+1\right)\right)\right)\right]+$$
$$+K_{T_{c.2}/T_{g.2}}\left[\left(T_{w_{g.2}}p+1\right)\left(\left(K_{T_{g.1}/w_{c.2}}\cdot K_{T_{g.2}/T_{c.2}}\right)-\left(K_{T_{g.2}/w_{c.2}}\cdot K_{G_{c.1}/T_{c.2}}\right)\right)\right]+$$
$$+\left(T_{T_{g.2}}p+1\right)\left[\left(T_{w_{g.2}}p+1\right)\left(\left(-K_{T_{g.1}/w_{c.2}}\cdot\left(T_{T_{c.2}}p+1\right)\right)-\left(-K_{T_{c.2}/w_{c.2}}\cdot K_{G_{c.1}/T_{c.2}}\right)\right)\right]$$

$$\left|\Delta D\right| = \left(T_{w_{c.2}}p+1\right)\left[\left(T_{w_{g.2}}p+1\right)\left(\left(\left(T_{T_{c.2}}p+1\right)\cdot\left(T_{T_{g.2}D}p+1\right)\right)-\left(K_{T_{g.2}/T_{c.2}}\cdot K_{T_{c.2}/T_{g.2}D}\right)\right)\right]$$

$$\left|\Delta_{T_{g.1}D}\right| = -\left(K_{T_{g.1}/T_{g.2}D}-T_{T_{g.2}D}p\right)\left[-\left(T_{w_{g.2}}p+1\right)\left(\left(K_{T_{c.2}/w_{c.2}}\cdot K_{T_{g.2}/T_{c.2}}\right)-\left(K_{T_{g.2}/w_{c.2}}\cdot\left(T_{T_{c.2}}p+1\right)\right)\right)\right]+$$
$$+K_{T_{c.2}/T_{g.2}D}\left[\left(T_{w_{g.2}}p+1\right)\left(\left(K_{T_{g.1}/w_{c.2}}\cdot K_{T_{g.2}/T_{c.2}}\right)-\left(K_{T_{g.2}/w_{c.2}}\cdot K_{G_{c.1}/T_{c.2}}\right)\right)\right]+$$
$$+\left(T_{T_{g.2}D}p+1\right)\left[\left(T_{w_{g.2}}p+1\right)\left(\left(-K_{T_{g.1}/w_{c.2}}\cdot\left(T_{T_{c.2}}p+1\right)\right)-\left(-K_{T_{c.2}/w_{c.2}}\cdot K_{G_{c.1}/T_{c.2}}\right)\right)\right]$$

$G_{c.1}$ – suspension consumption; $w_{c.1}$ – suspension relative moisture content; $T_{c.1}$– suspension temperature; $c_{c.}$ – specific suspension heat capacity; $G_{c.2}$ – dry matter consumption; $w_{c.2}$ – dry matter relative moisture content; $T_{c.2}$ – dry matter temperature; $G_{g.}$ – fuel gas consumption; $T_{g.1}$ – input fuel gas temperature; c_g – fuel gas heat capacity; $T_{g.2}$ – output fuel gas temperature; V_g – the volume filled with fuel gas; ρ_g – fuel gas density; ρ_c –suspension density; K_T – heat transfer coefficient; S – the heat exchange surface area between the suspension and the combustion gases; r – specific water vapor formation heat capacity; K_{T1} – heat transfer coefficient to the environment; S_1 – the heat exchange surface area between the combustion gases and the environment; T_{Env} – environmental temperature.

Thus, comparing the performance of fuzzy and MPC controllers, which are used for the technological processes' regulation, is an urgent task that requires the research. **The purpose** of this study is to compare the results of the specified controller for the technological object – the spray dryer.

Presenting main material. We used MATLAB Simulink software to study a simulation model of the spray dryer control system with the corresponding regulator. The technological object itself is modelled by using its transfer functions (1) and (2), respectively. The model is supplemented with initial conditions – the moisture content initial value (= 0.693). MPC-controller is modelled by the corresponding block, which structure is shown in fig. 1. The moisture content value, which is required at the exit from the apparatus (= 0.2), is set by the constant block. The simulation model for a system with the MPC-controller [12] presented in fig. 2.

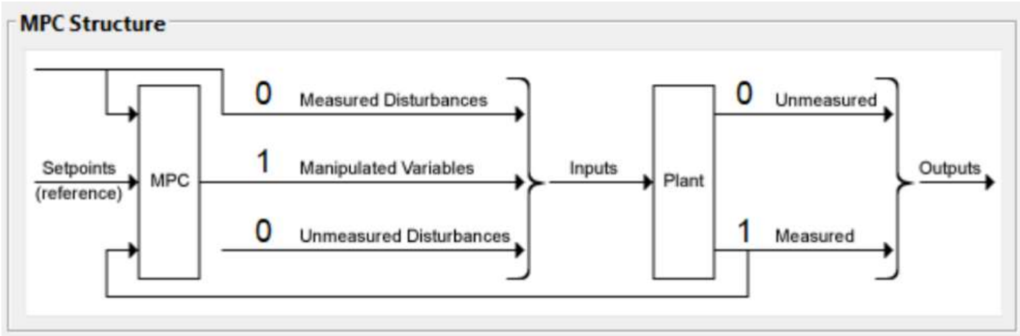

Fig. 1 – MPC-controller's structure

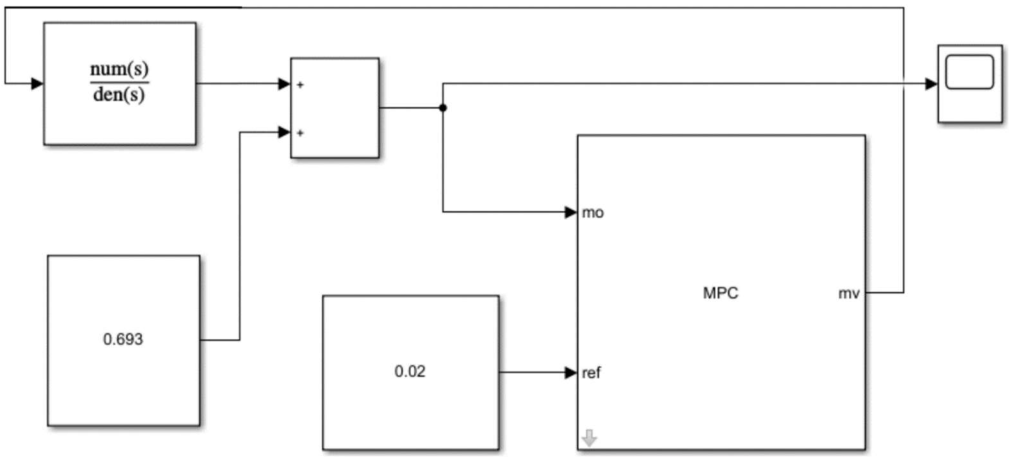

Fig. 2 – Simulation model for a system with the MPC-controller in software package Simulink

For modelling the spray dryer control system using a fuzzy controller, linguistic variables and its fuzzification must be specified. For the control variable – the drying agent temperature (*T*) – we propose the universum [663; 683] °C and three terms: {low; normal; high}. The membership functions for such terms are:

$$T_{low} = \left\{ \begin{matrix} 1, & T < 668 \\ \frac{673 - T}{5}, & 688 \le T \le 673 \\ 0, & T > 673 \end{matrix} \right\};$$

$$T_{high} = \left\{ \begin{matrix} 1, & T > 678 \\ \frac{T - 678}{5}, & 673 \le T \le 678 \\ 0, & T < 673 \end{matrix} \right\};$$

$$T_{norm} = \left\{ \begin{matrix} 0, & T < 688 \; OR \; T > 678 \\ \frac{T - 668}{5}, & 688 \le T \le 673 \\ \frac{678 - T}{5}, & 673 \le T \le 678 \end{matrix} \right\}.$$

For the controlled variable – moisture content in the dried substance (w) – we propose the universum [0.019; 0.021] g/g and the same three terms: {low; normal; high}. The membership functions for such terms are:

$$w_{low} = \left\{ \begin{matrix} 1, & w < 0.0195 \\ \frac{0.02 - w}{0.0005}, & 0.0195 \le w \le 0.02 \\ 0, & w > 0.02 \end{matrix} \right\};$$

$$w_{high} = \left\{ \begin{matrix} 1, & w > 0.0205 \\ \frac{w - 0.0195}{0.0005}, & 0.02 \le w \le 0.0205 \\ 0, & w < 0.02 \end{matrix} \right\};$$

$$w_{norm} = \left\{ \begin{matrix} 0, & w < 0.0195 \; OR \; w > 0.0205 \\ \frac{w - 0.0195}{0.0005}, & 0.0195 \le w \le 0.02 \\ \frac{0.0205 - w}{0.0005}, & 0.02 \le w \le 0.0205 \end{matrix} \right\}.$$

With the linguistic variables formed, we can start creating fuzzy control rules:

IF w is “low” **THEN** T is “low”

IF w is “normal” **THEN** T is “normal”

IF w is “high” **THEN** T is “high”

The specified fuzzy control rules are visited in Fuzzy Logic Toolbox, which is part of the MATLAB software product. The control system has one input and one output. The simulation model for the system with the fuzzy controller [12] presented in fig. 3.

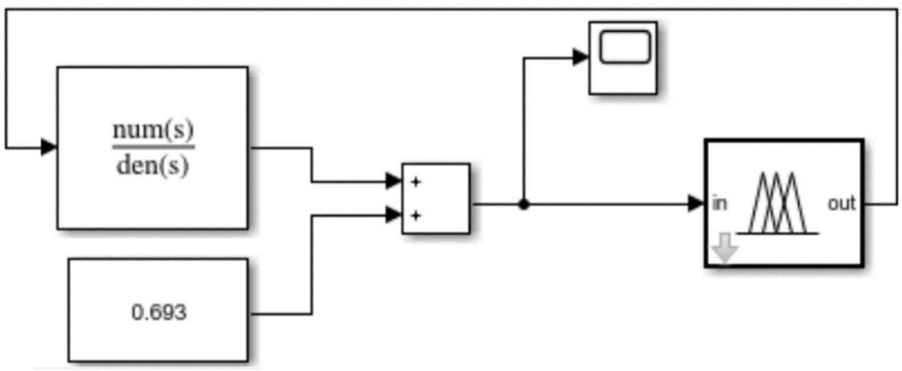

Fig. 3 – Simulation model for a system with the fuzzy controller in software package Simulink

The transient characteristics graphs of the closed loop control system with MPC on fuzzy controllers are presented in the figures 4 and 5.

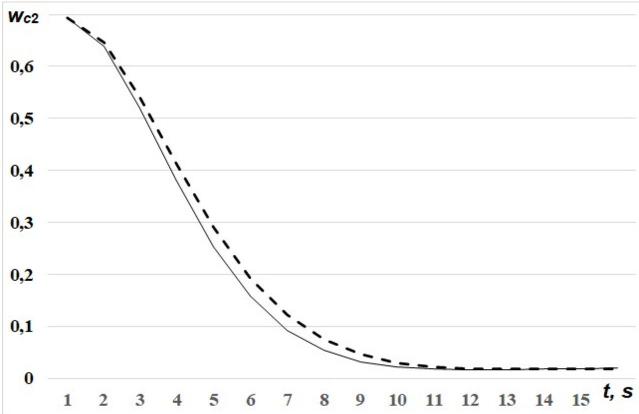

Fig. 4 – Transient processes for the system with the MPC-controller

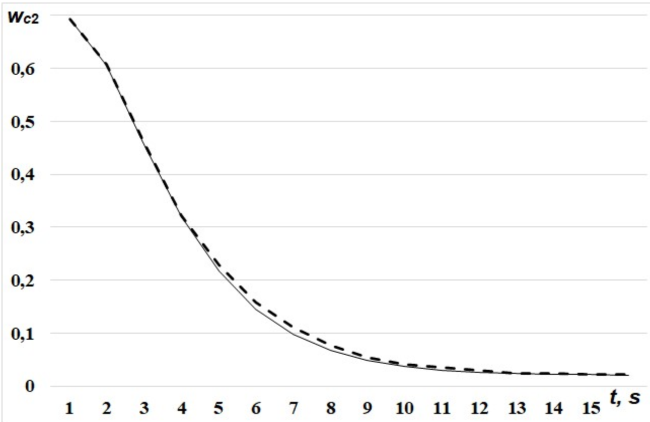

Fig. 5 – Transient processes for the system with the fuzzy controller

In both of these figures the solid line shows the transient characteristics for model which includes heat loss to the environment, dashed line for the model which does not include heat loss.

Conclusions. As can be seen in figures 4 and 5, the using the MPC-controller in the spray dryer's control system allow to reduce the transient processes time. The obtaining time a new mode for a system with an MPC-controller is about 10 seconds, while for a system with a fuzzy controller it is about 13 seconds. On the other hand, in the case of a fuzzy controller, the transient curves are closer to each other. This indicates that the system with fuzzy controller "smooth out" the mathematical model's inaccuracy to a certain limit. In addition, both figures 4 and 5 show that for the studied process, increasing the mathematical model accuracy leads to a reduction the transient processes time for the both systems with regulators, although not very significantly.

Further research prospects. Further research is aimed at studying the control system operation using other regulators – PID, linear-quadratic, etc. In addition, the research on improving the mathematical model accuracy with the purpose of determining the transient processes time reduction could be an interesting direction.

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Ситніков О. В., Складанний Д. М., Плашихін С. В., Соколов К. І.

ПОРІВНЯННЯ ЕФЕКТИВНОСТІ СУЧАСНИХ РЕГУЛЯТОРІВ У СИСТЕМІ КЕРУВАННЯ РОЗПИЛЮВАЛЬНОЮ СУШАРКОЮ

Процес розпилювального сушіння є одним із найбільш широко використовуваних подібних процесів, який знаходить застосування у хімічній, фармацевтичній та харчовій та інших галузях промисловості. Основною метою такого процесу є видалення води з готового продукту у випадках, коли готовий продукт виробляється у вигляді розчину. При цьому готовий продукт перетворюється на сипучий порошкоподібний матеріал, який значно краще придатний до транспортування та зберігання.

Очевидно, що процес розпилювального сушіння розчинених матеріалів потребує значної кількості теплової енергії. Переважна частина такої енергії спрямовується на нагрівання розчину готового продукту та на випаровування води з розчину. Іншою задачею практичної реалізації процесу розпиленого сушіння, як і в будь-якому подібному процесі, є проблема можливого пересушування матеріалу. Тому задача якісного керування процесом розпилювального сушіння залишається актуальною.

Традиційно розпилювальні сушарки працюють за допомогою систем керування з пропорційними та пропорційно-інтегральними регуляторами. Обидві зазначені системи керування засновані на фіксованій стратегії: один вхід – один вихід. У цій роботі ми хотіли б представити теоретичні результати досліджень систем керування розпилювальними сушарками з використанням сучасних регуляторів. Застосування таких регуляторів, на нашу думку, повинно істотно покращити техніко-економічні характеристики процесу сушіння. У роботі використано широко-відомий у теорії керування динамічними об'єктами модельно-прогностичний регулятор (MPC) та нечіткий регулятор на основі лінгвістичних змінних. Вибір регуляторів обумовлений як їх популярністю, так і високими показниками якості керування, які наведені в опублікованих наукових працях. Дослідження проводили на основі моделей процесу розпилювальної сушки, які були отримані в попередній роботі авторів.

Огляд попередніх публікацій включає аналіз дванадцяти джерел, п'ять з яких присвячені застосування різних стратегій керування процесом розпилювального сушіння та чотири – порівнянню ефективності використання MPC регулятора та нечіткого регулятора для керування процесами різних галузей. За результатами огляду показана доцільність порівняння результатів робота зазначених регуляторів для досліджуваного процесу.

У дослідженні використовувався програмний пакет MatLab Simulink для моделювання систем управління. Сам технологічний об'єкт моделюється за допомогою його передавальних функцій, які одержані у попередній роботі авторів. Модель доповнено початковими умовами – початковим значенням вологості. MPC-регулятор моделюється відповідним блоком, необхідне значення вологості на виході з апарату задається блоком констант. Для моделювання системи керування розпилювальною сушаркою з використанням нечіткого регулятора задані лінгвістичні змінні та проведено їх фазифікацію. Для контролюючої та контрольованих змінних – температури сушильного агенту та вологості одержаного матеріалу – запропоновано універсуми і три терміни: {низький; нормальний; високий}. Сформульовані нечіткі правила роботи регулятора.

Результати досліджень показали, що використання МПС-контролера в системі керування розпилювальною сушаркою дозволяє скоротити час перехідних процесів. Однак у випадку нечіткого регулятора система керування частково нівелює похибку математичної моделі.

Ключові слова: *енегоефективна технологія, розпилювальна сушарка, імітаційна модель, MPC-регулятор, нечіткий регулятор*

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