Adaptive microwave heating control for oily waste processing

R R Kadyrov
Ufa State Petroleum Technological University, Branch in the Sterlitamak, Pr. Oktyabrya, 2, Sterlitamak, 453118, Bashkortostan, Russia

E-mail: r_kadyrov@mail.ru

Abstract. Processing of petrochemical industry wastes involves the development of specific technologies and devices that require a significant investment of resources and time. To solve these problems, it is possible to develop universal technological, constructive, and managerial solutions capable of ensuring the adaptation of equipment to different raw materials, mode of operation, and yield of target products. The proposed reactor with a microwave effect on the catalyst and oil-containing raw materials with adaptive power control of the magnetron. Adaptive management is necessary because of the instability of the physicochemical characteristics of the raw materials. Adaptive control system takes into account the real state of the system and provides the necessary control. The advantage of the proposed method is that the entire algorithm is implemented in software, that is, for the introduction of this method of adaptive control does not require a change in the design of technological equipment. The implementation of this method comes down to the development of a special adaptive control driver. This approach greatly simplifies the adjustment of adaptive control systems for the considered processes of catalytic cracking, hydrocracking, visbreaking, coking.

1. Introduction

Modern solutions involve the development of specific technologies, apparatus designs for recycling a wastes of petrochemical production industries that require significant resources and time, which, in the context of market demand for products and changes priorities, requires more cost-effective solutions. Important role here plays an ensuring a quick changeover of equipment with preservation of high productivity and ecological cleanliness of production.

One of the acceptable approaches would be the development of new, more versatile technological, constructive, managerial solutions capable of ensuring the adaptation of equipment to different raw materials, mode of operation, yield of target products.

The proposed technology is based on the electrophysical method of influencing the technological environment. Unlike traditional heating of the reaction mass during catalytic cracking, hydrocracking, coking, visbreaking, the use of microwave energy has significant advantages:

- the absence of the traditional coolant provides low-inertia regulation, the heating rate is determined only by the speed of propagation of an electromagnetic wave in the medium, the dielectric properties of the medium and the radiation power;
- provides volume heating at once all material.
Features of exposure using microwave radiation allow us to offer a batch reactor for conducting the above-mentioned processes of universal construction, since the smoothness of controlling the radiation power of a magnetron from small values to large allows consistently heating the reaction mass and gradually recycle multi-component raw materials, selectively obtaining the target products (see figure 1) [1].

The operation of a batch reactor occurs as follows:

- the oil-containing raw material is loaded into the reactor after opening the cover interlocked with the magnetron switch;
- the feed oil-containing raw to the reactor continues until it reaches a required level;
- the required amount of catalyst is loaded into the reactor; after the loading process is over, the top cover closes and the magnetron is turned on for a certain power;
- microwave radiation begins to affect the solid - a catalyst that heats up and transfers heat to the raw materials;
- by the desired temperature is reached, the presence of a catalyst begins to significantly accelerate the reaction, it leads to the formation of light hydrocarbons, which are removed from the reactor;
- discretely increasing the power of microwave radiation, it is possible to consistently achieve the involvement in the reaction of the maximum amount of oil-containing materials present, and the resulting light hydrocarbons are selectively removed from the reactor by product type based on the analysis of the composition of the medium with a gas analyzer.

![Figure 1. Diagram of the electrodynamic microwave reactor.](image)

The functionality of the reactor will be determined by the features of the control system that collects information about the state of the technological object and determines the operating modes, as well as the behavior algorithms of individual nodes and devices. The main difficulty in organizing the management of the above processes is the instability of the physicochemical characteristics of the raw materials, which makes it difficult both to build a mathematical model and to define empirical dependencies. The way out of this situation would be to use an adaptive control system that takes into account the real state of the system and provides the necessary control actions.
2. Adaptive control block-diagram by process parameter errors

A common drawback of many adaptive systems is the need for a special sensor that needs to be embedded in a block-diagram (see figure 2) [2-8].

In figure 2 the following conventions are used:

- R - regulator;
- CO - control object;
- OS - feedback sensor;
- ACU - Adaptive Control Unit;
- ASFS - Adaptation Signal Feedback Sensor.

3. The logical scheme of adaptive control

The logical scheme of adaptive control is presented in figure 3.

The advantage of this method is that the entire algorithm is implemented in software, that is, for the introduction of this method of adaptive control does not require a change in the design of the process equipment. The implementation of this method is reduced to the development of a special adaptive control driver, which is included in the tasks of the microprocessor and processed in each period interrupt of the timer.

The adaptive error control algorithm can be represented as a unified module of the adaptation unit. The scheme of such a module has the form shown in figure 4.

The following signals are input to the adaptation unit: the specified value of the controlled variable $\varphi_s$, the specified error value $\varepsilon_s$, the change discrete of the controlled variable $\Delta$, the current error value $\varepsilon$.

The adaptation signal $\varphi_a$ is removed from the output of the adaptation unit, then this signal is compared with the actual value of the controlled variable, the difference between the signals $\varphi_a - \varphi_{real} = \varepsilon$ is fed to the input of the regulator.
4. The adaptive control method

The adaptive control method is as follows (see figure 5).

In figure 5 the following conventions are used:

- $T_s$ - temperature sensor;
- $V_s$ - voltage sensor;
- $T_R$ - temperature regulator;
- $V_R$ - voltage regulator;
- $\varepsilon_T$ - the temperature error signal;
- $\varepsilon_H$ - the voltage error signal;
- $T_s$ - set temperature;
- $\Delta T$ – the discrete change in temperature;
- $\varepsilon_{sT}$ - the set value of the temperature error;
- $T_{ad}$ - adapted temperature value;
- $\Delta U$ - discrete voltage change;
• $\varepsilon_{SU}$ - the set value of the voltage error;
• TAU - temperature adaptation unit;
• VAU - voltage adaptation unit.

When the temperature of the catalyst reaches the so-called zero point, the microcontroller (IPC) controls the magnitude of the actual error in the tracking loop at controlling the heating of the raw material. If this error exceeds a predetermined value, then there is a slow change (depending on the error sign) of the microwave field power before the signal "Starting point" arrival from the feedback sensor by temperature in the IPC, after which an instant termination of change of the microwave field power. When the temperature of the catalyst reaches the value required for the reaction (zero point), the actual error in the tracking system is less than the specified value of the constant, which is set programmatically. If this excess becomes greater than the value of the above-mentioned constant, the IPC records the error value and generates a command to change the power of the microwave field before the IPC receives the “Starting Point” signal, and reaches the zero point [10].

![Adaptive control block-diagram](image)

**Figure 5.** Adaptive control block-diagram.

Block-diagram for the considered processes of catalytic cracking, hydrocracking, visbreaking, coking, differing by the fact that the values a different technological parameter, other of the error signal and change discrete is fed to unified module of adaptation unit.

### 5. Summary
A method has been developed for calculating the tuning parameters of adaptive control systems by the magnitude of temperature error of catalytic cracking, hydrocracking, coking, and visbreaking processes.

The use of an adaptive system for the error allows for the stabilization of technological parameters on the basis of the existing element base, based on a software algorithm without complicating the control circuit of additional sensors.

The application of the concept of software adaptive control parameter by the error in the electrodynamic microwave installation will allow you to maintain the deviation of the heating temperature of an oily substance within the specified limits. With this control, the optimum power consumption is carried out.

Thus, it can be noted that the proposed solutions for managing the process of heating oil-containing substance can significantly reduce energy costs and increase the reliability of high-intensity technology in an electrodynamic furnace.

### References

[1] Bikbulatov I Kh, Kadyrov R R, Charikov P N and Bukharov V R 2011 Technology for producing benzine from residues of methyl-tret-butyl ether production using microwave radiation and in a special production building *Bash. Chem. J.* **18**(2) 169-72
[2] Aseltine J A, Mancini A R and Sarture C W 1958 A survey of adaptive control systems *IRE Trans. on Automatic Control* **AC-6**(12) 102-8

[3] Bastin G and Gevers M 1988 Stable adaptive observers for nonlinear timevarying systems *IEEE Trans. on Automatic Control* **33**(7) 650-8

[4] Bellman R and Kalaba R 1960 Dynamic programming and adaptive control processes: Mathematical foundations *IRE Trans. on Automatic Control* **AC-5** 5-10

[5] Bastin G, Bitmead R., Campion G and Gevers M 1992 Identification of linearly overparametrized nonlinear systems *IEEE Trans. on Automatic Control* **37**(7) 1073-8

[6] Krstic M, Kanellakopoulos I and Kokotovic P 1995 Nonlinear and Adaptive Control Design Wiley and Sons Inc.

[7] Krstic M and Wang H 2000 Stability of extremum seeking feedback for general nonlinear dynamic systems *Automatica* **36** 595-601

[8] Morse A S, Mayne D Q and Goodwin G C 1988 Applications of hysteresis switching in parameter adaptive control *IEEE Trans. on Automatic Control* **37**(9) 1343-54

[9] Kadyrov R R and Charikov P N 2014 High technologies in engineering industry *Proc. of All-Russia research and practice Conf.* (Ufa: USATU) p 25-6

[10] Grigoryev E S, Kadyrov R R, Charikov P N and Pryanichnikova V V 2017 Simulation of Honing of a Processed Workpiece on CNC Machine *K. E. M.* **743** 236-40