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MECHANIZATION

Organizational Features of Process Flow of Combined Feed Production with Disinfection of Raw Materials

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Abstract—The problem of including disinfection of combined feed components with active liquids and microwave radiation in the process flow scheme of on-farm combined feed production is considered. The elaborated operator model helps define the position of disinfection operations in the combined feed production system. The rational management of the processing line of combined feed production is validated.

Keywords: combined feed, disinfection, microwave radiation, ozone solution, biological safety of feed

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Today, the organization of efficient on-farm production of all-in-one combined feed based on local raw materials still remains a topical issue. What impedes their efficient use is their contamination with microscopic mold fungi and their hazardous byproducts, i.e., mycotoxins. In particular, the share of samples with excessive MPC of mycotoxins in the total number of combined feed samples taken in the southern regions of Russia is approximately 80%, and the share of positive samples is 100% [1]. The reason for this is contamination of vegetation feed components during cultivation and storage [1, 2]. The most contaminated components are cereal grain and oil plant cakes and coarse meal. Today, combined feed components are not disinfected at on-farm combined feed production facilities with a capacity of up to 3 t/h. Thus their feed output does not meet biological safety requirements. In addition, contamination of combined feed with mold fungi cuts its storage life.

Since 2010, the Northern-Caucasian Scientific Research Institute of Mechanization and Electrification of Agriculture (NCSRIMEA) has conducted studies to determine the most efficient methods of grain disinfection. It has been found that pathogenic flora is efficiently destroyed by microwave radiation, in ozone solution, and in alkaline water [2]. However, the strongest effect is produced by the joint action of microwave radiation and ozonized or alkaline electrolyzed water [2, 3]. Their joint impact produces a synergetic effect, destroying 95% of bacteria and up to 80% of mold fungi and their spores, while technological properties of grain and feed are retained. It has been found that the most efficient algorithm is to process the grain in an active liquid and then expose the moistened grain to microwave radiation [3, 4]. Oil plant cakes and coarse meal are efficiently disinfected by microwave radiation [5].

To translate the validated methods of disinfection into action, experts at the NCSRIMEA have developed respective technical tools [6, 7] and an assembly to disinfect grain with active liquids. This unit is a horizontal blade-paddle mixer, where ozone water solution or electrolyzed alkaline water is supplied via a system of nozzle and flow-regulating valves with the help of a pump [6]. The active liquid is sprayed onto the surface of the mixed grain. The ozone water solution is prepared by flowing the gas produced in the ozonizer through the water in the bubbler. The alkaline water is produced in an EAP-03 electric activating unit. The bulky components of the feed are exposed to the convective microwave action produced by a Sigma-1 microwave assembly, which leads to destruction of microorganisms [7].

It is, therefore, a topical problem to include the disinfection of the most affected components, i.e., fodder grain, oil plant cakes, and coarse meal, in the process flow scheme of on-farm combined feed production. Consequently, it is necessary to determine the position of these operations in the process flow. At the same time, the integrity of the existing production–engineering scheme shall be maintained without oversophistication.

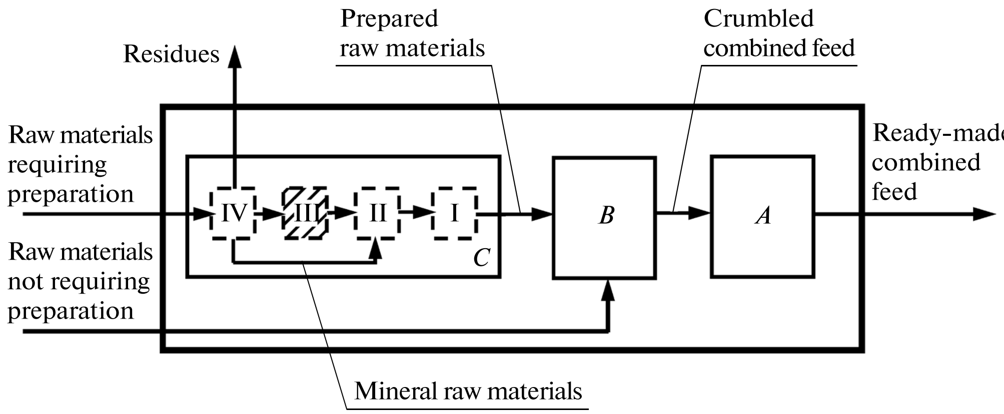

Fig. 1. Combined feed production system. A and B are the respective subsystems of ready-made and crumbled feed (dispensing and mixing of components), C is the raw materials preparation subsystem, consisting of the following steps: I is the intermediate storage of prepared raw materials, II is the grinding of raw materials, III is disinfection, IV is fractional separation and purification

METHODS

The provisions of the food production process flow theory were used [8]. In particular, the operator model of the on-farm combined feed production system was elaborated. In this model, the production system is given as a sum of single-operation subsystems. These operations are operators with a set of physical processes, i.e., processors interconnected by flows of processed raw materials. The experimental data were used to determine the stability of the subsystems, including the disinfection operations and the integrity level of the whole system.

RESULTS AND DISCUSSION

A typical combined feed production system includes raw materials preparation subsystem C, crumbled combined feed production (component dispensing and mixing) subsystem B, and ready-made combined feed production subsystem A (Fig. 1). Disinfection of ready-made combined feed (subsystem A) is unreasonable, because it leads to excessive consumption of electricity and other resources. It is optimal to disinfect raw materials in the preparatory phase (subsystem C), which shall be done only to raw materials with the highest pathogenic flora content, i.e., only to grain and protein components (oil plant cakes and coarse meal). As a result, cost-efficient use of resources will be ensured. To make the disinfection operations more efficient, the processed components of the feed shall undergo preliminary peeling [3, 4]. It is, therefore, reasonable to perform disinfection operations III as part of subsystem the preparatory phase C after fractional separation and peeling in phase IV and before grinding in phase II.

Raw materials requiring preliminary preparation are divided into three groups: grain components are disinfected with active liquid and microwave radiation, protein components are disinfected with microwave radiation, and mineral components do not require any disinfection at all. In this respect, it is reasonable for the synthesis of the combined feed production system to divide subsystem C into three subsystems: C_1 is the grain component preparation subsystem, C_2 is the protein component preparation subsystem, and C_3 is the mineral component preparation subsystem.

In Fig. 2, the operator model of the combined feed production system is presented. In this model, disinfection operations do not form a separate subsystem but are included into subsystem C, i.e., technological flows of raw materials are not interrupted in the course of processing. Thus, the disinfected raw materials are supplied to central subsystem B (dispensing and mixing phase), which makes it possible to produce biologically safe feed.

In 2012–2013, a fragment of the process line corresponding to the elaborated operator model was organized in the Rostov oblast by Svetloe Vremya AGRO corporation. The experimental data on the use of that fragment was used to estimate the operational stability of particular subsystems (η_i) according to equation (1):

$$\eta_i = H_i/H_{\max}, \quad (1)$$

where H_i and $H_{\max}$ are the entropy of the ith subsystem and the maximum entropy, respectively. All the systems involved in combined feed production are binary. In other words, either high-quality or poor-quality feed is produced. For this reason, the MPC of mold fungi content in combined feed was used as the factor of merit.

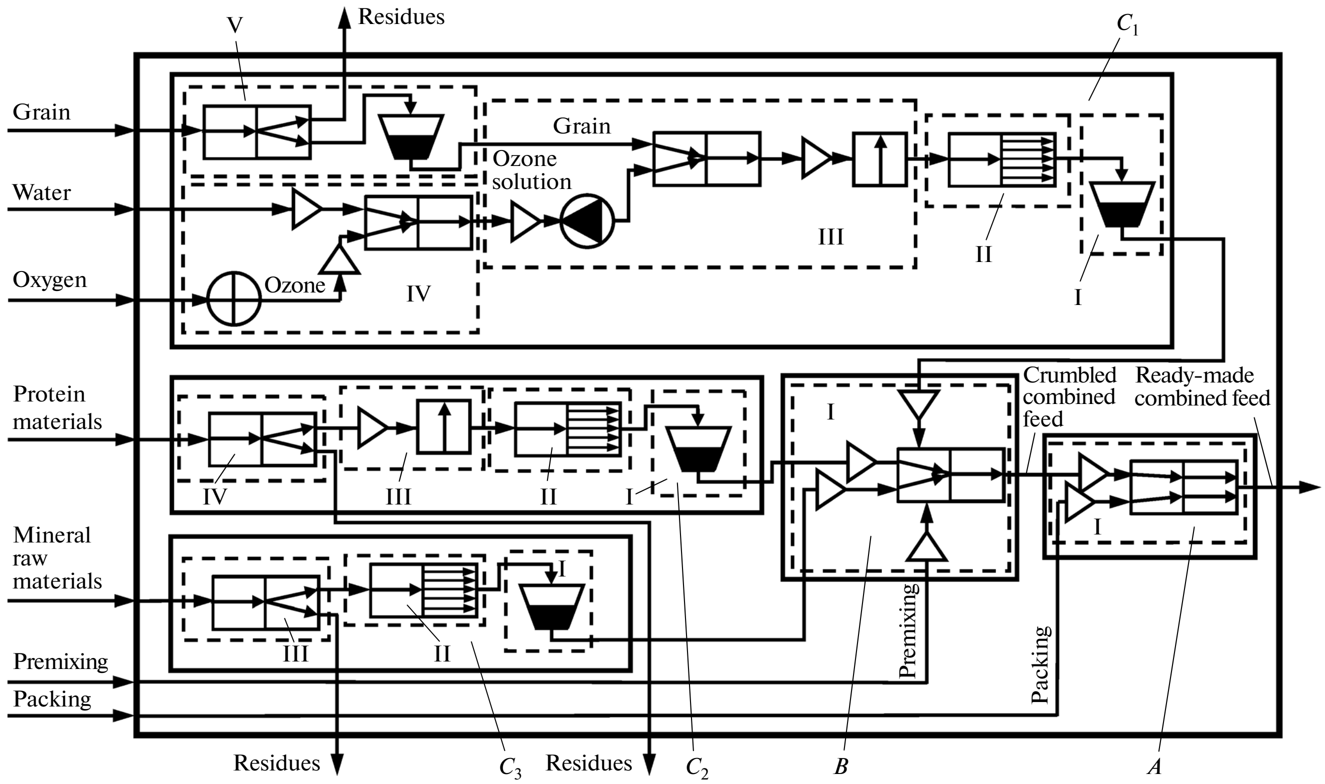

Fig. 2. Operator model of the on-farm combined feed production system, including disinfection of raw materials: A is the subsystem of ready-made combined feed production, including operator I, which is combined feed packing; B is the subsystem of crumbled combined feed production, including operator I, which is component dispensing and mixing; C_1 is the subsystem of grain components preparation, including operator I, which is intermediate storage of prepared grain, operator II, which is grain grinding, operator III, which is grain disinfection, operator IV, which is ozone solution production, and operator V, which is grain separation; C_2 is the subsystem of protein components preparation, including operator I, which is intermediate storage of prepared raw materials, operator II, which is raw materials grinding, operator III, which is raw materials disinfection, operator IV, which is fractional separation of raw materials; C_3 is the subsystem of mineral components preparation, including operator I, which is intermediate storage of prepared mineral materials, operator II, which is mineral materials grinding, operator III, which is fractional separation of mineral materials.

Integrity Θ_{CBA} of the processing system of subsystems A, B, and C is determined according to equation (2):

$$\Theta_{CBA} = \eta_C + \eta_{B/C} + \eta_{A/CB}, \quad (2)$$

and the stability of subsystem C, consisting of statistically autonomous subsystems C_1, C_2, and C_3, is determined according to the following equation:

$$\eta_C = \eta_{C_3C_2C_1} = \eta_{C_3} + \eta_{C_2} + \eta_{C_1} - 2. \quad (3)$$

Taking account of (3), equation (2) will be recorded as

$$\Theta_{CBA} = \eta_{C_3} + \eta_{C_2} + \eta_{C_1} + \eta_{B/C_3C_2C_1} + \eta_{A/C_3C_2C_1B} - 4. \quad (4)$$

According to (4), the integrity of the combined feed production system, including operations of raw materials disinfection, is $\Theta_{CBA} = 0.7 > 0$. In terms of integrity, the processing system belongs, therefore, to the domain of integral systems, which points at its high-quality organization.

The suggested scheme of organizing the process flow of on-farm combined feed production with disinfection operations can be characterized as sustainable and does not have any negative impact on the system's stability. Although the inclusion of additional operators in its subsystems makes the considered system somewhat more complex, this is compensated by the significantly improved quality of ready-made combined feed. The hardware-and-machinery structure of the respective processing line was validated and developed on the basis of the operator model of the considered system. The suggested technological solutions can encourage efficient integration of disinfection operations with already functioning on-farm facilities and facilities in the course of design. As a result, the quality and biological safety of combined feed output and farming products will be very much improved.

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