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Management of the Processes of Filling, Storage and Discharge of Grain Cargo at Transport Storage Facilities

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ABSTRACT

The active transformation of transport links and redistribution of cargo flows requires intensive development of new promising areas of cargo transportation. It is necessary to use existing transport and technological systems to develop measures to increase productivity and reduce non-production costs. This approach provides for increasing the efficiency of the transport and logistics system.

The objective of the article is to study, develop and specify transport and technological facilities intended to handle grain cargo and their individual, most significant elements.

The organisation of transportation of various cargoes, taking into account the parameters of rolling stock, handling and storage equipment, is of decisive importance in determining the efficiency of transport and technological schemes.

The paper considers the technology developed to move the material flow from the consignor to the consignee, which allows to supply cargo to the recipients at a fixed time while keeping its qualitative and quantitative characteristics. The study of the grain cargo transportation market made it possible to draw a conclusion about the importance of filling, discharge, and temporary storage operations for the entire operation chain.

A proposed innovative design of a class of bunker silos could significantly expand their functionality together with the developed technology of their operation to handle grain cargo.

Study on the analysis and modelling of the processes in proposed bunker silo considered physical and mechanical properties of the considered cargoes. The main parameters and factors, as well as the range of their influence on the efficiency of its operation were investigate for filling, storage and discharge stages.

Keywords: grain cargoes, transport and storage facilities, bunker silo, silos, filling, storage, discharge.

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INTRODUCTION

Volumes of bulk cargo transported in Russia are increasing every year thanks to offering of comprehensive transport and logistics services for shippers and improving the quality of transportation, thus also solving a task to attract new customers. According to forecasts, transportation by rail alone will soon increase by 30 %, for example, transportation of chemical and mineral fertilisers by 2025 will increase by 44,4 % to attain 85,5 million tons, grain cargo by 22 % to attain 140 million tons, etc.[1]

On public railways, for example, JSC Russian Railways provides various services at cargo terminals: warehouse rental, loading and unloading operations with packaged cargo, containers, heavy loads, crushed stone, etc., cleaning and washing of wagons/containers, as well as temporary storage of goods under customs control. To expand the scope of integrated transport and logistics business, it is necessary to handle grain cargo as well, for this it is necessary to build transport and storage facilities (elevators), to equip them with silos, and, namely, bunker silos.

Researchers in many countries also pay attention to that issue, particularly in the context of activity of different modes of transport, highlighting from diverse aspects the role of railways (e. g.[2, 3]). Harvesting of grain is accomplished and the grains cargoes are collected for handling in a certain period of the year, but these cargoes are transported all year round. The short-term or long-term storage implies use of silos and namely bunker silos; thus, they must function stably and ensure timely and uninterrupted loading of grain cargo on the rolling stock [1].

For that, it is necessary that the storage facilities (including transport storage facilities but not limiting to them) comply with rules (e. g.[4, 5, 6] [1]) and meet certain conditions: processing of grain cargoes should be fully automated, and qualitative and quantitative safety of the grain cargo, sanitary and hygienic treatment, protection against the penetration of rodents and birds should be ensured (e. g., [2–3]).

Based on the works of Russian and foreign scientists, a scheme of transport and storage facilities for grain cargo was developed (Pic. 1) [4; 5].

Transport and storage facilities (TSF) for grain cargo are divided into three levels. The first level includes procurement (or on-farm) transport and storage facilities; the second level – intermediate, basic, transshipment and stock TSFs: the third level – port, sales, and production TSFs.

Procurement transport and storage facilities are located near farms, where grain cargoes are received from the fields, processed, and stored. Subsequently, grain cargoes are shipped to water and railway transport and delivered to transport and storage facilities of the second and third levels. Procurement facilities ensure processing of the entire harvest due to the large capacity and productivity of the equipment.

Basic transport and storage facilities are located at the intersection of water and railway routes, at railway junctions and serve for constant handling of grain cargo. TSFs of the kind perform the following operations: reception and cleaning of grain cargoes, mainly long-term storage, drying and loading onto vehicles.

Transshipment TSFs are designed for reloading cargo from one mode of transport to another, they are equipped with high-performance equipment.

Stockpiling of grain cargoes is provided by *stock* TSFs. The shelf life of grain cargo is 3–4

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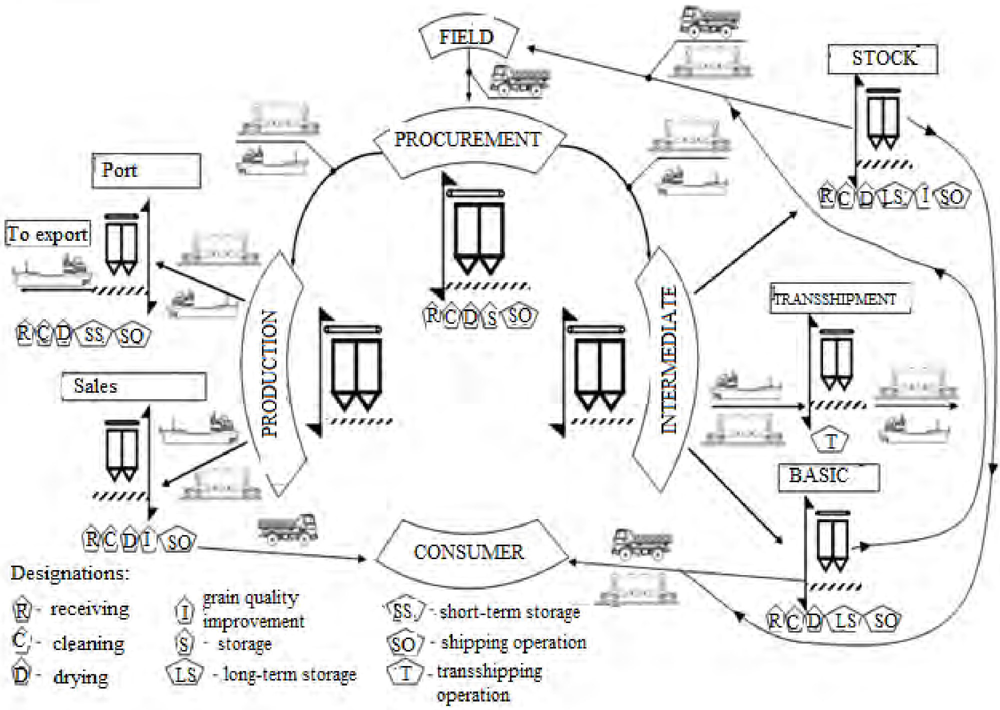


Pic. 1. Scheme of transport and storage facilities for grain cargoes [compiled by the authors].

years due to cleaning, drying, and maintaining the quality of grain cargo [6].

Production TSFs distribute grain cargo to various processing enterprises: feed mills, flour mills, etc. Grain cargoes are stored at a production TSF for 5–6 months.

Port TSFs are intended for shipment of grain cargo for export. Grain is supplied to the port elevators from water and railway transport. To ensure stable loading of grain cargo for export, a port TSF must be provided with the latest transport and storage equipment [7].

Sales TSFs are used for delivery of grain cargo to consumers. Most commonly, the cargo arrives by rail and is further shipped to road transport.

TSFs at all levels partially perform the functions of other types of TSFs.

The main elements of transport and storage complexes for grain cargo are silos, namely bunker silos, intended for various purposes. Problems arising in them are arching, segregation, compaction, caking, etc. These problems negatively affect functioning of TSFs [8; 9]. The delay of rolling stock during loading operations directly affects the turnover of wagons.

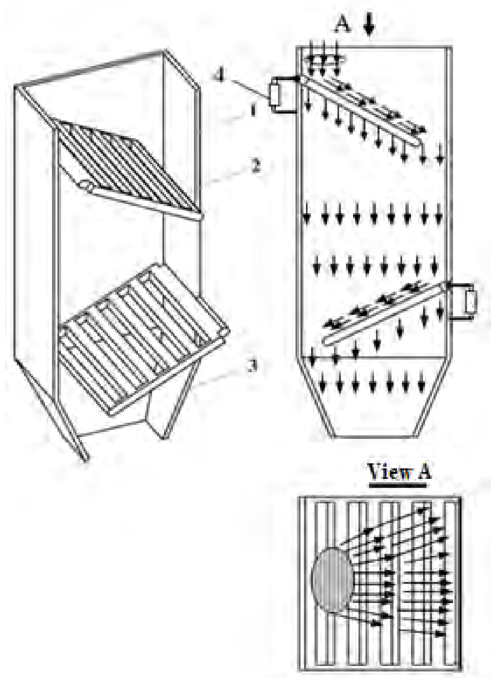
The *objective* of the work is to develop a bunker silo design that can ensure stable operation of a tank and will eliminate compaction of grain cargo during filling by uniformly distributing bulk cargo over the tank section, minimise segregation and arching of the cargo, and ensure uniform pressure inside the tank. This will allow to control the filling of bulk cargo into a silo, as well as to improve safety of the process and its efficiency.

RESULTS

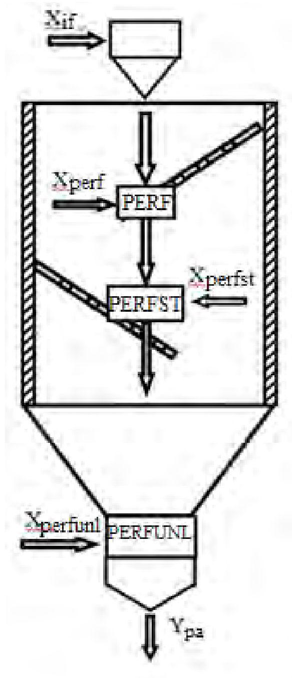
Based on the analysis of filling and discharge devices for silos, the design of a sector multifunctional bunker silo was developed (Pic. 2) [10].

The multifunctional bunker silo (1) is divided into sectors by means of perforated sieves (2). The sieves with rectangular holes are located at a certain angle to the horizontal plane. Due to the passive drive (4), the installation angle of the sieve changes. Rectangular holes of the sieve are located perpendicular to movement of the grain. The grain cargo is filled through funnel (3).

The multifunctional bunker silo works as follows: the perforated sieves are set at an angle to the horizontal plane. In the process of filling the multifunctional bunker silo, the grain load meets the first sieve on its way, which divides the loaded material into two streams, one of



Pic. 2. Multifunctional bunker [compiled by the authors].



Pic. 3. Scheme of a parametric model [compiled by the authors].

which descends along the sieve, the other passes through rectangular holes and enters the second sieve located lower on the opposite wall of the bunker, etc. until the bunker is fully filled.

Storage of grain cargo in silos is subject to various difficulties, partially mentioned above: arching, compaction, bridging, segregation, violation of the geometry of the output funnel due to mechanical impact, etc. This negatively affects operation of the entire TSF.

Many scientists have developed parametric models of the bunker silo during its operation. Based on these studies, we will consider a parametric model of a multifunctional bunker silo (Pic. 3).

The process of operation of this bunker silo must be divided into functional blocks:

1) The incoming flow of grain cargo (X_{if}).

2) The process of operation of a perforated sieve during filling (X_{perf}).

3) Operation of a perforated sieve during the storage of grain cargo (X_{perfst}).

4) Operation of a perforated sieve in the process of discharge a grain cargo ($X_{perfunl}$).

5) Parameters affecting the operation of the entire bunker silo (Y_{pa}).

The functioning of the multifunctional bunker can be written as follows:

$$Z_{perf} = Z_{perf}\ \{X_{if}, X_{perf}, X_{perfsf}, X_{perfunf}, Y_{pa}\}, \qquad (1)$$

Let us consider the factors affecting the input flow of grain cargo:

$$X_{if} = X\{x_{1if}, x_{2if}, x_{3if}, x_{4if}, x_{5if}, x_{6if}, x_{7if}, x_{8if}\}, \quad (2)$$

where x_{1if} – productivity of the feeder;

x_{2if} – cross-sectional area of the flow;

x_{3if} – flow density;

x_{4if} – fall height;

x_{5if} – moisture content of the cargo;

x_{6if} – content of impurities;

x_{7if} – windage coefficient;

x_{8if} – physical and mechanical properties of the cargo.

The perforated sieve, being inside the bunker silo, also affects the tank filling. Let us consider the factors affecting the functioning of the sieve during the filling process:

$$X_{perf} = X\{x_{1perf}, x_{2perf}, x_{3perf}, x_{4perf}, x_{5perff}, x_{6perf}, x_{7perf}, x_{8perf}, x_{9perf}\}, \qquad (3)$$

where x_{1perf} – productivity of the perforated sieve (the greater is the productivity, the faster the bunker silo is filled);

x_{2perf} – installation of a perforated sieve (if the installation angle is large, then the bulk of the cargo leaves the sieve, if the installation angle is small, the bulk of the cargo remains on the sieve);

x_{3perf} – configuration of openings (holes) in the sieve (it has a significant impact on cargo movement, if the configuration of openings is in the shape of a circle, it is necessary to shake the sieve, and if the configuration of openings is rectangular, then the cargo passes freely and descends along the sieve);

x_{4perf} – dimensions of holes in the sieve;

x_{5perf} – dimensions of jumpers between openings of the sieve;

x_{6perf} – dynamic indicator of filling the cross section of the bunker;

x_{7perf} – the number of perforated sieves in the bunker (affects the horizontal and vertical pressure in the bunker, as well as cargo segregation);

x_{8perf} – bulk (compaction) factor (affects the integrity of the cargo particles);

x_{9perf} – coefficient of the used volume (depends on the size of openings in the sieve).

Having considered all the factors that have a significant impact on the process of filling the bunker silo, it must be remembered that this process affects the storage of bulk cargo.

Factors affecting the operation of a perforated sieve during storage:

$$X_{perfst} = X\{x_{1perfst}, x_{2perfst}, x_{3perfst}\}, \quad (4)$$

where $x_{1perfst}$ – the number of perforated sieves in the bunker silo (affects the horizontal and vertical pressure in the bunker silo, as well as cargo segregation);

$x_{2perfst}$ – geometrical dimensions of the perforated sieve (if the sieve area is more than half of the cross-sectional area of the bunker silo, but less than the cross-sectional area of the bunker silo, then the perforated sieves can be the point of interaction between the controlled arching and the bunker structure, so that the discharge process will be controlled);

$x_{3perfst}$ – installation of a perforated sieve at an angle relative to the horizontal plane.

As it is known, the filling process affects the functioning of the entire bunker silo. During the storage of bulk cargo, undesirable phenomena occur, such as arching, bridging, compaction, segregation of bulk cargo [11; 12]. Bridging of bulk cargo often occurs in bunkers with a rectangular cross section. The arching is formed due to the increase in horizontal pressure inside the bunker silo. Compaction and segregation of bulk cargo appear due to extraneous vibration. These phenomena negatively affect the discharge of bulk cargo from the bunker. Discharge is followed by a pulsation, and the quality of the cargo is deteriorating, because of the segregation of the cargo [13–16].

In a multifunctional bunker silo, perforated sieves are not removed during the storage of bulk cargo, therefore, they constitute a support for arching, but it is enough to change the inclination of the perforated sieve by 1°, the arch will collapse, and discharge will proceed evenly, without pulsation. In this case, it will be possible to control the process of discharge of the bulk cargo [7].

Let's consider the parameters that affect the discharge process using a perforated sieve:

$$X_{perfunl} = X\{x_{1perfunl}, x_{2perfunl}, x_{3perfunl}, x_{4perfunl}, x_{5perfunl}, x_{6perfunl}, x_{7perfunl}, x_{8perfunl}, x_{9perfunl}, x_{10perfunl}\}, \quad (5)$$

where $x_{1perfunl}$ – linear values of bunker silo (rectangular, round and trough-(U-)shaped);

$x_{2perfunl}$ – the shape of the lower element of the bunker silo (funnel) (models and controls productivity and arching);

$x_{3perfunl}$ – the number of discharge openings (the more there are openings, the more uniform the discharge will be);

$x_{4perfunl}$ – the area of discharge opening relative to the axis of the bunker silo;

$x_{5perfunl}$ – the angle of the lower element of the bunker silo (funnel);

$x_{6perfunl}$ – the dependence of the cross-sectional area of the bunker silo and the area of the discharge opening;

$x_{7perfunl}$ – pitch from the discharge opening to the beginning of the perforated sieve;

$x_{8perfunl}$ – physical and mechanical properties of grain cargo;

$x_{9perfunl}$ – bunker silo manufacturing material;

$x_{10perfunl}$ – installation of a perforated sieve (the slope of the perforated sieve affects the discharge).

Let us consider the parameters of the discharge process for operation of a multifunctional bunker silo:

$$Y_{pa} = Y\{Y_{1pa}, Y_{2pa}, Y_{3pa}\}, \quad (6)$$

where Y_{1pa} – the capacity of the bunker silo;

Y_{2pa} – constant feeding of the input;

Y_{3pa} – the coefficient of cargo segregation.

CONCLUSIONS

Thus, after considering and estimating all the factors that affect the operation of the multifunctional bunker silo, we have determined the main parameters of the functioning of the bunker silo.

Due to perforated sieves, it is possible to regulate and control the process of filling, storage, and, most importantly, the process of discharge of the bulk cargo. The proposed design was patented in the Russian Federation [17].

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