Advances in Engineering Research, volume 151

International Conference on Smart Solutions for Agriculture (Agro-SMART 2018)

Tower-Type Grain Dryer with the Recovery of Cooling Air and Dryer Agent Operating on Liquid Fuel

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***Abstract*—The new space-planning solutions are proposed that allowed transferring a tower-type grain dryer from gas to liquid fuel while maintaining the recovery of cooling air and partial recovery of the dryer agent from the lower part of the drying zone. In this case, the drying zone is divided into upper and lower zones by a partition, and the mixing chamber is separated from the cooling zone by a partition and connected with the upper drying zone by an air pipe. This position of the mixing chamber allows recovering both the exhaust cooling air and the dryer agent delivering them into the upper drying zone together with the fresh dryer agent. In this case, the heat generator is removed from the air-pressure chamber of the grain dryer and can run on liquid or any other type of fuel. Based on the developed design model, the heat and aerodynamic calculations of the grain dryer were carried out as well as the sizes of drying zones, costs and air filtration rates for the productivity of 15 t/h with a decrease of humidity by 5% (from 19% to 14%). It was established that due to the recovery of cooling air and dryer agent the fuel economy up to 31% can be achieved. The engineering documentation is developed, a tower-type grain dryer is assembled, installed and tested at one of the grain-producing enterprises of the agricultural complex.**

***Keywords*— grain dryer, fuel, recovery, dryer agent**

I. INTRODUCTION

Currently, various designs of stationary and mobile grain dryers are used for drying grains of cereals, legumes and oilseeds, as well as corn kernels: louvre-type, column, tower-type, bin-type, batch, conveyor and others; most of them can work both in a flow and in the recirculation mode. They are usually convective grain dryers using liquid or gas fuel. At the same time, the gas-fired grain dryers usually work without a heat exchanger and dry the grain with the mixture of air and fuel combustion products. In a grain dryer running on liquid or low grade fuel a heat exchanger is usually used [1, 2, 3].

For the drying of coarse-grained crops, such as corn, legumes, rice, wheat, barley the tower-type grain dryers are successfully used. They have a relatively simple design and high assembly availability, which allows using the modular principle of increasing productivity.

The drying and cooling zones of these grain dryers are formed by parallel perforated columns with the discharging chambers between them; the dryer agent or cooling air is delivered into them. In these perforated columns there are inverters increasing the uniformity of drying and preventing overheating of the grain; by means of these inverters a layer of grain moving in the column by gravity periodically shifts from the point of entry into the layer of the dryer agent to its exit from the layer. However, such a basic design of the tower-type grain dryer, which does not divide the discharge chamber into drying zones, does not provide for the recovery of the exhaust cooling air and the dryer agent, which significantly reduces its efficiency [4].

It was established that for the flow grain dryers involving the tower-type grain dryer the efficiency does not exceed 42 and 49.2%, with indirect or direct heating of the dryer agent respectively and the heat input is 5985 and 5110 kJ/kg of the evaporant moisture without the preheating of the grain and recovery of the cooling air and exhaust dryer agent. At the same time, it was found out that with the recovery of cooling air and a dryer agent unsaturated with moisture, the efficiency of the grain dryer increases to an average of 56.9-64.5%, and the heat input decreases to 4418-3898 kJ/kg of the evaporant moisture [5].

In the horizontal tower-type grain dryer SZM [6] the designers implemented a traditional solution for recovery of exhaust heated cooling air by delivering it to a heat generator by a blower to mix it with atmospheric air. However, by doing so, the mixing chamber is a separate device and significantly increases the size of the grain dryer. Moreover, the recovery of the unsaturated dryer agent becomes complicated in the construction type. The GSCOR modular tower grain dryers [7] of the authorized dealer of Mathews Company (USA) also have a cooling air recovery system similar in design [8]. At the same time, according to the company's data, the recovery of cooling air can lead to fuel savings of up to 30%. A distinctive feature of these horizontal tower grain dryers is the installation of ventilation equipment outside the plenum chambers, which allows them to operate on both liquefied and natural gas, as well as on diesel fuel. However, an excessive increase in the length of the horizontal grain dryers with the one-sided supply of the dryer agent and cooling air into the plenum chamber leads to uneven drying and cooling of grain along the length of the horizontal chamber, due to uneven distribution of the dryer agent and cooling air.

To solve this problem and increase the productivity of the tower grain dryers, the vertical tower-type grain dryers are designed, where a heat generator, including blowers and burners, in the lower part of the air-pressure chamber. This design allows reducing the material intensity of the dryer due to the adequate space-planning solutions. The vertical structure of the grain dryer Brock (USA) allows the grain to move steadily through the tower, optimizing the air distribution system and recovering the cooling air delivered to the burner together with the fresh atmospheric air due to the vacuum generated by a centrifugal or axial blower [9]. According to the manufacturers' data, the recovery of cooling air makes it possible to reduce energy consumption of drying up to 25%.

The design of the vertical tower grain dryer DS-DSB developed by DeLux (USA) provides for the possibility of recovery not only of the exhaust cooling air, but also, of the part of the exhaust dryer agent from the lower section of the drying zone; the designers believe that it will reduce the energy consumption of drying to 30-50% [10]. Besides, from the lower part of the drying zone both the exhaust cooling air and the exhaust drying agent must flow into the suction port of the burner blower passing through the trapezoidal chambers (heat exchangers) located horizontally in the tower with the grain. At the same time, such a technical solution makes it difficult to regulate the drying process when it is necessary to simultaneously control and regulate the air flow needed for combustion, while simultaneously regulating the temperature of heating and cooling of the grain.

For this purpose, the developers changed the design of the vertical tower grain dryer, they installed a blower for cooling the grain and separated the drying and cooling zones; it can be seen in the tower grain dryer of the joint production of Melinvest OJSC (Russia) and QED (USA). The drying zone is divided into the upper zone, from where the drying agent saturated with moisture is removed outside and the lower zone, from where the unsaturated drying agent is utilized [11].

All the tower dryers with a burner located in the air-pressure chamber of the tower grain dryer use natural or liquefied gas fuel. Such design of the tower-type dryer allows providing for the recovery of cooling air and the partial recovery of the drying agent for the purpose of reducing energy consumption and increasing the efficiency of the drying process. The cooling air and the exhaust dryer agent are delivered from the lower part of the drying zone to the mixing chamber by the blower of the heat generator; there the blower of the heat generator creates vacuum. This allows disposing of the exhaust cooling air and partially of the exhaust dryer agent from the bottom part of the drying zone (Fig. 1).

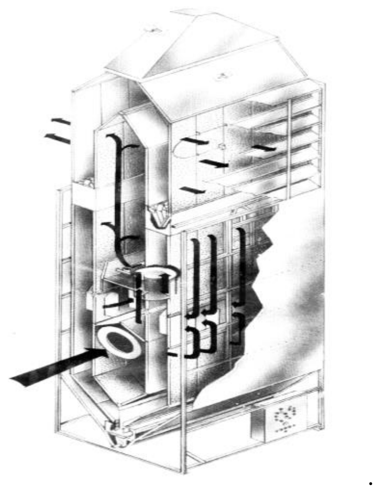

Fig. 1. The structural scheme of a gas-fueled tower-type grain dryer

According to the designers' data, such a disposal scheme will allow utilizing of up to 48% of the exhaust unsaturated dryer agent and the entire exhaust cooling air. The author's calculations based on the technical characteristics of the MiniMax (USA) grain dryer, which is analogous to the Astra tower-type dryer, show that the efficiency of the grain dryer is 68.8% [12].

The location of the heat generator in the air-pressure chamber of the grain dryer with the open flame between drying towers dramatically increases the fire and explosion hazard of the dryer; as there is possibility of sparks occurrence due to the dusty air and air trash delivered for recovery, which cannot be excluded from the grain. Therefore, the given grain dryer runs on gas only and cannot operate on liquid fuel due to a significant increase in the length of the torch and additional sparking.

To develop the technological scheme of the grain dryer with the recovery of the dryer agent and cooling air operating on liquid or any other type of fuel, the following tasks were solved: the calculations were made, the structural and technological schemes and design documentation were developed, the grain dryer was assembled and its performance tests were carried out.

II. Materials and Methods

For thermal and aerodynamic calculations the calculation model of a tower-type drain dryer is developed (Fig. 2) which involves the separation of the drying zone by a partition with the adjustable valves into the upper (first) and lower (second) drying zones; the mixing chamber is separated from the cooling zone by a partition and connected with the first drying zone by an air duct, while the air-collecting chambers and the heat exchanger are separated by a partition between the second drying zone and the cooling zone. In this case, the cooling blower is located in the cooling zone of the grain dryer, and the drying blower outside the dryer is arranged at the output of the heat generator.

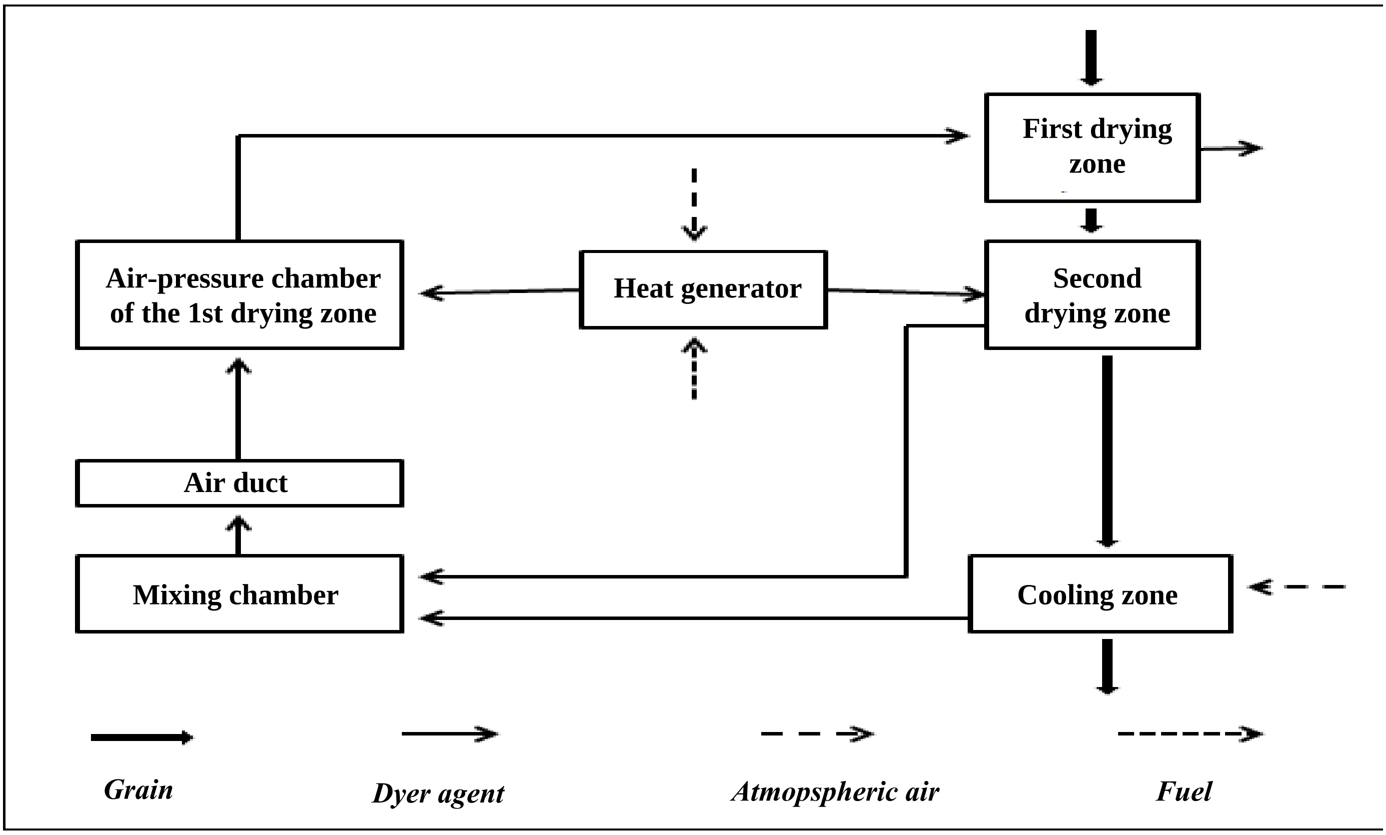

Fig. 2. The calculation model of a drain dryer with the recovery of the dryer agent and cooling air

The calculation was carried out for corn grain intended for the starch industry with the productivity of a grain dryer of 15 t/h, the outdoor temperature of 15°C and the relative humidity of 60%. The moisture content of the grain at the entrance to the grain dryer is 19%, at the output – 14%, the maximum heating temperature of the grain is 45^0C, the temperature of the dryer agent at the output of the heat generator is 120^0C. The diesel fuel is used. The combustion of fuel occurs in the furnace of the heat generator; the drying of the grain is conducted with the clean air heated in the heat exchanger of the heat generator. The calculation was made in accordance with the method of calculation of a flow grain dryer [13].

III. Findings

The results of the thermal calculation (Table 1) allowed determining the volumetric and mass flow rates of the dryer agent and cooling air.

The designed tower grain dryer (Fig. 3) with an external heat generator allows the grain to be dried with clean heated air when using liquid fuel or any low-grade one.

According to the results of the thermal calculation, the filtration rates and the aerodynamic resistance of the cooling air and the drying agent were determined. It is proved that due to the installation of the mixing chamber in the air-pressure chamber the aerodynamic resistance when delivering the exhaust drying agent and cooling air to the first drying zone increases with the existing size of the analog dryer. Therefore, the results of the calculation allowed the designers to increase the height of the first drying zone to 4 meters. In this case the air filtration rate on conversion to the clear opening of the perforated grille will amount for 0.35 m/s for the cooling zone of the first drying zone, and 0.7 m/s for the cooling zone of the second drying zone, whereas, the aerodynamic resistance of the blowers of the cooling zone and drying zones will be 1160 and 1490 Pa.

TABLE I. Results of Parameters Calculation of Dryer Agent and Cooling Air

Parameters of Drying Agent and Cooling Air			
Indicators	***First drying zone***	***Second drying zone***	***Cooling zone***
Temperature,^{0}C	65	120	15
Relative humidity, %	9.96	0.97	60
Moisture content, g/kg of dry air	16.08	6.47	6.47
Enthalpy,kJ/kg	107.44	137.67	31.41
Air flow rate, m^3/h	54100	25000	15000
Mass air flow, kg/h	53997	21777	17963

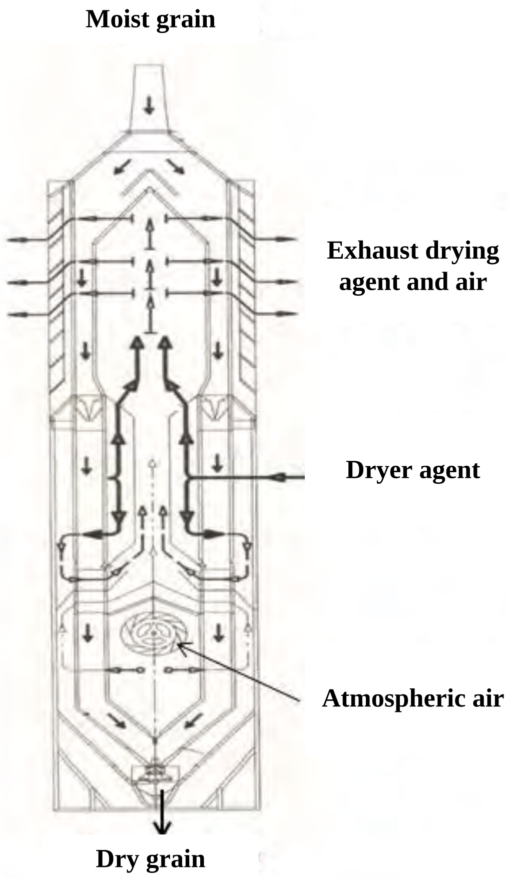

Fig. 3. The structural scheme of the tower grain dryer with the recovery of the cooling air and dryer agent with an external heat generator.

IV. DISCUSSION

The grain dryer R1-SZG-20ZH (the previous name was Astra) is a tower-type flow liquid-propellant dryer manufactured by Melinvest OJSC and installed at the enterprise Grudzyno APC in the Pavlovsky district of Nizhny Novgorod region; it is a part of the drying-cleaning complex having a preliminary purification system and six BV-40 tanks for the efficient storage of grain before drying.

After pre-cleaning the moist grain is delivered from the operational tanks with the total capacity of 40 t/h into the over-the-dryer hopper by the band elevator and gets into the first drying zone and then into the second one. The dried grain passes through the heat exchanger and after cooling in the cooling zone of the dryer it is delivered to the scraper conveyor through unloading aids, then it is delivered to the drying hoppers for the shipment to the warehouse. The clean heated air from the heat generator enters the second drying zone, passes through the grain layer and, after mixing with the exhaust cooling air, is delivered to the first drying zone through the heat exchanger from; then the saturated air is released into the atmosphere. It is possible to return the grain from the dryer to the over-the-dryer hopper if there is need for further drying or drying the first batch of grain.

The tests were carried out on wheat grain with the initial moisture content up to 19.1% at the atmospheric air temperature of 6.9-13°C with the average value of 7.8 and 12.7°C in two experiments and the relative humidity of 83-93% with the average value of 90%. The temperature of the grain before drying was 12.4-15.4^{0}C, after drying – 23.8-26.5^{0}C. The temperature of the drying agent in the first drying zone was 89.4-90^{0}C, in the second drying zone – 108.0-109.5^{0}C.

Parameters of the atmospheric air and the drying agent allowed determining the values of their moisture content and enthalpy, which are necessary for further calculations while closing the heat balance of the grain dryer (Table 2).

TABLE II. PARAMETERS OF MOISTURE CONTENT AND ENTHALPY OF THE ATMOSPHERIC AIR AND DRYER AGENT

Parameters of the Atmospheric Air and Dryer Agent		
Parameter name	***Experiment 1***	***Experimen t 2***
Atmospheric air temperature,^{0}C	7.8	12.7
Atmospheric air relative humidity, %	90	84
Atmospheric air specific volume, m^3/kg of dry air	0.8181	0.8375
Atmospheric air specific gravity, kg of dry air/m^3	1.222	1.194
Atmospheric air enthalpy, kJ/kg of dry air	23.15	32.72
Atmospheric air moisture content, g/kg of dry air	6.1	7.92
Temperature of dryer agent ,^{0}C	108.0	109.5
Specific volume of dryer agent, m^3/kg of dry air	1.1130	1.1212
Specific gravity of dryer agent, kg of dry air/m^3	0.989	0.892
Enthalpy of dryer agent, kJ/kg of dry air	125.14	132.03

After the recovery of the exhaust cooling air and the drying agent from the second drying zone and drying the grain in the first zone, at the output of the grain dryer the drying agent becomes almost completely saturated with moisture, indicating a high efficiency of the drying process (Table 3).

TABLE III. PARAMETERS OF MOISTURE CONTENT AND ENTHALPY OF THE DRYER AGENT PASSING OUT THE FIRST DRYING ZONE

Parameters of the Dryer Agent at the Output of the First Drying Zone		
Parameter name	***Experim ent 1***	***Experime nt 2***
Temperature of dryer agent ,^{0}C	22.2	27
Relative humidity of dryer agent, %	97	94
Specific volume of dryer agent, m^3/kg of dry air	0.8767	0.9018
Specific gravity of dryer agent, kg of dry air/m^3	1.141	1.109
Enthalpy of dryer agent, kJ/kg of dry air	65.22	86.77
Moisture content of dryer agent, g/kg of dry air	16.88	23.05

When processing the experimental data, the performance of the tower grain dryer was recalculated in accordance with the Instructions on drying food and feed grains, oilseeds and operation of grain dryers with a decrease in the moisture of wheat grain by 4 and 5%, as well as on a planned ton with a decrease in moisture content from 20 to 14% [14].

The volume of flow rate of the air entering the heat generator and the cooling air blower was 28844 and 17530 m^3/h, respectively, the mass flow was 35358 and 21422 kg/h, respectively. The volumetric flow rate of the drying agent measured at the outlet of the dryer was 51330 m^3/h, the mass flow rate was 57748 kg/h.

The diesel fuel for drying was delivered from the fuel depot.

It was established that the data of the performance tests of the grain dryer almost coincide with the calculated values when the moisture content of the grain decreases by 5%; the discrepancy of 12.8 and 14.7% is conditioned by the slight overdrying of the grain up to 12.8 and 13.7%, instead of the calculated 14% to ensure its safe storage in wet weather (Table 4).

TABLE IV. INTEGRATED DATA OF THE PERFORMANCE TESTS OF THE TOWER-TYPE LIQUID-PROPELLANT GRAIN DRYER

Tests Results		
Parameter name	***Calculation***	***Tests***
Real capacity at the decreased humidity, %, t/h	15.0 (19.0 – 14.0)	15.0 (18.8 – 13.7)
Calculated capacity at:		
-the humidity decrease by 5%	16.3	17.6
- the humidity decrease by 4%	18.8	22.1
Atmospheric air temperature,^{0}C	15	10,3
Atmospheric air relative humidity,%	60	87
Grain temperature at the inlet to the grain dryer,^{0}C	15	13.9
Temperature of dryer agent,^{0}C		
- in the first drying zone	65	90
- in the second drying zone	120	109
Specific charge of dryer agent, $m^3/h/t$	1667	1923
Flow intensity of cooling air, $m^3/h/t$	1000	1169
Caloric power of the heat generator, kW	1047	907
Consumption of reference fuel, kg of ref.fuel/t%	1.71	1.45
Heat input for water evaporation,kJ/kg of evap.water	4120	3685
Efficiency factor, %	61	68.2

The accuracy of integrating the data of the moisture evaporated from the grain and the moisture carried out from the grain dryer with the drying agent was 2.4%. According to the test results, the inaccuracy of the heat balance of the grain dryer was 6.9%, which can be considered satisfactory.

According to the results of the test, the efficiency factor of the tower grain dryer is almost the same as that of the corresponding calculated value of the analogue – the MiniMax gas-fueled grain dryer. This indicates that the original technical solutions for the recovery of the exhaust cooling air and drying agent are retained.

Moreover, the developed tower grain dryer can run on any type of fuel.

Acknowledgment

The author expresses his gratitude to M.Yu. Soskin, Technical Director of Melinvest OJSC, and V.I. Obrubov and S.E. Sautkin, working at the Special Design Technological Bureau of the enterprise, as well as to the employees of the APC Grudytsino for providing technical assistance in testing the trial model of a tower-type grain dryer.

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