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Thermal Analysis of a Vertical Kiln Dryer for Drying Sunflower Seeds in the Oil Mill "Banat", Nova Crnja, Serbia

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***Abstract*—**The aim of the paper was the thermal balance control of vertical kiln dryer indirect type (VSU-36) for drying sunflower seed, produced by "Cer" - Cacak, capacity 39 [t/h]. The balance control was executed because the dryer was damaged by NATO bombing in 1999, and it was planned for its reconstruction. The structural and geometric characteristics of the dryer were known, and it was necessary to determine the parameters of wet air as a drying agent and the sunflower seeds. The thermal balance control was the basis for the replacement of damaged parts of the dryer during its reconstruction. After that, it was necessary to perform the subsequent calculation of strength. The accuracy of strength had a large influence on the cost-effectiveness and safety of a single drying chamber. Also, the work provides guidelines for the regimes of drying grain crops with an explanation of the specificity of drying sunflowers.

***Keywords*—**Sunflower seeds, regimes of drying, vertical kiln dryer, thermal analysis.

I. Introduction

THE schematics of the technological process of getting the fine refined sunflower oil is shown in Fig. 1.

The final product is fine refined sunflower oil, which is also the main product of "Cvet Banata" AD, Nova Crnja company. This process is the most complex, as it varies depending on the type of oil and the specific plant being processed, each requiring its own tailored approach and duration.

Drying involves reducing the moisture content of seeds, as grains with moisture levels above the allowable limit cannot be stored. Excess moisture can lead to germination, increased temperature, deterioration, mold growth, and, in the presences of many impurities, even self-ignition. During the process of drying, the grain is heated, causing water on its surface to evaporate. However, this lost moisture is compensated with water migrating from the interior of the grain. The drying rate depends on how quickly the moisture can move from the inside the grain to its surface. If the process is too rapid, surface moisture evaporates faster than it can be replenished from within, leading to surface overdrying, pore closure, and complications that may impair the drying process. In some cases, this can accelerate grain deterioration. To mitigate these issues and ensure balanced drying, the grain should be pre-heated before the process begins. The drying regime depends on several factors including grain type, initial moisture content, grain purpose, dryer construction, drying temperature, and relative humidity.

The sunflower drying process begins when the air reaches a working temperature of 45 °C. The air is then further heated to a peak of 90 °C. During the drying phase, air temperatures range between 60 °C and 90 °C, and the process continues until the grain's moisture is approximately 0.5% above the target value. The grain temperature must not exceed 55 °C during the process to prevent damage. Once this threshold is reached, drying with hot air is stopped, and cooling with fresh air begins. The purpose of cooling is to lower the grain's temperature until it reaches 5 °C above the ambient air used for cooling. At the end of the drying process, the moisture content of the sunflower grain should be between 6-7%. If the grain's moisture level rises after exiting the dryer, the grain is redirected back into the dryer using an elevator for additional drying.

II. Work Process of Vertical Dryer Used for Drying Sunflower Grain

The dryer, designation as "VSU", stands for Vertical Oil Dryers in Serbian. It is versatile and can also be used for drying seeds of various other crops. The final part of the label describes the dryer's approximate capacity and highlights that it incorporates technological intervention with steam during the drying process. A key feature of the VSU dryer is the so-called "honeycomb" structure, which enhances heat and mass exchange between the grain and hot air. This generation of dryers distinguishes itself by lower fuel consumption compared to previous models, complete air filtration at the dryer's exit, minimal electrical energy usage, and automatic regulation of the grain's moisture at the outlet. Technical data for the dryer are given in Table I [1].

A. Technical Description of the Dryer VSU-36 md-p

The description of the operation of the dryer is shown in Fig. 2. The figure shows the following components of the dryer:

1. The hot air fan,
2. Lower heat exchangers,
3. The hot air channel,
4. Lower drying zone,
5. Recirculation channel,
6. Top heat exchangers,
7. Upper drying zone,

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8. Air purifiers,
9. Dump basket,
10. Cold air fan,
11. A cold air channel,
12. Cooling zone.

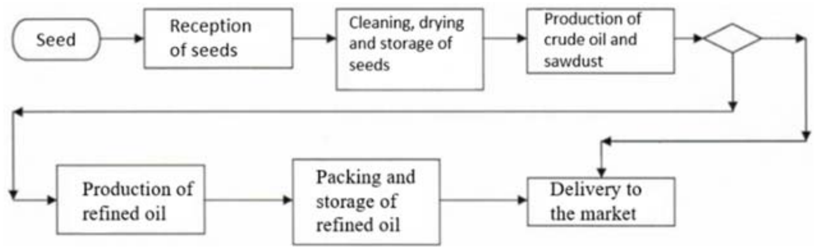

Fig. 1 The schematics of the technological process of getting the fine refined sunflower oil

TABLE I
TECHNICAL DATA FOR THE DRYER

What	Physical quantity	Value with unit
Material (sunflower seeds) and air	Raw grain base capacity	$\dot{m}_{sm}$ = 39 t/h = 10.83 kg/s
	Home humidity of sunflower seeds	X_{M1} = 0.163 kg_{VL}/kg_{SM}
	Moisture of dried grains of sunflower	X_{M4} = 0.075 kg_{VL}/kg_{SM}
	Sunflower drying temperature	θ_{VC1} = 60 – 90 °C
	State of atmospheric air	θ_{VCO} = 15°C, X_{VO} = 0.0063 kg_{VL}/kg_{SV}
Steam heat exchangers	Working pressure of steam	p_p = 4 - 5 bar
	Heat capacity of the lower exchanger	Q_1 = 2.7 MW
	Heat capacity of the upper exchanger	Q_2 = 1.27 MW
Installed electricity	Fan for warm air	2 · 22 kW
	Cold zone fan	2 · 11 kW
	Electric engine for grain pulling	2 · 0.75 kW
	Engine - reducer of the purifier	2 · (4 · 0.25 kW)
	Worm conveyor	2 · 0.55 kW
	High-pressure fan	11 kW
	Anti-theft filter	3.5 kW

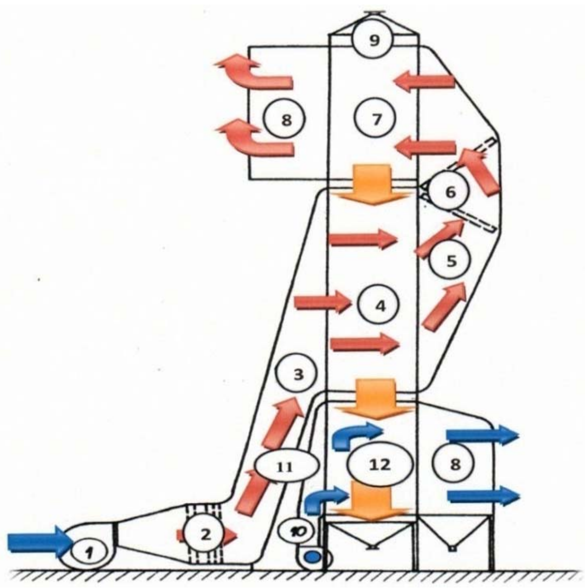

Fig. 2 Vertical dryer VSU-36md-p

The orange arrows show the flow of sunflower grains, the red flow of the heated air, and the blue flow of cold air.

The grain is fed into the dryer through the crucible (9) at the top and descends vertically through the upper drying zone (7) and lower drying zone (4). After passing through these zones, the grain proceeds to the cooling zone (12). If the desired moisture level of 6-7% is not achieved for the sunflower seeds, the grain is returned via an elevator for additional drying. Once properly dried, the grain is transported through designated lines to silos.

The hot air fan (1) draws in fresh air in and pushes through the lower heat exchanger (2), sending it into the lower drying zone via the hot air channel. Here, the hot air passes transversely through the grain, drying it while absorbing the moisture released from the grain. The warm, moisture-laden air is then redirected to the recirculation channel (5) for reheating through the upper heat exchangers (6). This reheated air is again used for drying in the upper zone (7). After its second pass, the air flows into the purifiers (8) before being released into the atmosphere. For the cooling process, the cool air channel (11) supplies fresh air to the cooling fan (12). The cooled air passes through the air purifiers (8) before it is discharged into the atmosphere.

The VSU-36 dryer is designed as a two-tower dryer to double its capacity, meaning, it can handle twice the mass flow of grain per unit of time. To support this increased capacity, each tower is equipped with its own heat generator. The design also allows for independent operation, enabling the dryer is built in to run at half capacity by using only one of the towers. In Fig. 2, two distinct structural components of the dryer are visible: the dryer towers, where the grain drying process takes place, and the heat generators, which provide the hot air necessary for the drying process.

B. Grain Crops' Drying Regimes in Dryer and Equilibrium Humidity

A drying regime refers to the specific combination of parameters that govern the grain drying process. Key parameters include the temperature of the drying agent, its moisture at the entry point, and the temperature to which the grain is heated inside dryer. The selection of the drying regimes is crucial to preserve grain quality. The optimal drying regime minimizes drying time, heat energy, and the amount of drying agent used, without compromising the quality of the grain. Several factors influence the drying regime, including the grain's initial moisture, type, construction specifications of the dryer, and the intended use of the dried grain. A critical factor in this process of grain thermostability, which refers to the grains ability to retain quality at specific drying temperatures. This thermostability decreased with higher moisture levels, requiring grains with higher moisture to be dried at lower air temperatures.

For sunflower grain, the maximum allowed drying temperature is 55 °C to maintain quality. Efficient drying involves controlling speed at which the grain reaches the maximum air temperature of 90 °C, as well as the rate of moisture removal. Equilibrium moisture is the point at which the moisture content of the grain balances with the relative humidity of the surrounding air, based on temperature and atmospheric humidity (Table II). Different anatomic parts of the grain, particularly in oilseeds, may have varying equilibrium moisture levels, which must be carefully considered during drying and storage.

The regulation of the drying agent's temperature (heated air) is managed automatically through electromotive control valves. These valves, located at the steam inlet of the heat exchanger, ensure precise regulation via a transistor rectifier and a thermal probe position in the hot air channel. Beyond automatic control, drying can also be regulated by increasing or reducing the volume of hot air using clappers (airflow regulators), and regulating the grain flow at the dryer's bottom using pullers. These adjustments aim to maintain moisture levels at the dryer`s exit, aligning with the equilibrium moisture level at the average temperature and humidity of the external environment during storage. It is crucial not to over dry the grain beyond its equilibrium moisture, as this results in unnecessary energy consumption and higher costs. Regular monitoring of grain moisture at the dryer`s exit is essential, and adjustments to the pullers may be needed to ensure optimal performance. If burned grains are detected (though this is unlikely in this type of dryer), it is necessary check if the dryer is clean and thermostats in hot air channel are functioning. Particular care must be taken with soyabeans, which are highly sensitive to intensive drying regimes. Precise control of hot air temperatures is especially important to prevent damage to the crop during the drying process.

TABLE II
EQUILIBRIUM GRAIN MOISTURE OF INDIVIDUAL CULTURES (ACCORDING TO [2])

Culture	Temperature of grains [°C]	Equilibrium relative humidity [%] for temperature							
		20 °C	30 °C	40 °C	50 °C	60 °C	70 °C	80 °C	90 °C
Wheat	20	8.2	9.9	11.9	11.3	14.8	16.4	18.9	25.2
	30	7.9	9.3	11.1	12.7	14.0	16.1	18.6	24.2
Corn	20	9.0	10.4	12.0	13.5	15.2	17.5	20.4	23.7
	30	8.5	9.9	11.3	12.7	14.2	16.2	18.9	22.4
Soya	20	5.7	7.0	7.6	8.7	10.5	12.0	18.0	26.4
	30	5.0	6.0	6.8	7.8	9.8	12.0	17.0	25.3
Sunflower	20	3.4	4.6	5.7	6.8	7.8	8.9	10.2	12.0
	30	2.9	4.0	5.1	6.1	7.1	8.3	9.6	11.3

When grain exits the dryer at a temperature 5 °C higher than the outside air, the diffusion of moisture is slowed down, but not stopped. This triggers the stabilization process, which continues in the silo and can result in dew formation on the grain pile. To prevent dew accumulation, it is advisable to aerate the silo or turn the grain (redistribute it) at least once during the first week of storage. It is a mistake to over dry grain by 1-2% beyond the recommended moisture level in an attempt to avoid moisture redistribution. Such over drying negatively impacts the process by: reducing dryer capacity, lowering grain quality, and failing to prevent moisture return.

C. Thermal Calculation of Sunflower Drying

Fig. 3 shows the physical quantities that are necessary for the current-thermal calculation according to the individual drying zones.

1. Input Parameters of the Drying Process

The data presented here are collected from the technical documentation of the VSU-36 dryer [1] and literature [3]-[6]. Other input parameters are not given because of the workload.

$$\dot{V}_{SV} = 120000\ \frac{\mathrm{m^3}}{\mathrm{h}} = 33.33\ \frac{\mathrm{m^3}}{\mathrm{h}} - \text{volume flow of dry air,}$$

$$for\ \theta_{VC0} = 15\ ^\circ\mathrm{C}\ and\ p = 1.013\ \mathrm{bar} \Rightarrow \rho_{SV} = \frac{1.247+1.205}{2} = 1.226\ \frac{\mathrm{kg}}{\mathrm{m^3}}$$

$$\dot{m}_{SV} = \rho_{SV} \cdot \dot{V}_{SV} = 1.226 \cdot 33.33 = 40.86\ \frac{\mathrm{kg}}{\mathrm{s}} - \text{mass flow of dry air}$$

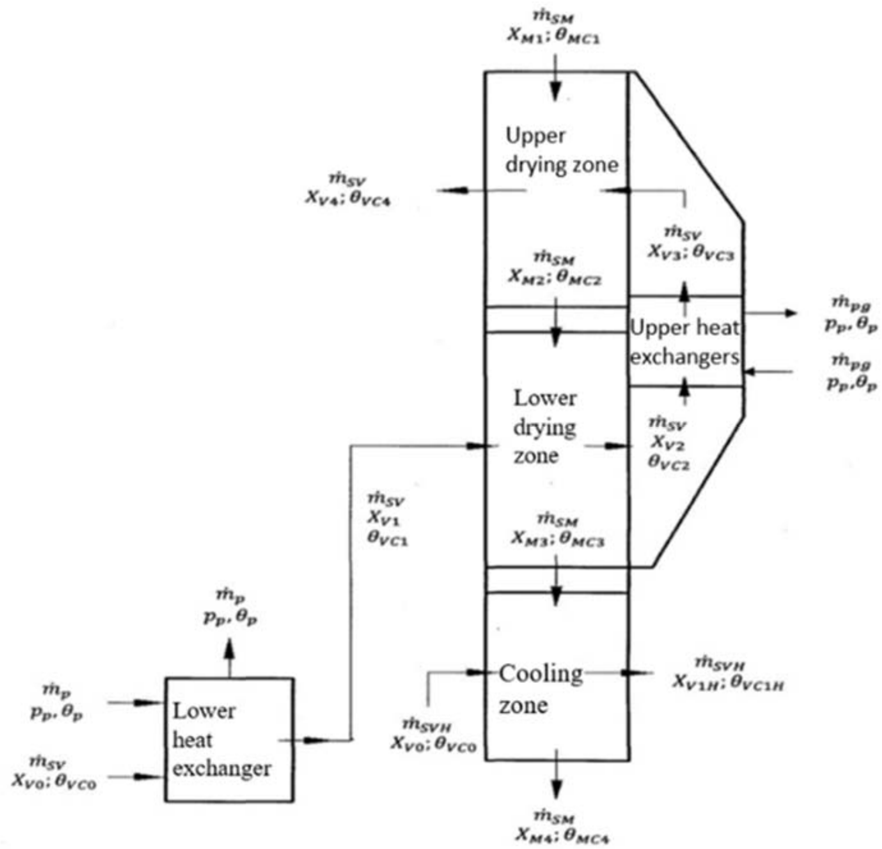

Fig. 3 Thermo-thermal parameters of the heat and mass exchange process in the dryerVSU-36

Before the destruction of the dryer during its operation, the following data were measured:

- θ_{VC2} = 40 °C – humid air temperature at the exit from the lower drying zone,
- θ_{VC4} = 44 °C – humid air temperature at the exit from the upper drying zone,
- $X_{V2} = 0.017 \frac{kg_{VL}}{kg_{SV}}$ – absolute air humidity at the exit from the lower drying zone,
- $X_{V3} = X_{V2} = 0.017 \frac{kg_{VL}}{kg_{SV}}$ – absolute air humidity at the exit from the upper drying zone.

2. Thermal Calculation of Unknown Physical Quantities in the Drying Process

a. Lower Heat Exchanger

The mass flow of dual-fuel steam ($\dot{m}_p$) bearing in mind the heat balance of the heat exchange amounts:

$$\dot{m}_{SV}(c_{pSV} + X_{V0}c_{pVP})\theta_{VC0} + (1 - x_p)\dot{m}_p r(p_p) = \dot{m}_{SV}(c_{pSV} + X_{V1}c_{pVP})\theta_{VC1} \quad (1)$$

$$\dot{m}_p = 1.469\ \frac{\text{kg}}{\text{s}}$$

b. Upper Drying Zone

The absolute moisture content of the sunflower grain (X_{M2}) at the exit from the upper drying zone according to the moisture balance:

$$\dot{m}_{SV}(X_{V2} - X_{V1}) = \dot{m}_{SM}(X_{M2} - X_{M3}) \quad (2)$$

$$X_{M2} = 0.117 \frac{kg_{VL}}{kg_{SM}}$$

The heat flux that the drying agent (air) transmits to the sunflower seeds ($\dot{Q}_{g2}$) amounts:

$$\dot{m}_{SV}[(c_{pSV} + X_{V1}c_{pVP})\theta_{VC1} + X_{V1}r_0] - \dot{Q}_{g2} = \dot{m}_{SV}[(c_{pSV} + X_{V2}c_{pVP})\theta_{VC2} + X_{V2}r_0] \quad (3)$$

$$\dot{Q}_{g2} = 288970.092\ \text{W}$$

The absolute humidity of the exit from the upper drying zone (X_{V4}) is:

$$\dot{m}_{SV}(X_{V4} - X_{V3}) = \dot{m}_{SM}(X_{M1} - X_{M2}) \quad (4)$$

$$X_{V4} = 0.029 \frac{kg_{VL}}{kg_{SM}}$$

The heat flux that the air transfers to the sunflower seeds ($\dot{Q}_{g1}$) amounts:

$$\dot{m}_{SV}[(c_{pSV} + X_{V3}c_{pVP})\theta_{VC3} + X_{V3}r_0] - \dot{Q}_{g1} = \dot{m}_{SV}[(c_{pSV} + X_{V4}c_{pVP})\theta_{VC4} + X_{V4}r_0] \quad (5)$$

$$\dot{Q}_{g1} = 40784\ \text{W}$$

The sunflower temperature at the exit from the upper drying zone (θ_{MC2}) is:

$$\dot{m}_{SM}(c_{SM} + X_{M2}c_{WL})\theta_{MC1} + \dot{Q}_{g1} = \dot{m}_{SM}(c_{SM} + X_{M2}c_{WL})\theta_{MC2} \quad (6)$$

$$\theta_{MC2} = 30.2\ °\text{C} < 55\ °\text{C}$$

c. Lower Drying Zone

The sunflower temperature at the exit from the lower drying zone (θ_{MC3}) is:

$$\dot{m}_{SM}(c_{SM} + X_{M3}c_{WL})\theta_{MC2} + \dot{Q}_{g2} = \dot{m}_{SM}(c_{SM} + X_{M3}c_{WL})\theta_{MC3} \quad (7)$$

$$\theta_{MC3} = 47.4\ °\text{C} < 55\ °\text{C}$$

d. Upper Heat Exchangers

The mass flow of dry saturated steam from the heat balance exchange ($\dot{m}_{pg}$) now stands out:

$$\dot{m}_{SV}(c_{pSV} + X_{V2}c_{pVP})\theta_{VC2} + \dot{m}_{pg}r(p_p) = \dot{m}_{SV}(c_{pSV} + X_{V3}c_{pVP})\theta_{VC3} \quad (8)$$

$$\dot{m}_{pg} = 0.875\ \frac{\text{kg}}{\text{s}}$$

e. Cooling Zone

The heat flux is taken from the sunflower seed grain ($\dot{Q}_{g3}$):

$$\dot{m}_{SM}(c_{SM} + X_{M3}c_{WL})\theta_{MC3} - \dot{Q}_{g3} = \dot{m}_{SM}(c_{SM} + X_{M4}c_{WL})\theta_{MC4} \quad (9)$$

$$\dot{Q}_{g3} = 460283.935\ \text{W}$$

The temperature of the humid air to the outlet of the cooling zone (θ_{VC1H}) is:

$$\dot{m}_{SVH}\left[(c_{pSV} + X_{V0}c_{pVP})\theta_{VC0} + X_{V0}r_0\right] + \dot{Q}_{g3} = \dot{m}_{SVH}\left[(c_{pSV} + X_{V1H}c_{pVP})\theta_{VC1H} + X_{V1H}r_0\right] \quad (10)$$

$$\theta_{VC1H} = 37.3\ °\text{C}$$

III. Conclusion

The thermal calculations demonstrate that the heat losses are significantly lower in the upper drying zone compared to the lower zone. This is outcome is logical, when we consider that the upper zone requires less energy to heat the already-dry sunflower grain base, as opposed to the energy required for actual drying in the lower zone. The difference is further confirmed by the grain temperature increase, which amounts to 2.2 °C in the upper zone and 17.2 °C in the lower zone. Due to the temperature limit of 55 °C, the drying process remains well below the point of humid air saturation, with the drying agent temperature varying around 29 °C. The absolute air humidity of the air shows a similar rise across both zones: 0.011 for the lower zone and 0.012 for the upper drying zone. Similarly, the absolute moisture of sunflower grain is nearly identical, with 0.046 in the upper zone and 0.042 in the lower drying zone. In conclusion, these results confirm that the calculated drying regime is both stable and continuous, meeting all of the necessary criteria for efficient grain drying and satisfying the constraints defined in the problem task.

References

[1] Instructions for operation and maintenance of vertical dryer, *VSU-36 md-p*, Company „Cer", Čačak, Serbia, 1986.
[2] Ginzburg, A., The technology of Raw Food Products, Pchjevaya Intelligence, Moscow, Russia, 1976.
[3] Babić, Lj., Drying of biomaterials,www.polj.uns.ac.rs, 2012.
[4] Žeželj, M., Technology of grain storage, Scientific book, Belgrade, Serbia,1989.
[5] Salemović, D., D. Ješin, Manual for Process Technique, VTŠSS Zrenjanin, Zrenjanin, Serbia, 2008.
[6] Topić, R., Fundamentals of Design, Calculation and Design of Dryers, Scientific edition, Belgrade, Serbia, 1989.