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ASSESSMENT OF UTILIZATION POSSIBILITIES OF HEAT CONDUCTED BY WASTE GASES EXHAUST PIPE OF SB 1.5 DRUM DRIER FOR DRYING WOOD CHIPS

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ABSTRACT

Based on the exploitation research, the authors evaluated the possibilities of using the heat conducted through the side surface of the waste gases exhaust pipe of SB 1.5 drum drier for drying wood chips. According to the estimated calculations within one hour approximately 173 thousand of kJ of heat may be obtained from the external surface of the waste gases exhaust pipe with the height of 7 m and temperature of approximately 78°C which constitutes an equivalent of approximately 4 kilo of heating oil. In case the above mentioned heat source for drying wood chips in SPA 20 silo with a volume of 6800 kilo within 50% to 20% humidity is used, one may expect that the drying time will be approximately 100 hours.

Introduction

Driers used in agriculture, agri-food industry and chemical industry include high-temperature drum driers. Schematic representation of SB 1.5 drum drier used, inter alia, for drying fodder, by-products of the agricultural industry (figure 1 shows beet pulp, potato pulp, post-slaughtering blood with bran, fish waste, brewers' grains, sawdust).

According to the Research and Development Centre of Fabryka Maszyn Rolniczych (Agricultural Machines Factory) RPFAMA in Rogoźno Wielkopolskie (presently "AGROMECH" - Rogoźno Wlkp.) the amount of the heat flowing from the waste gases exhaust pipe of SB 1.5 drum drier is estimated at approximately 1.6 mln $kJ \cdot h^{-1}$. Exploitation research conducted by Kalisiewicz (1965), Kulik (1982), Biłowicki (1984) show that the amount of waste heat of SB 1.5 drum drier is approximately 1.7 mln $kJ \cdot h^{-1}$.

The authors conducted exploitation research of drum driers, inter alia, of SB 1.5 - however, they were partial. Therefore, they recognized that the research carried out by IBERU team was more representative and complex (Kalisiewicz et al., 1965) and they applied it in this article.

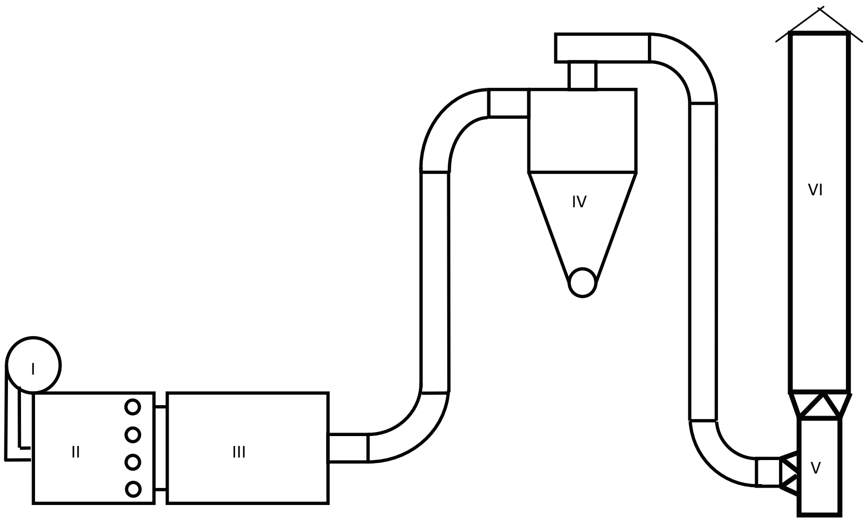

Fig. 1.Schematic representation of SB 1.5 drum drier with a stove for liquid fuel, I – furnace fan blower, II – furnace, III – drying drum, IV – main cyclone, V – main fan, VI – waste gases pipe

Table 1 presents the selected data from 7-day exploitation measurements of SB 1.5 drum drier with a mazut furnace – during drying of green meadow fodder (Kalisiewicz et al., 1965).

Table 1.
Selected data from measurements on a drying facility

Average								
Heat drifted with a drying medium (kJ·h^{-1})	1856170	1520970	1575440	1705330	1743040	1877120	1759800	1719700
Temperature of a medium at the outlet from a fan (°C)	99	93	94	99	96	99	102	97.5
External temperature of the wall of the waste gases pipe (°C)	78	75	76	79	74	79	82	78
Main fan output (m^3·h^{-1})	27400	27690	25700	26580	26780	27900	25990	26863
Relative humidity of air in the vicinity of a drier (%)	58	55	65	58	58	66	60	60
Relative moisture of the surrounding (%)	85	65	90	70	75	85	67	77
Surrounding air temperature (°C)	17	27	18	17	17	16	17	18
Temperature next to the drier (°C)	24	32	29	25	26	25	24	26.4

source: Kalisiewicz et al., 1965

Concepts of using waste heat of drum driers

Aiming at energy savings some companies which produce drum driers (Van der Broec'k, Promill, Atlas, Swiss Combi, Kunz) cooperating with the users or research centres developed numerous manners and devices for heat recovery from waste gases (Peroń and Zdrojewski, 1990; Strawiński, 1984; Siatka and Mieczyński, 1985).

They mainly consist in:

- partial recirculation of waste gases to the modified furnace,
- use of waste heat for blanching raw materials which facilitates mechanical squeezing of cell sap. This sap subsequently compacted in an evaporator is added to the squeezed fraction of raw material and transferred to the drier therewith,
- partial use of the waste heat energy for the drive of the absorption fridge. The authors do not present a detailed description of these methods due to the limits of the article. In relation to the solution, they enable reduction of a unit demand for heat from approximately 10% to approximately 30%. Majority of the mentioned concepts have not been accepted by domestic users of drying facilities because of many reasons (high costs of adaptation of existing devices, change in the technology, disturbances in the pneumatic transport system of the drying factor etc.) Discussions between the authors and managers of the drying facilities, equipped with SB 1.5 driers (facilities in Blizanowice near Wrocław, Ciechów near Środa Śląska, Boguszyce near Oleśnica, Sępno Wielkopolskie voivodeship) show that they would be able to accept simple solutions which do not disturb the pneumatic transport system. (Peroń and Zdrojewski, 1992; 1987) presented a model research and the manner of using the heat conducted by the side surface of waste gases for drying agricultural grain raw materials. Figure 2 explains the concept. The suggested solution does not disturb the drying agent transport.

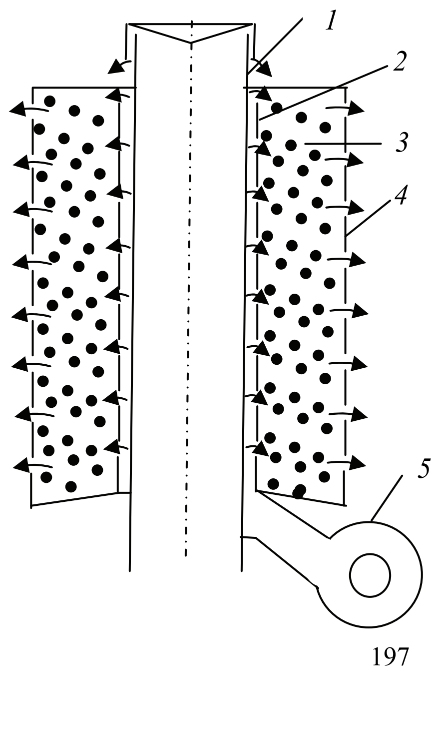

Figure 2. Concept of utilization of heat conducted through the waste gases exhaust pipe of SB 1.5 drum drier for drying grain 1 – waste gases exhaust pipe, 2 – internal screening cylinder, 3 – grain, 4 – external screening cylinder, 5 – fan

The objective of the paper

In this article the authors suggest a different, more universal concept of using the heat conducted by the waste gases exhaust pipe for drying purposes. The solution enables connection of the waste heat source with any drying chamber (silos, floor drier, etc.) filled with grain raw material (grain, wood chips) or non-refined raw material (straw, corn cobs etc.) Figure 3 presents a concept suggested by authors.

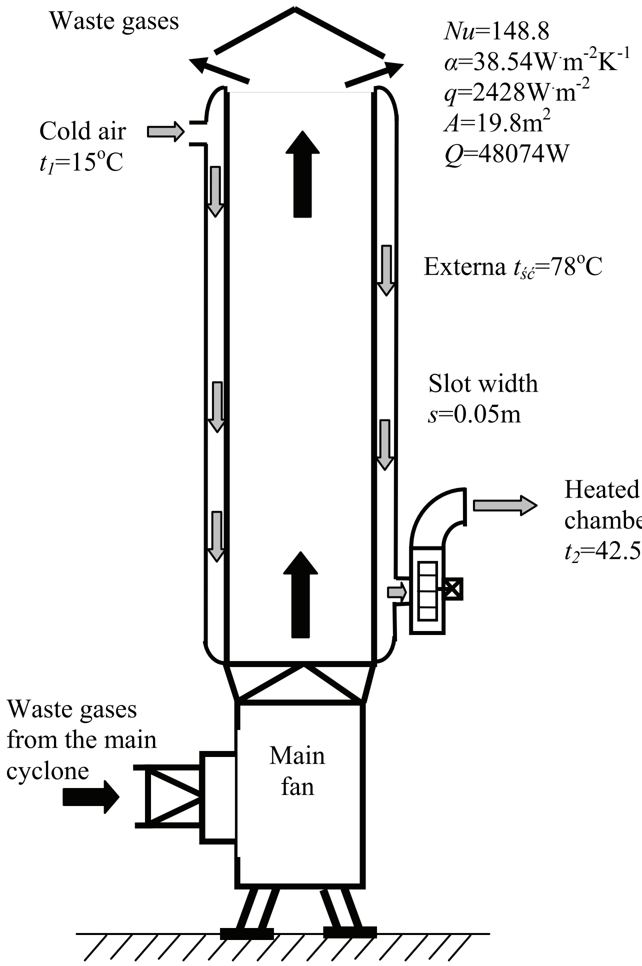

Figure 3. The concept of using heat conducted by the waste gases pipe for drying

According to table 1, average temperature of the external surface of waste gases pipe wall of the drum drier is 78ºC. Taking into consideration its external diameter which is approximately 0.9 cm and its height of approximately 9 m, we have a heat source with the surface area of approximately 23 m^2. The objective of the paper is to evaluate the utilization possibilities of such heat source for drying.

Having no information on the distribution of gas temperature along the waste gases exhaust pipe and on its side surface, the authors knew only the temperature of the external surface of the pipe at the half of its height, which gave a chance for an approximate evaluation of the heat source penetrating air therefrom. Taking into account that the heat flowing out with waste gases is at the average 10 times higher than the heat lost through cylindrical walls of apparatus laved by air (Gawrzyński and Glaser, 1998) the authors assumed that the average temperature of the external wall of the pipe will change slightly at the length.

Assessment of the amount of heat which can be obtained from the external surface of the waste gases pipe

The authors assumed that

- the height of the length of waste gases from which heat will be collected will be h = 7 m with its area of A =19.8 m^2 and the average temperature at the surface of the entire pipe, which was approximately 78^{o}C;
- the width of the slot between the internal and external pipe was s = 50 mm;
- the external pipe will be insulated with "afol" type insulation to reduce the heat losses;
- the exchanger will cooperate with SPA20 flat-bottom silos with the diameter of ϕ=3.05 m, the height of the cylindrical part H=3.65 m and the utility volume of V=26.6 m^3 filled with chips with a bulk density of ρ_m=255 kg/m^3 and mass M=6800 kg;
- the flow speed of the drying agent through a layer of chips was assumed as w_s=0.2 m·s^{-1} (Hunder, 2007), which means that the required volumetric expenditure of the fan cooperating with a silo is:

$$\dot{V}_a = \frac{\pi \cdot \phi}{4} \cdot w_s = \frac{\pi \cdot 3{,}05^2}{4} \cdot 0{,}2 = 1{,}461 \mathrm{m^3 \cdot s^{-1}} = 5260 \mathrm{m^3 \cdot h^{-1}} \tag{1}$$

and the mass

$$m_a = \dot{V}_a \cdot \rho = 5260 \cdot 1{,}2 = 1{,}75 kg \cdot s^{-1} \tag{2}$$

at the air density of ρ=1.2 kg·m^{-3}

- the air flow speed in the ring conduit of the heat exchanger resulting from the fan expenditure:

$$w = \frac{\dot{V}_a}{\frac{\pi D^2}{4} - \frac{\pi d^2}{4}} = \frac{1{,}461}{\frac{\pi \cdot 0{,}997^2}{4} - \frac{\pi \cdot 0{,}897^2}{4}} = 9{,}82 \mathrm{m \cdot s^{-1}} \tag{3}$$

- Reynolds' number (Serwiński, 1971):

$$Re = \frac{w \cdot d_z \cdot \rho}{\eta} = \frac{w \cdot (D-d) \cdot \rho}{\eta} = \frac{9{,}82 \cdot (0{,}997-0{,}897) \cdot 1{,}2}{18{,}14 \cdot 10^{-6}} = 64995 \tag{3}$$

where:

d_z – hydraulic diameter,
D – internal diameter of the external pipe,
d – external diameter of the waste gases exhaust pipe.

– thermal transmittance coefficient α from the internal pipe of the exchanger (external surface of the waste gases pipe) to air was calculated from McAdams equation (Troniewski et al., 2012):

$$Nu=0{,}021Re^{0{,}8} = 0{,}021 \cdot 64995^{0{,}8} = 148{,}8 \quad (4)$$

it will be

$$\alpha=\frac{Nu\cdot\lambda}{d_z}=\frac{Nu\cdot\lambda}{(D\text{-}d)}=\frac{148{,}8\cdot 2{,}59\cdot 10^{-2}}{0{,}1}=38{,}54W\cdot\left(m^{-2}\cdot K^{-1}\right) \quad (5)$$

where:
λ – coefficient of thermal transmittance through air ($W\cdot(m^{-1}\cdot K^{-1})$),
thus the heat stream collected by air:

$$q=\alpha(t_{śc}\text{-}t_1)=38{,}54(78\text{-}15)=2428W\cdot m^{-2} \quad (6)$$

and heat obtained from the entire area of the exchanger:

$$Q = q \cdot A = 2428 \cdot 19{,}8 = 48074W \quad (7)$$

If Q heat is entirely (without losses) collected by air laving from outside the hot wall of waste gases exhaust pipe thus $Q=m_a\cdot C_a\cdot\Delta t_w$ the change of air temperature at the outlet from the exchanger is:

$$\Delta t_w=\frac{Q}{m_a\cdot C_a}=\frac{48078}{1{,}75\cdot 1000}=42{,}5^oC \quad (8)$$

where:
C_a – specific heat of air ($J\cdot(kg^{-1}\cdot K^{-1})$).

Assessment of the drying time of chips based on the i-x diagram
– Assuming the initial humidity of chips w_1=50% and the final w_2=20%
Mass of dried chips

$$S=M\frac{100\text{-}w_1}{100\text{-}w_2}=6800\frac{100\text{-}50}{100\text{-}20}=4250kg \quad (9)$$

Thus the mass of water to be evaporated

$$W=6800\text{-}4250=2550kg\ H_2O \quad (10)$$

– the i-x diagram shows that for air temperature at the inlet t_1=15°C and relative humidity ϕ_1=0.8 the water content is x_1=8.2 g $H_2O\cdot kg^{-1}$ s.p. After heating to the temperature of 42.5°C its relative humidity dropped to ϕ_2=0.15. According to the theoretical drying process, after going through the layer of material, each kilo of air contains x_2=17.5 g $H_2O\cdot kg^{-1}$ s.p. Therefore, it may take Δx=17.5-8.2=9.3 g H_2O. Knowing the mass of water to be evaporated W=2550 kg H_2O and Δx=9.3 g $H_2O\cdot kg^{-1}$ s.p theoretical mass of air required for drying is

$$m_p=\frac{2550000}{9{,}3}=274193{,}5\ kg \quad (11)$$

and time

$$\tau = \frac{m_p}{m_a} = \frac{274193{,}5}{6312} = 43{,}5 \text{ godzin} \tag{12}$$

Evaluation of energy profits

According to calculations, 48 kJ of heat may be obtained within one second from the entire surface and 172,800 kJ of heat within one hour. It is an equivalent of approximately 4.12 kilo of heating oil (it was assumed that the calorific value of diesel oil was 42,000 $kJ \cdot kg^{-1}$). At the drying time of τ=43.5 hours savings of heating oil (indispensable for heating air) will be approximately 416 kilo. Assuming that SB 1.5 drum drier works ca. 1000 hours a year (100 days x 10 hours) an energy profit from using the authors' concept - expressed in heating oil may achieve 4000 $kilo \cdot year^{-1}$.

Literature (Rybak, 2006) proves that chips in relation to humidity have a calorific value of 6,000 to 16,000 $kJ \cdot kg^{-1}$. Assuming that drying from 50% to 20% will cause the increase of the calorific value from 6,000 to 15,000 $kJ \cdot kg^{-1}$, we may obtain the energy increase with reference to the entire mass of raw material due to drying in the amount of:

$$\Delta E = \Delta w_u \cdot W = (15000 - 9000) \cdot 2550 = 22950000 kJ \tag{13}$$

where:

Δw_u - change of the calorific value.

The value of 22950000kJ constitutes an equivalent of approx. 546 kilo of heating oil.

The evaluated energy profits should be reduced by energy indispensable for driving the fan which sucks air by the heat exchanger. Assuming previously evaluated fan expenditure as $\dot{V}_a$=5.260 $m^3 \cdot h^{-1}$ = 1.461 $m^3 \cdot s^{-1}$, elasticity ΔP=1,000 Pa, fan performance η_w=0.7 and performance of the fan engine η_s=0.85 - electric power collected from the network may be evaluated as approx. 2.5 kW which constitutes approx. 5% of thermal power obtained from the exchanger. Losses resulting from the real process of drying are at the average of 10%-20% in comparison to the theoretical drying process in relation to the conditions of the process.

Conclusion

The suggested solution does not disturb the pneumatic transport system of SB 1.5 drier and constitutes the source of "clean" heat, without fumes, which may be used both for drying consumption or sowing grain and other raw materials (e.g. chips, straw, pomace).

According to the authors the concept enables, the use of exhaust heat of SB 1.5 drier within 8-10%. This solution creates a possibility of connecting the heat source with driers with an immovable bed of raw material (silo, floor drier, etc.). In case of using an additional heat source for drying, approximately 6,800 kilo of moist wood chips may be dried. In SPA 20 silo from moisture w_1=50% to w_2=20% – it may be expected that the drying time will be ca. 100 hours. According to calculations within one hour from the entire surface of the exchanger one may obtain approx. 113,000 kJ of heat, which constitutes an equivalent of approximately 4 kilo of heating oil.

Assuming that SB 1.5 drum drier works ca. 1000 hours, the expected energy profit resulting from the applied solutions expressed in the heating oil may be ca. 4000 kilo·year^{-1}. The estimated electric power indispensable for the drive of the fan which sucks air through the heat exchanger constitutes ca. 5% of the thermal power obtained from the exchanger.

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OSZACOWANIE MOŻLIWOŚĆI WYKORZYSTANIA CIEPŁA PRZEWODZONEGO PRZEZ RURĘ GAZÓW ODLOTOWYCH SUSZARKI BĘBNOWEJ SB 1,5 DO SUSZENIA ZRĘBKÓW DREWNA

Streszczenie. W oparciu o badania eksploatacyjne autorzy dokonali oceny możliwości wykorzystania ciepła przewodzonego przez pobocznicę rury gazów odlotowych suszarki bębnowej SB 1,5 do suszenia zrębków drewna. Jak wynika z szacunkowych obliczeń w ciągu godziny z zewnętrznej powierzchni rury gazów odlotowych o wysokości 7 m i temperaturze ok. 78°C można uzyskać ok. 173 tys. kJ ciepła, co stanowi ekwiwalent ok. 4 kg oleju opalowego. W przypadku wykorzystania wyżej wymienionego źródła ciepła do suszenia zrębków drewna w silosie SPA 20 o pojemności 6800 kg od wilgotności 50% do 20% można oczekiwać, że czas suszenia wyniesie ok 100 godzin.

Słowa kluczowe: ciepło odlotowe, suszarka bębnowa, zrębki drewna, suszenie