Biblid: 1450-5029, (2024); 1; p 27 - 30
UDK: 631.3
DOI: 10.5937/jpea28-49537

Original Scientific Paper.
Originalni naučni rad

EVALUATION OF TECHNICAL AND ECONOMIC ASPECTS OF REPLACING MECHANICAL TRANSPORT WITH PNEUMATIC

PROCENA TEHNIČKIH I EKONOMSKIH ASPEKATA ZAMENE MEHANIČKOG TRANSPORTA PNEUMATSKIM

Nikola OLUŠKI, Petar POPOVIĆ, Marko VUKIĆ, Andreja ŽIVKOV, Maša BUKUROV
University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia;
**Correspondence: mbukurov@uns.ac.rs*

ABSTRACT

This paper explores the cost-effectiveness of pneumatic transport of wheat compared to mechanical transport on agricultural premises. A comparison was made with the existing mechanical transporter at the "Aleksić" agricultural farm in Novi Slankamen. The chosen method, flying pneumatic transport, underwent experimental capacity determination using volumetric methods for pneumatic transport calculations. With an initial wheat mass flow of 4.8 kg/s, calculations aimed to ascertain the motor power required to operate the blower, factoring in pressure drop in the pipeline. Results indicated a 4230 Pa pressure drop and a 2.12 kW blower motor power. Economic analysis revealed less favorable outcomes, with a payback period of 10500 working hours or 436 days due to seasonal transportation needs. Performance analysis suggested over 6000 trailers would be required for investment repayment. Notably, the analysis solely focused on wheat transport, overlooking the potential for service work or modern pneumatic transport solutions, underscoring the necessity for further research for more relevant conclusions.

Keywords: *pneumatic transport; grain transportation; economic analysis.*

REZIME

Ovaj rad istražuje isplativost pneumatskog transporta pšenice u odnosu na mehanički transport na poljoprivrednom dobru. Poređenje je napravljeno s postojećim mehaničkim transporterom na poljoprivrednom gazdinstvu „Aleksić" u Novom Slankamenu. Kao najpogodniji za potrebe transporta pšenice, odabran je leteći pneumatski transport. Eksperimentalno određivanje kapaciteta postojećeg mehaničkog transportera zapreminskom metodom poslužilo je kao osnova za proračun pneumatskog transporta. Maseni protok pšenice od 4,8 kg/s korišćen je kao polazni podatak. Cilj proračuna bio je utvrditi snagu elektromotora potrebnog za pogon duvaljke, zahtevajući izračunavanje pada pritiska u cevovodu. Nakon proračuna, rezultati su pokazali pad pritiska u cevovodu od 4230 Pa i snagu elektromotora duvaljke od 2,12 kW. Analizirani su rezultati, a usvojena je potrebna oprema za zamenu mehaničkog transportera pneumatskim. Početna investicija za novo postrojenje iznosi 97425 dinara na osnovu odabrane opreme i aktuelnih cena na tržištu. Analiza isplativosti primene pneumatskog transporta pokazuje teorijsku isplativost na nivou poljoprivrednog gazdinstva. Međutim, ekonomska analiza otkriva manje povoljne zaključke. Rok otplate dostiže 10500 radnih sati ili 436 radnih dana, što je uzrokovano sezonskom potrebom za transportom. Takođe, analiza po učinku sugerira potrebu preko 6000 prikolica za otplatu investicije. Važno je napomenuti da je analiza fokusirana samo na transport pšenice, bez uzimanja u obzir mogućnosti uslužnog rada ili najmodernijih rešenja za pneumatski transport. Ovi rezultati ističu potrebu za daljim istraživanjem kako bi se doneli relevantniji zaključci o isplativosti pneumatskog transporta.

Ključne reči: *pneumatski transport, transport žitarica, ekonomska analiza.*

INTRODUCTION

Wheat, like other grains, is an essential part of a balanced human nutrition, making it crucial to consider every step in its lifecycle, including transportation. Two commonly used types of wheat transportation systems are mechanical and pneumatic, with one type of mechanical transporter being the screw conveyor. Screw conveyors are widely utilized in the food and agricultural industries, as well as in other sectors such as construction, mining, chemicals, and processing (Pezo et al., 2016). However, pneumatic systems have also found broad application in process engineering: in dryers, oil factories, animal feed factories, finishing systems, and in solving complex transport problems; without their application, modern industry is practically inconceivable (Živković, 2001). Pneumatic transport offers numerous advantages over mechanical systems, such as adaptability to spatial constraints (it can be implemented in all directions and generally occupies less space than mechanical systems) and the potential for high levels of automation (Mošorinski et al., 2017). In the work of the authors (Nikolić et al., 2014), the possibility of using programmable logic controllers and SCADA systems for monitoring and supervision in modern pneumatic transport systems is demonstrated. The question arises as to which of these systems is more cost-effective for a typical agricultural enterprise. Cost-effectiveness is indeed one of the most important parameters when choosing a system, but, of course, other aspects of the application of a particular type of system should also be considered. For example, in the work of the authors (Đukanović et al., 2006), the impact of different transport systems on mechanical damage to maize seeds is presented.

Nomenclature:

c (m/s)	– average velocity of the particle cloud
c_k (%)	– mass concentration of wheat
C_{kWh} (RSD)	– price of electricity
D (mm)	– pipeline diameter
e (kWh/kg)	– specific energy consumption
Fr (-)	– Froude number
g (m^2/s)	– gravitational acceleration
H (m)	– height
I_{nv} (RSD)	– initial investment
K (kg)	– material quantity
L (m)	– length
$\dot{m}$ (kg/s)	– mass flow rate

p (Pa) – pressure
P (W) – power
R (J/kgK) – specific gas constant of air
t (s) – time
T (K) – temperature
v (m/s) – mean airflow velocity
v_s (m/s) – particle settling velocity
V (m^3) – volume

Greek symbols

Δ – change of parameter value
λ_f – coefficient of resistance of the airflow
λ_m – coefficient of resistance of the mixture flow
λ_s – coefficient of resistance of the solid particles
η_d - air blower efficiency coefficient
η_m - motor efficiency coefficient
ρ (kg/m^3) – air density
ρ_ε (kg/m^3) – bulk density

MATERIAL AND METHOD

EXPERIMENTAL RESEARCH

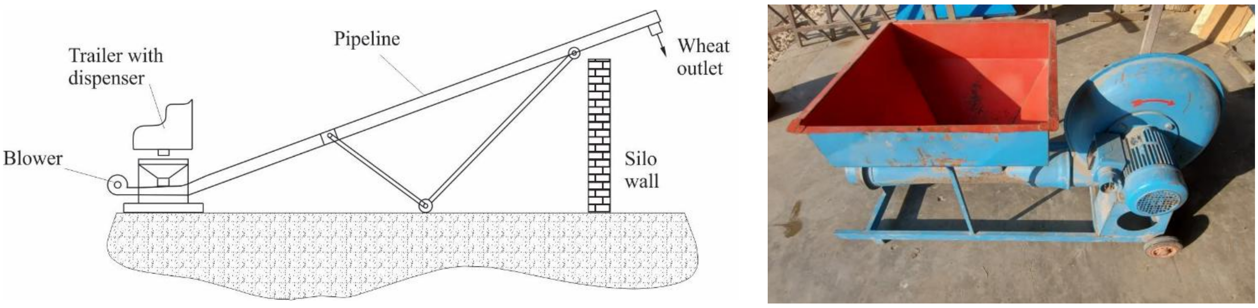
The aim of the experimental research was to determine the capacity of the mechanical screw conveyor during wheat transportation, which would later be used to calculate the replacement pneumatic conveyor. The transport capacity was measured using a stopwatch and a container of regular shape and known volume. The transport capacity was measured by timing the duration it took for the conveyor to fill the container with wheat, using a stopwatch. The value of the bulk density of wheat was taken from the literature ρ_ε = 800 kg/m^3 (Mane Sasic, 1990). Based on the calculated volume and the measured time, the wheat mass flow rate $\dot{m}$ was calculated using the following formula *(1)*:

$$\dot{m} = \frac{\rho_\varepsilon \cdot V}{t} \qquad (1).$$

The measurement was done seven times and finally, the mean value of mass flow was calculated.

PNEUMATIC TRANSPORT CALCULATION

The aim of the calculation was to determine the power of the electric motor needed to drive the blower for pneumatic transport, as shown in *Fig 1 (a)*, in order to later calculate the economic viability. This required calculating the pressure drop in the pipeline between the section immediately after the air exits the blower and the section at the end of the pipeline. The blower model chosen was the "KM I" model from the manufacturer "HIMEL", *Fig 1 (b)*.



(a) *(b)*

Fig. 1. (a) Schematic representation of pneumatic transport; (b) The blower manufactured by "HIMEL," model "KM I"

It was assumed that atmospheric pressure prevails at the end of the pipeline, while the pressure at section 1 was determined using the formula *(2)*:

$$p_1^2 - p_2^2 = RT\left(\frac{4\dot{m}_f}{D^2\pi}\right)\cdot\left\{\lambda_m\frac{L}{D} + 2\cdot\left[1+\left(\frac{c}{v}\right)c_k\right]ln\frac{p_1}{p_2}\right\} \qquad (2)$$

To determine the coefficient of resistance to particle flow, it was necessary to calculate the Froude numbers for the mean flow velocity and the settling velocity of the particle cloud, using formulas *(3)* and *(4)*. Subsequently, the coefficient of resistance of the mixture flow was obtained using formula *(5)*.:

$$Fr = \frac{v}{\sqrt{gD}}, \qquad (3)$$

$$Fr^* = \frac{v_s}{\sqrt{gD}}, \qquad (4)$$

$$\lambda_m = \lambda_f + c_k\lambda_s. \qquad (5)$$

The required motor power was calculated using the formula (6):

$$P = \frac{\dot{m}_f \cdot \Delta p}{\rho_1 \eta_m \eta_d}. \qquad (6)$$

ECONOMIC ANALYSIS

The aim of the economic analysis is to ascertain the cost-effectiveness of the pneumatic conveyor in terms of more efficient utilization of electrical energy compared to mechanical conveyors. The chosen drive electric motor model is ZK 100 L-4 (ATB SEVER DOO, Subotica Serbia), featuring a nominal power rating of 2.2 kW, selected from the catalog based on the requisite power for driving the pneumatic transport. The kWh electricity tariff for daily consumption is adopted from the pricing schedule of AD 'Elektroprivreda Srbije'. The payback period for replacing the mechanical transporter with the pneumatic one can be computed using formula *(7)*:

$$t = \frac{I_{nv}}{(P_{meh} - P_{pn})\cdot c_{kWh}}, \qquad (7)$$

In order to determine the necessary material quantity for investment repayment, according to formula *(8)*, it was imperative to compute the specific energy consumption for both mechanical and pneumatic transport, in accordance with formula *(9)*.

$$K = \frac{I_{nv}}{(e_{meh} - e_{pn})\cdot c_{kWh}} \qquad (8) \text{ and}$$

$$e = \frac{P}{\dot{m}_s}. \qquad (9)$$

RESULTS AND DISCUSSION

The initial data for the calculation of pneumatic transport was the capacity of the mechanical transporter, i.e., the mass flow rate of wheat. The capacity measurement was determined based on the bulk density and the time required to fill a vessel of known volume, as per formula (1). To obtain the most accurate value, the measurement was conducted seven times, and the average value was subsequently used. The measurement results are presented in tabular form, in Table 1.

Table 1. Results of wheat mass flow rate measurement.

No of measurement	Vessel filling time [s]	Mass flow [kg/s]
1	61	4.46
2	59	4.61
3	58	4.69
4	62	4.48
5	60	4.53
6	59	4.61
7	61	4.55

According to the obtained results, the average value of the wheat mass flow rate is 4.56 kg/s. Due to potential measurement errors, losses during vessel filling, and for the sake of pneumatic transport calculation safety, the adopted value of the mass flow rate is $\dot{m}_s$ = 4.8 kg/s.

The pneumatic transporter calculation entailed the assessment of pressure drop between sections 1 and 2, serving as the basis for determining the requisite motor power. Key parameters include:

- Pipeline length L=7 m;
- Lifting height H=2.9 m;
- Pipeline diameter D=100 mm;
- Mass flow rate $\dot{m}_s$ =4.8 kg/s;
- Air temperature T_a=305.15 K;
- Atmospheric pressure p_a=1014 mbar.

Additional required values for wheat were adopted from the literature *(Šašić M., 1990)*:

- Particle settling velocity v_s=8 m/s;
- Minimum air velocity v_{min}=23 m/s;
- Mass concentration of wheat c_k=15;
- Coefficient of resistance of the airflow λ_f=0.02.

The results derived from computations utilizing formulas *(2)* through *(5)* have been organized and presented in *Table 2*. This tabular representation serves to offer a comprehensive overview of the obtained values, facilitating a structured analysis of the pneumatic transport system parameters.

Table 2. The calculation results.

p_1 [Pa]	Fr [-]	Fr^* [-]	λ_m [-]	λ_s [-]	Δp [Pa]	P [W]
105630	29.88	8.08	0.0725	0.0035	4230	2120

The objective of the economic analysis was to assess the feasibility of the pneumatic transport system, with a focus on optimizing the utilization of electrical energy relative to traditional mechanical conveyors. The initial investment was determined based on the required equipment, with prices sourced from the catalogue. The value of the initial investment is presented in *Table 3*.

Table 3. Initial investment.

Equipment	Quantity	Price per unit	Total price [RSD]
Motor SEVER ZK 100 L-4	1	12000.00 RSD	12000.00
Seamless steel pipe	7 m·8.6 kg/m=60.9 kg	250 RSD/kg	15225.00
Air blower: HIMEL KM	1	70200.00 RSD	70200.00
	Total investment		97425.00

The following tabulated data presents the electricity cost for daily usage, along with the specific energy consumption rates for both mechanical and pneumatic transport systems. Additionally, the tables include the projected payback periods for replacing the mechanical transport with the pneumatic alternative. Furthermore, the cost-effectiveness per performance metric is outlined, indicating the quantity of material required to be pneumatically transported for the investment to yield returns, *Table 4*.

Table 4. Results of economic analysis.

C_{kWh} [RSD]	e_{meh} [kWh/kg]	e_{pn} [kWh/kg]	t [h]	K [t]
11.648	0.0001736	0.0001273	10455	180650

Based on these parameters, a comprehensive economic analysis can be conducted to determine the most cost-effective system. It can be noticed that the payback time is 10455 working hours or 436 working days, which is a relatively long period considering that the harvest season is short. Generally, lower rates of specific energy consumption, shorter payback periods, and higher cost-effectiveness per performance metric would favor pneumatic transport over mechanical.

CONCLUSION

The results of the calculation have demonstrated that pneumatic transport, at the level of agricultural holdings, could theoretically be cost-effective. However, upon examining the results of the economic analysis, less favorable conclusions emerge. Firstly, the calculated payback period reaches 10,500 working hours or 436 working days. Considering that this transport is only needed during the harvest season, which lasts at best two or two and a half months, and that it is unrealistic for the transporter to operate continuously throughout the day, the payback period could extend to 8 to even 15 years. The question arises whether someone who owns a smaller agricultural holding would opt for such a move, especially if they already possess other transport systems. Furthermore, analyzing the cost-effectiveness per performance leads to similar conclusions. Given that, on the property where the experiment and calculation were conducted, the largest trailer can carry thirty tons of wheat, it is evident that over 6000 such trailers would be needed for the transporter to begin to pay off.

However, the analysis presented in this study is rather limited in scope. It focuses solely on the transportation of wheat, overlooking potential revenue streams from service-based operations which could significantly improve profitability. Additionally, it fails to consider the latest advancements in pneumatic transport technologies. These findings underscore the necessity for further research and the generation of new insights, whether favorable or unfavorable.

ACKNOWLEDGMENT: This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-65/2024-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project “Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad” (No. 01-3394/1).

REFERENCES

ATB Sever DOO (accessed on 01.10.2023.). http://vozila.etf.rs/literatura/sever.pdf

Elektroprivreda Srbije (accessed on 01.10.2023.). https://www.eps.rs/lat/snabdevanje/Stranice/cene.aspx

Himel Machines (accessed on 29.09.2023.). https://web-mechanics.com/en/products/grain-systems/grain-handling

Nikolić, P., Bugarski, V., Matić, D., & Kulić, F. (2014). Moderan sistem upravljanja i nadzora u sistemu pneumatskog transporta - praktična realizacija. Journal on Processing and Energy in Agriculture, 18(2), 91-93.Mošorinski, P., Prvulović, S., & Palinkaš, I. (2017). Improving the characteristics of pneumatic transport of grain. Journal of Applied Engineering Science, 15(3), 218-224. https://doi.org/10.5937/jaes15-12734

Pezo, L., Pezo, M., Jovanović, A., Lončar, B., Filipović, V., Nićetin, M., & Kosanić, N. (2016). Primena modela diskretnih elemenata na protok zrnastog materijala u pužnom transporteru. Journal on Processing and Energy in Agriculture, 20(1), 29-32.

Šašić M. (1990). Transport fluida i čvrstih materijala cevima, Naučna knjiga Beograd.

Đukanović, L., Milićević, M., Pavlov, M., Jovin, P., Biserčić, D., & Glumac, M. (2006). Uticaj različitih tipova transportera na stepen mehaničkog oštećenja semena kukuruza. Časopis za procesnu tehniku i energetiku u poljoprivredi / PTEP, 10(3-4), 129-130.

Živković, D. (2001). Primena pneumatike u centrima za sušenje i doradu žitarica. Časopis za procesnu tehniku i energetiku u poljoprivredi / PTEP, 5(1-2), 45-47.

Trgometal (accessed on 01.10.2023.). https://www.trgometal.rs/celicne-besavne-cevi/

Received: 28. 02. 2024. Accepted: 29. 03. 2024.