American Journal of Applied Science and Technology

VOLUME Vol.06 Issue 05 2026
PAGE NO. 22-26
DOI 10.37547/ajast/Volume06Issue05-03

Evaluation of The Effect of Material Feed Rate on The Drying Process

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Received: 28 March 2026; **Accepted:** 22 April 2026; **Published:** 08 May 2026

Abstract: This article analyzes the influence of material feed rate on the drying of dispersed materials in a rotary drum dryer equipped with improved lifting-distributing flights. The study was carried out under the following operating conditions: T = 120°C, v = 10 m/s, and nflig = 30 flights. The material feed rate was evaluated within the general range of G = 0.05-0.1 kg/s, and its influence on aerodynamic resistance (pressure drop), residual moisture content, evaporated moisture rate, and total specific heat consumption was investigated using graphical dependencies. The analysis showed that an increase in material feed rate increases the dryer throughput; however, under overload conditions, the material bed becomes thicker and the efficiency of contact with the drying agent decreases. Therefore, the operating range for each material must be selected according to its particle-size distribution and technological properties. From the standpoint of industrial and laboratory investigations, the range G = 0.073-0.083 kg/s was substantiated as the rational operating range for loam, whereas G = 0.09-0.10 kg/s was substantiated for superphosphate. These results are important for planning subsequent theoretical and experimental studies.

Keywords: Rotary drum dryer, material feed rate, loam, superphosphate, aerodynamic resistance, residual moisture, evaporated moisture, heat consumption.

INTRODUCTION:

Drying of dispersed materials, particularly loam and superphosphate, in rotary drum dryers is one of the important operations in industrial technologies. The efficiency of the drying process depends not only on the temperature and velocity of the drying agent but also directly on the feed rate of the material supplied to the dryer. Increasing the material feed rate improves the throughput of the dryer; however, after a certain value, the material bed inside the drum becomes thicker, the free motion of granular or dispersed particles is restricted, the contact surface with the drying agent decreases, and the residual moisture content may increase. Therefore, the material feed rate should be selected not only from the viewpoint of increasing productivity but also with consideration of aerodynamic resistance, heat consumption, moisture removal, and product quality [1-4].

In existing rotary drum dryers, lifting the material and distributing it uniformly over the drum cross-section are not always ensured at a sufficient level. This problem becomes especially relevant for materials with different particle-size distributions. Loam consists of fine dispersed particles; therefore, its motion and drying behavior differ from those of superphosphate granules. Superphosphate is composed of relatively larger granules, and its lifting, falling, and contact with the drying agent inside the drum occur according to different regularities. For this reason, adopting the same throughput range for both materials is not scientifically justified [5-7].

To address this problem, the use of a three-section smooth lifting-distributing flight in a rotary drum dryer is proposed. This flight lifts the material from the lower bed and ensures its curtain-like falling in the central region of the drum. As a result, the contact surface between the material and the drying agent increases, moisture removal becomes more intensive, and the stability of the drying process improves.

At the same time, the effective material feed-rate intervals for drying loam and superphosphate in a rotary drum dryer equipped with the improved flight have not been sufficiently investigated. Although existing studies mainly analyze drying temperature, gas velocity, or general drying indicators, the determination of the lower and upper limits of material feed rate under the conditions of this flight design has not been studied separately [5].

Therefore, this study aims to graphically analyze the influence of material feed rate within the general range *G* = 0.05-0.10 kg/s on the main drying-process indicators and to determine separate rational operating ranges for loam and superphosphate. The main focus is placed on evaluating the effect of material feed rate on aerodynamic resistance, residual moisture content, evaporated moisture rate, and total specific heat consumption. As a result, a scientific basis is formed for selecting the throughput limits required for experimental and theoretical investigations of each material in a rotary drum dryer with an improved flight system [8].

RESULTS

The determination of the throughput range for drying superphosphate and loam in a rotary drum dryer equipped with improved three-section flights was carried out in two stages. In the first stage, the process was evaluated visually; in the second stage, graphical dependencies were constructed in the MATLAB environment based on the visual-analysis results, and the lower and upper operating limits of material feed rate were specified.

At the initial stage of the visual analysis, the ability of the three-section flight to lift, redistribute, and disperse the material into the hot gas stream inside the drum was evaluated.

In the MATLAB environment, the inlet parameters included the drying-agent temperature T, gas velocity v, material feed rate G, number of flights N, initial moisture content W0, drum geometric dimensions, and material type. On the basis of these parameters, the main evaluation indicators of the drying process were calculated: aerodynamic resistance ΔP, final moisture content W2, evaporated moisture rate Gevap, and total specific heat consumption qum.

The visual analysis divided the process into three coded operating states. The first state corresponds to the lower operating limit: due to the low material feed rate, the flights are only partially filled, a continuous material curtain is not formed, and heat and mass transfer remain limited. The second state corresponds to the rational operating range: the flights are filled normally, a stable material curtain is formed, and the material is uniformly distributed over the drum cross-section. The third state corresponds to the upper operating limit: when the material feed rate is excessive, the flights become overfilled, the material flow is compacted, accumulation appears in the lower part of the drum, and aerodynamic resistance increases. These operating states are coded in MATLAB using conditional operators as follows:

```
% Determining the operating state according to
material feed rate
if G < G_min
state = "Lower operating limit";
elseif G >= G_min && G <= G_max
state = "Rational operating range";
else
state = "Upper operating limit";
end
```

For each state, a visual model of the dryer was developed and the results were evaluated (Figure 1).

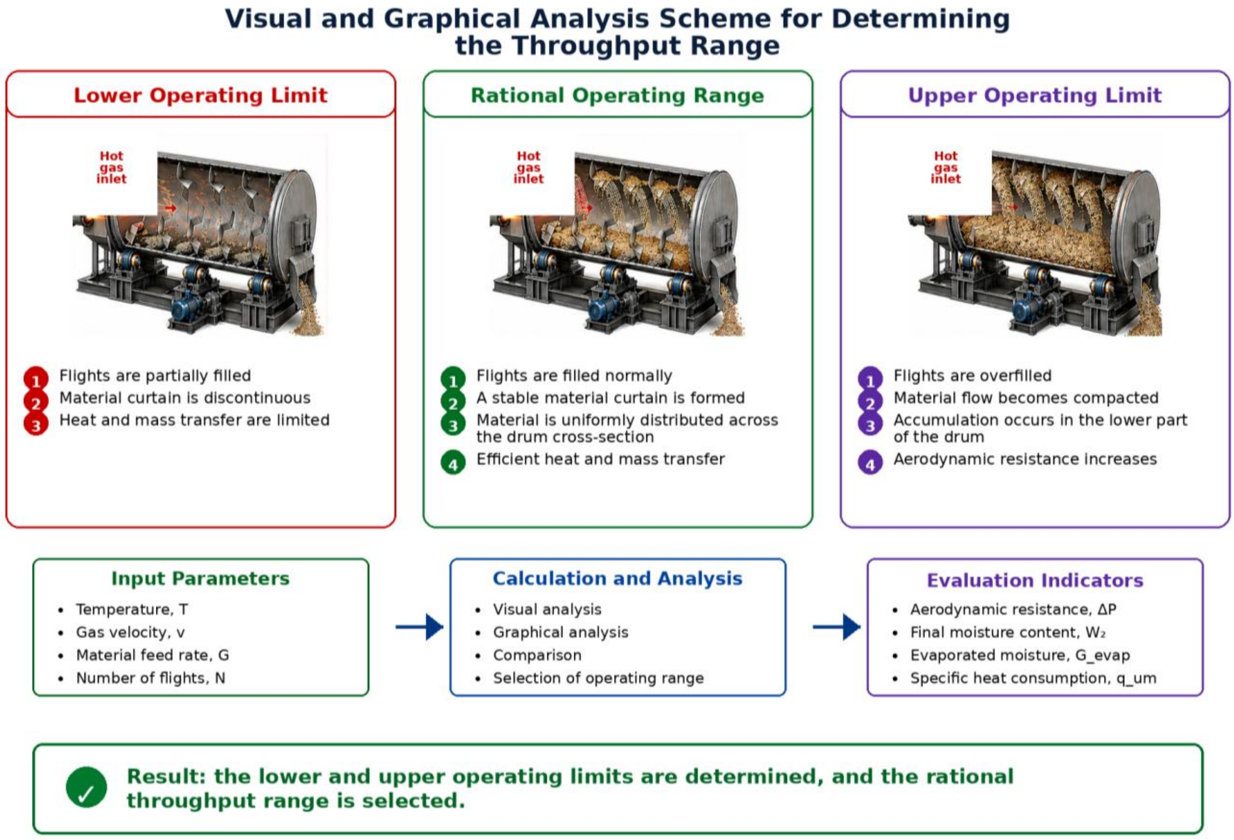

Figure 1. MATLAB-based visual analysis for the lower and upper throughput ranges.

In the second stage, the visual-observation results were investigated using graphical analysis in the MATLAB environment. The drying process was studied under constant technological conditions, namely T = 120°C, v = 10 m/s, and n_{flig} = 30 flights, for the case of the three-section flight. The material feed rate was varied within the general interval G = 0.05-0.10 kg/s. For each value, aerodynamic resistance ΔP, residual moisture content W_2, evaporated moisture rate Gevap, and total specific heat consumption q_{total} were evaluated.

The following dependencies were constructed during the graphical analysis (Figure 2):

$$\Delta P = f(G), \text{ Pa};$$

$$W_2 = f(G), \text{ \%};$$

$$G_{evap} = f(G), \text{ kg/s};$$

$$q_{total} = f(G), \text{ kJ/kg vapor}.$$

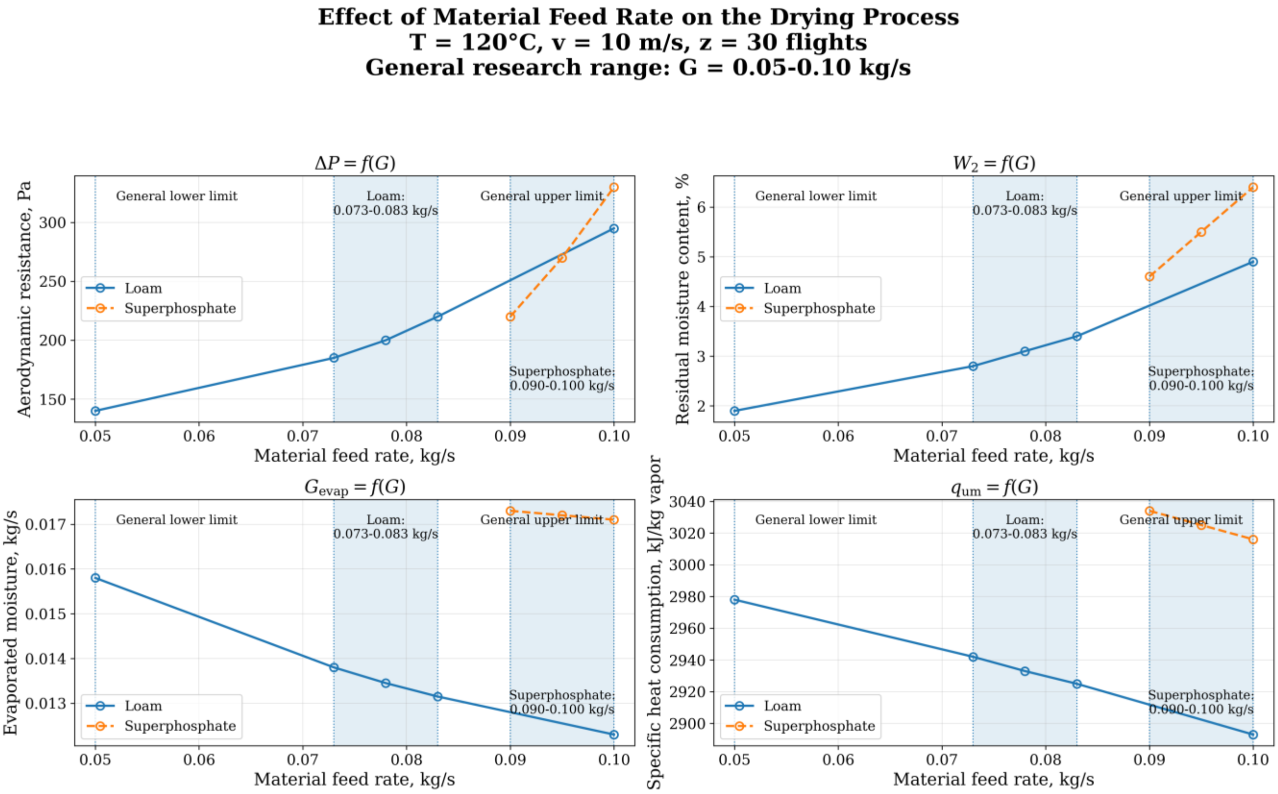

Figure 2. Effect of material feed rate on the drying-process indicators of loam and superphosphate in a rotary drum dryer equipped with three-section flights.

As seen from Figure 2, the aerodynamic resistance increases with increasing material feed rate. For loam, within the range G = 0.073-0.083 kg/s, ΔP increases approximately from 185 to 220 Pa. For superphosphate, within the range G = 0.09-0.10 kg/s, the resistance varies approximately from 220 to 330 Pa. This behavior is explained by the compaction of the material bed inside the drum and the corresponding increase in resistance to the gas flow as the material feed rate rises.

The residual moisture content W_2 also increases with increasing material feed rate. For loam, W2 is approximately 2.8% at G = 0.073 kg/s and increases to about 3.4% at G = 0.083 kg/s. For superphosphate, within the range G = 0.09-0.10 kg/s, the residual moisture content increases from about 4.6% to 6.4%. This is associated with the reduction in the contact time between the particles and the gas flow when the material feed rate is increased.

The evaporated moisture rate G_{evap} decreases slightly with increasing material feed rate for loam, from approximately 0.0138 kg/s to 0.0131 kg/s. For superphosphate, this indicator is relatively higher and varies within the range 0.0173-0.0171 kg/s. This difference is explained by the moisture-release behavior of superphosphate and the heat-transfer conditions during drying.

The total specific heat consumption qum tends to decrease with increasing material feed rate for both materials. For loam, qum decreases approximately from 2942 to 2925 kJ/kg vapor, whereas for superphosphate it decreases from about 3034 to 3016 kJ/kg vapor. This indicates that, with increasing throughput, the heat consumption per unit of evaporated moisture decreases to a certain extent.

DISCUSSION

The obtained dependencies reveal the direction of change of the main process indicators when the material feed rate is increased. The $\Delta P = f(G)$ graph shows how the aerodynamic resistance inside the drum changes with material feed rate. The $W_2 = f(G)$ graph makes it possible to evaluate the increase in residual moisture content with throughput. The $G_{evap} = f(G)$ dependency is used to assess the stability of the evaporated moisture rate, while the $q_{total} = f(G)$ graph is used to evaluate the specific heat consumption per unit of evaporated moisture.

When determining the operating range, regimes with very low and very high material feed rates were excluded. The lower operating limit was taken as the feed rate at which the flights are sufficiently filled with material and a continuous material curtain begins to form over the drum cross-section. The upper operating limit was taken as the maximum material feed rate at which the drying process remains stable without a sharp increase in residual moisture content and aerodynamic resistance.

According to the graphical analysis, the operating material feed-rate range for loam was determined to be G = 0.073-0.083 kg/s. Within this interval, the three-section flight lifts the material sufficiently, redistributes it over the drum cross-section, and disperses it into the gas flow. At the same time, the aerodynamic resistance does not increase excessively, and the residual moisture content remains at a technologically acceptable level.

For superphosphate, the operating material feed-rate range was determined to be G = 0.09-0.10 kg/s. This result is associated with the granular structure of superphosphate and its moisture-release behavior during drying. Within this range, even at a higher material feed rate, the evaporated moisture rate remains stable, and the total specific heat consumption per unit of evaporated moisture remains within acceptable limits.

Thus, the determination of the throughput range was carried out by first visually analyzing the lifting, redistribution, and dispersion of the material inside the drum by the three-section flight. These visual results were then numerically substantiated using the dependencies $\Delta P = f(G)$, $W_2 = f(G)$, $G_{evap} = f(G)$, and $q_{total} = f(G)$ constructed in the MATLAB environment. As a result, the operating material feed-rate range of 0.073-0.083 kg/s for loam and 0.09-0.10 kg/s for superphosphate was recommended.

CONCLUSION

The material feed rate has a significant influence on all the main indicators of the drying process. An increase in feed rate increases aerodynamic resistance and residual moisture content; however, it decreases the total specific heat consumption per unit of evaporated moisture to a certain extent. The range G = 0.073-0.083 kg/s for loam and the range G = 0.09-0.10 kg/s for superphosphate were evaluated as technologically rational operating ranges. For a stable drying process, the material feed rate, gas velocity, drying-agent temperature, and number of flights should be selected in mutual balance.

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