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Research Article

Determination of The Optimal Ratio Between Moisture Reduction and Energy Consumption in Superphosphate Drying

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Abstract

This article investigates the optimal relationship between moisture reduction and energy consumption during the drying of superphosphate in a drum dryer equipped with three-section modified lifting flights. The drying process was evaluated using final moisture content, total heat consumption, evaporated moisture flow rate, and aerodynamic resistance. The main operating parameters were drying agent temperature, gas velocity, material productivity, and the number of lifting flights. Particular attention was given to the balance between achieving low final moisture content and avoiding excessive heat consumption. The analysis was carried out for a material productivity of 0.095 kg/s and gas velocity of 20 m/s, with drying agent temperatures of 100, 120, and 140 °C and 24, 30, and 36 lifting flights. The results showed that increasing temperature and the number of lifting flights reduced the final moisture content, but also increased total heat consumption. For example, at 140 °C, increasing the number of lifting flights from 24 to 36 reduced final moisture from 4.874% to 3.266%, while total heat consumption increased from 3046.098 to 3111.135 kJ/kg of evaporated moisture. The results indicate that 30 lifting flights at 120–140 °C provide a rational balance between moisture reduction and energy consumption.

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Keywords

Superphosphate, drum dryer, moisture reduction, energy consumption, three-section lifting flights, drying efficiency, heat consumption, optimal drying regime.

Introduction

Drying is one of the key technological stages in superphosphate production. The final moisture content of the product affects granule strength, storage stability, transportability, and resistance to agglomeration. If the drying process is insufficient, excess moisture remains in the material, which may reduce product quality and cause technological problems during storage and handling [1-4].

However, reducing moisture content requires energy. In drum dryers, moisture removal can be intensified by increasing the drying agent temperature, increasing the gas velocity, or improving material distribution inside the drum. In this study, a drum dryer equipped with three-section modified lifting flights was considered [5-7]. These lifting flights perform three functions: lifting the material, redistributing it across the drum cross-section, and dispersing it into the hot gas flow. As a result, the contact surface between the material and the drying agent increases, and heat and mass transfer become more intensive [8].

At the same time, a higher number of lifting flights may increase aerodynamic resistance and heat consumption. Therefore, the most effective drying regime is not necessarily the regime with the lowest final moisture content. A rational regime should provide sufficient moisture reduction with acceptable energy consumption [9].

The aim of this study is to determine the optimal ratio between moisture reduction and energy consumption in the superphosphate drying process.

Methodology

The analysis was carried out for superphosphate drying in a drum dryer. The main geometric parameters of the dryer were assumed to be constant: drum diameter D = 0.3 m, drum length L = 2 m, rotation speed n = 12 rpm, and structural coefficient α = 0.25. The initial moisture content of the material was taken as;

$$W_0=20\%$$

The investigated parameters were drying agent temperature, gas velocity, material productivity, and the number of three-section modified lifting flights. For the graphical analysis, the following operating conditions were selected;

$$G=0.095kg/s;\ v=20m/s$$

The drying agent temperature was varied as;

$$T=100,120,140^{o}\ C$$

The number of lifting flights was considered at three levels;

$$N=24,30,36$$

The main output parameters were final moisture content W_2, total heat consumption q_{total}, evaporated moisture flow rate G_{ev}, and aerodynamic resistance ΔP.

The total heat consumption was determined as, kJ/kg;

$$q_{total}=2660.078+q_{heating}$$

where 2660.078 kJ/kg is the main heat required for moisture evaporation, and $q_{heating}$ represents the heat used to warm the material.

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To evaluate the relationship between moisture reduction and energy use, the energy efficiency coefficient was introduced, %/(kJ/kg);

$$K_q = \frac{W_0 - W_2}{q_{total}}$$

A higher value of K_q indicates that more moisture is removed per unit of heat consumption.

RESULTS AND DISCUSSION

The relationship between final moisture content and total heat consumption is shown in Figure 1.
The results show that final moisture content decreases as total heat consumption increases. For example, at N = 24, when the drying agent temperature increased from 100 °C to 140 °C, the final moisture content decreased from 6.878% to 4.874%, while total heat consumption increased from 2964.545 to 3046.098 kJ/kg of evaporated moisture.

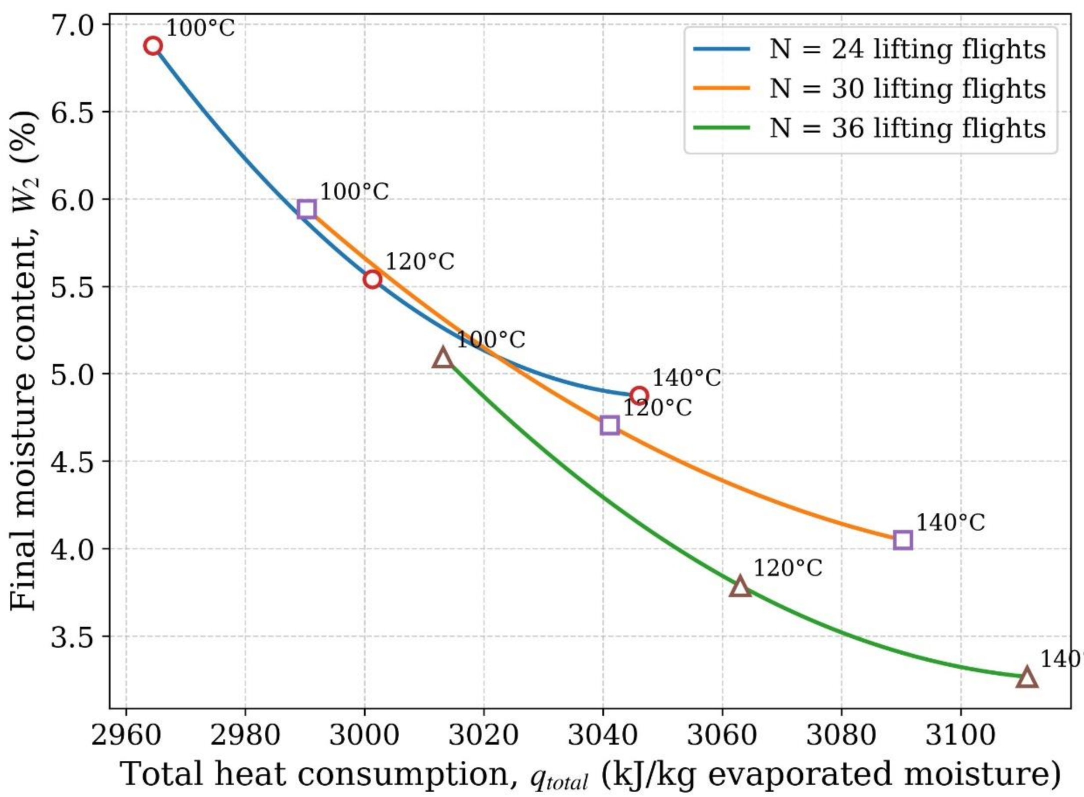

Figure 1. Relationship between final moisture content and total heat consumption, $W_2=f(q_{total})$.

A similar trend was observed for 30 and 36 lifting flights. At N = 30, increasing the temperature from 100 °C to 140 °C reduced final moisture from 5.941% to 4.048%, while total heat consumption increased from 2990.344 to 3090.363 kJ/kg. At N = 36, final moisture decreased from 5.094% to 3.266%, while heat consumption increased from 3013.222 to 3111.135 kJ/kg.
These results confirm that increasing the number of lifting flights improves drying intensity. However, the improvement is accompanied by higher heat consumption. Therefore, the choice of

drying regime should not be based only on the minimum final moisture content.

To evaluate the drying process more objectively, the energy efficiency coefficient K_q was analyzed. The variation of K_q with temperature and the number of lifting flights is shown in Figure 2.

The energy efficiency coefficient increases with temperature and the number of lifting flights. This means that additional heat input contributes to more effective moisture removal. However, the difference between 30 and 36 lifting flights should be evaluated carefully. Although 36 lifting flights provide the lowest moisture content, they also require higher heat consumption and cause greater aerodynamic resistance.

For instance, at T = 140 °C, the final moisture content was 4.874% for 24 lifting flights, 4.048% for 30 lifting flights, and 3.266% for 36 lifting flights. At the same time, total heat consumption increased from 3046.098 to 3090.363 and 3111.135 kJ/kg, respectively.

This indicates that 36 lifting flights are preferable when the main technological goal is maximum moisture removal. However, if energy saving and operational stability are also important, 30 lifting flights at 120–140 °C can be considered a more rational solution.

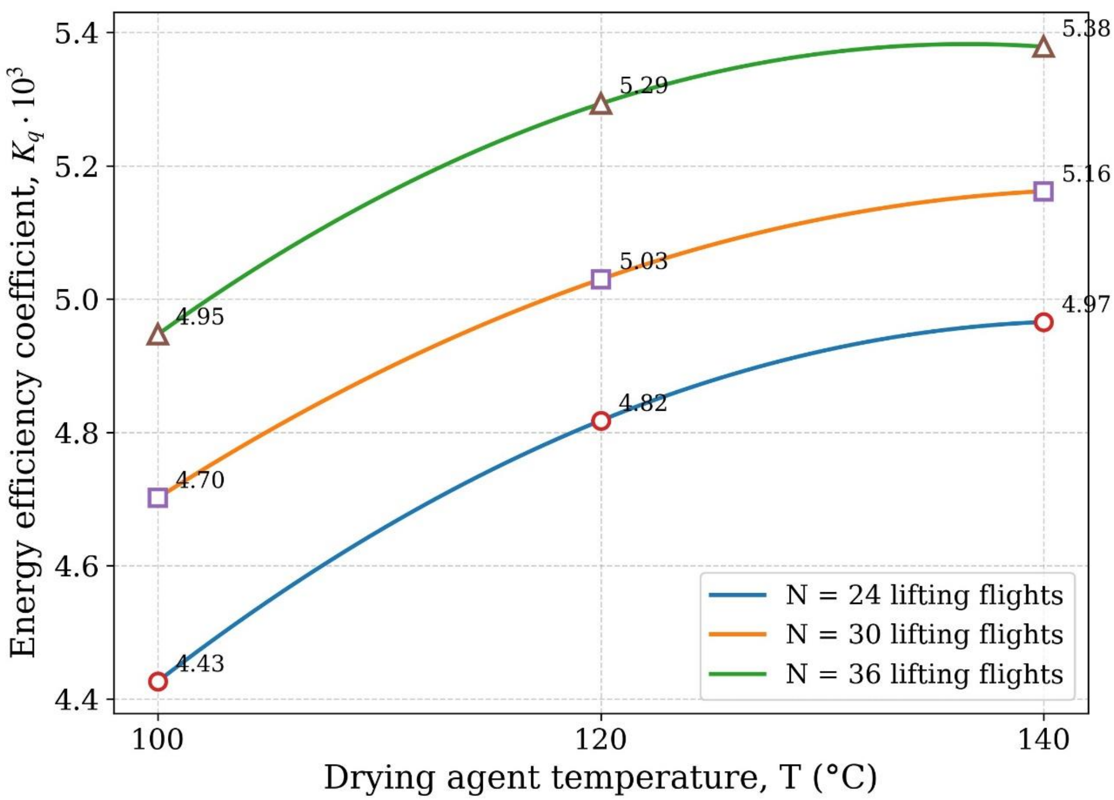

Figure 2. Effect of drying agent temperature and number of lifting flights on the energy efficiency coefficient, $K_q=f(T)$.

Thus, the optimal ratio between moisture reduction and energy consumption is achieved not by the maximum number of lifting flights, but by selecting a regime where moisture reduction is sufficient and heat consumption remains moderate. For industrial operation, the range of 30 lifting flights, 120–140 °C, and 15–20 m/s gas velocity can be recommended as an energy-efficient drying regime.

Conclusion

The analysis showed that moisture reduction and energy consumption in superphosphate drying are strongly interrelated. Increasing drying agent temperature and the number of three-section modified lifting flights reduces final moisture content, but also increases total heat consumption.

At G = 0.095 kg/s and v = 20 m/s, the final moisture content decreased from 6.878% at N = 24 and T = 100 °C to 3.266% at N = 36 and T = 140 °C. At the same time, total heat consumption increased from 2964.545 to 3111.135 kJ/kg of evaporated moisture.

The proposed energy efficiency coefficient $K_q=(W_0-W_2)/q_{total}$ made it possible to compare moisture reduction and heat consumption in one criterion. Based on the results, 36 lifting flights at 140 °C provide the deepest drying, while 30 lifting flights at 120–140 °C provide a more balanced regime in terms of moisture reduction and energy consumption.

Therefore, for practical operation of a drum dryer, 30 three-section modified lifting flights, 120–140 °C drying agent temperature, and 15–20 m/s gas velocity can be recommended as a rational operating range. If maximum drying depth is required, 36 lifting flights at 140 °C may be used, but the increase in heat consumption and aerodynamic resistance should be considered.

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