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REDUCTION OF ENERGY CONSUMPTIONS IN THE PRODUCTION OF LARGE-GRAINED HOT ASPHALT BY IMPROVING THE FEATURES OF THE DRYING DRUMS (FLIGHTS)

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Abstract

This article examines the placement and structural function of drying drum blades (flights) in the production of coarse-grained hot asphalt, as well as approaches to reducing energy consumption through design improvement. In asphalt mixture production, the drying drum is a key piece of equipment whose efficiency mainly depends on the movement of material inside the drum and the process of heat exchange. The shape, arrangement, and surface area of the blades significantly affect how stone materials are lifted, dispersed, and interact with the gas flow inside the drum.

In this study, both scientific and practical calculations were performed to reduce the heating and drying time of the material, enhance heat utilization efficiency, and decrease fuel and energy consumption by optimizing the blade area. The results obtained are valuable for implementing energy-saving technologies in asphalt production plants.

Keywords. Large-grained hot asphalt, Drying drum, Drum areas, blades, Heat content, Moisture, Evaporation, SolidWorks, Inert material film.

Introduction

Throughout the world, the problem of energy conservation and the search for cheaper alternatives are among the main challenges of our time. Our important task is to regulate the use of non-renewable energy sources and thereby preserve energy resources for future generations.

Considering these tasks, we focus on one of the key issues in achieving innovative solutions: the use of energy-saving equipment and technologies in road construction. Currently, coarse-grained hot asphalt concrete mixtures are widely used in road construction. [1]

Since the main energy consumption in the production of coarse-grained hot asphalt occurs in the drying and mixing drum, we will consider ways to reduce energy consumption in the drum. [2]

1. We will accept the following as input data:

- Drum type: Drum mixer for inert materials of various fractions
- Geometric dimensions: Drum length L = 12 m, drum diameter D = 2.2 m
- Productivity: 100 t/h
- Moisture content of inert material: 3%
- Fuel type: Natural gas
- Main fraction: 10–20 mm (coarse-grained aggregate) [3]

Goal:

To reduce fuel consumption per 1 ton of hot asphalt mixture, the main approach is to increase the heat-exchange surface between the material and the gas flow in the drying zone by spreading the material in the form of a “curtain,” while reducing excessive lifting and scattering in the mixing zone. For this purpose, the drying and mixing drum is divided into separate zones (regions).

Drum Zoning Recommended zones for 12-meter drums:

Area	Length range, m	Main task	Blade Type (General)
Z1	0-2.5	Reception and quick moisture removal	Aggressive lifting
Z2	2.5 - 7.5	Basic drying/heating: Maximum filming	More susceptible to inert material and heat
Z3	7.5 - 9.0	Heating to working temperature	Slow lifting
Z4	9.0 - 12.0	Mix/Exit: Mix, Minimum lift	Mixing blades

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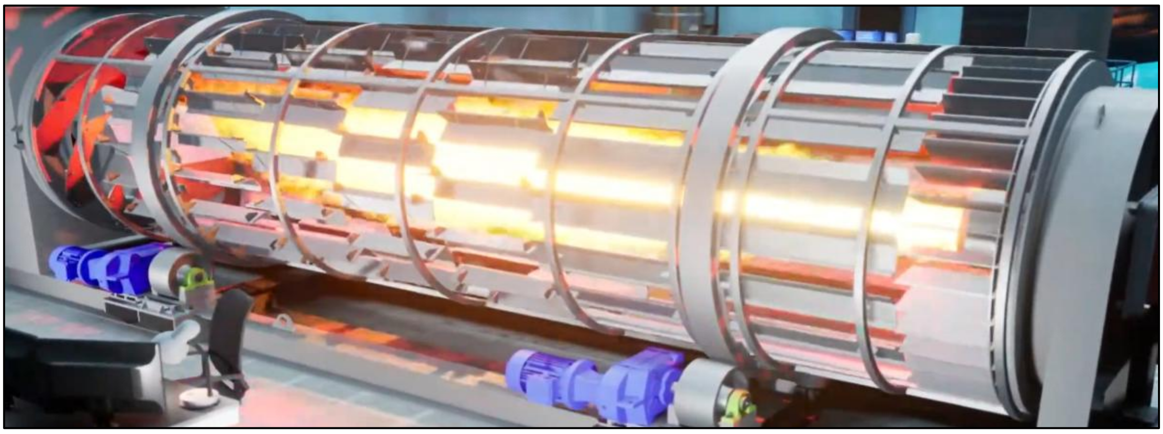
Recommended blade parameters (working range).The following ranges represent "working" values used in production practice. Final dimensions are determined in accordance with the specific drawings and metal structure. [4]

Area	Number of rows	Flight height, mm	Shelf angle β, degrees	Pitch, mm	Explanation
Z1	8.	120 - 160	35 - 45	250 - 350	Lifting and rapid spraying of wet material; reducing loosening.
Z2	8.	80 - 120	25 - 35	200 - 300	More susceptible to inert material and heat
Z3	6 - 8	60 - 90	20 - 30	300 - 450	Reduction of excess lifting when entering the mixture zone.
Z4	6.	40 - 70	15 - 25	400 - 600	Mixing/output: mixing, minimum lifting: reduction of bitumen smoke and dust.



1. Internal section of the drying drum.

For technological purposes, the drying drum is usually divided into 4-5 main zones. The loading (inlet) zone is the initial part of the drum through which cold and moist stone materials (coarse-grained inert materials) enter the drum. The initial heating zone - in this section, the materials gradually begin to interact with the hot gas stream. In this zone, stable and uniform heating is important. The main drying zone is the most important part of the drum. In this zone, most of the moisture evaporates, the number of blades and their working surface are at their maximum, the materials are constantly lifted and scattered in the fomrm of a "curtain". The heating and temperature stabilization zone is where the materials are almost completely dried.

Its main functions are to bring the materials to the required temperature for the asphalt mixture, to distribute the temperature evenly, and to prevent overheating. The shape of the blades here is designed for soft mixing. As a result, heat exchange intensified and energy is used efficiently. The discharge zone is the final section of the drum, where the finished heated and dried materials are discharged.

Calculation of heat input and energy balance equations.

1. Calculation of mass balance (Moisture evaporation).

$\dot{m}_{\mathrm{ev}}(z) = \dot{m}_{s,dry}(-\frac{dX_d}{dz})$; (1)

Where:

$\dot{m}_{s,dry}$ dry aggregate mass flow rate (constant),

X_d- moisture content in the aggregate, [5]

2. Change in gas moisture content.

$\dot{m}_{\mathrm{g},dry}\frac{dY}{dz} = \dot{m}_{\mathrm{ev}}(z)$; (2)

$\dot{m}_{\mathrm{ev}}(z)$- mass flow rate of evaporating water along the drum length z.

3. Heat-limited evaporation (typical for hot asphalt drums) Since evaporation is often limited by available heat, the evaporation rate can be expressed as:

$\dot{m}_{\mathrm{ev}}(z)\frac{Q_{ev}(z)}{r_{ev}(T_s)}=$; (3)

$r_{ev} \approx T_s$Here 2257 kJ/kg (100^0 C; (initial temperature of the aggregate (varies by zone). [6]

4. Heat used for evaporation

$Q_{ev}(z) = \eta_{ev}(z)h(z)a_v(z)V'(z)(T_g(z) - T_s(z))$; (4)

Where:

$V'(z)V'$Volume of the drum per 1 meter of length: =A-1

$\eta_{ev}(z) \in \eta_{ev}(0,1)$ - the "distribution" of heat to evaporation (the remaining part goes to heating the inert material). In practice, Z1-Z2 is large, Z3-Z4 is small.

5. Energy balance (for gas and inert material). Gas energy calculation equation.

$\dot{m}_{p,}c_{pg}\frac{dT_g}{dz} = -h(z)a_v(z)V'\left(T_g - T_s\right) - U_w(z)P(T_g - T_{amb})$; (5)

$-h(z)a_v(z)V'\left(T_g - T_s\right)$- heat transfer from gas to inert material.

$U_w(z)P(T_g - T_{amb})$-removal through the drum wall.

6. Equation for the change in energy expended on an inert material.

$\dot{m}_{s,}c_{ps}\frac{dT_s}{dz} = h(z)a_v(z)V'\left(T_g - T_s\right) - \dot{m}_{\mathrm{ev}}(z)r_{ev}$; (6)

$h(z)$ heat transfer coefficient;

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$a_v(z)$ effective contact surface area.

Here, depending on the blade design, the energy efficiency varies according to how effectively the blades form a material curtain. Let φ(z)\varphi(z)φ(z) be the fraction of material present in the curtain. Then, the amount of material participating in "active" heat exchange is proportional to φ(z)\varphi(z)φ(z).

7. Simplified parametric representation of the contact surface:

$a_v(z)a_0\,\varphi(z)\frac{N_f(z)\cdot H_f(z)}{D}$= (); (7)

Where:

N_f- number of blades per row

H_f-blade height (m)

a_0- calibration constant (depends on drum inner surface area, screening efficiency, and aggregate shape).

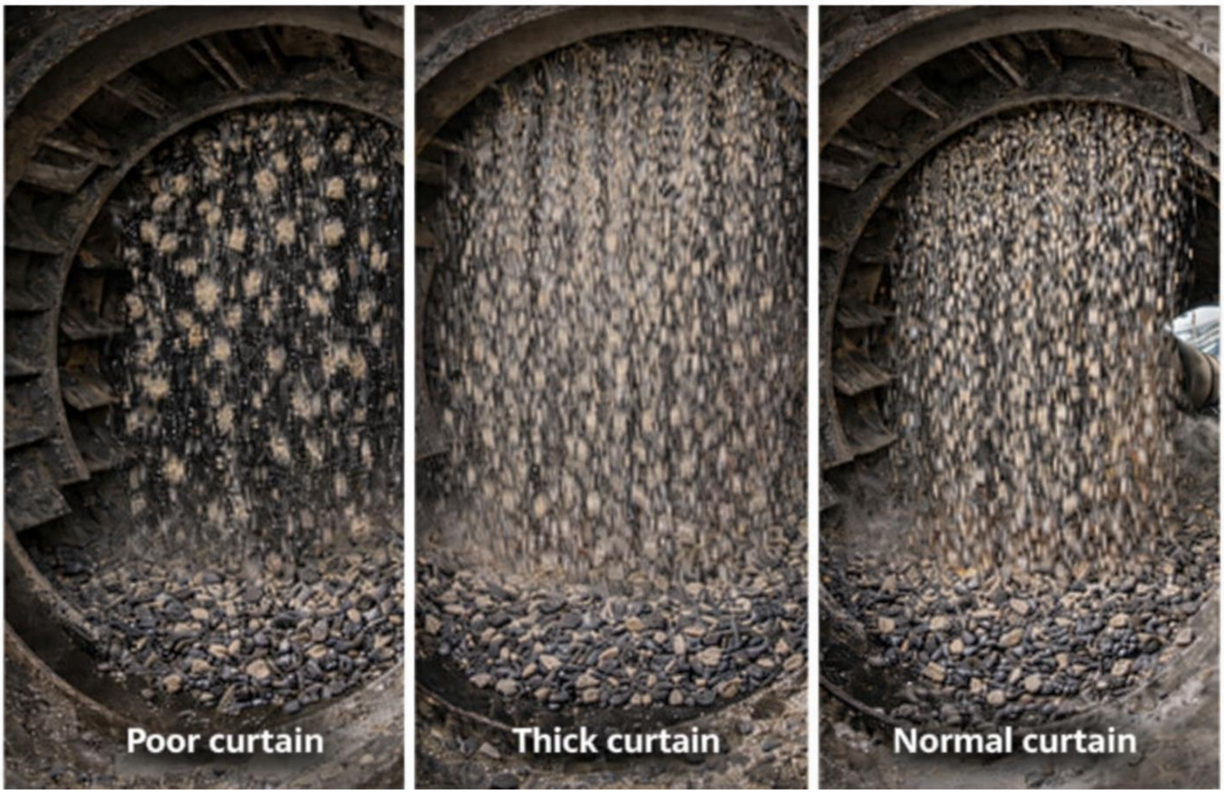

Figure 2. Inert material film inside the drum

The efficiency of drying inert materials in the drying drum of a counter-current asphalt concrete plant is directly related to the condition of the material curtain (film) formed inside the drum. The presence, density, and stability of this curtain are the main factors determining the heat-exchange mechanism.

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Poor curtain formation (non-curtain state)

In this case, the inert materials accumulate in the lower part of the drum and move mainly in a rolling mode. The contact area between the material and the hot gases is very limited, and heat exchange occurs mainly through the drum wall. As a result, the moisture evaporation rate is low, the drying time is longer, and fuel consumption increases. This mode is considered the least efficient from the standpoint of the technological process.

Normal curtain formation (stable curtain state)

When an optimal curtain is formed, the inert materials are lifted by the blades and fall freely, being evenly distributed across the drum cross-section. In this case, the contact surface between the hot gases and the material particles reaches its maximum. As a result, convective heat transfer is intensified, moisture evaporates quickly and uniformly, and the outlet temperature of the material remains stable. The optimal curtain provides the most energy-efficient and technologically effective drying process.

Thick curtain (excessive dense curtain state)

Under thick curtain conditions, inert materials form a very dense layer and restrict the free movement of the gas flow inside the drum. As a result, the gas velocity decreases, heat transfer in some zones deteriorates, and material heating may become uneven. In addition, an excessively dense curtain leads to increased dust formation during the drying process and a decrease in technological stability. Therefore, this condition is also unsuitable for long-term operation.

8. Convective heat transfer

Depending on the turbulence of the gas flow: Analyzing how quickly the hot gas is heating the stone, we call the velocity the heat transfer coefficient in physics and denote it as h.

$h(z)\frac{k_g}{D_h}N_u$=; (8)

Here h is the unit of heat transfer coefficient: W/ (m2·K). If there is a temperature difference between the gas and the material, it shows how much heat passes through 1 m2 of surface (z) along the drum where the gas velocity, temperature, and turbulence change therefore (h) also changes.

k_g- thermal conductivity of gas.

D_h- when gas burns, the movement diameter is approximately equal to the drum diameter.

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N_u -Nusselt number

N_u=CRe^{m}Pr^n; (9)

$\frac{\rho_g u_g D_h}{\mu_g}$ R$_e$=; (10)

u_g ≈Here - average gas velocity in the drum, D$_h$D can be taken. C, m, n are selected experimentally or from the literature. [7]

$h(z), \varphi(z)$ In practice: = h$_0$ is also taken, and (h) increases as the blade increases.

N$_u$ is high, fuel consumption in the drum decreases because heat is transferred efficiently. Drying time is reduced, drum productivity increases. If N$_u$ is small, the material does not heat up sufficiently, and moisture is not released well. The Nusselt number expresses the efficiency of heat dissipation in the drying drum. Its increase is achieved through the speed of the gas flow, the degree of turbulence, and the effective mixing of the material with the gas.

We analyze this situation using a software package. Below, the flow trajectories are shown as clear visualizations obtained using SolidWorks. These trajectories provide a good representation of the three-dimensional gas flow inside the drum. By exporting the data to Excel, we can also examine how the parameters change along each trajectory. In addition, the results can be stored in SolidWorks as corresponding plot curves. [8]

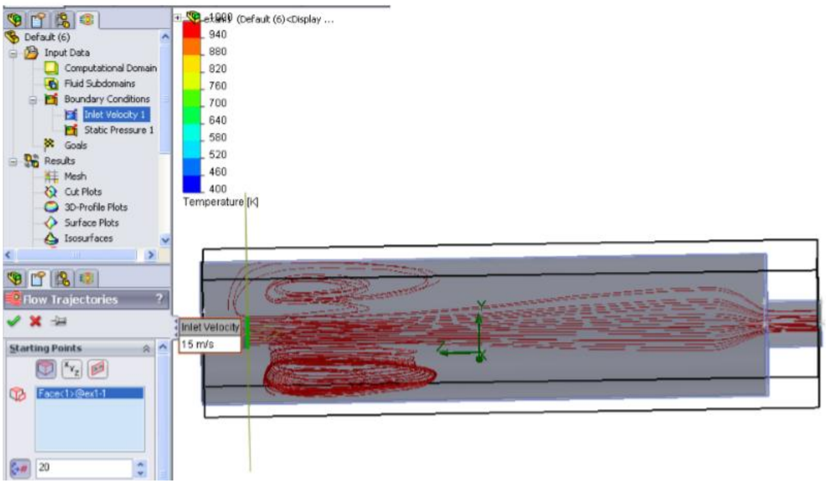

Figure 3. High-pressure gas flame movement in SolidWorks.

Before and after the change of the blade under the same conditions, the following are noted:

- •Gas consumption: Nm3/h and Nm3/t (main KPI).
- •Outlet gas (stack) temperature, °C (a decrease indicates improved heat transfer).
- •Inert outlet temperature, °C.
- •Baghouse (filter) ΔP and dust load (if measurable).

•Quality of the mixture: signs of moisture, uniform heating, quality of bitumen coating.
•Performance: tph stability/preservation.

Expected economic effect (realistic range)

Under the given conditions (100 t/h, 3% moisture, natural gas, no ΔP limitation), proper zoning and the use of curtain-forming blades in zone Z2 can typically reduce fuel consumption by **5–12%**. The exact result depends on the condition of the existing blades, the stack temperature, and the quality of the material curtain.
When developing the final structural design, the inner lining of the drum, available supports, welded joints, thermal deformation, and ease of inspection must be taken into account. If the length of the existing mixing zone and the drum rotational speed are known, the material drop point and curtain density can be adjusted more precisely.

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