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Study on the Cooling Chracteristics of Urea Fertilizer Particle by Blower Reforming in Urea Prilling Tower

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Abstract: The purpose of the urea granulation tower is to establish the cooling process of fertilizer granules by scientifically and theoretically exploring the granulation tower tuyere structure, air temperature and the characteristics of temperature change of fertilizer granules with change of exhaust air volume, moisture change characteristics and residence time of granules.
Keywords: Prilling tower, Tuyere structure, Heat and mass transfer, Temperature variation

I. INTRODUCTION

Urea is produced as a solution or in the solid form. Phase change process of urea from melt to solid prills takes place in the tower. Through the open literature, there are few studies discussed the modeling of the prilling process beginning from the work of Mehrez [1]. RAHMANIAN et al [2] used a simple shrinking unsolidified core model for the tower-prilling to introduce a new design for the prilling tower. The model was based on a lumped method where the whole particle temperature is assumed constant. Alamdari et al [3] introduced a more enhanced model. In this study, the prilling process was simulated by a simultaneous solution of the continuity, hydrodynamics, mass, energy transfer equation of gas, and momentum equation, energy equation of particle.

II. MATHEMATICAL MODELING OF HEAT AND MASS TRANSFER IN UREA FERTILIZER GRANULATION TOWERS

The granulation tower consists of a jet for feeding fertilizer feed, four fans for discharging air inside the tower, air intake, observation window and fertilizer outlets.

The granulation tower sucks ambient air and enters the tower to cool the fertilizer particles sufficiently to release the cooled fertilizer particles at the outlet at the bottom of the tower.

The fertilizer particles entering the tower are injected into the liquid phase and the air at low temperature in the tower is transformed into solid particles to form fertilizer solid particles.

The carbamate component in the tower is decomposed to form ammonia and carbon dioxide, which accounts for less than 1% of the total gas content [1].

In addition, less than about 0.5% of the water evaporates to water vapor and undergoes phase transformation to (NH2)2CO H2O (liquid)- (NH2)2CO (solid)+ H2O (gas).

The aim of the study was to establish the phase change characteristics of urea solution in the granulation tower and the method to determine the outlet temperature of fertilizer particles, and to determine the structure of the air tuyere that provides the outlet temperature of fertilizer in the summer tower below 60°C.

Urea fertilizer undergoes phase transformation from liquid to solid at 132.6°C.

The model equations for analyzing the heat transfer characteristics of particles in this prilling tower are [2,3].

Equation of motion

$$\frac{du_p}{d\tau} = \frac{u_i - u_p}{\tau_r} + \frac{g_i \cdot (\rho_p - \rho)}{\rho_p} + F_i \tag{1}$$

Where u_p is the particle's velocity of motion (m/s), F_i is the mass force acting on the additional particle.

The law of damping acting on particles is used by the Stokes-Cunningham damping law.

-The heat transfer equation of particles in a prilling tower.

The heat transfer equation is given by the phase change of the particle as follows:

$$m_p \cdot \left(c_{p_p} + \frac{L}{T_{p,l} - T_{p,s}} \right) \frac{dT_p}{d\tau} = \alpha A_P \left(T_f - T_p \right) + \sum \frac{dm_i}{d\tau} h_{vap,i} \tag{2}$$

Here, c_{p_p} is the constant pressure specific heat of the particle [J/kg K], T_p and T_f are the particle temperature and ambient air temperature [K], τ is time [s], and $h_{vap,i}$ are the latent heat of evaporation of component *i* in the particle [J/kg], respectively.

Also, *L* is the latent heat of solidification [J/kg], $T_{p,l}$ is the liquid phase temperature [K], and $T_{p,s}$ is the solid phase temperature [K].

α is the heat transfer coefficient, which is determined as follows:

$$Nu = \frac{\alpha d_p}{\lambda} = 2 + 0.6 \mathrm{Re}_d^{1/2} \mathrm{Pr}^{1/3} \tag{3}$$

Where λ is the thermal conductivity of the continuous fluid [W/(m·K)], Re_d is the Reynolds number based on the particle diameter and relative velocity.

-diffusion-controlled evaporation model equation

$$m_{p,0} \frac{dw_{P,i}}{d\tau} = -A_P M_{w,i} k_c \left(C_{s,i} - C_{\infty,i} \right) = \dot{m}_{p,i} \tag{4}$$

$w_{p,i}$ - mass component of component i in the particle;

By Raoult's law, the concentration of the *i* component at the particle surface is determined as follows:

$$C_{i,s} = \frac{P_i}{RT}$$

Moisture concentration in air

$$C_{\infty,i} = Y \frac{p}{R_M T_\infty} \quad [\text{ K mol/m}^3]$$

$M_{w,\mathrm{i}}$ is the molecular weight of component *i* and $k_{c,i}$ is the mass transfer coefficient of component *i*.

$$\mathrm{Nu_m} = \frac{\mathrm{k_c d_p}}{\mathrm{D_{H_2O,m}}} \mathrm{O2} + 0.6 \mathrm{Re}_d^{1/2} \mathrm{Sc}^{1/3} \tag{5}$$

k_c is the mass transfer coefficient [m/s], R is the universal gas constant [J/ (mol K)].

S_c is the Schmidt number and $\mathrm{D_{H_2O,m}}$ is the diffusion coefficient of water vapor in the fluid [m^2/s].

$$\mathrm{Sc} = \frac{\mu}{\rho \mathrm{D_{H_2O,m}}}$$

The model equations for the continuous fluid are used as the continuity equation, the equations of motion, the energy equation and the mass fraction equation of the component air.

III. NUMERICAL SIMULATION OF THE COOLING PROCESS OF UREA FERTILIZER IN UREA FERTILIZER GRANULATION TOWER

Numerical simulation of the cooling process of urea fertilizer was carried out using the thermo-fluid analysis program ANSYS Fluent 2023, and 454,726 hexahedral elements were selected and used, which did not affect the numerical simulation results.

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For a given prilling tower, less than about 1% carbamate is dissolved and the components of the gas are NH_3, CO_2, and the components of the gas are considered negligible, since the vapor H_2O, air, etc. evaporated with liquid urea with a liquid moisture content of about 0.5% are very small in mass fraction.

The mass fraction of air entering the granulation tower, air mass and temperature are as follows:

Water vapor mass fraction: Y_{H2O}=0.0198 (water vapor mass fraction at 30 °C air temperature and 75% relative humidity), air mass: G=440,000 m^3/h, air inlet temperature: 30 °C, specific heat 1003J/ (kg K), density 1.225 kg/m^3, and thermal conductivity of air 0.025 W/ (m K).

The feed particle conditions are as follows:

The feed particle injection temperature was 141°C, feed volume 39m^3/h, particle size 0.00125, 0.0015, 0.00175, 0.002, and 0.0025 m .

The distributor used in the prilling tower was considered assuming that the dispersion was distributed from small to large in size with a mass-phase distribution in each divided section, with a 5-min dispersion to this height, as the solution was dispersed by field measurements up to a height of 0.6 times that of the distributor.

And at 0.098Mpa, the melting point is 132.7°C; density is 1335kg/m^3 at 0°C, 1330kg/m^3 at 25°C, 1225kg/m^3 (liquid) at 132.7°C, specific heat is 2375J/(kg·K), and melting heat is 242 kJ/kg.

The boundary conditions of the granulation tower wall are considered as follows;

The outer wall of the tower consists of 250mm concrete (thermal conductivity 1.4 W/(m·K), density 2300kg/m^3 and specific heat 880 J/(kg·K). The external wall is provided with heat transfer boundary conditions (heat transfer coefficient 23W/(m^2·K), ambient fluid temperature 30°C).

The wall with the fertilizer outlet of the granulation tower is equipped with a stainless- steel wall. The boundary conditions for heat transfer (heat transfer coefficient 8W/(m^2K), ambient fluid temperature 308°C) are given on the stainless- steel wall.

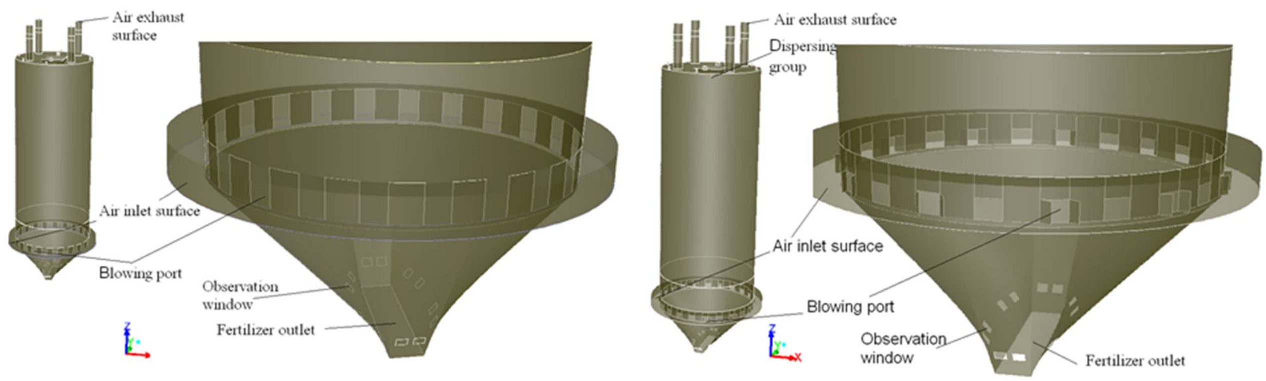
The equations given were calculated using the Medium Transport Model (Species Transport) and the Granular Phase Model (Discrete Phase) in ANSYS Fluent 2023.

In addition, the energy equation and turbulence model equations are introduced.

Table 1. Operating characteristics of fertilizer particles in a distributor rotating at 306rpm

No	area radius (m)	area per area (m^2)	particle feed rate (m/s)	mass flow rate (kg/s)	grain size (m)
1	0.2	0.184	11.8	4.17	0.00125
2	0.167	0.151	9.6	3.42	0.0015
3	0.134	0.118	7.5	2.67	0.00175
4	0.101	0.085	5.41	1.92	0.002
5	0.068	0.0517	3.3	1.17	0.0025

The blast outlet considered in this paper is considered as follows.



Type 1. Type 2.

Fig. 1 Tuyere configuration

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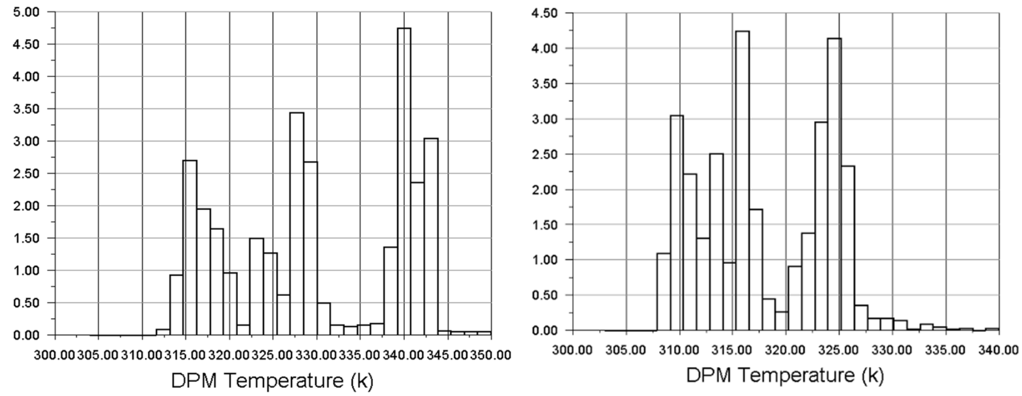
Type 1 is the fan of the existing tower, while type 2 is the fan that crosses one fan and installs a 45° angle flow guide, reducing the fan area of the existing fan by half.

When the summer air temperature is elevated, the fertilizer outlet temperature is calculated as follows:

The cases of type 1 and type 2 with a ventilation rate of 550,000m^3/h and an air temperature of 30°C were considered.

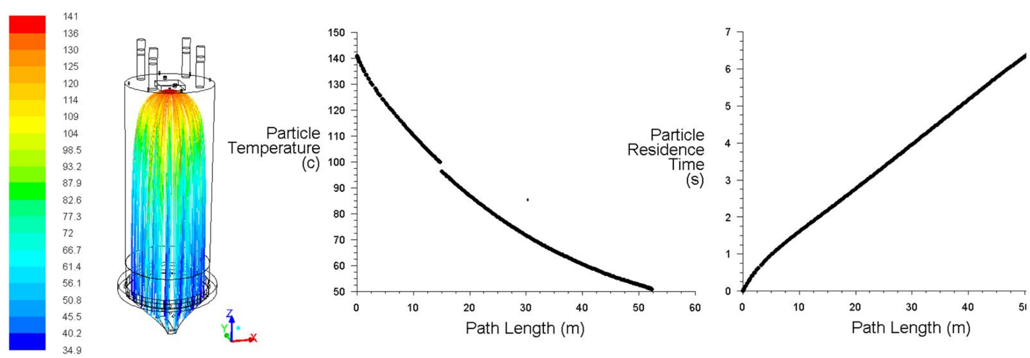


a) Type 1 b) Type 2

Fig. 2 The temperature distribution of fertilizer at the bottom of the fertilizer outlet according to the type of tuyere at 550,000m^3/h and 30°C air temperature (℃).

Fig. 2 shows that the maximum temperature of fertilizer in the granulation tower with type 2 tuyere structure decreases by an average of 10°C compared to that in the granulation tower with type 1 tuyere structure when the air temperature is 30°C at 550,000m^3/h.

Considering the temperature and residence time of fertilizer particles, the temperature distribution and velocity distribution of air in the tower with the type 2 tuyere structure at 550,000m^3/h air temperature of 30°C, the following are the results:



(a) (b) (c)

Fig. 4 Temperature distribution and residence time of urea fertilizer particles (a) temperature change during prilling process of urea fertilizer, (b) temperature change of fertilizer particles with a particle size of 2.5mm in the tower, (c) residence time of fertilizer particles with a particle size of 2.5mm in the tower.

IV. CONCLUSION

We have considered the temperature distribution of urea solution particles along the tuyere structure in the urea tower and scientifically confirmed that the tuyere structure with a 45° angle flow guide across one tuyere with a half reduction in the tuyere area is a reasonable tuyere structure to achieve the cooling characteristics of the fertilizer. This structure revealed that the outlet fertilizer particle temperature, which was 75°C on average in the conventional structure, could be reduced to 55°C when the draught rate was 550,000m^3/h in the tower in summer.

Declaration of Competing Interests

The authors have no financial conflict for this paper.

V. ACKNOWLEDGMENTS

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