# 03TCQ - PRODUCTION OF AMMONIUM NITRATE IN THE VORTEX GRANULATORS: RECYCLING OF PRODUCTION WASTE

**ARTYUKHOV, A.E.**[1]**; LEVCHENKO, D.A.**[2]**; ROSSI, P.C.**[3]

[1]**Processes and Equipment of Chemical and Petroleum-Refineries Department, Sumy State University, Ukraine.**
**artyukhov@pohnp.sumdu.edu.ua**
[2]**Department of Technical Thermal Physics, Sumy State University, Ukraine.**
**levchenkodmitryalex@gmail.com**
[3]**Department of Chemical Technology, Faculty of Engineering, National University of Río Cuarto, Argentina.**

## Abstract

Production of ammonium nitrate granules is energy-intensive process that is accompanied by the release of a sufficiently large number of gaseous nitrous oxide $N_2O$. Furthermore, the production process of granular ammonium nitrate by the tower method or in fluidized bed it is inevitable losses in the form of unmarketable (small) fraction and dust.

The main objective of the research is the substantiation the possibility of using vortex devices for recycling of ammonium nitrate.

The problem of waste disposal in the production of ammonium nitrate is described. Methods for processing of waste gases and ammonium nitrate granules are presented. Some of the advanced methods of waste disposal are described in detail.

The mathematical description results of the vortex and vortex ejector plates will be based on the methods of engineering calculation of utilization equipment. Experimental lapping of the recycling module constructed using the above provisions, suggests their correlation to account for the chemical reactions in the flow path of utilizing the module. In the future, a detailed description of the study and other methods of waste disposal of ammonium nitrate is plan.

## 1. Introduction

The environmental safety problem of chemical production is becoming increasingly important. The main environmental issues are: water pollution, air, an increase in production and consumption waste, etc (Spitz, 2003).

Production of granular products (including granules nitrogen fertilizer ammonium nitrate, urea) a major sector of the chemical industry (Litster and Ennis, 2004).

Improving the quality of nitrogen fertilizers and indicators for the consumption of energy and environmental security in their production to the highest international requirements (an important task of enterprise-producers) (Galloway at al., 2008). Improving the performance of production and improve the quality of the products obtained in two directions: the changes in technology and processes; increase in energy and environmental efficiency of existing production equipment (Raun and Johnson 1999

## 2. Aims

1) Development of new approaches to address waste nitrogen impurities in the production of ammonium nitrate; 2) Substantiation the possibility of using devices with

vortex flow in the disposal of waste products of ammonium nitrate; 3) Theoretical description of the mechanism of gas flow interaction on vortex trays with heat-mass transfer separation elements (HMTSE); 4) Theoretical description of catalytic thermal recycling of modules with different types of ejectors, in particular, vortex ejectors.

## 3. Methodology

Waste production plants, for example, ammonium nitrate, are:

- Air, which contains ammonium nitrate dust, nitrogen oxides and ammonia;
- Fine fraction granules, which cannot be used in agriculture.

Modern production of nitrogen fertilizers is carried out mainly in two ways:

- Granulation of the liquid phase by dispersing it into droplets, followed by crystallization by dewatering and cooling;
- Granulation of the liquid phase in the fluidized bed.

Weighted layer granulator of high power density successfully can be use in the production of ammonium nitrate. Separate class of weighted layer granulator the vortex granulators with variable cross-sectional area of the working space (Artyukhov, 2006). Environmental benefits of such devices are the possibility of classifying the granules in the working volume and internal circulation of small granules (Artyukhov & Sklabinskyi, 2012). These advantages reduce the amount of small fraction granules and ammonium nitrate dust.

The main directions of waste disposal of ammonium nitrate and equipment:

1) Capturing of small fraction and dust with further sending to the preparation of the melt - vortex precipitators (Galich at al., 2014), the separation stage (Artyukhov at al., 2010); 2) Capturing of ammonia to form ammonia water for industrial purposes - vortex heat and mass transfer contact stage (Korobchenko at al., 2010), counter-swirl atomized mass transfer devices (Sklabinskyi at al., 2011); 3) Capturing of small fraction and send it to the rearing - takes place directly in the vortex granulator; 4) Capturing of lower oxides of nitrogen, oxidation of them to the higher oxides, shipping on the production of nitric acid - system "reactor-vortex ejector" (Prokopov at al., 2014); 5) Thermal decomposition of unconditioned ammonium nitrate with the formation of lower oxides of nitrogen, oxidation of them to the higher oxides, shipping to the production of nitric acid - a system of "reactor-

Thus, for waste disposal such methods are used: hydro mechanical, reactionary, mass transfer, combinational.

Let look at some of them.

To describe the motion of an axisymmetric gas with rotation, Navier-Stokes differential equations are used, which are simplified depending on the task and received physical flow model as well as the differential equations of motion of a particle in a swirling gas flow.

To describe the work processes in the vortex ejector mathematical model is given, which is based on the use of the law of conservation of momentum flux within the cross sections

## 4. Results and discussion

*Vortex tray with heat-mass transfer separation elements (HMTSE)*

During the design contact stages for the absorption of gas cleaning issue is to reduce entrainment. Entrainment depends on the magnitude of the efficiency of mass transfer processes within the contact stage. Analysis of the sieve, bubble cap, valve and vortex contact devices identified the lowest value of entrainment using vortex contact devices (fig. 1). The presence of such contact device, swirls node of gas flow allows changing the parameters of swirls and significantly affecting the flow resistance of the contact device and the amount of entrainment of the liquid phase of the contact step.

On the basis of theoretical modeling and experimental studies (Artyukhov, 2014; Artyukhov & Liaposhchenko, 2014) proposed an algorithm for the calculation of the vortex tray with HMTSE, which consists of the following stages:

1: Determination of the hydrodynamic conditions of gas flow.

Gas flow calculation, is performed by numerically solving the system of equations describing the most general case of the medium. These are the Navier-Stokes equations (1) and continuity (2):

$$\frac{\partial}{\partial t}\left(\rho V_i\right)+\frac{\partial}{\partial x_j}\left(\rho V_i V_j\right)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial V_i}{x_j}+\frac{\partial V_j}{x_i}\right)\right]+f_i \tag{1}$$

$$\frac{\partial}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho V_j\right)=0, \tag{2}$$

where: $\mu$ - dynamic viscosity of the gas; $t$ - time; $V_i$- instantaneous speed component along the selected axis; $\rho$ - gas density; $p$ - pressure; $f_i$ - represents the action of mass forces; $x_j$ - coordinate axis $i,j$ - 1 ... 3; for a cylindrical coordinate system index "1" - the longitudinal / perpendicular direction ($z$), index "2" - radial direction ($r$), index "3" - the circumferential direction ($\varphi$)

2: Determination of the hydrodynamic conditions of fluid motion.

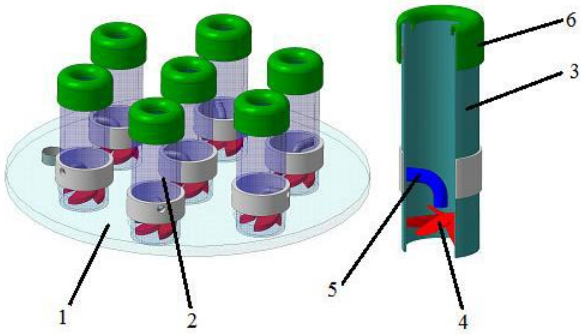

Fig.1 - Vortex tray with HMTSE: 1 - web plate; 2 - heat-mass transfer separation element; 3 - pipe; 4 - swirler; 5 - liquid injection tube; 6 – tape.

Theoretical calculation was based on system of differential equations (3) of the drop motion in the vortex gas stream:

$$\left.\begin{aligned} m\frac{d^2x_1}{dt^2} &= -g+\psi\cdot\frac{\pi\cdot\mu\cdot d_{dr}}{8\cdot m}\ V_1-W_1), \\ m\frac{d^2x_2}{dt^2} &= \frac{W_3^2}{r}+\psi\cdot\frac{\pi\cdot\mu\cdot d_{dr}}{8\cdot m}\ V_2-W_2), \\ m\frac{d^2x_3}{dt^2} &= -\frac{W_2W_3}{r}+\psi\cdot\frac{\pi\cdot\mu_S\cdot d_{dr}}{8\cdot m}(V_3-W_3), \end{aligned}\right\} \qquad (3)$$

where: $m$ - mass of drop; $r$ - the current radius of the HMTSE; $W_1, W_2, W_3$ - longitudinal / perpendicular, radial and circumferential and velocity components of the drops, respectively; $g$ - acceleration of gravity; $\psi$ - linear coefficient of the drop's resistance to the gas flow; $d_{dr}$ - diameter of the drop.
Here an abbreviated form of the equations is used.

3: Calculation of the optimal size of HMTSE.
For a software implementation the results of mathematical modeling is used:
- Height of the HMTSE

$$L=\frac{s}{g}\cdot\frac{W_3{}^2}{R}; \qquad (4)$$

- Liquid film thickness, rising through the inner wall of contact tube

$$s=\frac{1}{2}\cdot\frac{C\cdot R}{\rho_L}, \qquad (5)$$

where: $R$ - the radius of the contact tube of HMTSE; $C$ - the amount of liquid per unit volume of the contact tube; $_L$ - liquid density.

Equations (4) and (5) were obtained by analyzing the effect of external forces on the liquid film in the contact tube. Optimum radius $R$ should provide maximum value of upward velocity of the gas stream component, which performs balance of forces.

*Vortex ejector*
Existing methods for the conversion of nitrous oxide to higher oxides involve the use of natural gas, which leads to additional costs for the organization of this process (laying of the pipeline, related communications, ensuring security of exploitation).
The authors propose a new approach to the implementation of integrated waste disposal systems of ammonium nitrate production using a vortex ejector.
Type selection of ejector stage liquid ring vacuum pump (LRVP) depends on the operating conditions of the vacuum unit. At a constant temperature in the liquid ring and consumable parameters of the system is the most rational choice of straight jet ejector (Levchenko at al., 2009). The liquid ring vacuum pump unitization by the ejector stage, however, if the layout of the technological scheme granulation of ammonium nitrate

with LRVP and using circulating water system, the temperature in the liquid ring vacuum pump is not constant due to the change in time of the concentration of ammonia and ammonium nitrate in a circulating water. In this case, it is more expedient to use the vortex ejector as an upstream stage LRVP and install recycling nitrous oxide (Levchenko at al., 2009). The use of the air ejector stages for Lubrication Free vacuum pump rotary type.

Conditions of work vortex ejector consisting LRVP in different modes and the basic operating parameters of a vacuum unit can be described by three basic equations for the coefficient of ejection $U$ , The pressure ratio of the passive flux $\varepsilon$ and closing complex gas dynamic equations correlation functions and the geometrical parameters of the ejector (Levchenko, 2011, Levchenko at al., 2012):

$$U\sqrt{\theta} = \frac{\hat{Z}\ \psi_A \cdot \lambda_{IIA}\ \ \beta_{IIA}, \alpha))-\hat{Z}\ \psi_{mix} \cdot \lambda_{III}\ \ \beta_{III}))}{\hat{Z}\ \psi_{mix} \cdot \lambda_{III}\ \ \beta_{III}))-\hat{Z}\ \psi_P \cdot \lambda_{IIP})}, \tag{6}$$

where $\hat{Z}\ \lambda_{IIP})$ - a complex gas-dynamic function of the passive flow; $\hat{Z}\ \lambda_{III}, \beta_{III})$ - a complex gas-dynamic function of the mixed stream; $\hat{Z}\ \lambda_{IIA}, \alpha, \beta_{IIA})$ - a complex gas-dynamic function of the active thread; $\lambda_{IIA}$, $\lambda_{IIP}$, $\lambda_{III}$ - given the rate of active, passive and mixed, respectively; $\beta_{IIA}, \beta_{IIP}, \beta_{III}$ - twist angle of active, passive and mixed-flow, respectively; $\alpha$ - Angle of taper of the swirl chamber; $\psi_A$, $\psi_P$, $\psi_{mix}$ - correlation coefficients, taking into account the dissipative processes in the ejector for active, passive and mixed flows, respectively; subscripts $IIA$, $IIP$ parameters of the flows in the cross section of the interaction $II$ , respectively, for active and passive protection; $III$ - the cross section of completely mixed stream; $\hat{}$ - average values for the section under consideration; $\sqrt{\theta} = \frac{a_{crP}}{a_{crA}} = \sqrt{\frac{R_P \cdot T_{0P}}{R_A \cdot T_{0A}}}$ - ratio of the critical flow velocities of passive to active.

$$\varepsilon = \sigma_{III} \cdot \frac{\Pi \cdot F_{IIA} \cdot \hat{f}\ \ \lambda_{IIA}, \alpha, \beta_{IIA}) + F_{IIP} \cdot \hat{f}(\lambda_{IIP})}{F_{III} \cdot \hat{f}\ \ \lambda_{III}, \beta_{III})}, \tag{7}$$

where $\Pi = P_{0A}/P_{0P}$ - the expansion of the active flow (pressure ratio of active to passive flow); $\hat{f}(\lambda_{IIA}, \alpha, \beta_{IIA})$, $\hat{f}\ \ \lambda_{IIP})$, $\hat{f}\ \ \lambda_{III}, \beta_{III})$ - averaged complex gas-dynamic functions for the active, passive, and mixed flows, respectively; $\sigma_{III}$ - the degree of reduction of the total pressure of the mixed stream; $F_{IIA}$, $F_{IIP}$, $F_{III}$ - cross-sectional areas of active, passive and mixed streams respectively.

$$\hat{q}_3 \qquad \frac{\cdot \sigma}{\varepsilon} \qquad \frac{N \cdot \overline{r}_1^{2}}{\overline{R}_k^{2}}, \tag{8}$$

where $\hat{q}_3 = \frac{q(\lambda_{III})\cos\hat{\beta}_{III}}{\hat{q}(\lambda_{UI})}$ - the ratio of gas-dynamic functions of consumables; $\mu = \frac{F_{II}}{F_{III}}$ - the ratio of the cross sections areas II and III; $N$ - the number of active inputs nozzle flow; $\overline{R}_k$, $\overline{r}_1$ - the relative radii of the vortex chamber and the nozzle of the active flow (related to the radius of the location of the active flow nozzles)

It should be noted that equation (6) workflow vortex ejector recorded for the conditions of equality environments and temperatures of active and passive flow, as well as excluding the thermal effect of their interaction. Obviously, this is a very crude approximation, therefore, the various properties of the active and passive flows must be considered at the stage of removing, the basic equation for the coefficient of ejection from the equation of the law of conservation of energy:

$$\dot{m}_{III} \cdot i_{0III} = \dot{m}_A \cdot i_{0A} + \dot{m}_P \cdot i_{0P} + \dot{Q}, \tag{9}$$

where $i_{0III}, i_{0A}, i_{0P}$ - total enthalpy of corresponding streams; $\dot{m}_A, \dot{m}_P, \dot{m}_{III}$ - mass flow rates of active, passive and mixed flows; $\dot{Q}$ - heat through the wall of the working chamber and the thermal effect of reacting flows.

Using the equation of isobaric heat capacity for ideal gases $c_p = R \cdot \frac{k}{k-1}$, we write the equation (9) as follows:

$$\dot{m}_{III} \cdot R_{III} \frac{k_{III}}{k_{III}-1} T_{0III} = \dot{m}_A R_A \frac{k_A}{k_A-1} T_{0A} + \dot{m}_P \cdot R_P \frac{k_P}{k_P-1} T_{0P} + \dot{Q}. \tag{10}$$

When using the notation:

$\theta = \frac{R_P T_{0P}}{R_A T_{0A}}$; $\tilde{k}_{III} = \frac{k_{III}}{k_A} \cdot \frac{k_A - 1}{k_{III} - 1}$; $\tilde{k}_P = \frac{k_P}{k_A} \cdot \frac{k_A - 1}{k_P - 1}$; $\vartheta = \frac{\dot{Q}}{c_{PA} \cdot T_{0A} \cdot \dot{m}_A}$, equation (10) takes the form:

$$(U+1) \cdot \frac{R_{III} T_{0III}}{R_A T_{0A}} \cdot \tilde{k}_{III} = 1 + U \cdot \theta \cdot \tilde{k}_P + \vartheta, \tag{11}$$

where $\frac{R_{III} T_{0III}}{R_A T_{0A}} = \frac{1 + U \cdot \theta \cdot \tilde{k}_P + \vartheta}{(U+1) \cdot \tilde{k}_{III}}$. Finally, we obtain:

$$\frac{a_{crIII}}{a_{crA}} = \sqrt{\frac{R_{III} T_{0III}}{R_A T_{0A}}} = \sqrt{\frac{1 + U \cdot \theta \cdot \tilde{k}_P + \vartheta}{(U+1) \cdot \tilde{k}_{III}}} \tag{12}$$

Writing the energy conservation equation (9), using a complex gas-dynamic functions and taking into account equation (12) we obtain:

$$\sqrt{\frac{U+1}{\tilde{k}_{III}}\left(1 + \ldots + \ldots\right)} \cdot \hat{z} \ldots \lambda_{IIP}) \tag{13}$$

Equation (13) corresponds to the same equation for gas straight jet ejectors (Abramovich, 1991), and requires clarification of the flow structure in the cross section of interaction and mixing of active and passive media in the vortex ejector to determine the average values of complex gas-dynamic functions. These studies were conducted (Levchenko at al., 2012) for the air, which, nevertheless, allows extending the results of an experiment on the other sparse medium. In addition to reducing the computational work, use of gas-dynamic functions can greatly simplify the conversion of the simultaneous solution of the basic equations of WPP. In such a calculation, more clearly identifies the main qualitative behavior of the flow and the relationship between the parameters of the gas flow. It can be seen that the functions $Z(\lambda,\alpha,\beta)$ (fig. 2) and $Z\ \lambda,\beta)$ (fig. 3) very little change at transonic speeds, so in these areas a small error in the value, function can lead to a large error in the calculation of the reduced velocity $\lambda$. Because of finding this $\lambda$ on the function value $Z(\lambda)$ (graphical method) is not appropriate to use in contrast to the use of regression equations (Levchenko, 2011) obtained for the absolute velocity of the gas flow, the accuracy of which is determined by the coefficient of determination and is acceptable for practical use.

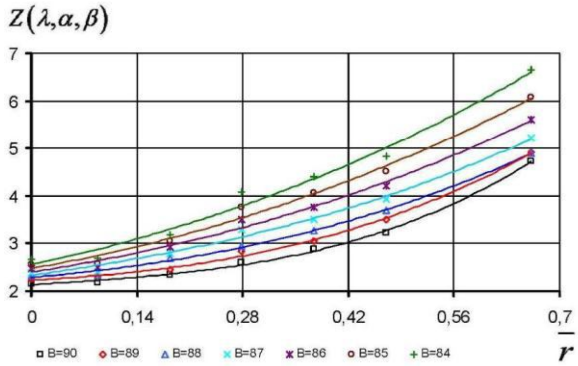

Fig.2 - The relationship between the complex gas-dynamic functions $Z\ \lambda,\alpha,\beta)$ the relative radius in the section II of the vortex flow ejector vacuum at different levels of B (%).

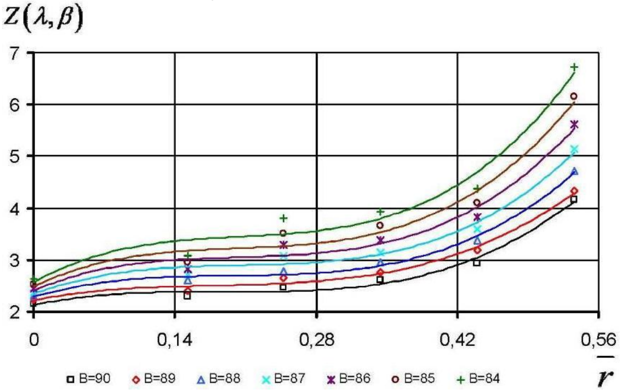

Fig. 3 - Dependence of complex gas-dynamic functions $Z$ $)$ the relative radius of the cross section of the vortex flow III ejector at different vacuum level B (%).

## 5. Conclusions

The mathematical description results of the vortex and vortex ejector plates will be based on the methods of engineering calculation of utilization equipment. Experimental lapping of the recycling module constructed using the above provisions, suggests their correlation to account for the chemical reactions in the flow path of utilizing the module. In the future, a detailed description of the study and other methods of waste disposal of ammonium nitrate is plan.

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