ЕНЕРГОЗБЕРЕЖЕННЯ ТА БЕЗПЕКА ЖИТТЄДІЯЛЬНОСТІ

УДК 621.926.4/088.8

RATIONAL ENERGY USE UNDER THE PROCESS OF GRANULATED PHOSPHATE FERTILIZER COOLING

N. A. Artukhova, Sumy State University

This paper investigates the multistage countercurrent shelf coolers for granular phosphate fertilizers in order to increase product quality and reduce energy consumption. In theory, identifying the most economic mode heat and mass transfer at different ratios of costs of interacting flows. Introduction shelf devices fluidized bed increases the contact time of the cooling agent to stabilize the interaction of the gas flow with dispersed particles of the product and to solve the problem of energy conservation.

Keywords: *fertilizers, multistage coolers, mass transfer, dispersed particles, energy conservation, heat-exchange equipment.*

INTRODUCTION

Many researchers have done a lot of contribution concerning the heat-exchange equipment applied to the dispersed materials. The first part of this work deals with the review of different inventions and technical publications. This allows us to create the most reasonable prospective model of fluidized bed cooler involving some important results of the previous investigations.

In many industrial processes, there is a need of bringing granular solids into the contact with cooling medium. One way to do it is to apply a fluid bed. In this process, an upward directed gas stream causes a bed of granular solids to be fluidized. Fluid beds offer advantages in performing processes such as heating, drying, roasting, or cooling [1-5].

The mode of operation with positive conveying action is the good technological solution. The material is directed through the rectangular inlet into the process zone. The cooling air is fed through the individual pipe across the entire process area thanks to a special screen bottom. The cooling air flow fluidizes the material. A special conveying chain with flights forming a chamber system conveys the material within a closely controlled resident time through the process zone to the outlet. This positive conveying action at a continuously variable speed allows accurate control of the resident time [3-5].

The advanced ability of the fluid-bed heat exchanger is based on the specific characteristics of the granulated material to be processed. In many applications, these are known only to a limited extent. A comprehensive material test giving consideration to physical and chemical aspects is therefore necessary. The chemical laboratory conducts such tests and verifies the results

Heat-exchange equipment with fluidized bed devices is known to play a very important role in fertilizers industry. Two processes are used to produce phosphate fertilizers: run-of-pile and granular. The granular process uses lower-strength phosphoric acid (40%, compared to 50% for run-of-pile). The reaction mixture, a slurry, is sprayed onto recycled fertilizer fines in a granulator. Granules grow and are then discharged to the screens, crushers, cooler and are sent to storage. Thus, the multistage fluidized bed can be used for granular solids cooling. But the solid particles do not reach the thermal equilibrium due to relatively short residence time in cooler.

So, first of all a rational perforated plate construction and optimal regime is needed to establish. Second, we have to propose some method for energy saving.

TECHNOLOGICAL PARAMETERS ANALYSIS

The improvement of the heat-exchange efficiency of cooling equipment can be regarded as one of the most significant tasks of this investigation. One of the ways to solve this problem is the design and practical application of new high-performance fluidized bed coolers that is based on effective interactions between granules and air stream. The fluidized-bed devices with perforated plates are mainly used for intensive treatment of granulated materials as well as classification under required dispersion factors. Their efficiency was proved on the basis of the results of modern technology analysis and experimental investigation with new approach. In the proposed apparatus a fluidized bed has an perforated plate which is inclined to the horizontal so that excessively sized or dense particles migrate to a collection point from which they may be removed, such as by a gate in the side of the bed.

The course and behavior of particles that formed a dense and stable fluidized bed are discussed. Both the experimental and simulation results of this study show that the process of forming a suspension bed can be categorized into an induced stage, a growing stage, and a stable stage. The velocity of air through the orifice directly controls the formation of the bed while the solid flow rate over a considerable range maintains a balanced hold-up in the suspension bed system without downcomers.

The existence of a multiplicity of steady states corresponding to different gas flow rates, for the same feed rate and perforated plate type and slope, was observed. Results show that the design of the plate, the particle feed rate and the gas velocity distribution through the holes affect the stability of the fluidized bed. The simulated results agree qualitatively well with experimental observations.

The research of the combined cooling-classification systems and the development of column apparatus with the perforated inclined plates represented by new coolers is the urgent matter of R&D on this scope. But there are several shortcomings of the granulation process typical design. With the theoretical models developed and tested in this work the different aerodynamic parameters and technical economic factors can be taken into account. Even in the case of single-phase turbulent flows, which have been extensively studied over the last century, the theory has remained at the level of semi-empirical generalizations. The same can be said of two-phase flows, which are physically more complex. Hence the importance of any regularities or laws discovered by experimentation for the future development of a theory of fluidized bed appearance and particles classification is indisputable.

The first part of the investigation deals with the problem of supporting granules into fluidized bed by the minimum air rate. When there is an excess flow of air, it is reasonable to take into consideration its usage and regime optimization. One of the most workable decisions is to use the special devices (perforated plates) to support fluidized bed and increase the average resident time.

Technological characteristics of particles temperature under different resident time and air flow velocity are given below (Table 1).

Table 1 - Temperature of the phosphate granules under different resident time **t**

t, sec	Particles temperature, C under different flow velocity, m/s										
	1,08 m/s	п w1,47 m/s	П w1,86 m/s	П 22,25 m/s c	П=2,65 m/s	П W3,04 m/s	п 3,43 m/s	П,3,82 m/s	п 4,22 m/s	П 4,61 m/s	П=5,0 m/s
1	69,56	64,98	58,49	56,62	54,38	51,34	50,24	48,91	46,15	44,8	43,68
1,9	61,88	56,35	49,63	47,2	45,13	41,63	40,29	38,86	36,41	35,12	34,06
2,8	55,4	49,38	42,8	40,21	38,67	34,92	33,61	32,3	30,3	29,22	28,35
3,7	49,91	43,75	37,55	35,01	34,3	30,3	29,13	28,03	26,47	25,63	24,96
4,6	45,28	39,19	33,51	31,15	30,38	27,11	26,13	25,24	24,06	23,43	22,95
5,5	41,36	35,51	30,4	28,28	27,54	24,9	24,11	23,41	22,55	22,09	21,75
6,4	38,06	32,54	28	26,15	25,47	23,38	22,76	22,23	21,6	21,28	21,04
7,3	35,26	30,13	26,16	24,57	23,97	22,33	21,85	21,45	21	20,78	20,62
8,2	32,9	28,19	24,74	23,39	22,88	21,61	21,24	20,95	20,63	20,43	20,37
9,1	30,9	26,62	23,65	22,52	22,09	21,11	20,83	20,62	20,4	20,29	20,22
10	29,21	25,35	22,81	21,87	21,52	20,77	20,56	20,4	20,25	20,18	20,13
10,9	27,78	24,32	22,16	21,39	21,1	20,53	20,38	20,26	20,16	20,11	20,08

We can see with increasing resident time that a temperature tend to decline but the air velocity contribution is also noticeable. Unfortunately, on the basis of these experimental results the type of fluidized bed cooler cannot be clearly defined. Moreover, demanded regime parameters according heat-exchange theory do not describe satisfactory the constructive features for the saving energy solution. A possible way of approaching suitable aerodynamic factors is the application of the combined technical economic criterion.

On the other illustration, experimental series of kinetic curves was presented to indicate the detailed factors of aerodynamic regime influence on the heat-exchange efficiency. Figure 1 shows the jumping growth of heat-transfer Nusselt number for bed fluidized regime.

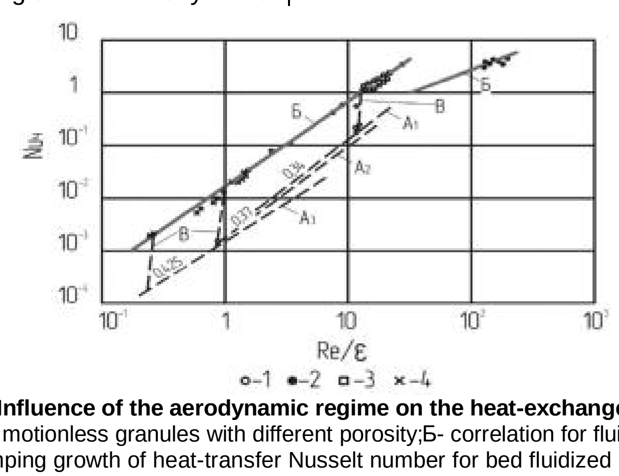

Figure 1- Influence of the aerodynamic regime on the heat-exchange efficiency

A- correlation for motionless granules with different porosity;Б- correlation for fluidized bed system;

В- jumping growth of heat-transfer Nusselt number for bed fluidized regime.

1- glass granules 0,132 mm; 2- 0,444 mm; 3- 1,1 mm; 4 – aluminium granules 0,09 мм.

There seemed to be no significant difference between the Nusselt number growth for type of granulated materials, but the bed fluidized regime appearance is extremely important factor.

EXPERIMENTAL SECTION

When an air stream is passed through a permeable support (perforated plate) on which the free flowing material rests, the bed starts to expand when a certain velocity is reached. The superficial velocity of the air at the onset of fluidization is the minimum fluidization velocity. With a further increase in air velocity, bed reaches a stage where the pressure-drop across fluid bed drops rapidly and the product is carried away by the air. The velocity at this stage is known as terminal velocity and an important parameter in fluidization operations. The operational velocity must remain between these two velocities.

All fluidization regime experiments were conducted in a bath type flexi-glass fluidizing column 50?100 mm section and 750mm height (figure 2) .The cooling air was taken from a ventilator system and directed to the fluidizing column by flexible ducts. Air entered the material bed through a perforated plate with circular holes of 1 mm diameter (18 holes/cm2). Wall effects, slugging and channeling behaviour can be of concern in small- scale experiments. They have been given sufficient consideration during planning of experimentation. In this study initial ratio of bed diameter to effective particle diameter was 18. It was mentioned that if this ratio is greater than 16 there is no effect from the walls. Therefore, wall effect was considered insignificant in the working range.

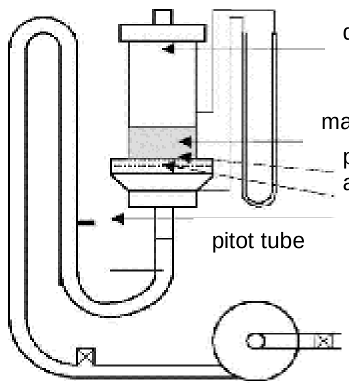

Figure 2 - Schematic of the fluidization setup

Real process exhibits a wide range of random factors, the most important of which are turbulent eddies of different scales, non-uniformity of the concentration fields and agglomeration of particles within the flow. These phenomena are easily observed with high-speed cinematography or photography under stroboscopic lighting. Airflow entering the fluidization column was varied by means of varying the incoming rate with the manual valves in the system. Differential pressure of incoming air was read from a digital manometer connected to a flow sensor of the Pitot tube through transparent vinyl tubes.

Flow rates entering the fluidizing column were calculated and average air velocity of air passing through the material was determined. Resolution of air velocity measurement was 0.05m/s, minimum fluidization velocity was 1.2 m/s, terminal velocity was 3.8 m/s. Pressure drop across the bed was measured by a U-tube manometer connected to the fluidizing column below the air perforated plate, and above the bed of samples. Bed height was measured from a scale attached to the column. The change of bed pressure drop was measured while increasing the velocity through the bed for each height. In order to determine the optimum bed height for improved fluidization bed heights of 100, 80, 60 and 40 mm were used. Measurements of pressure drop for each bed height took less than 3 min. Our experiments have been conducted in a variety of instruments differing in porosity and air flow velocity. These curves present to be quite different depending on whether we were looking at the turbulent zone of two-phase mono-dispersion flows or the zone of non-regular fluidized bed regimes.

The experimental flexi-glass fluidizing column was completed by special vertical cooling device of 50-100 mm section with the perforated plates (fig.3).

Hot granular product of 90-120?C was fed into dosing section gateway at the top of column. The dispersion granules moved through the column from the upper perforated plates to low one. The fine fraction of product transported by raising air flow was captured with the cyclone and stored in the receiver box. During the experiment all representative samples were removed from the box for dispersion analysis.

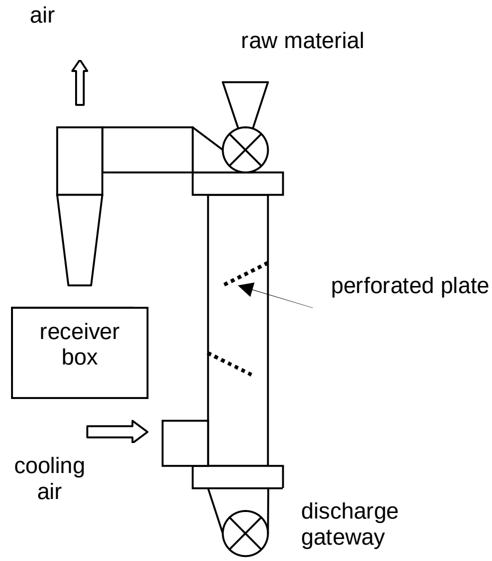

Figure 3 - Experimental cooling column with perforated plates

The existence of a multiplicity of steady states corresponding to different air flow rates, for the same feed rate and perforated plate type and slope, was observed. Results show that the design of the plate, the particle feed rate and the air velocity distribution through the holes affect the stability of the fluidized bed. The simulated results agree qualitatively well with experimental observations.

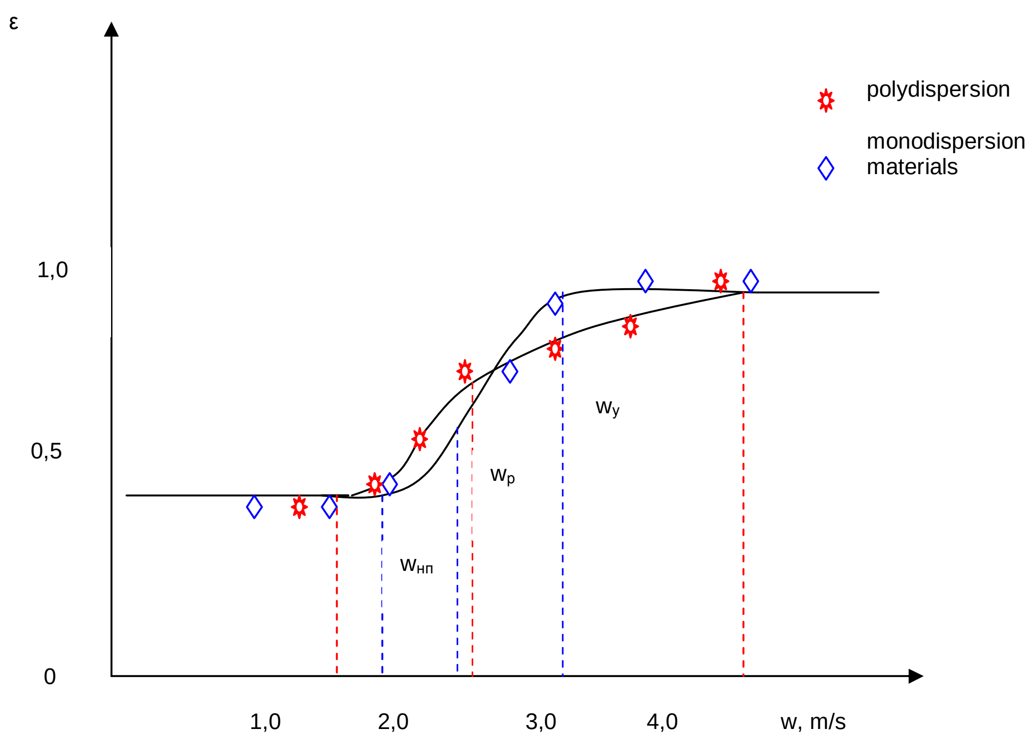

Figure 4 - Influence of air velocity on porosity

In figure 4, which shows the porosity at the different air velocity we can observe a general trend to expand the fluidized bed from initial porosity of motionless product

ε_0 = 0,45 to maximum. At the first stage, the porosity was stable until the air flow velocity did not exceed the minimum fluidized velocity. It can be seen that the character of fluidized bed expansion depends on the product species and granularity.

MATHEMATICAL MODEL FOR ENERGY RATE OPTIMIZATION

The fluidized bed volume on the perforated plates is expressed:

$$V = LBH\ ,\qquad (1)$$

where L, B, H – accordingly length, width and height of fluidized bed.

Average resident time of granules in fluidized bed can be represented by:

$$t = \frac{\rho LBH(1-\varepsilon)}{G}\ ,\qquad (2)$$

where G – product rate, t/h, ρ – granule density, ε – porosity.

Economic function of intensification expenses may be proposed with a two-component expression:

$$F = (aV + b)/\theta \qquad (3)$$

where a - energy resource (air) cost;

V - air consumption for fluidization;

b -production component without air cost;

θ - process productivity.

$$\theta \approx (P)^{0,25} \qquad (4)$$

Air flow specific power is defined as:

$$P = V\Delta p\ ,\qquad (5)$$

where *V* – rate, *Δp* – aerodynamic resistance of fluidized bed or

$$P = wLB\varepsilon\Delta p \qquad (6)$$

After the assessment the target economic function results in:

$$F = aV^{0,75} + bV^{-0,25} \qquad (7)$$

which can be transformed to:

$$\frac{dF}{dV} = 0{,}75aV^{-0,25} - 0{,}25bV^{-1,25} \qquad (8)$$

The usual optimization procedure under condition *dF/dV* = 0 or *dF/dw* = 0 gives the relation:

$$V_{opt} = \frac{b}{3a} \qquad (9)$$

or more detalized:

$$w_{opt} = \frac{b}{3aLB\varepsilon} \qquad (10)$$

This result clearly demonstrates that increasing air velocity or/and its production cost for fluidized bed process intensification as well as porosity becomes too expensive as some economic limit has been reached. Consequently, it will be reasonable to apply the combined construction with perforated supporting plates for improving economic technological parameters according to condition $w_0 \le \dfrac{b}{3aLB\varepsilon}$.

SUMMARY

- The solid particles do not reach the thermal equilibrium due to relatively short residence time in cooler. The investigation was devoted to the problem of supporting granules in fluidized bed by the minimum air rate. One of the most workable decisions is to use the special devices (perforated plates) to support fluidized bed and increase the average resident time.
- There is a multiplicity of steady states corresponding to different air flow rates for the same feed rate and perforated plate type and slope. The results show that the design of the plate, the particle feed rate and the air velocity distribution through the holes affect the stability of the fluidized bed. The simulated results agree qualitatively well with experimental observations.
- The necessary regime parameters according to heat-exchange theory do not describe in a satisfactory way the constructive features for the saving energy solution. The investigations clearly demonstrate that increasing air velocity or/and its production cost for fluidized bed process intensification as well as porosity becomes too expansive as some economic limit has been reached. Consequently, it will be reasonable to apply the combined construction with perforated supporting plates for improving economic technological parameters according to the definite conditions.
- The considerations concerning the realization of simple, inexpensive, but nevertheless effective equipment with combined fluidized bed and perforated plates system is the perspective research and a developed way.

REFERENCES

1. Кононов А.В., Стерлин В.В., Евдокимова Л.И. Основы технологии комплексных удобрений. – М.: Химия, 1988.- 320 с.
2. Юхименко М.П., Вакал С.В., Кононенко М.П., Філонов А.П. Апарати завислого шару. Теоретичні основи і розрахунок. – Суми: Собор, 2003. – 304 с.
3. Расчёты кипящего слоя: Справочник / Под ред. А.П. Мухлёнова, Б.С. Сажина, В.Ф.Фролова. – Л.: Химия, 1986. – 352 с.
4. Тодес О.М., Цитович О.Б. Аппараты с кипящим зернистым слоем. – Л.: Химия, 1981. – 296с.
5. Liu, Y.; Leong, K.C. Numerical modeling of combined heat and mass transfer in theadsorbent bed of a zeolite/water cooling system. Applied Thermal Engineering 2004, 24, pp.2359-2374.
6. Linnhoff, B. User Guide on Process Integration for the Efficient Use of Energy; TheInstitution of Chemical Engineers: Rugby, UK, 1994.

Артюхова Н.О. РАЦІОНАЛЬНЕ ВИКОРИСТАННЯ ЕНЕРГІЇ В ПРОЦЕСАХ ОХОЛОДЖЕННЯ ГРАНУЛЬОВАНИХ ФОСФАТНИХ ДОБРИВ

В статті досліджуються багатоступеневі протитічні поличні охолоджувачі гранульованих фосфатних добрив з метою підвищення якості продукту та зниження енерговитрат. Теоретично визначено найбільш економічні режими тепломасообміну при різніх співвідношеннях витрат взаємодіючих потоків. Впровадження поличних апаратів з киплячим шаром дозволяє збільшити час контакту з охолоджуючим агентом, стабілізувати взаємодію газового потоку з дисперсними частинками продукту і вирішити питання енергозбереження.

Ключові слова: *добрива, багатоступеневий охолоджувач, масообмін, дисперсні частинки, енергозбереження, теплообмінне обладнання.*

Артюхова Н.А. РАЦИОНАЛЬНОЕ ИСПОЛЬЗОВАНИЕ ЭНЕРГИИ В ПРОЦЕССАХ ОХЛАЖДЕНИЯ ГРАНУЛИРОВАННЫХ ФОСФАТНЫХ УДОБРЕНИЙ

В статье исследуются многоступенчатые противоточные полочные охладители гранулированных фосфатных удобрений с целью повышения качества продукта и снижения энергозатрат. Теоретически определены наиболее экономичные режимы тепломассообмена при различных соотношениях расходов взаимодействующих потоков. Внедрение полочных аппаратов с кипящим слоем позволяет увеличить время контакта с охлаждающим агентом, стабилизировать взаимодействие газового потока с дисперсными частицами продукта и решить вопросы энергосбережения.

Ключевые слова: *удобрения, многоуровневый охладитель, массообмен, дисперсные частицы, энергосбережение, теплообменное оборудование.*

Стаття поступила в редакцію: 14.09.2013р.
Рецензент: д.т.н., професор Якуба О.Р.

УДК 662.8: 62 - 662

ДОСЛІДЖЕННЯ КОНСТРУКЦІЙ ТА РОБОЧИХ ОРГАНІВ ЗАСОБІВ ДЛЯ УЩІЛЬНЕННЯ РОСЛИННИХ МАТЕРІАЛІВ

С. П. Соколік, асистент, Сумський національний аграрний університет

В роботі проведено огляд та аналіз досліджень конструкцій засобів для ущільнення рослинних матеріалів. Визначено переваги та недоліки основних типів робочих органів пресуючих пристроїв. Визначено найбільш перспективний засіб для виготовлення паливних брикетів.

Ключові слова*: преси, гранули, паливні брикети.*

Постановка задачі. Сучасна енергетика базується на використанні не поновлюваного викопного палива – вугіллі, нафті і газі, а також ядерній енергії та гідроенергії, що веде до прогресуючої деградації оточуючого середовища. Тому в останній час зріс інтерес до поновлюваних джерел енергії, зокрема енергії біомаси. Вадою використання рослинних матеріалів як палива є їх низька енергетична щільність. Тому використовувати відходи виробництва АПК в якості палива без спеціальної підготовки не ефективно. Для спалювання рослинних матеріалів контролюємим способом одним з найбільш перспективних напрямків є брикетування. Це підтверджують численні лабораторні дослідження процесу брикетування паливних матеріалів.

Мета роботи: провести огляд та аналіз досліджень конструкцій засобів для ущільнення рослинних матеріалів, визначити найбільш перспективний засіб для виготовлення паливних брикетів.

Аналіз робочих органів пресуючих пристроїв створених в Україні та за її межами дозволяє виділити такі основні їх типи: транспортерні, штемпельні та вальцеві робочі органи, матричні преси, преси ударної, вібраційної дії та інші.

Транспортерний робочий орган преса досліджував Голяновський А.В. [1] Енергоємність процесу пресування рослинних матеріалів ним складає 0,375 кДж.год/т, що в 2...3 рази нижче, ніж найбільш поширеним пресом з поршневим робочим органом.

Захоплююча здатність гладких стрічок обмежується кутом їх розведення 2a = 30°, а для ступінчастих - 45°. Продуктивність такого робочого органу достатньо велика, оскільки швидкість транспортерних стрічок можна доводити до 1 м/с. Проте застосування їх в пресуванні без зв'язування обмежено, оскільки щільність одержуваних пресувань не перевищує 200 кг/м^3.

Класифікація робочих органів приведена на рис. 1

Штемпельні преси досліджені найповніше. У класифікації Особова В.І. [2] вони розділяються по конструкції камери пресування на преси із закритою і відкритою камерами.

Дослідженням штемпельних пресів присвячені роботи С.А. Алфьорова [3], І.А. Долгова [4],