INTEGRATED APPARATUS FOR THE GRANULAR MATERIAL THERMAL TREATMENT

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Abstract

Integrated thermal apparatus represents an advanced technology focused on low granular materials thermal treatment. ITA technology is based on compact, vertical, dynamic thin layer principals. Processes in the layer are executed in the cross flow. Advantage of the vertical arrangement is the possibility to influence layer permeability. Permeable layer enables significantly increase furnace performance and product quality. Furnace research was based on physical a mathematical modeling. Process verification was executed on the experimental laboratory and pilot furnaces. Co temporally research is focused on caustic magnesia production. Achieved results confirmed high potential of ITA technology for low granular materials thermal processing and for preheating and cooling processes.

Keywords: integrated thermal apparatus, process, thermal treatment

Introduction:

Integrated thermal apparatus (ITA) is a unique advanced technology of raw materials thermal treatment based on the principle of cross-flow of gas medium through dynamic thin layer of granular materials. The principle of a dynamic thin layer is based on gravity granular material flow which comes in contact with a gas or liquid medium by volume or surface. The equipment based on this principle can be used for the technological purposes (heating, drying, calcination, sintering, etc.), energy purposes (lumpy material burning) and ecology purposes (capture of solid flue dust, waste combustion, capturing of air pollutants, reusable water neutralization).

The principle of a dynamic thin layer is based on material flow gravity in the layer. Thermal treatment is carried out by cross-flow gas or liquid medium through a layer. A major advantage of the solution is that all of the grains in the layer come directly in contact with a working fluid and thus ensuring a great intensity of the process. The devices based on the ITA technology are in comparison with conventional devices several times smaller: e.g. in comparison with the dimensions of the rotary furnace, the ITA dimensions are up to 10 times smaller. Used principle permits to minimize the overall energy consumption in the process of the border near the optimum technology. At many ITA applications the energy savings can be 50 % higher. The ITA technology is suitable for granular materials thermal treatment, drying, heating, sintering, calcination, cooling, thermal and chemical conversion etc. The technology can also be used for the processing of gas or liquid media, or flue gas deducting and desulphurization. More than 100 thermal apparatus based on the market research results, are operated in Slovakia. In the future they can be replaced with the technology.

1. Integrated thermal apparatus (ITA)

ITA equipment for the granular materials thermal processing operates on the principle of the thin compact layer (Fig. 1). In relation to the existing technologies the ITA supplements, extends and replaces these technologies. Thereby a spectrum of the processable materials is expanded and quality and efficiency of processing is increased. One of the significant benefits is also environmental benefit consisting of a smaller environmental burden, respectively the direct use of thin layer for the environmental equipment solving.

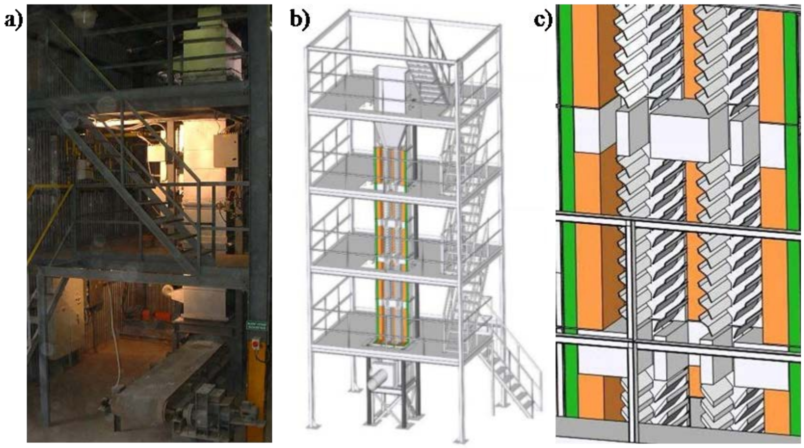

Fig. 1 Integrated thermal apparatus a) semi-operational plant b) scheme c) details

1.1 Principle and characteristics

Contrary to conventional layers, a thickness of a thin layer usually does not exceed 25 cm while the fine-grained and coarse-grained materials are considered. The material motion is vertical and a gas motion is transverse (Fig. 2).

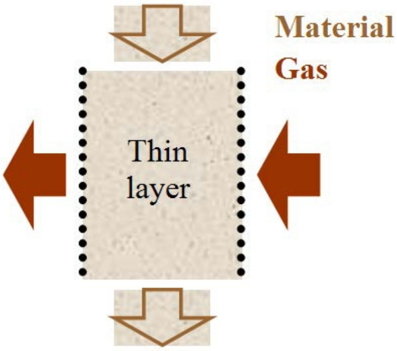

Fig. 2 Principle of movement in a thin layer

The layer is created by the system of lamellas whose slope is minimally in the size of the material angle of repose. The lamellas are alternately arranged. The gap between the lamellas can be more or less equal to zero. So we get specific layer configuration (Fig. 3).

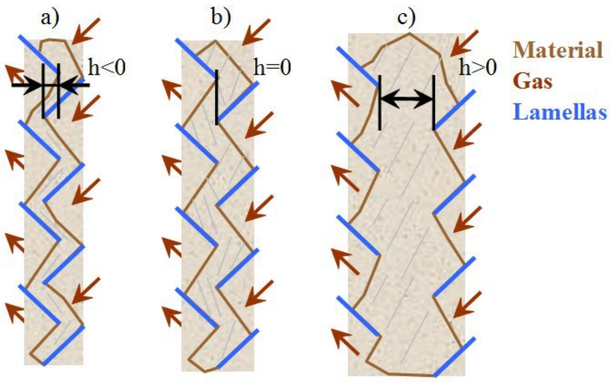

Fig. 3 The shape of the layer thickness a) h<0; b) h=0; c) h>0

1.2 Mathematical model

Model represents aggregate decomposed on zones which have equal parameters, for example, equal fuel input, or layer thickness. Each zone is decomposed on layers which consist from elements (Fig. 4). Material and thermal balance is executed for each element.

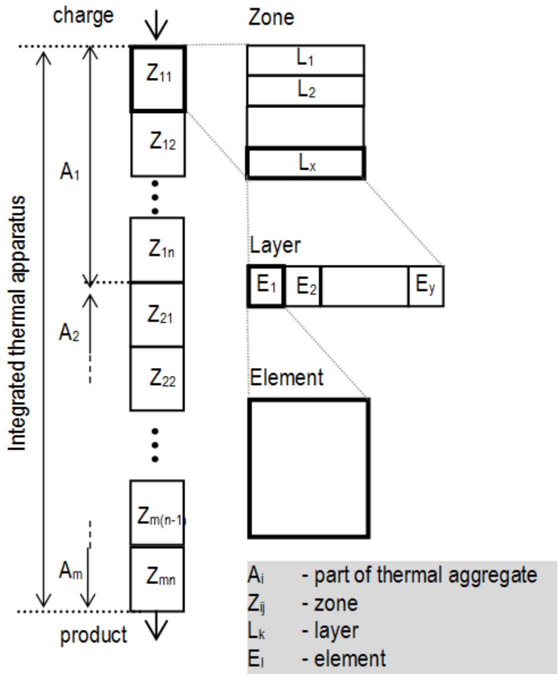

Fig. 4 Decomposition of aggregate

Processes of heating, drying, combustion, cooling and condensation and calcinations are regarded for element of the model. Material and heat balance is preserved for each process.

Mass balance for the element:

- material:

  m_{mI} - m_{er} = m_{mO} [kg.s^{-1}]

- gas:

  m_{gI} + m_{er} = m_{gO} [kg.s^{-1}]

where m_{mI} , m_{gI} is mass of the input (materials and gaseous); m_{er} is mass transferred between material and gas; m_{mO}, m_{gO} is mass of the material and gas output.

Heat balance for the element:

- material:

  $Q_{mI} + Q_t - Q_{er} = Q_{mO}$ [W]

- gas:

  $Q_{gI} - Q_t + Q_{gc} + Q_{mer} - Q_{hl} = Q_{gO}$ [W] where Q_{mI},Q_{gI} is the physical heat of the material and gas input; Q_t is heat transferred between gas and material; Q_{gc} is the heat generated by gas combustion; Q_{er} is the heat of endo or exothermic reactions; Q_{mer} is the physical heat of reaction products; Q_{mO},Q_{gO} is the output material and gas physical heat; Q_{hl} represents the element surrounding heat losses.

1.3 Physical model

Elementary physical model (Fig. 5) was made of plexiglass, it was mutually transparent and one part of the model was flexible, which allows us to set any layer thickness of granular material.

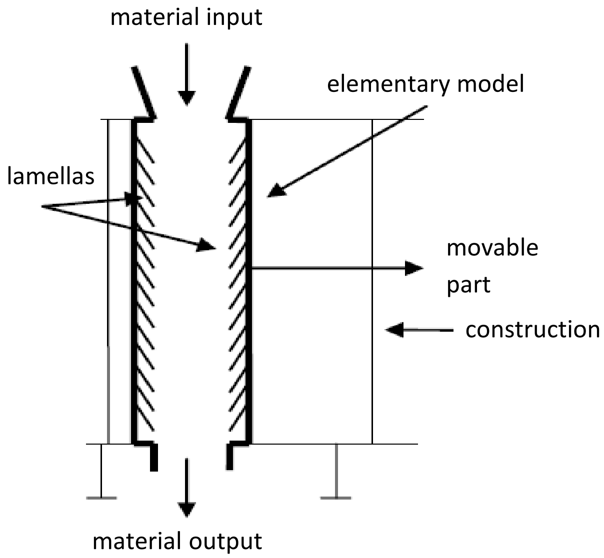

Fig. 5 Elementary model

On this elementary model the flow of material has been experimentally verified at various thicknesses of granular material and various different inclinations lamellae. To define the optimum thickness there was created simplified model in order to determine the resistance of the layer depending on its thickness.

The experiments performed on the elementary model consisted in material flow simulations at different inclinations and positions lamellae determining the shape of a thin layer in the apparatus. A shape of the layer has to be chosen in order to provide equal vertical and lateral movement of the material gas layer. Dependence of the minimum thickness and inclination of lamellae on the material granularity and its moisture content was also found. It was experimentally detected that the minimum thickness must be 3 times greater than the diameter of the largest grain of the material to avoid material vaulting in the apparatus.

2. Results:

The result of physical modelling on elementary model was to verify continuous piston flow of granular material, to refine the essential parameters for the design of laboratory model. For the lamellae inclination, an angle of 50° was designed; the layer thickness of 10 cm based on the experiments for the required resistance and pressure loss in the apparatus was determined.

2.1 The laboratory physical model

The aim of the experiments on the laboratory model (Fig. 6) was validation of the knowledge from the elementary model regarding piston material flow in the apparatus, technical design of material input and output in the apparatus, burner proposal and its location. The partial thermodynamic processes have been verified.

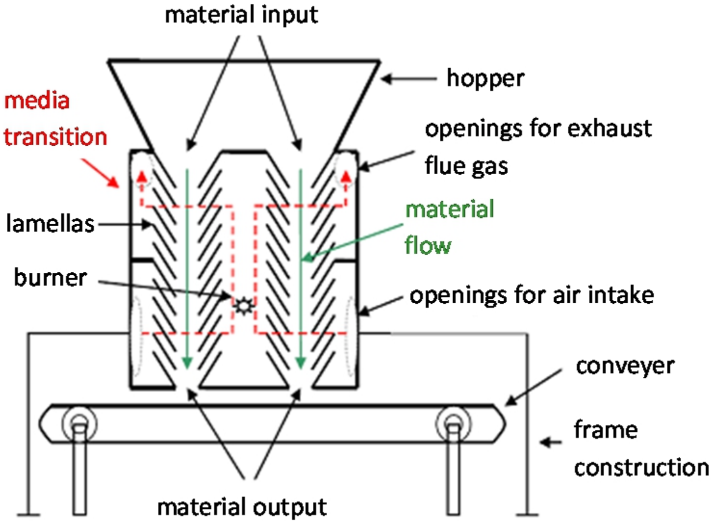

Fig. 6 Laboratory model

The continuous material flow was provided by continuous material refilling into the model hopper, and at the same time has been withdrawn from the model by conveyors. The flow of granular material layer has been visually observed through glass viewing windows in a longer period of time (2 hours). During the experiment there was monitored the change in the pattern layer of the flow, depending on the speed of the conveyor belt.

2.2 Proposal for a pilot integrated thermal aggregate - DolomITA

For a verification of the mathematical model there was designed a semi-operational equipment for magnesite caustification 900 kg/h with an average granularity of 2 mm based on the validation results of the experimental facilities and mathematical simulations.

Semi-operational equipment (Fig. 7) is composed from six segments: hopper, conveyor belt and fan at the inlet air into the aggregate, flue gas fan, four burners, cyclone, flue gas analyzer and the number of thermocouples.

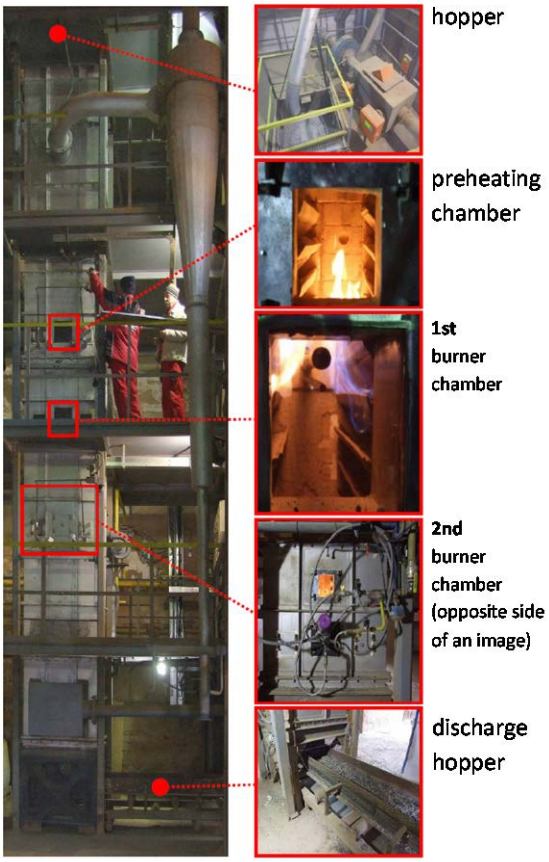

Fig. 7 Semi-operational equipment of ITA

Based on the ITA technology parameters verification performed on the pilot technological line, the significant reduction of operational costs and the reduction of natural gas consumption by approx. 60 %, energy consumption by approx. 45 % and raw materials by approx. 25 %. Have been achieved.

2.3 The pilot operation

The experiment was focused on the verification of the burning caustic magnesite quality and also validation of the apparatus parameters. During the pilot operation there was confirmed the correct setting for the entire system, especially apparatus parameters which are suitable for high-quality burning of caustic magnesite. As an input material there was used talc-magnesite raw material of the size of 3 - 10 mm from the Mútnik deposit. The samples were collected separately at the exit of material from the conveyor belt from each chamber of the apparatus (right and left chamber). Subsequently, they were submitted to chemical analysis (content of SiO_2, Fe_2O_3, Al_2O_3, CaO), loss annealing and the content of magnetic and nonmagnetic proportion at a magnetic field intensity of 0,1 T.

Individual values detected in the analysis are presented in Tab. 1, 2, 3, 4.

Table 1 The combustion loss values depending on the time

Time of sampling (hours)	Page	Loss on ignition (%)
17:00	L	14,64
	P	8,95
21:30	L	0,31
	P	0,10
23:30	L	22,93
	P	8,73
02:45	L	9,83
	P	0,03
07:45	L	2,40
	P	0,66

On 25.08.2010 at 09:00 am there happened the apparatus shutdown when the last sample was collected and analyzed in the chemical laboratory of SMZ, a.s. Jelsava, which was submitted to sieve analysis. The achieved individual fractions with the following results of the loss on ignition are presented in the following table (Table 2).

Table 2 The values of combustion loss, depending on the grain size classes

Grain size class	Loss on ignition
The entire range	1,38
> 6	1,00
4 – 6	0,91

2 – 4	1,48
0,5 – 2	1,73

Table 3 Chemical composition of the input material and the end product (caustic magnesite)

Chemical	**input material**	**caustic magnesia**
SiO_2	15,51 %	6,856 %
Fe_2O_3	2,602 %	5,598 %
Al_2O_3	0,256 %	6,460 %
CaO	1,436 %	5,487 %
Loss by annealing	45,690 %	1,380 %

The end product (caustic magnesite) was by magnetic separation in magnetic field intensity of 0.1 T divided into magnetic and non-magnetic portion having the following chemical composition (Tab. 4).

Table 4 Chemical composition of magnetic and nonmagnetic proportion of caustic magnesite

Chemical	**magnetic**	**nonmagnetic**
SiO2	4.842 %	14.680 %
Fe2O3	6.037 %	5.057 %
Al2O3	1.193 %	74.500 %
CaO	2.012 %	6.886 %
Loss by annealing	1.150 %	4.110 %

3. Discussion:

The layer thickness depends on the maximum size of treated grain and rheological properties of the material. The minimal thickness should not be less than three times the maximum grain size. In terms of rheological properties, a flowability of the material is required It is associated with a formation of arches and material flow stop. For dry materials, this parameter is not limiting. For wet materials the parameter depends on grain size and a flowability decreases with decreasing the average of grain. For wet materials (grain 0 - 4 mm) the minimal thickness is around 9 cm (experimentally determined). At lower speed, the motion of layer is piston - approx. up to 0,5 m/min, the larger speed generates a mutual mixing of grains.

Conclusion:

The integrated thermal apparatus represents conceptually new technology of material thermal treatment in thin dynamic layer. Advantages of thin layer are following:

- conceptual - zones where conventional methods are not applicable, respectively their use is inefficient,
- better parameters - better material or energy efficiency,
- performance - devices have a higher power density and are often 5 - 10 times smaller than conventional (large exchange area as a result of direct contact of grains with the gaseous medium, better transfer parameters),
- operational - can be reduced, respectively eliminated operational problems of the conventional devices (production of channels, dead spaces and sticks),
- better control of the course of thermal and concentration fields - multi-zone character.

In comparison with the used technologies ITA is more effective. Developed mathematical model of the processes occurring in a material thin layer was used to design integrated thermal apparatus. Model parameters were performed on laboratory and semi-operational equipments. The model has been used to support the design. Results of experiments on laboratory model have confirmed the correctness of the aggregate parameters model design (lamellae inclination, thickness layer, material input and output) for rheological processes, as well as the right was the burner proposal.

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