DOI 10.1007/s10556-020-00814-8
Chemical and Petroleum Engineering, Vol. 56, Nos. 7-8, November, 2020 (Russian Original Nos. 7-8, July–August, 2020)

CLASSIFICATION OF CONVECTIVE DRUM DRYERS (SURVEY OF PATENTS)

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UDC 66.047.57:66.047.4/.5(048.83)

A classification of convective drum dryers of bulk materials used in chemical and food enterprises as well as enterprises that work with construction materials is proposed. A critical survey of the most characteristic designs of convective drum dryers developed by designers and inventors from the leading countries of the world is performed.

Keywords: bulk materials, drum dryer, classification, design

Drum dryers are the among the most efficient and productive types of dryer equipment intended for processing bulk materials in the chemical and food enterprises as well as in enterprises that work with construction materials [1–3]. Drum dryers are characterized by simplicity of design, universality, high rate of mixing of material being dried, and reliability of operation, though they are distinguished by elevated consumption of energy (chiefly in the rotation of the drum) as well as in dust formation in the course of drying of brittle materials.

A number of different methods of drying bulk materials are implemented in drum dryers, for example, with the use of a vacuum (Patents No. RU2120589C1, No. RU45018U1, and No. UA95451C2); radiation heat exchange (Inventor's Certificate No. SU901774A1, Patent No. RU10448U1, and Claim No. WO2012/140305A1); induction heating (Patents No. RU2374580C1 and No. RU15622U1, along with Claims No. WO0107850A1 and No. WO2008/113338A2) [4]; contact heating (for example, with the use of indirect heating steam or electric heating elements; Patents No. US3852892A and No. 6415527B1, and No. CN107462031A, Claims No. WO98/02700A1, No. WO99/54674A1, and No. US2006242855A1). However, of all drum dryers, convective dryers are the most in demand.

Through an analysis of the different designs of convective drum dryers we are led to propose the following classification of these types of dryers (Fig. 1).

By type of heat-transfer agent (drying agent), we distinguish drum dryers with the use of heated air, flue gases, and mixtures of flue gases and free (cold) air [1, 3].

By relative direction of travel of the heat-transfer agent and material being dried, drum dryers are divided into those that function with parallel-current flow and counterflow, and in compound regimes.

Parallel-current flow is used in the case of high initial humidity and/or low thermal stability of the material being dried, while counterflow is used where it is necessary to obtain maximally dehydrated product and/or with a level of high thermal stability of the material being dried [1].

In dryers with two sections of compound flow of the drying agent (along the length of the drum) the direction of travel of the heat-exchange agent in each section may be varied, which makes it possible to regulate the intensity of the drying process in general (Patents No. RU2159915C1 and No. RU2367864C1).

By type of internal nozzle of drum, we distinguish between dryers with ascending impeller, sectional, distributive, and transfer nozzles along with compound nozzles. The type of nozzle employed depends on the dimensions of the particles and the properties of the material being dried.

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Translated from Khimicheskoe i Neftegazovoe Mashinostroenie, Vol. 56, No. 7, pp. 43–48, July, 2020.

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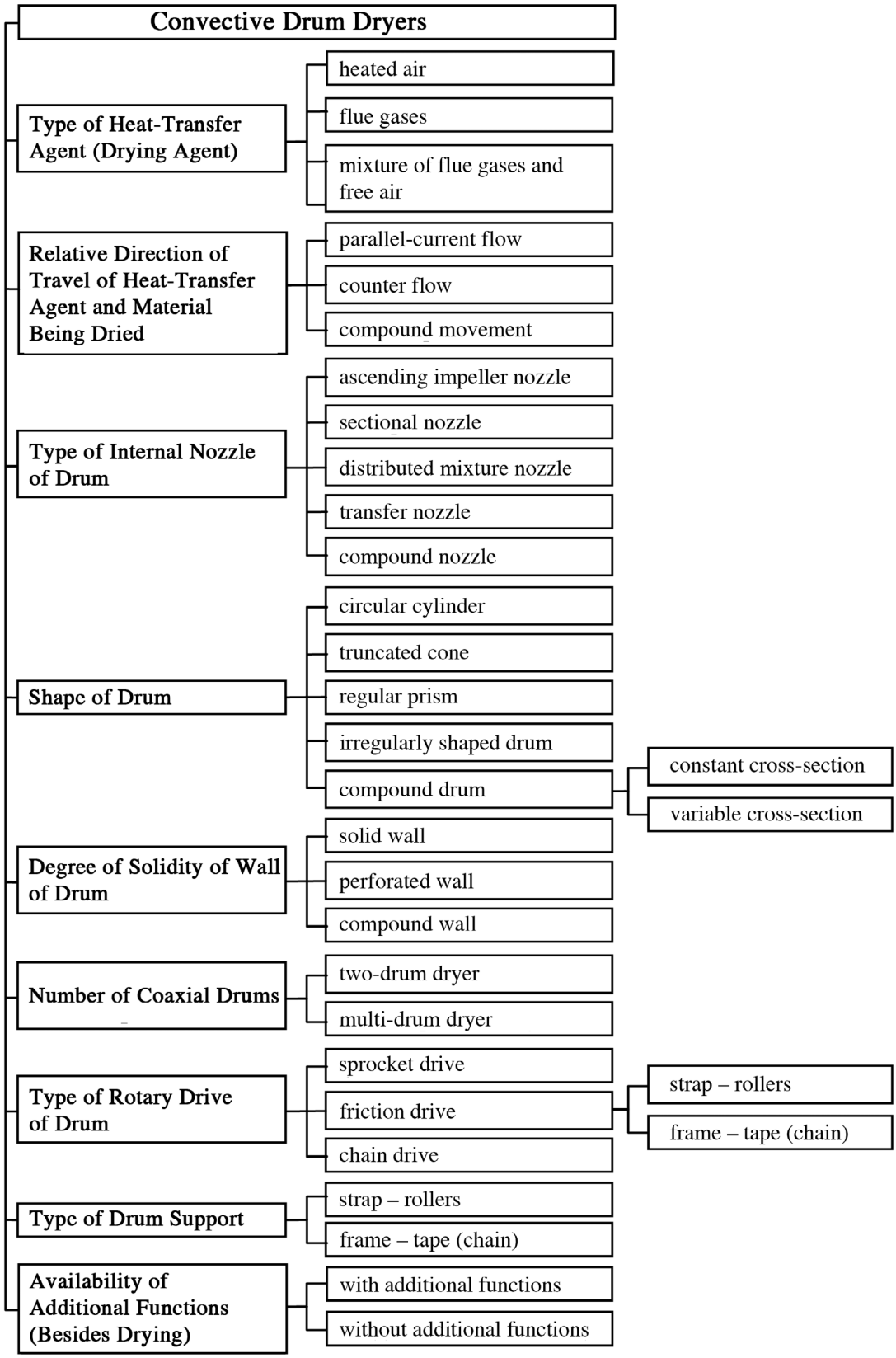

Fig. 1. Classification of convective drum dryers.

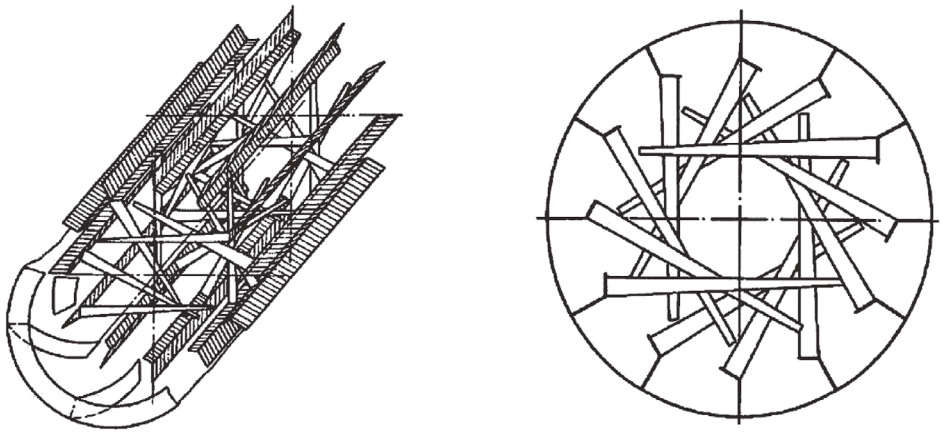

Fig. 2. Overall view and cross-section of drum of dryer drum (Inventor's Certificate SU1341472A1).

An ascending impeller nozzle is used with dry lumpy materials that are prone to adhere, while a sectional nozzle for lumpy materials that do not flow easily and are of high density; distributor nozzles are designed for fine particles that flow easily; transfer nozzles for drying powdery dusty materials; compound nozzles to process materials whose properties vary substantially in the course of drying.

In the course of drying the drying agent partially passes through the holes of an ascending impeller nozzle, which is produced in the form of a lattice as well as through a layer of material being dried present on the lattice (Patent UA126209U). However, the probability that the drying agent will land in the holes of the lattice as it travels on the lattice is extraordinarily low while the probability that the lattices will become clogged with material which is being dried (particularly material with elevated moisture content) is high.

The blades of an ascending impeller nozzle (Claim No. DE10038911A1) are fabricated in compound form and are created from several parts, which makes it possible to achieve elevated stability of the blades to abrasive wear.

Through the use of the hollow perforated elements of an ascending impeller nozzle it is possible to minimize adherence of dried material to the elements of the drum (Claim No. CN109341272A), moreover, the cavities of the elements communicate with the cavity of the two-layer wall of the dryer drum within which compressed air is fed under pressure. By means of the compressed air adhering fragments of dried material present in the drying chamber (in the cavity) of the drum are blown away.

In a drying kiln with nozzle in the form of hollow feed hoppers not only is convective, but also contact drying realized to enable circulation of the drying agent in the hoppers (Patent No. UA119355U) (when the material being dried is present in the hoppers in the course of rotation of the drum).

In an ascending impeller nozzle in the form of rotating hoppers attached to the hood of the drum and able to vary their slope relative to the hood (Patent US4307520A) by rotating and clamping the hoppers in a fixed position a required mode of spillage of material being dried from the hoppers is realized as the drum rotates.

The blades of an ascending impeller nozzle (Inventor's Certificate No. SU1341472A1) are equipped with attached cantilevered transverse plates situated in the vertical planes with the site of their attachment displaced in the vertical plane (along the length of the drum) along a helical line (Fig. 2). A substantial drawback of the process of drying is the fact that material of high moisture content is prone to adhere to the elements of the nozzle.

The radial plates of a drum with sectional nozzle (Claim No. WO2010/002092A1) are equipped with diverging baffle plates.

A drum with sectional nozzles is also described in Patent No. US4193208A.

In Claim No. DE19933246A1 a sectional nozzle is formed by a set of longitudinal tubes situated in rows in the radial direction within which heat-transfer agent is fed, moreover not only is convective, but also contact drying realized on the surface of the tubes.

In Claim No. WO9512795A1 a nozzle with extraordinarily highly developed surface assures effective mixing and heating of material being dried, though it can become clogged with moist material.

A drying drum with compound nozzle (variable standard size along the length of the drum) is described in Claim No. JPS61116279A.

Dryers with drums with nozzles that differ along the length of the drum are also proposed in Patent No. RU2364808C2 and in Claim No. US2002184787A1.

An unusual ascending screw-type nozzle in the form of a set of screw conveyors mounted uniformly around the circumference of a cylindrical drum (near its inner surface) is used in one dryer (Inventor's Certificate No. SU853322A1). Moreover, the conveyors at one end are equipped with gear wheels engaged with an arc-like fixed bottom feed (situated on the side of the lower part of the drum).

As the drum rotates the gear wheel engaged with the toothed rack sets the corresponding screw conveyor into rotation and the conveyor mixes and transports the layer of material being dried into the lower part of the drying drum.

With further rotation of the drum the particular gear wheel becomes disengaged from the toothed rack and the corresponding screw conveyor ceases rotating and then performs the function of a hoisting nozzle.

The drawback of the dryer lies in the difficulty of fabricating the device and its operation.

Besides these common nozzles, other types of nozzles are also encountered. Thus, a drying drum with longitudinal and transverse chains suspended in the drum, forming the body of a regular polyhedron, is described in Inventor's Certificate No. SU1374011A1.

A chained nozzle assures efficient mixing of material being dried, though its teeth are susceptible of becoming clogged.

A drum with teeth is proposed in Claim No. DE1940342A1. The ends of each of the chains are attached to different points on the inner surface of the drum (along its length), moreover, the length of each chain exceeds the distance between the points of attachment, so that the middle part of the chain sags when it is raised or lies on the wall of the drum when it is let down in the course of rotation of the drum.

The dryer is intended for treating especially moist and very sticky materials.

Other technological designs with nozzle in the form of chains attached to the inner surface of the drying drum have been proposed (for example, Patent No. RU20156U1, Inventor's Certificates No. SU840636A1, No. SU1211555A1, No. SU1252631A1, No. SU1374012A1, and No. SU1622740A2).

By the shape of the drum, we distinguish between dryers with drum in the form of a circular cylinder, truncated cone, or regular prism, as well as with drums of compound and irregular shape.

The construction of a dryer with cylindrical drum (separated by radial partitions into individual sections) and supply of drying agent both directly into the drum as well as into a perforated tube situated coaxially in the drum (Inventor's Certificate No. SU614301A1, Fig. 3) assures efficient mixing and drying of material which is being processed.

In Claim No. EP0365851A1, the drying drum is situated horizontally and movement of the material being dried along the drum is realized by at least one screw conveyor mounted along the length of the entire drum in the lower part of the drum.

It is possible to operate the dryer both continuously and periodically.

A similar drum of lesser diameter is mounted rigidly in a drum in the shape of a circular cylinder (Patent No. UA97001U), moreover, the inner surface of the outer drum and the outer surface of the inner drum are equipped with ascending impeller nozzles. As the drums rotate, the material being dried is poured from the nozzle

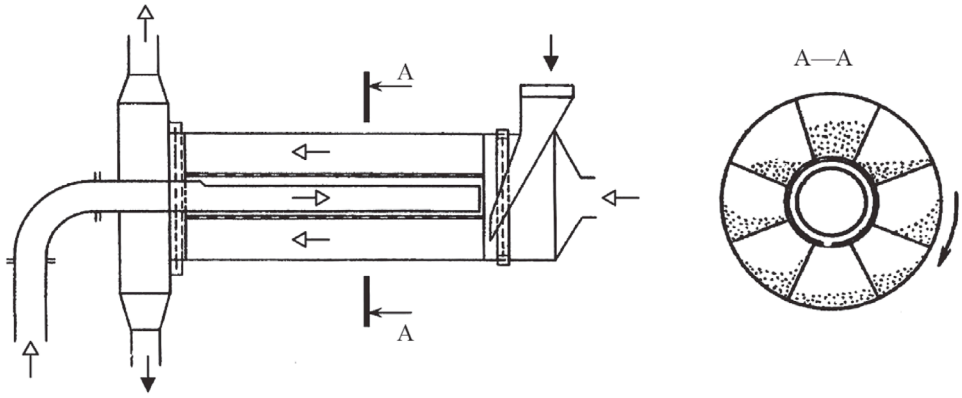

Fig. 3. Schematic diagram of dryer (Inventor's Certificate No. SU614301A1).

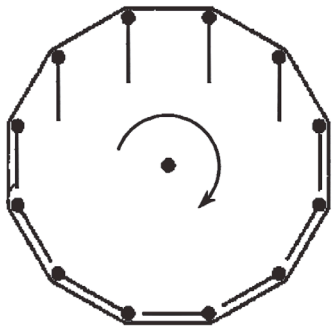

Fig. 4. Cross-section of drying drum (Claim No. JP2009092311A).

of the outer drum into the nozzle of the inner drum and from the latter again into the nozzle of the outer drum. Moreover, the material is intensively mixed though the length of time the material is in contact with the drying agent is significantly reduced which tends to reduce the intensity of the drying process.

A drying kiln with drum in the form of a regular prism (hexagon or dodecahedron) is described in Claim No. DE2119645A1. The advantages of such drums include effective mixing of material being dried and simplicity of the process of repair of the planar elements of the walls of the drum.

A dryer with drum in the form of a regular prism (decagon or dodecagon) is also described in Claim No. JP2009092311A. Moreover, each of the faces of the drum (viewed from the inside of the drum) is equipped with a plate freely attached to the longitudinal axis that rotates under the effect of the force of gravity in the upper part of the drying chamber (Fig. 4). Such a construction not only assures effective mixing of the material being dried, but also promotes self-cleaning of the drum from adhered material.

A drying kiln with blades that are hinged to the core of a screw conveyor coaxial with the drying drum is proposed in Inventor's Certificate No. SU924476A1.

A cylindrical drum with blades mounted with the ability to rotate relative to the longitudinal axes and anchored in a required position is described in Claim No. EP2679103A2. The advantage of such a design is that it makes it possible to vary the angle of inclination of the blades and, correspondingly, the nature of the movement of the material being dried in the drying chamber.

A drum of unusual design (Claim No. DE3635639A1) is produced in sectional form in the form of a bundle of irregularly shaped hoods, for example, regular hexagonal prisms tightened by straps in the form of round rings. In cross-section such a drum constitutes a cellular structure.

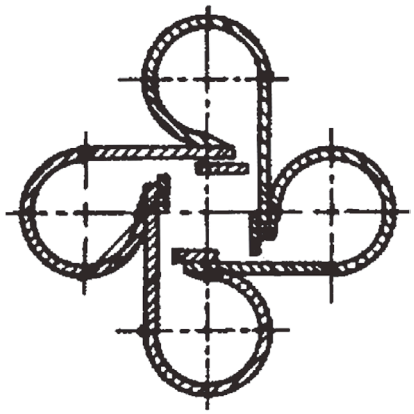

Fig. 5. Cross-section of nozzleal section of dryer drum (Inventor's Certificate No. SU775556A1).

Motion of the particles of material being dried that is nonuniform in terms of direction and speed of travel is realized in Patent No. RU2425307C2. The wall of the drum of the kiln is produced with helical corrugations.

Constructions of several different types of drums, including conical and stepwise cylindrical drums as well as compound drums, such as stepwise cylindical–conical–cylindrical drums, is described in Patent No. US1422039A. By successively increasing the diameter of the stages, the material being dried gradually disintegrates, which promotes more thorough desiccation of the material.

Patent No. RU2386092C2 proposes a design of a compound, irregularly shaped drum with cross-section of variable curvature (in the form of an ellipse or other shape along the length of the drum). With uniform rotation of the drum the dried particles travel in a complex trajectory with variable speed, making it possible to intensify the drying process.

A drawback of such a drying kiln derives from the dynamic nonequilibrium nature of the drum.

The nozzleal section of a drying drum (Inventor's Certificate No. SU77555A1) created in the form of a set of tubes with common cavity (Fig. 5) promotes effective redistribution of the material being dried on the nozzleal drying stage and more complete dessication of the material.

A drawback of this type of drum (as of most irregularly shaped and compound drums) lies in the complexity of the fabrication process.

By degree of uniformity of the wall of the drum, we distinguish between drums with solid wall, perforated wall, and compound wall.

A completely perforated drying kiln drum (Patent No. UA83969U) assures drying in a fluidized bed throughout the entire volume of the drum. However, such a design is not entirely justified, since the sense of rotation of the drum is practically lost (the material being dried is not captured by the rotating drum, but is instead present in the fluidized layer inside the drum).

A similar design is proposed in Patent No. UA107554U.

Unlike the previous designs, in Patent No. RU2051321C1 the drying agent in a drying kiln with perforated drum passes through a layer of material being dried at a speed below the initial rate of fluidization.

A dryer with perforated drum the effective cross-section of which increases in the direction of travel of the heat-transfer agent is proposed in Patent No. RU2178130C2.

Such a design of the drum assures a process of "gentle" drying of bulk material.

A dryer with annular drum produced in the form of two coaxially situated perforated truncated cones is described in Patent No. RU2244229C1. The drying agent passes through the perforation of an outer cone and then through a layer of material being dried present between the cones, subsequently passing through the perforation

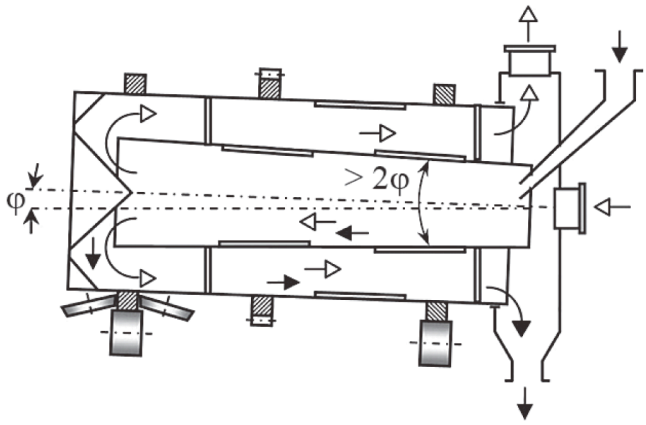

Fig. 6. Schematic diagram of dryer (Patent No. UA75171U): φ – angle of inclination of axis of outer drum to the horizontal.

of an inner cone and is eliminated from the drum through the cavity of the latter cone. Drying of the material in the drum is realized practically in a continuous layer, hence the productivity of the plant is substantially increased, though the hydraulic resistance of the drying kiln also substantially grows.

In Patent No. UA56359U the dryer drum is in the form of a truncated cone that expands in the course of the travel of the material. The compound wall of the drum is produced perforated on the initial segment and is solid along the remaining length of the drum, with the drying agent fed through the perforations of the drum. Such a structural design produces drying in two stages, initial intensive removal of moisture in the fluidized layer, with subsequent convective drying under conditions that are characteristic of classical drum drying kilns.

By number of drums situated coaxially next to each other, we distinguish between two-drum and multi-drum dryers.

In addition to drum dryer kilns with a single drum, constructions with two (and more) drums situated next to each other have also been developed. Such a structural design produces an effective increase in the length of the drying process (i.e., the path along which the material being dried travels) as well as a reduction in the overall length of the dryer.

A dryer with two coaxial cylindrical drums with transporting helical combs is proposed in Claim No. WO9119145A1.

In the dryer of Patent No. UA75171U the outer drum is in the form of a circular cylinder, and the inner drum in the form of a truncated cone (Fig. 6).

The dryers of Patents No. UA84913U, No. UA97000U, and No. UA111192U are all similar.

An unusual two-drum dryer for simultaneous processing of flows of two materials of different fractions (for example, rubble and sand in the preparation of a construction composition) is proposed in Claim No. DE235078A1.

In a multi-drum (in particular, three-drum) dryers (Patents No. CN206320992U and No. CN109253597A) loading of the raw material is performed on one side of a bundle of drums and unloading of dry product on the opposite side.

A significant reduction in the overall length of the dryer is achieved in the design of a dryer (Patent No. RU171941U1) with three coaxially situated horizontal drums in the form of truncated cones (moreover, with adjacent drums facing each other with different bases). A drawback is the increased hydraulic resistance.

A multi-drum dryer (Patent No. GB220836A) features cylindrical drums situated coaxially next to each other.

Among the drawbacks of two- and multi-drum dryers we may note the difficulties involved in the operation of these types of drums and their increased hydraulic resistance.

By type of rotation drive of the drum, we distinguish between drums with toothed gearing, friction drive, and chain drive.

The drum is usually set into rotation from the toothed gear of the drive station to the crown gear attached to the station. In Patent No. UA68880U, however, the drive gear is equipped with inner teeth and is mounted inside the drum on its end face on the side of the loading station. Such a design yields a reduction in the material consumption of the dryer, though it does not eliminate the possibility that lubricant from the drive gear could enter the material being dried.

A dryer with friction support drive rollers that are in contact with the drum straps is presented in Patents No. RU176123U1 and No. RU178453U1, and a dryer with friction driver roller in direct contact with the outer surface of the drum in Claim No. WO89/09303A1.

A dryer with chain transmission of torque to the dryer drum is proposed in Patent No. US4317291A. Here the drive chain comprises a П-shaped strap (in the form of a channel section) of the drum.

By type of support of the drum, we distinguish between drums with supports of the type strap – roller and those with supports of the type shell – tape (chain).

In most constructions of dryer drums the outer surface of the annular straps (in the form of a right annular cylinder) rests on cylindrical rollers. In addition, in stop-support stations the lateral surface (on the side of the "lower" part of the drum) of similar straps lean against conical support rollers. Moreover (Patent No. CN206670252U, No. CN106679364A, No. CN106679365A, No. UA98489U) the support devices of the dryers are produced in such a way as to enable regulation of the angle of inclination of the drum and, correspondingly, the duration of the drying process.

A drum apparatus with "exposed" support station produced in the form of a set of support rollers mounted uniformly in a circle on a cylindrical drum and able to make contact with a support element produced in the form of an annular sector, is proposed in Patent No. UA90398U.

Unlike the preceding structural design, instead of an annular sector in the drying station, a fixed thrust ring is installed in a similar construction (Patent No. RU132875U1). A drawback of the dryer is the inconvenience of the process of assembly and disassembly of the thrust ring.

In Claim No. CN108317826A the straps of the drum are produced with a round annular groove that interacts with spheres attached to the fixed axes. Moreover, each of the straps together with the corresponding spheres form stop support stations. A drawback of such a construction is that it not possible to compensate for any variation in the length of the drum that occurs under the effect of a temperature drop.

П-shaped straps in the form of a channel section (Patent No. RU15622U1) are supported by the edges of a shelf in the hollows of W-shaped rollers.

In Claim No. DE3110406A1 the dryer drum rests not on support rollers, but instead on an innozzleite chain that envelops the rollers or a tape which assures a substantial decrease in the contact stresses that arise in the drum.

In terms of the existence (or lack of existence) of additional functions, besides drying, we distinguish between dryers with additional functions and dryers without any additional functions.

A common additional function in a dryer drum is grinding of dried material. Thus, freely lying cylinders that additionally grind materials being dried, i.e., the specific technology, are situated in the sunken part of the drum (Inventor's Certificate No. SU1370400A1), thus the device represents a combined dryer – grinder.

A section with free heat-exchange nozzle-like bodies of revolution capable of heating and additional grinding of material being dried is also provided in a drum with two sections of chain-link curtain (Patent No. RU2027128C1).

A similar dryer is described in Inventor's Certificate No. SU107135A1.

The dryer drums (Claim No. WO2010/011157A1 and No. EP2397239A1) is divided along its length into sections filled with inert bodies that also tend to promote additional grinding of material being dried and contact heating of the material.

Other improvements in convective drum dryers have been proposed by inventors.

Thus, an impeller mixer that rotates in a direction opposite to that of the drum is mounted coaxially with the dryer drum to a shaft in Patent No. RU170138U1.

Mixing of material being dried as well as regulation of the length of time the material remains in the drum are achieved by the inclined mixer drum.

A mobile drum dryer plant mounted on a car trailer (Patent No. US3764258A) is preferable for drying of small quantities of moist materials right at the sites where the materials are collected, formed, or processed.

A similar mobile plant is proposed in Patent US5305533A.

A set of improved drum dryers concerns the nozzles of dryer drums that also yield an improvement in the travel and heating of material being dried.

In the present article the constructions of convective drum dryers for use in drying of bulk materials used in production plants in the chemical and food branches of industry as well as in enterprises involved in the production of different types of construction materials have been considered.

Moreover, despite the many years of experience with successful operation of traditional drum dryers, designers and inventors continue to work on improving the designs of drum dryers.

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