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Bauer

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[54] **SOLIDS-TO-SOLIDS HEAT EXCHANGE APPARATUS**

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[52] **U.S. Cl.** **165/111,** 432/110
[51] **Int. Cl.** **F28c 3/18**
[58] **Field of Search** 165/111; 432/107, 108, 432/110

[56] **References Cited**

UNITED STATES PATENTS

2,754,105	7/1956	Pistorius et al.	432/110
3,039,753	6/1962	Eketorp et al.	432/107

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[57] **ABSTRACT**

An inclined rotary kiln for direct-contact heat exchange between a coarse and a fine granular material. The coarse material travels downward through the kiln. The fine material is introduced near the lower end of the kiln and is transferred up the kiln stagewise via helical ducts in the kiln's wall. Inlets to the ducts have grates which reject the coarse material but accept the fine material. The ducts extend helically upwardly relative the kiln and rearwardly relative kiln rotation so that the fine material is discharged from the ducts up the kiln.

7 Claims, 7 Drawing Figures

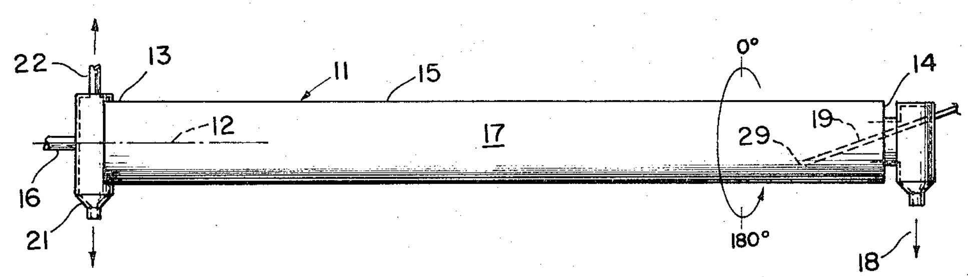
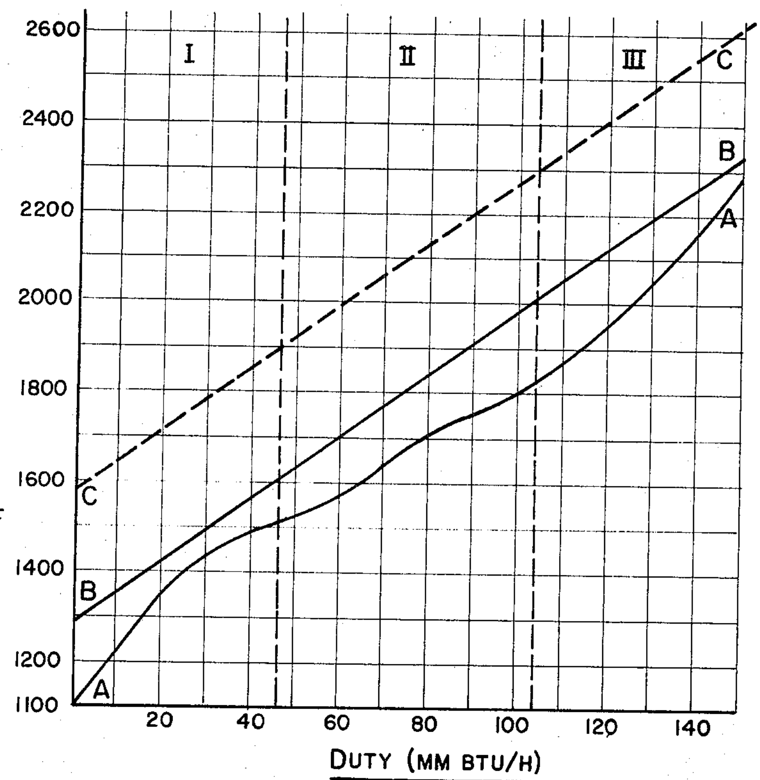


FIG. 1



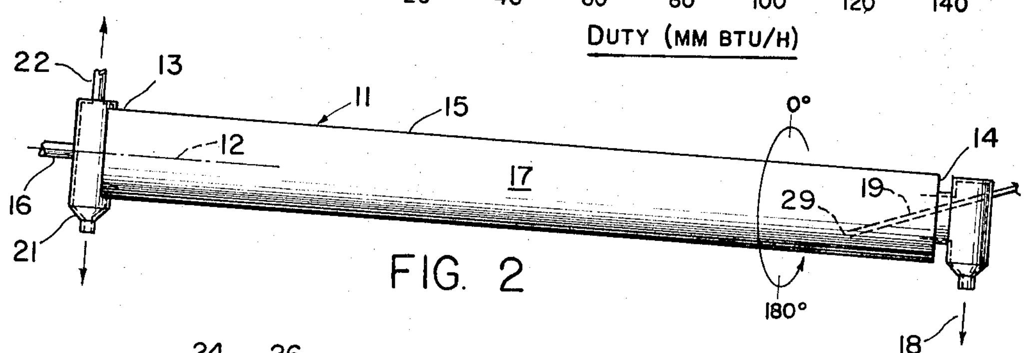


FIG. 2

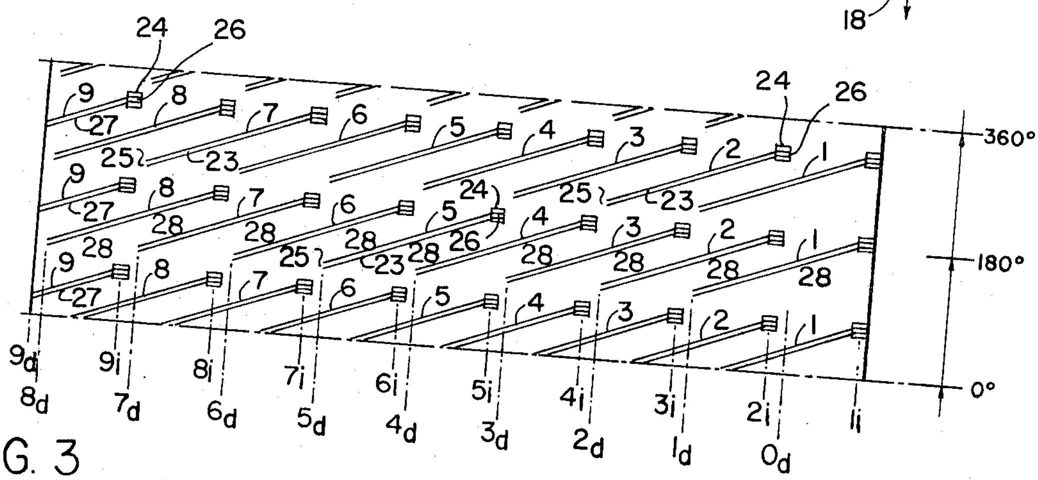


FIG. 3

FIG. 4

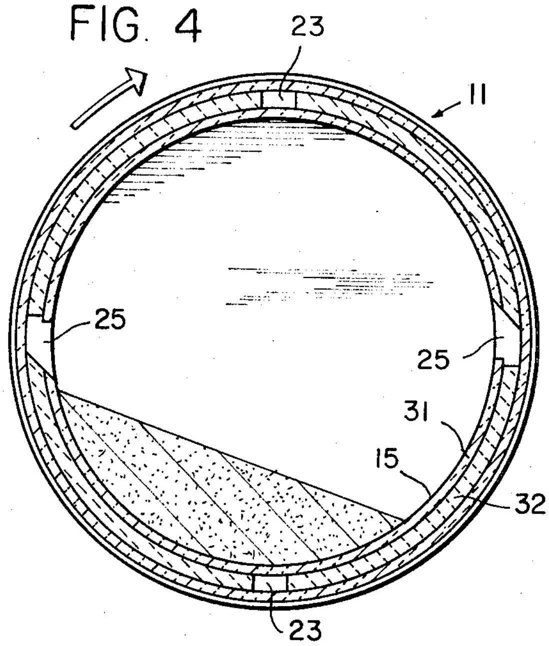
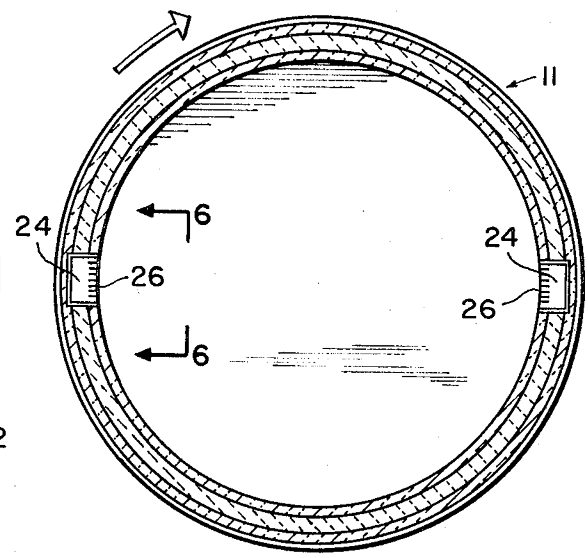


FIG. 5



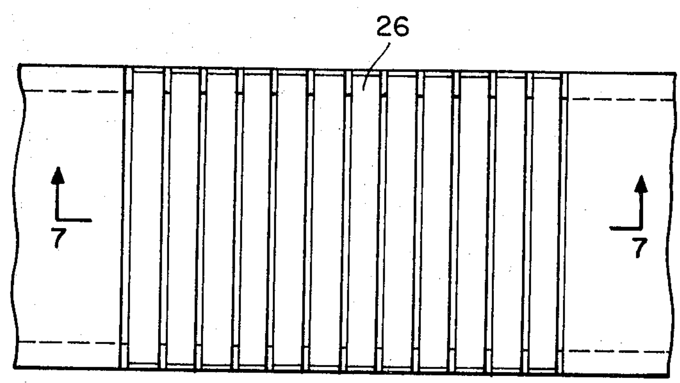


FIG. 6

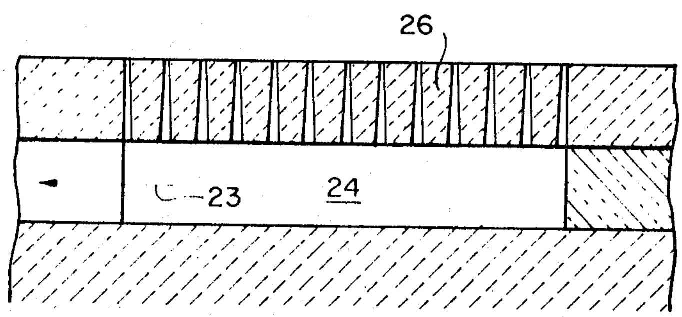


FIG. 7

SOLIDS-TO-SOLIDS HEAT EXCHANGE APPARATUS

BACKGROUND OF THE INVENTION

In many industrial operations, it is advantageous to exchange heat between hot and cold streams of granular materials having different particle size ranges. For example, in heating granular materials which may react with hot CO_2 or H_2O vapor, it is necessary to conduct heating with combustion gases having high CO/CO_2 and H_2H_2O ratios, a requirement which connotes very low thermodynamic efficiency due to poor heat radiation properties of such gases with low CO_2 and H_2O concentrations. I have recognized that it is possible to transfer heat from an inert stream of a granular material to another stream of a granular material, with the inert stream picking up its heat content from combustion gases generated by combustion performed under advantageous conditions, thereby yielding significant improvements in thermodynamic efficiency.

Prior attempts to achieve such heat exchange made use of an intermediate heat-transfer fluid. The hot stream of a granular material was cooled by the fluid stream which then was contacted with the cold stream of the other granular material. That method suffered from the following technical and economic disadvantages:

Two separate heat transfer operations were required.

Use of the intermediate heat-transfer fluid presented problems of matching duty versus temperature patterns against both hot and cold streams, with attendant change of temperature effects to avoid "temperature cross" twice. This effect and the requisite change of temperatures in two exchangers imposed a severe penalty of thermodynamic efficiency.

The heat-transfer fluid needed pressure adjustment somewhere in its cycle to achieve circulation. This pressure adjustment was difficult to achieve operating at high temperatures.

Transfer of heat to and from the intermediate fluid was not always easy. At high temperatures, for example, one could use a gaseous fluid rich in radiating components such as CO_2 and H_2O; such a fluid would absorb or remit radiant energy effectively at temperatures around red heat or higher. Below these temperature levels, or if use of CO_2, H_2O, and other good radiators was precluded by sensitivity or reactivity of the granular materials, it became necessary to seek heat transfer to and from the gaseous fluids by intimate contact and this usually resulted in expensive complications.

Another attempt to achieve such heat exchange has been to use staged tumblers. Disadvantages of the staged-tumbler approach were:

Multiple units were needed, generally three or more stages were required to simulate countercurrent action.

Means were required for particle size separations after each unit and means were necessary to convey hot streams to inlets of the next unit.

Thermodynamic inefficiency and instability of cold stream discharge also resulted.

The foregoing thermodynamic inefficiency and instability of cold stream discharge will be understood by reference to FIG. 1 which is a temperature-enthalpy diagram. Line A applies to the burden (solids being heated) and line B applies to the hot solids flowing countercurrent to the burden (assuming existence of suitable means for achieving such countercurrent exchange). Constant heat capacities are assumed in the interest of simplicity of representation; the burden undergoes two exothermic heat reactions causing the plateaus at temperature levels of 1,500° F. and 1,850° F. Temperature "pinches" occurred at abscissae of about 27 and 140 MM BTU; a temperature difference of about 50° F. is shown at the "pinch" regions (the differences in temperature will actually depend on intimacy and uniformity of contact between the solids streams, etc.).

If the same heat exchange were effected in three separate tumblers, represented by zones I, II, and III, the hot solids temperature-enthalpy plot would have to follow line C to satisfy the requirement of a minimum temperature difference of 50° F. (in this case at the outlet from each zone or tumbler). That is, line C is so located as to satisfy the above requirement.

It is seen that use of cascade tumblers (line C), as compared to use of ideal countercurrent exchange (line B), requires input of hot solids at a much higher temperature (2,630° F. v. 2,330° F.). This higher input temperature implies a significantly lower thermodynamic efficiency and fuel utilization, as well as difficulties and costs attendant to handling solids at the higher temperature. Additionally, it should be noted that because of the greater spread between curves A and C at the high temperature end, overheating of the solids becomes quite possible as a result of minor upsets or operating instability.

SUMMARY OF THE INVENTION

This disclosure solves the foregoing problems and achieves efficient direct-contact heat exchange between a coarse and a fine granular material in a particularly useful, novel, inventive and facile way. One of the granular materials travels downward through the kiln in the usual manner. The second granular material is caused to be transferred stagewise upward in the kiln opposite to the direction of flow of the first material through the kiln. By this arrangement improved thermodynamic efficiency is achieved.

A further object of this arrangement is to provide apparatus that is simple to operate, reliable and otherwise well suited to its intended purpose.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features and advantages will be seen more fully from the accompanying drawings taken with the following detailed description of a preferred embodiment. In the drawings:

FIG. 1 is an illustrative temperature-enthalpy diagram which has already been discussed.

FIG. 2 is a side elevation of a kiln embodying this invention.

FIG. 3 is a planar development of the wall of the kiln of FIG. 2.

FIG. 4 is an enlarged sectional view illustrating duct outlets in the wall of the kiln.

FIG. 5 is an enlarged sectional view of the kiln showing duct inlets in the wall of the kiln.

FIG. 6 is a view taken along line 6—6 of FIG. 5.

FIG. 7 is a sectional view taken along line 7—7 of FIG. 6.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Apparatus embodying this invention, as illustrated in the drawings include cylindrical kiln **11** mounted for inclined rotation about its cylindrical axis **12** by means not shown. Kiln **11** is inclined from the horizontal to induce downward travel of burden therein. Kiln **11** has upper end **13**, lower end **14** and wall **15**. Coarse input **16** is provided at upper end **13** for introducing the coarse granular material into chamber **17** so that it travels down kiln **11** to coarse discharge **18** via which it exits kiln **11**. Fine input **19** is provided in the vicinity of lower end **14** for introducing the fine granular material into chamber **17**. The fine material travels stagewise up kiln **11** by means which are at the core of this invention, and which will be explained further in this disclosure, so that the fine material reaches fine discharge **21** at upper end **13** for exit from kiln **11**. Vapor outlet **22** is provided to exhaust any vapor evolved.

Heat exchange between streams of granular materials implies a hot stream and a cold stream and it is contemplated that one of the streams will be inert and will be heated by conventional means (not shown here).

Rotation of kiln **11** is indicated in FIG. 2 and this rotation corresponds with the planar development of kiln wall **15** shown in FIG. 3. As seen in FIG. 3, kiln wall **15** is provided with a plurality of ducts **23** each of which has an inlet **24** and an outlet **25**. Each of the inlets **24** is provided with a grate **26** which accepts the fine material but rejects the coarse material. Ducts **23** extend from their inlets **24** helically upwardly relative kiln **11** and rearwardly relative the rotation of kiln **11** so that as kiln **11** rotates, fine material passing through ducts **23** is transferred stagewise out its outlet **25** to a position higher in kiln **11**.

Ducts **23** are parallel each to the other end, except for ducts **27** at the upper end of kiln **11**, they are of equal length. Inlets **24** are arranged in rows spaced along the length of the kiln to define zones **28** therebetween. In FIG. 3 ducts **23** are numbered from 1 to 9 and subscripts "*i*" and "*d*" represent inlets **24** and outlets **25** respectively. The position designated "Od" refers to injection point **29** of the fine material corresponding to the projection **29** of fine input **19** shown in FIG. 1. The combined burden (coarse and fine materials) travels uniformly in the direction of the slope of kiln **11**, from left to right in FIGS. 2 and 3. Movement of the fine material in helical ducts **23** is opposite to the movement of the burden in kiln **11** and is from right to left in FIGS. 2 and 3. The fine material is introduced a certain distance into the kiln from lower end **14** at Od and it travels with the burden to inlets 1i and upward through ducts 1 to outlets 1*d* from whence it reenters chamber **17** for travel with the burden down the kiln from outlet 1*d* to inlet 2i and then through ducts 2 to outlet 2*d* and then with the burden in chamber **17** from outlets 2*d* to inlets 3*i* and so on up the kiln to outlet 9d which delivers them to fine discharge **21**. It is preferred, except for ducts **9**, that each duct extends slightly less than two zones as shown in FIG. 3.

Basically grates **26** serve to isolate portions of the fine material and ducts **23** serve to transfer those portions stagewise up kiln **11**. Each grate **26** with its related duct **23** achieves separation and transfer of some of the material introduced in the vicinity of lower end **14** of kiln **11** toward upper end **13** counter to the generally downward travel of the burden induced by inclination of kiln **11**, while allowing normal travel of the material introduced at upper end **13** downward through kiln **11**. The cumulative effect of these devices **23, 26** is to achieve substantially countercurrent flow of the two streams of granular materials with the one introduced at lower end **14** of kiln **11** moving stagewise to upper end **13** thereof. The number of stagewise movements is a function of the number of devices **23, 26**; the size separating capacity of each device; the upstream "throw" of each device and the speed of rotation of kiln **11**. However, the speed of kiln **11** is usually determined by other considerations.

The devices employed to isolate and transfer one of the materials up the kiln may vary widely in construction and configuration as well as in mode of operation. For example, the device may move the fine materials up the kiln and reject the coarse materials or vice versa. The device may project into chamber **17** with features for scooping the burden, screening and delivering either the coarse or the fine material upward through a duct, or it may be buried in a brick lining or even pierce the kiln so that conveying ducts are outside the kiln. The device may be constructed of metal, refractories, etc., depending upon temperature, corrosiveness, abrasion and other factors. In essence, the device must include the following features:

Means to separate burden into coarse and fine fractions.

Means to transfer one of the fractions stagewise upward in the kiln. With respect to ducts **23** in the preferred embodiment shown in the accompanying drawings, the ducts must; by reason of their cross sections, inclination and other designed features; have greater solids carrying abilities than the screening capacity of their grates **26**. Ducts **23** form helixes wrapped about an inner layer of brick **31** and extend about 90° about the circumference of wall **15**. Ducts **23** terminate in sloped outlets **25** through inner brick layer **31** thereby permitting easy discharge of the fine material into chamber **17**. These features are seen best in FIGS. 4 and 5.

FIGS. **6** and **7** illustrate construction of a seperator grate suitable for high-temperature operations. In this case, the duct consists of a 4½"×2½" channel in a second layer of brick **32**. Grate **26** consists of hard refractory elements, 6½" long × 3¼" thick and 2½" deep, set with ⅛" to 3/16" spacers over about a 9 inch length of the duct. It is generally preferable to use tapered grate elements to form tapered slots so as to facilitate downward flow of fine materials.

The following examples are representative of processes to which this invention is applicable:

EXAMPLE 1

Taconite fines (80 percent through 325 mesh) containing 8 percent moisture may be heated and dried by contact with a countercurrently moving stream of preheated spherical balls, wherein the water vapor generated by such countercurrent contact may be treated to recover elutriated fines, such as by a water scrub. On the other hand, if such fines are heated conventionally by being subjected to hot gases, problems arise with respect to the volumetric flow of gas, the carryover of fines, and the cost of recovery of the elutriated fines.

EXAMPLE 2

Heat exchange and coking pellets, containing binders such as resin or tar, can be obtained by countercurrent movement of the pellets against a preheated powder such as sand or ground ore, wherein the dilution of cracked gases and partial vaporization of the binder is avoided because it is unnecessary to contact the coking pellets with heating gases.

EXAMPLE 3

The heat treatment of friable or abradable solids can be advantageously conducted in a bed of fines which provide a support and "cushion" against abrasive and disintegrating effects.

EXAMPLE 4

Solids which are sensitive to CO_2 and/or H_2O can be heated in a thermodynamically efficient manner by processing such solids in a countercurrently moving stream of heated inert solids as described above.

It will be apparent to those skilled in heat transfer and/or handling of granular materials that wide deviations may be made from the preferred embodiment set forth in this disclosure without departing from the main theme of invention set forth in the following claims.

I claim:

1. Apparatus for direct-contact heat exchange between a coarse and a fine granular material comprising:

an inclined cylindrical kiln mounted for and having means for rotation about its cylindrical axis,
the kiln defining a chamber as well as an upper end and a lower end,
the kiln provided at its upper end with a first input means for introducing a first one of the granular materials and provided at its lower end with a first discharge means for removing the first material,
the kiln provided near its lower end with a second input means for introducing a second one of the granular materials and provided at its upper end with a second discharge means for removing the second material,
the kiln having a cylindrical wall with a plurality of inlet openings each having selector means to receive a portion of the second granular material from the chamber but to reject the first granular material,
the inlet openings arranged in rows spaced along the length of the kiln to define zones therebetween,
a plurality of the inlet openings in each of the rows and the inlet openings of each row spaced about the circumference of the wall,
the wall provided with a duct for each of the inlet openings which duct is in flow communication with its related inlet opening and which duct extends helically upwardly relative the kiln and rearwardly relative the rotation and which duct is in flow communication with the chamber via an outlet opening provided in the wall so as to transfer the portion of the second granular material stagewise to a position further removed from the lower end than the inlet opening for further travel down the kiln with the first granular material,
a major portion of the ducts arranged to transfer a portion of the second granular material stagewise at least one of the zones up the kiln.

2. Apparatus for direct-contact heat exchange between a coarse and fine granular material and comprising:

an inclined cylindrical kiln mounted for and having means for rotation about its cylindrical axis,
the kiln defining a chamber as well as an upper end and a lower end,
the kiln provided at its upper end with a first input means for introducing a first one of the granular materials and provided at its lower end with a first discharge means for removing the first material,
the kiln provided near its lower end with a second input means for introducing a second one of the granular materials and provided at its upper end with a second discharge means for removing the second material,
the kiln having a cylindrical wall with a plurality of inlet openings each having selector means to receive a portion of the second granular material from the chamber but to reject the first granular material,
the inlet openings arranged in rows spaced along the length of the kiln to define zones therebetween,
a plurality of the inlet openings in each of the rows and the inlet openings of each row spaced about the circumference of the wall,
the wall provided with a duct for each of the inlet openings which duct is in flow communication with its related inlet opening and which duct extends helically upwardly relative the kiln and rearwardly relative the rotation and which duct is in flow communication with the chamber via an outlet opening provided in the wall so as to transfer the portion of the second granular material stagewise to a position further removed from the lower end than the inlet opening for further travel down the kiln with the first granular material,
a major portion of the ducts arranged to transfer a portion of the second granular material stagewise almost two of the zones up the kiln.

3. The apparatus of claim 2 with the selector means being a grate.

4. The apparatus of claim 3 and the grate mounted flush with the wall.

5. Apparatus for direct-contact heat exchange between a coarse and a fine granular material and comprising:

an inclined cylindrical kiln mounted for and having means for rotation about its cylindrical axis, the kiln defining a chamber as well as an upper end and a lower end,
the kiln provided at its upper end with a coarse input means for introducing the coarse material and provided at its lower end with a coarse discharge means for removing the coarse material,
the kiln provided near its lower end with a fine input means for introducing the fine material and provided at its upper end with a fine discharge means for removing the fine material,
the kiln having a cylindrical wall with a plurality of inlet openings each having selector means to receive a portion of the fine material from the chamber but to reject the coarse material,
the inlet openings arranged in rows spaced along the length of the kiln to define zones therebetween,

a plurality of the inlet openings in each of the rows and the inlet openings of each row spaced about the circumference of the wall,

the wall provided with a duct for each of the inlet openings which duct is in flow communication with its related inlet opening and which duct extends helically upwardly relative the kiln and rearwardly relative the rotation and which duct is in flow communication with the chamber via an outlet opening provided in the wall so as to transfer the portion of the fine material stagewise to a position further removed from the lower end than the inlet opening for further travel down the kiln with the coarse material,

a major portion of the ducts arranged to transfer a portion of the fine material stagewise almost two of the zones up the kiln.

6. The apparatus of claim **5** with the selector means being grates.

7. The apparatus of claim **6** and the grates mounted flush with the wall.

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