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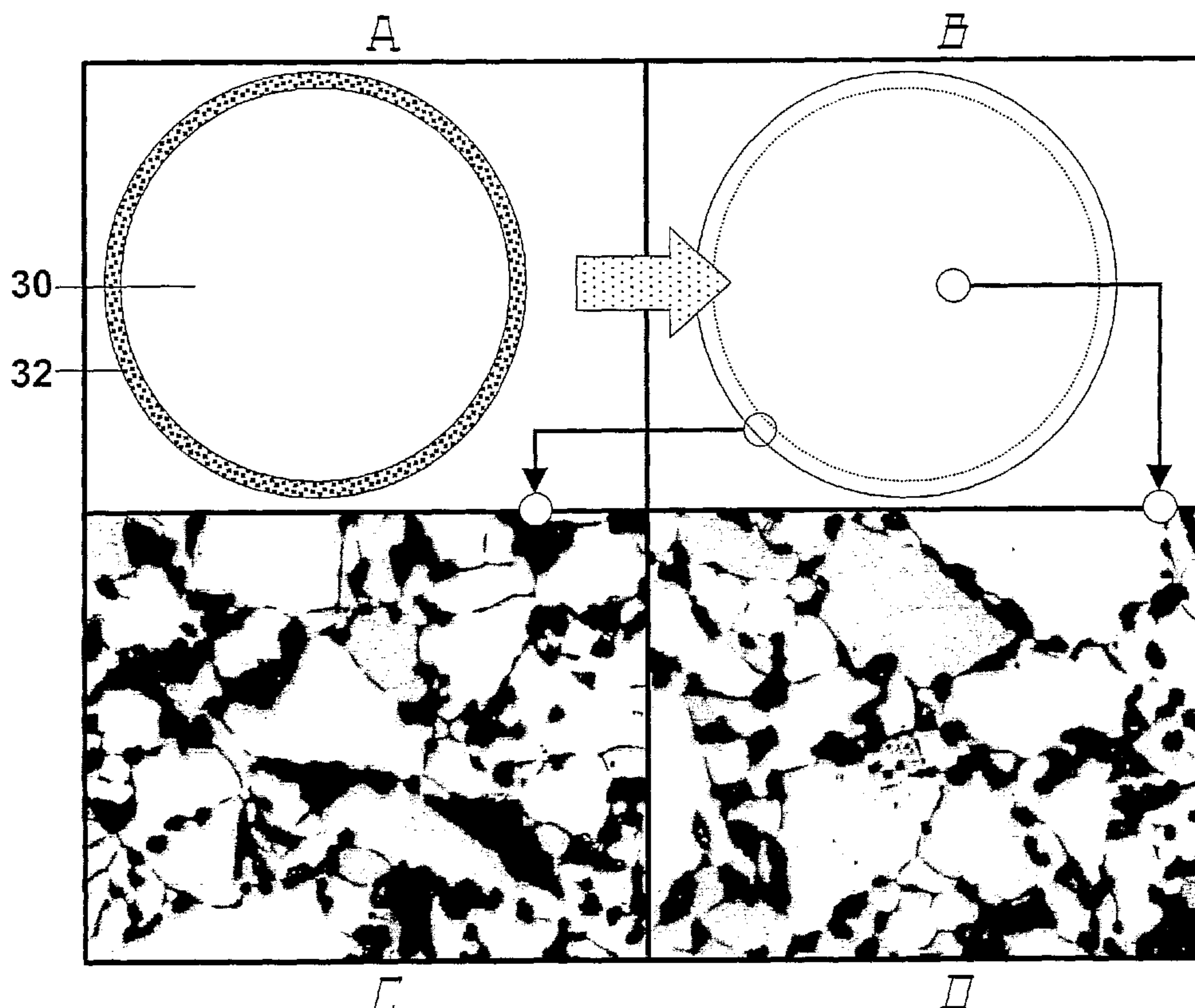
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(54) Title: LAYERED AGGLOMERATED IRON ORE PELLETS AND BALLS



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A layered iron ore ball has a core portion and a shell portion covering the core portion. The core portion contains a first iron-oxide concentrate and is internal fuel additive free. The shell portion contains a second iron-oxide concentrate and at least one internal fuel additive added to the second iron-oxide concentrate. The layered iron ore balls reduce the induration energy costs and increase induration productivity while obtaining good quality fired pellets. Such pellets are used for reduction in the ironmaking process.

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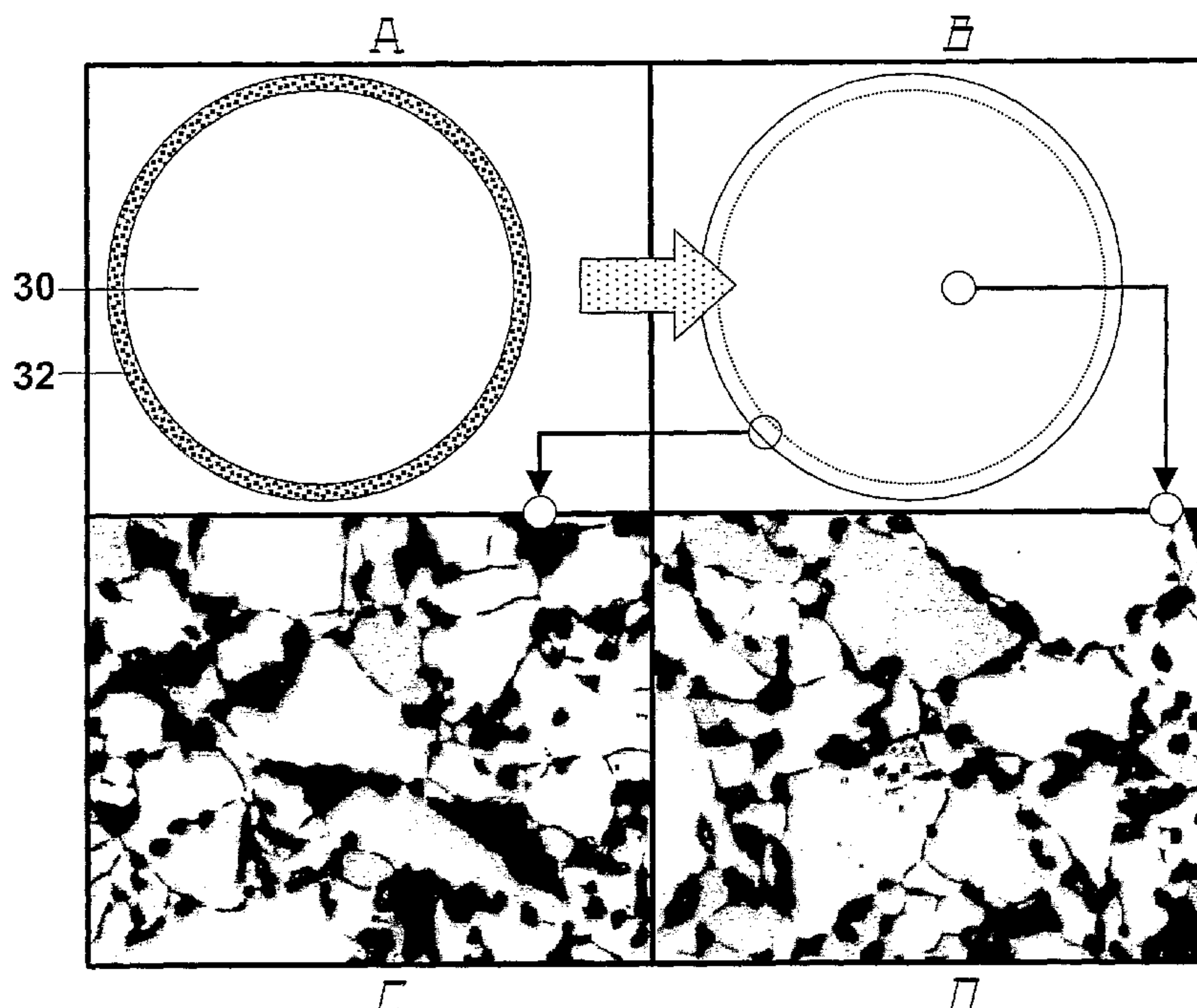
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(54) Title: LAYERED AGGLOMERATED IRON ORE PELLETS AND BALLS



(57) Abstract: A layered iron ore ball has a core portion and a shell portion covering the core portion. The core portion contains a first iron-oxide concentrate and is internal fuel additive free. The shell portion contains a second iron-oxide concentrate and at least one internal fuel additive added to the second iron-oxide concentrate. The layered iron ore balls reduce the induration energy costs and increase induration productivity while obtaining good quality fired pellets. Such pellets are used for reduction in the ironmaking process.

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LAYERED AGGLOMERATED IRON ORE PELLETS

AND BALLS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority of US provisional patent application 60/564,582 filed
5 on April 23, 2004, the specification of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1) Field of the Invention

The present invention relates to agglomerated ores and, more particularly, to layered
agglomerated iron ore pellets and balls. The present invention also relates to a
10 method of producing same.

2) Description of the Prior Art

An important proportion of iron oxides used for reduction (ironmaking) are used in
the shape of a pellet. The pellets are manufactured by mixing iron oxide
concentrates, additives required by the client, and one or several binders. The iron
15 oxide concentrates typically contain goethite ($\text{FeO}(\text{OH})$), hematite (Fe_2O_3), and/or
magnetite (Fe_3O_4) and usually a small portion of silica (SiO_2) as an impurity.
Additives such as fluxes, binders and internal fuel are typically added to the iron-
oxide concentrate. Fluxes, such as CaO and MgO , are usually added to obtain the
desired slag during reduction. The binders, which can either be mineral or organic,
20 improve the adhesion of the pellet mixture. It is now frequent to add carbon as an
internal fuel to facilitate pellet induration (or cooking) by improving the heat transfer
towards the pellet core.

The agglomerated pellets are fired in order to obtain the necessary mechanical
properties for their handling and transportation to the oxide reduction and iron or
25 steel making sites. The mechanical properties of the fired pellets are evaluated,
among others, by their compression strength which is expressed in kilogram per
pellet (kg/pellet). An efficient pellet firing is targeted at this step.

However, the gas diffusion towards the pellet core is a slow kinetic and produces an oxygen debt therein. Therefore, the carbon dioxide, which is the result of the coke oxidation, oxidizes the coke in the pellet core into carbon monoxide. The carbon monoxide reduces the hematite (Fe_2O_3) into secondary magnetite (Fe_3O_4) that is later re-oxidized into secondary hematite. These unnecessary reactions reduce the process efficiency and increase the energy cost to indurate the pellets. Therefore, there is an economic incentive to optimize the pellet composition.

US patent No. 4,851,038 discloses a method to manufacture agglomerated and fired pellets. The pellets produced have a core including the iron ore and lime and are coated with coke powder as a solid fuel. However, coke powder is easily removed from the pellet surface when they enter into the furnace. In important quantity, free coke powder generates high risks of explosion.

US patent No. 4,504,306 discloses a method to produce iron oxide pellets having a two-layered structure with a core portion and a shell portion covering the core portion. The core portion contains between 0.3 to 1.0% by weight of carbon while the shell portion contains between 1.0 and 4.5% by weight of carbon.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide improved ore balls that reduce the induration energy costs while obtaining good quality fired pellets.

One object of the invention provides a method for producing layered iron ore balls. The method comprises: providing a first feed material containing a first iron-oxide concentrate, the first feed material being internal fuel additive free; primarily pelletizing, during a first residence time, the first feed material to form a core portion; providing a second feed material containing a second iron-oxide concentrate and at least one internal fuel additive; and secondary pelletizing, during a second residence time, the second feed material with the core portion to form a first superficial layer over the core portion.

The method can optionally further comprise at least one additional step selected amongst the group of steps comprising: screening the core portion before secondary

pelletizing the second feed material with the core portion to form the first superficial layer over the core portion and withdrawing at least one of the iron ore balls coarser than a first predetermined ball size and smaller than a second predetermined ball size; grinding the withdrawn iron-ore balls coarser than the first predetermined particle size to obtain a grinded recycled feed material and mixing the grinded recycled feed material with the first feed material; pelletizing the withdrawn core portions smaller than the second predetermined particle size with the first feed material; mixing at least one binder with at least one of the first feed material and the second feed material; mixing at least one fluxing agent with at least one of the first feed material and the second feed material; firing the layered iron ore balls to obtain fired pellets; and providing a third feed material and tertiary pelletizing the third feed material with one of the core portion and the core portion covered with the first superficial layer.

The at least one internal fuel additive can be added to the second feed material can be in an amount ranging 1.5 and 15 wt%.

Another object of the invention provides a layered iron ore ball comprising: a core portion containing a first iron-oxide concentrate, the core portion being substantially internal fuel additive free; and a shell portion covering the core portion, the shell portion containing a second iron-oxide concentrate and at least one internal fuel additive added to the second iron-oxide concentrate.

The core portion is preferably agglomerated on a first balling device and the shell portion is agglomerated over the core portion on a second balling device. The at least one internal fuel additive preferably comprises carbon and the carbon concentration in the shell portion is preferably between 1.5 and 15 wt% and, more preferably, between 1.5 and 10 wt%.

The shell portion has preferably a thickness ranging between 250 and 3000 μm and, more preferably, ranging between 500 and 1000 μm . The volume of the core portion is preferably at least 60% of the volume of the iron ore ball.

A further object of the invention provides iron ore pellets resulting from an induration process applied on the layered agglomerated iron ore balls as described above. The iron pellets thus obtained preferably have a cold compressive strength (CCS) above 350 kg/pellet.

- 5 In the specification, the term "ball" refers to the agglomerated material before its induration while the term "pellet" refers to the same agglomerated material after its induration. The term "layered pellet" is used to designate a pellet originating from layered balls. The term "conventional pellet" is used to designate a pellet originating from a ball having the same internal fuel content in the shell and the core portions.

10 **BRIEF DESCRIPTION OF THE DRAWINGS**

Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

- Fig. 1. is a schematic view of a quarter of a conventional fired pellet representing the
15 proportion of secondary hematite and secondary magnetite inside the fired pellet;

Fig. 2 includes Figs. 2A, 2B, 2C and 2D, Figs. 2A and 2B are two micrographs of a conventional fired pellet and Figs. 2C and 2D are two schematic views of the fired pellet showing respectively where the micrographs of Figs. 2A and 2B were taken;

- Fig. 3 is a schematic flow sheet of a process for the production of layered balls in
20 accordance with an embodiment of the invention;

Fig. 4 includes Figs. 4A, 4B, 4C and 4D, Figs. 4A and 4B are two micrographs of a layered fired pellet and Figs. 4C and 4D are two schematic views of the fired pellet showing respectively where the micrographs of Figs. 4A and 4B were taken;

- Fig. 5 includes Figs. 5A, 5B, 5C and 5D, Fig. 5A is a micrograph, taken in the shell
25 portion, of a conventional fired pellet having a low silica content, Fig. 5B is a micrograph, taken in the core portion, of the conventional fired pellet having a low silica content, Fig. 5C is a micrograph, taken in the shell portion, of a layered fired pellet having a low silica content, and Fig. 5D is a micrograph, taken in the core portion, of the layered fired pellet having a low silica content;

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Fig. 6 includes Figs. 6A, 6B, 6C and 6D, Fig. 6A is a micrograph, taken in the shell portion, of a conventional fired limestone pellet, Fig. 6B is a micrograph, taken in the core portion, of the conventional fired limestone pellet, Fig. 6C is a micrograph, taken in the shell portion, of a layered fired limestone pellet, and Fig. 6D is a micrograph, taken in the core portion, of the layered fired limestone pellet;

Fig. 7 is a graph representing the cold compressive strength (CCS) of low-silica pellets having a variable coke content; and

Fig. 8 is a graph representing the cold compressive strength of limestone pellets having a variable coke content.

It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

An important proportion of the iron oxides that are used for ironmaking are used in a pellet shape. To manufacture pellets, a fine iron ore concentrate is first agglomerated on one or several balling devices (disk, drum or any equipment allowing ball agglomeration) and the agglomerated balls are fired in an induration furnace to increase their mechanical properties such as their cold compression strength (CCS), which is expressed in kilogram per pellet (kg/pellet).

Iron ore concentrates usually contain goethite ($\text{FeO}(\text{OH})$), hematite (Fe_2O_3), and/or magnetite (Fe_3O_4) and usually a small portion of silica (SiO_2) as an impurity. Additives such as binders, solid fuels (internal fuel or carburant), and fluxes are typically added at the agglomeration step (pelletization step). The concentration of each additive varies according to the user's needs.

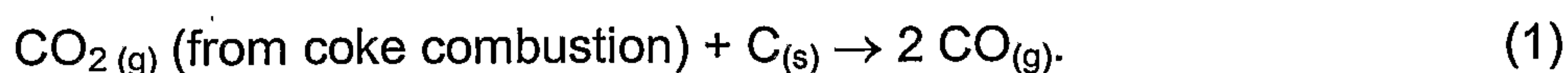
The binders, which can either be mineral or organic, improve the adhesion of the ball mixture. It is now frequent to add an internal fuel to facilitate pellet induration by improving the heat transfer towards the ball core. The internal fuel is either added as coke, low temperature coke, pulverized coal, petroleum coke or anthracite.

The agglomerated balls are usually fired in a moving grate furnace or a grate kiln wherein they are first dried to remove their water content. The agglomerated balls are then indurated to create physical links between the particles and consequently increase their mechanical properties. Finally the fired pellets are cooled down to
 5 recover their energy content and to obtain pellets at a suitable temperature for subsequent handling. Several chemical reactions occur during the induration process such as the solid fuel combustion, the oxidation of magnetite, if any, and the calcination of fluxes.

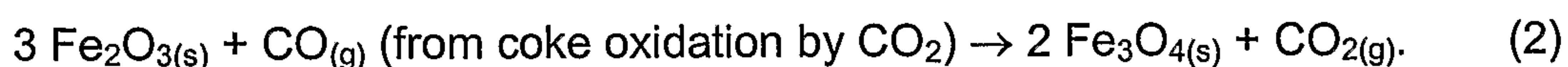
Referring to FIG. 1, it will be seen that a pellet 20 can be divided, for the gas
 10 behavior, into two zones: an advection zone 24 and a diffusion zone 26. The advection zone 24 is a superficial layer of the pellet 20 wherein the air is continuously replaced without having recourse to diffusion phenomena. The thickness of the advection zone 24 can vary but is usually between 250 and 3000 μm . The diffusion zone 26 is located inside the pellet 20 and the air circulates
 15 through diffusion therein. The diffusion kinetic is faster proximate to the advection zone 24 and slower proximate to core of the pellet 20.

When the agglomerated balls have a uniform composition, FIGS. 1 and 2 show that the fired pellets include more secondary magnetite sites in the diffusion zone 26 than in the advection zone 24. Secondary magnetite is formed when combustion is
 20 incomplete due to an oxygen debt.

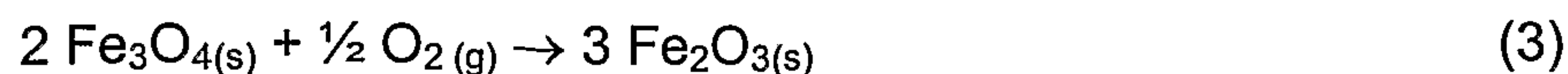
At the beginning of the induration process, an oxygen debt occurs in the diffusion zone 26 since the gas diffusion towards the core of the pellet 20 is a slow kinetic. Therefore, the carbon dioxide, which is the result of the coke combustion and/or the calcination of the flux additives, oxidizes the coke contained in the core of the pellet
 25 20 into carbon monoxide:



The carbon monoxide reduces the hematite (Fe_2O_3) into secondary magnetite (Fe_3O_4):



An important proportion of the secondary magnetite is later reoxidized into secondary hematite:



5 These unnecessary reactions reduce the process efficiency and increase the energy costs to indurate the balls. Therefore, there is an economic incentive to optimize the ball composition.

10 In accordance with an embodiment, agglomerated balls are manufactured without internal fuel in the diffusion zone 26 and, therefore, only the advection zone 24 has internal fuel in its composition. The internal fuel in the advection zone 24 can be coke, half-coke, pulverized coal, petroleum coke and/or anthracite.

The internal fuel is therefore rapidly consumed, solely by a complete combustion reaction. Substantially no residual carbon monoxide is formed and thus substantially no secondary magnetite. The time required to form the secondary magnetite and to reoxidize the later into secondary hematite is eliminated and it allows, among others,
15 to increase the process productivity or modify the induration cycle to save fossil energy used at the burners (or a combination of both).

To manufacture layered pellets with a core portion 30 and a shell portion 32, or a superficial layer, (see FIG. 4), the balls are agglomerated in at least two agglomeration steps since the core portion 30 and the shell portion 32 have a
20 different fuel content. A first agglomeration step produces the core portion 30 and a second agglomeration step agglomerates the shell portion 32 over the core portion 30.

Balls are usually agglomerated on one or several balling devices such as balling disks and balling drums. Since the pellet manufacturers usually have predetermined
25 specifications for the pellet granulometry, largest and smallest balls are rejected. The largest balls are grinded and the grinded particles are returned with the finest balls as a feed material to a balling device which can be the same or a different one than the balling device(s) used for the agglomeration of the grinded feed material. The

smallest ball can be either grinded or sent to a balling device. Usually an important proportion of the agglomerated balls are rejected.

It is preferable to use at least one balling device for each agglomeration step since the core portion 30 does not contain internal fuel. Moreover, the rejected balls of each agglomeration step can be grinded separately and sent to feed at least one balling device of the appropriate agglomeration step. For example, the balls rejected after the agglomeration of the core portion 30 are fine balls and coarse balls. The coarse balls are grinded and the grinded particles are fed with the fine balls 60 (FIG. 3) to at least one balling device that agglomerates the core portion 30. The additives (fluxes, binders, and internal fuels) contents can be adjusted in the feed material depending on the level and the content of the recirculated material. The same can be done during the second balling step where fine layered balls (the core portion 32 with an outer layer of carbon rich material) and coarse layered balls can be recirculated, preferably only into the feed of the second balling or agglomeration step.

15 **Example 1**

Several processes can be designed to produce layered balls. An example of a manufacturing process for two layered balls is now described referring to FIG. 3. In the first agglomeration step, an iron oxide concentrate provided from a first iron oxide concentrate bin 40 is mixed in a first mixer 42 with recirculated mineral provided from a first recirculation bin 44, as will be explained in more details below. Iron-oxide concentrate from bin 40 and recirculated mineral from the bin 44 are mixed in predetermined proportions to meet the ball specifications for the core portion 30. Thereafter, the output of mixer 42 is mixed in a second mixer 46 with additives, such as binders and fluxes, provided from a first additive bin 48. Additives of the first additive bin 48 are substantially free of internal fuel since they are mixed with the iron oxide concentrate of bin 40 and the recirculated material of the bin 44 to form the core portion 30 of the balls. The output of mixer 42 and the additives of bin 48 are also mixed in predetermined proportions to meet the ball specifications. One skilled in the art will appreciate that the content of bins 40, 44, 48 can be mixed in a single mixer. The output of the second mixer 46 forms a core portion feed material 50. A first balling device 52 is fed with the feed material 50 to agglomerate the core

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portions 53 of the two-layered balls 90. The core portions 53 are screened on a first screen 54 to withdraw coarse core portions 56 that have a diameter larger than a predetermined value. The remaining core portions 53 are screened on a second screen 58 to withdraw fine core portions 60 characterized with a diameter smaller than a specified value. The coarse core portions 56 are recovered, grinded (not shown), and sent to the first recirculation bin 44 as a feed material for the core portion 30. One skilled in the art will appreciate that the fine core portions 60 can also be grinded, either together or separately from the coarse core portions 56 or sent directly to a bin or the balling device. The coarse and fine core portions 56, 60 can be sent either to the same or a different bin. The number and the content of the bins 40, 44, 48 and the mixers 42, 46 can differ from the one shown in FIG. 1.

In the second agglomeration step, a shell portion 82 is added to the core portion 30 having a diameter corresponding to the predetermined specifications. The core portions 30 are sent to a second balling device 70. A second recirculation bin 64 containing recirculated material 68, as will be explained in more details below, and a second iron oxide bin 72 containing an iron oxide concentrate feed are mixed, in predetermined proportions in a primary mixer 74. The output of the primary mixer 74, the content of a second additive bin 76, and the content of a second internal fuel bin 78 are mixed in predetermined proportions in a secondary mixer 80. As for the first agglomeration step, one skilled in the art will appreciate that the content of bins 64, 72, 76 and 78 can be mixed in one or more mixers. The additive bin 76 contains additives such as binders and fluxes and the internal fuel bin 78 contains internal fuels such as coke, half-coke, pulverized coal, petroleum coke, and anthracite. The content of the additive bin 76 and the fuel bin 78 can be contained in a single bin as one skilled in the art will appreciate.

The output of mixer 80 forms a feed material 82 that is agglomerated over the core portion 30 to form the two-layered balls 90. The feed material 82 contains a mixture of the iron oxide concentrate and the additives, including the internal fuel, that composes the shell portions 32. The shell portions 32 are agglomerated over the core portions 30 in the second balling device 70 producing two-layered balls 90 with a size distribution. The two-layered balls 84 can be screened on a screen 88 to withdraw the fine agglomerates 68 that have a diameter smaller than a specified

value. The fine agglomerates 68 are recovered and are sent to the second recirculation bin 64. Since the core portion 30 are substantially internal fuel free, the recirculated agglomerates 68 are preferably returned only to the second agglomeration step. One skilled in the art will appreciate that the two-layered balls 84
5 can also be screened on a first screen (not shown) to withdraw coarse two-layered balls that have a diameter larger than a predetermined value.

The two-layered balls 90 having a diameter, or size, that corresponds to the specifications are recovered and sent to a storage bin 92 until they are fired into pellets in an induration furnace (not shown).

10 One skilled in the art will understand that each feed material such as the iron oxide concentrate, the additives, including the internal fuel, and the recirculated material can be contained in more than one bin. Each additive can be contained in its own bin. The mixing step before each agglomeration step can be carried out in any number of mixers and/or in any mixing order of the feed material. Furthermore, more
15 than one balling device can be used for each agglomeration step.

The core portion 30 and the shell portion 32 can contain different additives or iron oxide concentrates. For example, the shell portion 32 can contain olivine as fluxing agent while the core portion 30 can contain dolomite. Alternatively for iron-oxide concentrates containing magnetite, the core portion 30 can contain an iron oxide
20 concentrate having a low magnetite content while the iron oxide concentrate of the shell portion 32 can have a high magnetite content. Furthermore, any additive can be added in different proportions in the core portion 30 and the shell portion 32. For example, the core portion 30 can contain a low dolomite content comparatively to the shell portion 32.

25 The internal fuel concentration in the shell portion 32 can vary depending on several parameters. A carbon concentration in the shell portion 32 ranging between approximately 1.5 and 15 wt% is adequate and, more preferably, between 1.5 and 10 wt%. Above 15 wt%, it is typically difficult to uniformly disperse the internal fuel.

The core portion 30 represents typically between 60 and 80 % of the volume of a
30 ball. Therefore, the residence time of the balls on the balling devices 70 of the

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second agglomeration step is relatively short comparatively to the residence time of the balls on the balling devices 52 of the first agglomeration step.

Preferably, the thickness of the shell portion 32 corresponds substantially to the thickness of the advection zone 26 during the induration process.

- 5 The two-layered balls 84 withdrawn from the balling device 70 and/or the core portion 53 do not have to necessarily be submitted to screening steps if it is presumed that the balls 84 and/or the core portions 53 already meet the specifications. As mentioned earlier, the core portion 30 represents usually the most important portion of the ball volume. If the core portions 30 are screened adequately
- 10 after the first agglomeration step, the screening after the second agglomeration is optional since the residence time of the balls on the balling devices 70 of the second agglomeration step is relatively short. Therefore, two-layered balls are usually produced with a narrow distribution of the ball size or granulometry, even without a screening step following the agglomeration of the shell portion. Obviously, no
- 15 screening are necessary after any agglomeration if there is no ball size specifications.

The recirculated coarse material 56 of the first agglomeration step can be grinded and the grinded particles can be sent as a feed material to the second agglomeration step. On the opposite, the recirculated material 68 of the second agglomeration step

20 should not be sent as a feed material to the first agglomeration step since it contains internal fuel while the core portion 30 substantially does not.

As people in the art will understand, the process can produce balls that have more than two layers. The process can include any number of agglomeration steps.

Referring simultaneously to FIGS. 2 and 4, it will be seen that the core portion of the

25 fired two-layered pellets (FIG. 4D) contains less secondary magnetite than the core portion of a conventional pellet (FIG. 2D). The terms "conventional pellets" or "conventional balls" refer to pellets or balls having the same internal fuel content in the core portion 30 and in the shell portion 32. Moreover, the core and shell portions 30, 32 of the fired two-layered pellets (FIGS. 4C and 4D) have similar micrographs.

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On the opposite, the micrographs of the core and shell portions 30, 32 of the conventional pellets (FIGS. 2C and 2D) differ.

As it will be seen with the following examples, the layered balls provide important energy reduction combined with an increase of the productivity of the induration process following the ball agglomeration. Moreover, it reduces the production of green house gases (GHG).

As people in the art will understand, the layered balls are preferably used by pelletizing plants that add an internal fuel to their balls and indurate them in a moving grate induration furnace.

10 Example 2

The second example concerns the cold compressive strength (CCS) of fired layered pellets comparatively to conventional pellets having the same internal fuel content in the core portion 30 and in the shell portion 32. The CCS is a normalized index to measure the mechanical properties of the balls or pellets respectively before or after induration.

The pellets were pellets for blast furnaces (acid pellets) originating from balls containing approximately 5 wt% of silica, between 0.75 and 1.5 wt% of coke as an internal fuel, 0.6 wt% of CaO, 0.25 wt% of MgO, and substantially no magnetite in the iron oxide concentrate. Dolomite and limestone were added as fluxes.

20 Table 1 shows the results obtained for pellets wherein the core portion 30 represented 78% of the volume of the ball and the shell portion 32 represented the remaining 22%. The first pellet batch was conventional pellets having the same coke content in the shell and the core portions 32, 30. A CCS of 366 kg/pellet was obtained for pellets originating from balls containing 1.5 wt% of coke.

25 The second pellet batch was two-layered balls having a total coke content of 1.5 wt%. The core portion 30 did not contain coke and the coke content of the shell portion 32 was 6.82 wt%. A CCS of 517 kg/pellet was obtained, which is 1.4 times higher than for conventional pellets.

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Since the CCS obtained was higher than the usual specifications, the total coke content was reduced for the third and the fourth pellet batches, which also contained two-layered pellets. The total coke content for the third and the fourth pellet batches were 1.0 wt% and 0.75 wt% respectively in the balls prior to induration. For both
 5 batches, the core portion 30 did not contain coke and the shell portion 32 contained 4.55 wt% coke for the third batch and 3.41 wt% for the fourth batch. CCS of 532 kg/pellet and 549 kg/pellet were obtained for the third and fourth batches respectively.

Consequently, higher CCS than for conventional pellets can be obtained with pellets
 10 originating from layered balls having lower coke contents.

Table 1

Core / Shell (vol%)	78/22			
Total coke added (wt%)	1.5		1.0	0.75
Coke in core / in shell (wt%)	1.5 / 1.5	0 / 6.82	0 / 4.55	0 / 3.41
CCS (kg/pellet)	366	517	532	549

Example 3

The third example is similar to the second one but acid pellets were tested. Acid pellets originate from balls containing approximately 5 wt% of silica, between 0.75
 15 and 1.5 wt% of coke as an internal fuel, 1 wt% of CaO, and 0.33 wt% of MgO. The fluxes were added as limestone.

Table 2 shows the results obtained. The first pellet batch was conventional pellets originating from balls having the same coke content in the core and the shell portions 30, 32. A CCS of 373 kg/pellet was obtained for pellets containing 0.97 wt% of coke.

20 The second pellet batch was two-layered pellets originating from balls having a total coke content of 0.97 wt%. The core portion 30 did not contain coke and the coke content of the shell portion 32 was 4.43 wt%. A CCS of 537 kg/pellet was obtained, which is 1.4 times higher than for conventional pellets. The third and the fourth pellet batches were also two-layered pellets. The total coke content of the balls for

the third and the fourth pellet batches were 0.65 wt% and 1.3 wt% respectively. For both batches, the core portion 30 did not contain coke and the shell portion 32 contained 2.72 wt% coke for the third batch and 5.9 wt% for the fourth batch. CCS of 498 kg/pellet and 419 kg/pellet were obtained for the third and fourth batches respectively.

Consequently, higher CCS than for conventional pellets can be obtained with layered pellets having lower coke contents. High coke contents in the shell portion 32 of layered pellets reduced the mechanical properties of the pellet. There is probably an optimum coke content for the shell portion 32 for each type of pellets.

Table 2

Core / Shell (vol.%)	78/22			
Total coke added (wt%)	0.97		0.65	1.30
Coke in core / in shell (wt%)	0.97 / 0.97	0 / 4.43	0 / 2.72	0 / 5.9
CCS (kg/pellet)	373	537	498	419

Example 4

The fourth example concerns the mechanical properties of layered pellets comparatively to conventional pellets having the same internal fuel content in the core portion 30 and in the shell portion 32. It also concerns two-layered pellets with different internal fuel contents that were fired under different operating conditions. The pellets were low silica pellets originating from balls containing approximately 1.5 wt% of silica, between 0.75 and 2 wt% of coke as internal fuel, 0.4 wt% of CaO, and 0.3 wt% of MgO. The fluxes were added as dolomite.

In addition to the CCS, the mechanical properties of the pellets were also evaluated with the ISO tumble index. The ISO tumble index is a relative measure of the resistance of the pellets to size degradation by impact and abrasion, when subjected to a tumble test in a rotating drum.

During the tests, the gas flow rate for the induration process was modified between two levels: a regular and a higher gas flow rates. The productivity of the induration process was also measured in tons of green balls per hour (TGB/h).

5 Table 3 shows the results obtained for the fired pellets. The first pellet batch was conventional pellets that were fired with a regular gas flow. A CCS of 314 kg/pellet and a tumble index of 97.0 were obtained for pellets originating from balls containing 1.6 wt% of coke. The productivity was 615 tGB/h.

10 Batches 2 to 6 relate to two-layered pellets. The productivity variations (wt%), the variation of the fuel (oil) burned at the burners during the induration (wt%), the variation of coke contained in the pellets (wt%), the variation of the energy costs to manufacture the fired pellets (%), and the variation of the GHG released per ton of fired pellets (tFP) (wt%) were also calculated.

15 The second pellet batch had a total coke content of 0.9 wt% and was fired with a regular gas flow. A CCS of 364 kg/pellet and a tumble index of 95.9 were obtained. The CCS of the two-layered pellets was better than the one of conventional pellets with a lower internal fuel content. The tumble index was however slightly lower. A productivity gain of 8 wt% combined with reductions of 19 wt% and 44 wt% of the oil burned and the coke added to the balls were obtained. Consequently, the overall energy cost was reduced by 32 wt%. The GHG released were also reduced by 36%.

20 Similar results are given in Table 3 for balls containing different internal fuel contents that were fired in different operating conditions.

25 In conclusion, while keeping similar mechanical properties than with conventional pellets, the layered pellets allow a significant increase of the productivity combined with reduction of the overall energy costs and the GHG released. Increasing the gas flow rate in the furnace allows an additional productivity gain.

FIG. 5 compares the micrographs of the core and the shell portions 30, 32 of conventional and two-layered pellets. The core portion 30 of the two-layered pellets (FIG. 5D) contains less secondary magnetite than the core portion 30 of a conventional pellet (FIG. 5B). Moreover, the core and shell portions 30, 32 of the 30 two-layered pellets (FIGS. 5C and 5D) have similar micrographs. On the opposite,

the micrographs of the core and shell portions 30, 32 of the conventional pellets (FIGS. 5A and 5B) differ.

Table 3

Description	Conven- tional	Layered				
Gas flow rate	Regular				Higher	
Batch	1	2	3	4	5	6
Coke (%)	1.6	0.9	1.6	2.0	1.6	2.0
ISO Tumble (% +6.3mm)	97.0	95.9	94.0	94.3	94.7	94.3
CCS (kg/pellet)	314	364	378	415	404	396
Productivity (tGB/h)	615	665	740	745	795	815
Productivity gain (%)		+8	+20	+21	+18	+21
Oil (%)		-19	-27	-67	-68	-67
Coke (%)		-44	0	+25	0	+25
Energy (global) (\$)		-32	-13	-21	-34	-21
GHG (per tFP) (%)		-36	-8	-3	-20	-3

Example 5

- The fifth example is similar to the fourth one but self-fluxed pellets were manufactured. Self-fluxed pellets originate from balls containing approximately 3.75 wt% of silica, 2 wt% of coke as an internal fuel, 3.7 wt% of CaO, and 1.3 wt% of MgO. Dolomite and limestone were added as fluxes. During the tests, the gas flow rate for the firing was kept constant.

Table 4 shows the results obtained for the fired pellets. The first pellet batch was conventional pellets. CCS of 294 kg/pellet and a tumble index of 96.8 were obtained. The productivity of the induration process was 345 tGB/h.

Batches 2 and 3 relate to two-layered pellets. As for the fourth example, while
5 keeping the mechanical properties similar to the ones of the conventional pellets, the layered pellets allow a productivity increase combined with reduction of the overall energy cost and the GHG released.

FIG. 6 compares the micrographs of the core and the shell portions 30, 32 of
10 conventional and two-layered pellets. Fig. 6A is a micrograph of the shell portion 32 of a conventional pellet which is compared to a micrograph of the shell portion 32 of the two-layered pellet (Fig 6C). Fig. 6B is a micrograph of the core portion 30 of a conventional pellet which is compared to the micrograph of the core portion 30 of the two-layered pellet (Fig. 6D).

Table 4

Description	Conventional	Layered		
Gas flow rate	Regular			
Batch	1	2	3	
ISO Tumble (% +6.3mm)	96.8	95.8	94.7	
CCS (kg/pellet)	294			
Productivity (tGB/h)	345	370	405	
Productivity gain (%)		+7	+17	
Oil (%)		-39	-43	
Coke (%)		0	+31	
Energy (global) (\$)		-24	-13	
GHG (per tFP) (%)		-14	-3	

FIG. 7 is a graph comparing the CCS of low-silica pellets for various coke contents. The CCS of layered pellets is higher than the one of conventional pellets. The maximum CCS is obtained for pellets having an overall coke content proximate to 2 wt%.

- 5 FIG. 8 is similar to FIG.7. However it concerns self-fluxed pellets with various coke contents. As for the low-silica pellets, the CCS of self-fluxed layered pellets is higher than the one of conventional pellets. Higher CCS are obtained for layered pellets having low coke content (less than 1.5 wt%).

Even if the above examples use mainly dolomite and limestone as fluxing agents
10 and coke as internal fuel, one skilled in the art will understand that any appropriate material can be used. For example, forsterite (Mg_2SiO_4), olivine, and slaked lime ($\text{Ca}(\text{OH})_2$) can be used as fluxing agent. Similarly, low temperature coke, pulverized coal, petroleum coke and anthracite can be used as internal fuel.

The shell portion has preferably a thickness ranging between 250 and 3000 μm ,
15 more preferably 500 and 2000 μm . The volume of the core portion is typically above 60% of the ball volume, preferably above 70%.

It will be appreciated that the nature and the content of the additives added to the first and second feed materials can vary. Moreover, one skilled in the art will appreciate that a liquid, usually water, is typically added to the first and second feed
20 material for their agglomeration. The moisture content of the first and second feed material can vary in accordance with the nature of the ball produced. Similarly, the nature, the content and the particle size distribution of the additives such as the fluxes can vary in accordance with the nature of the pellets produced.

The embodiments of the invention described above are intended to be exemplary
25 only. One skilled in the art will appreciate that the numerical values such as percentages are approximations and are not exact numbers. One skilled in the art will also appreciate that the term "free of" means "substantially free of". The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.

AMENDED CLAIMS

received by the International Bureau on 05 October 2005 (05.10.05): original claims 1-25 have been replaced by amended claims 1-27.(4 pages).

1. A method for producing iron ore pellets comprising:

providing a first feed material containing a first iron-oxide concentrate,
the first feed material being internal fuel additive free;

primarily pelletizing, during a first residence time, the first feed material
to form a core portion;

providing a second feed material containing a second iron-oxide
concentrate and at least one internal fuel additive;

secondary pelletizing, during a second residence time, the second feed
material with the core portion to form a first superficial layer over
the core portion; and

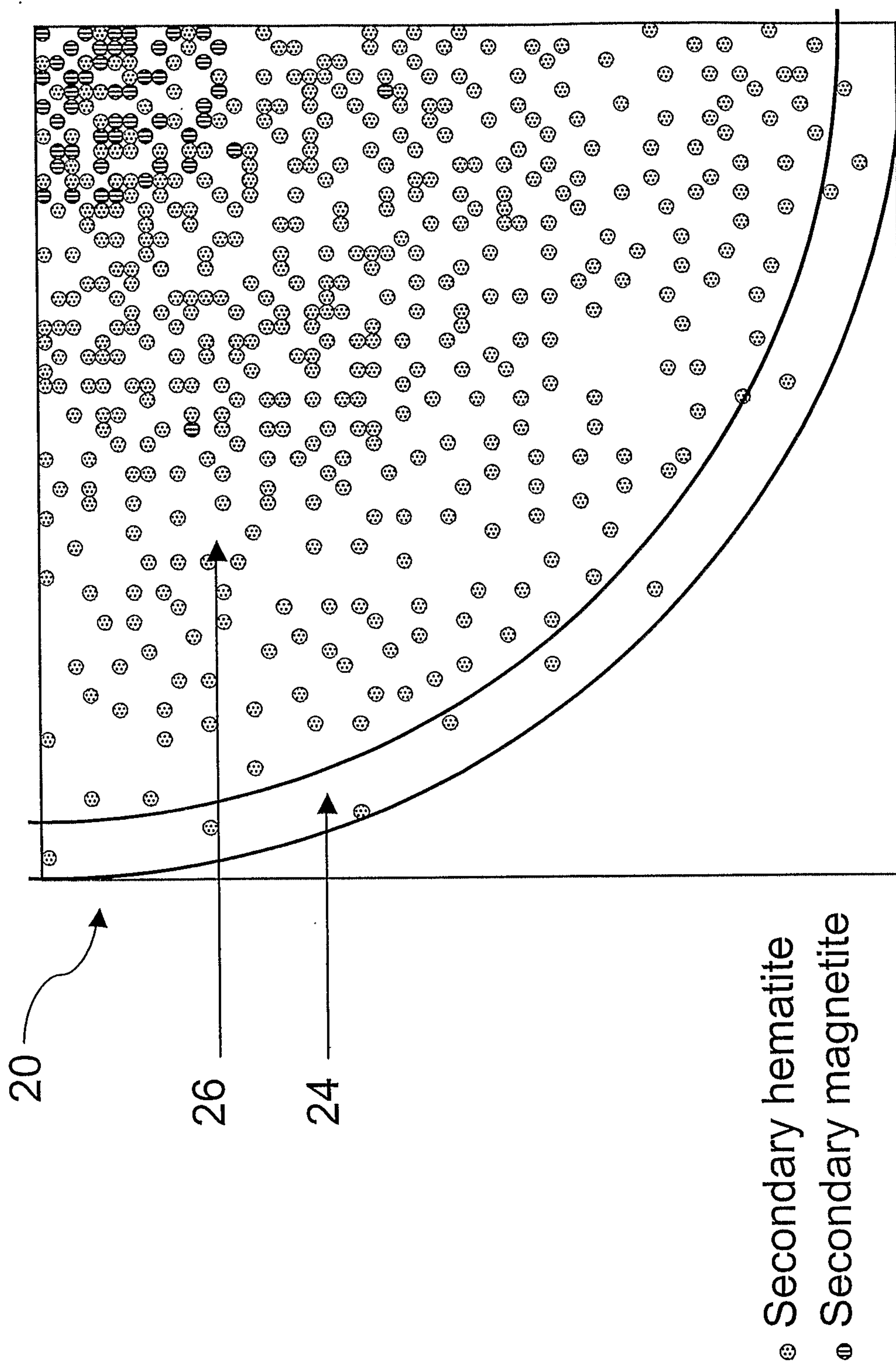
firing the layered iron ore balls in an induration furnace to obtained
individual fired pellets.
2. A method as claimed in claim 1, comprising screening the core portion
before secondary pelletizing the second feed material with the core
portion to form the first superficial layer over the core portion and
withdrawing at least one of the iron ore balls coarser than a first
predetermined ball size and smaller than a second predetermined ball
size.
3. A method as claimed in claim 2, comprising grinding the withdrawn iron-
ore balls coarser than the first predetermined particle size to obtain a
grinded recycled feed material and mixing the grinded recycled feed
material with the first feed material.
4. A method as claimed in claim 2, comprising pelletizing the withdrawn
core portions smaller than the second predetermined particle size with
the first feed material.
5. A method as claimed in claim 1, wherein the first residence time is
longer than the second residence time.

6. A method as claimed in claim 1, comprising adding between 1.5 and 15 wt% of the at least one internal fuel additive to the second feed material.
7. A method as claimed in claim 1, comprising mixing at least one binder with at least one of the first feed material and the second feed material.
8. A method as claimed in claim 1, comprising mixing at least one fluxing agent with at least one of the first feed material and the second feed material.
9. A method as claimed in claim 1, comprising providing a third feed material and tertiary pelletizing the third feed material with one of the core portion and the core portion covered with the first superficial layer.
10. A layered iron ore ball indurable into individual iron ore pellets comprising:
 - a core portion containing a first iron-oxide concentrate, the core portion being substantially internal fuel additive free; and
 - a shell portion covering the core portion, the shell portion containing a second iron-oxide concentrate and at least one internal fuel additive added to the second iron-oxide concentrate.
11. A layered iron ore ball as claimed in claim 10, wherein the core portion is agglomerated on a first balling device and the shell portion is agglomerated over the core portion on a second balling device.
12. A layered iron ore ball as claimed in claim 10, wherein the at least one internal fuel additive comprises carbon.
13. A layered iron ore ball as claimed in claim 12, wherein the carbon concentration in the shell portion is between 1.5 and 15 wt%.
14. A layered iron ore ball as claimed in claim 12, wherein the carbon concentration in the shell portion is between 1.5 and 10 wt%.

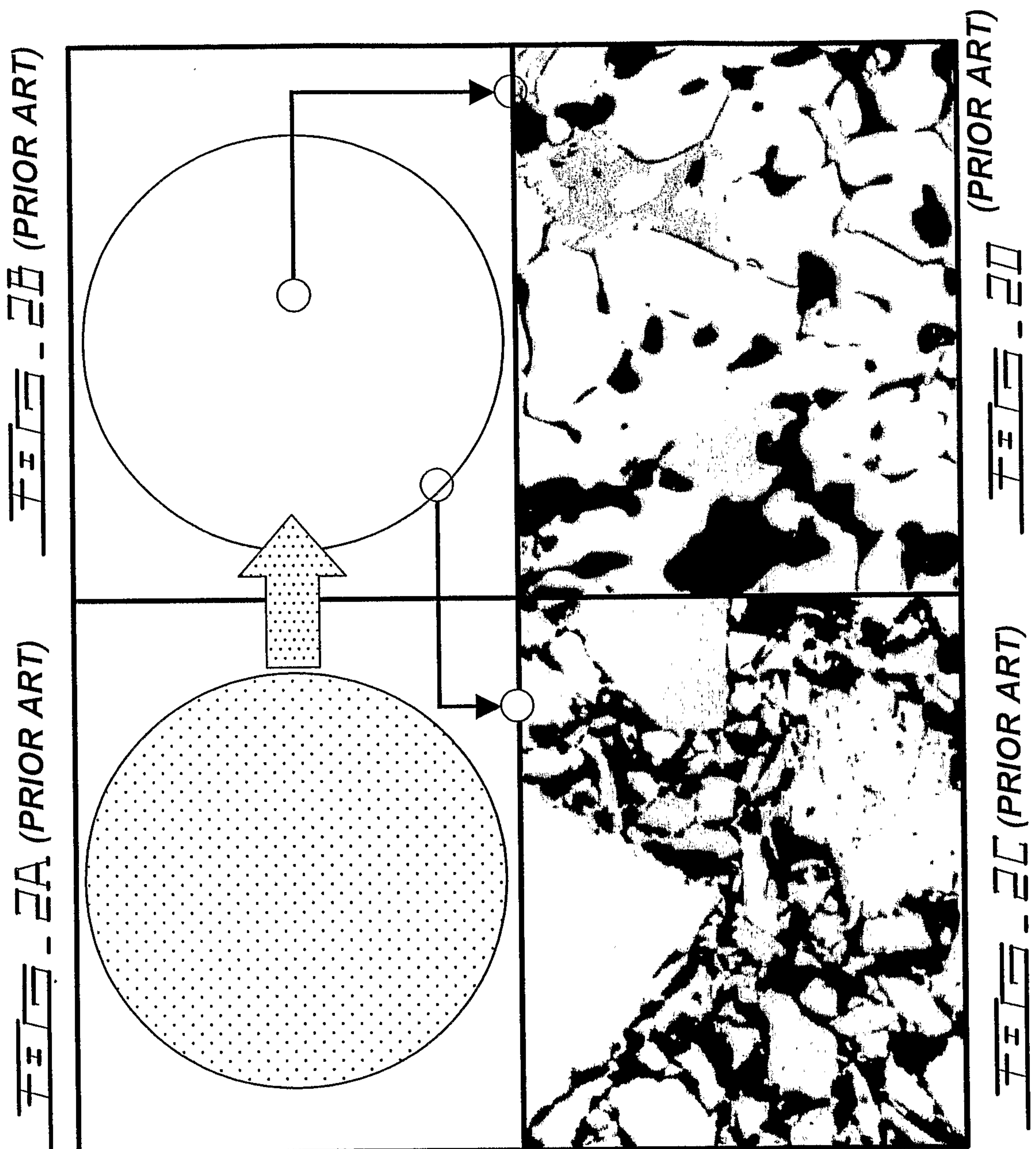
15. A layered iron ore ball as claimed in claim 10, wherein the shell portion has a thickness ranging between 250 and 3000 μm .
16. A layered iron ore ball as claimed in claim 10, wherein the shell portion has a thickness ranging between 500 and 2000 μm .
17. A layered iron ore ball as claimed in claim 10, wherein the shell portion has a thickness ranging between 500 and 1000 μm .
18. A layered iron ore ball as claimed in claim 10, wherein the volume of the core portion is at least 60% of the volume of the iron ore ball.
19. A layered iron ore ball as claimed in claim 10, wherein at least one of the core portion and the shell portion comprises an additive selected from the group consisting of binders and fluxes.
20. A layered iron ore ball as claimed in claim 10, wherein the core portion and the shell portion have respectively a first moisture content and a second moisture content.
21. A layered iron ore ball as claimed in claim 10, wherein the first and the second iron oxide concentrates comprises an iron oxide selected from the group consisting of goethite, hematite, magnetite and mixtures thereof.
22. A layered iron ore ball as claimed in claim 10, wherein the at least one added internal fuel additive is selected from a group consisting of: coke, half-coke, pulverized coal, petroleum coke, low temperature coke, anthracite and a mixture thereof.
23. A layered iron ore ball as claimed in claim 10, wherein the layered iron ore ball has a diameter ranging between 9000 and 14 000 μm .
24. A layered iron ore ball as claimed in claim 10, wherein the core portion has a diameter ranging between 8000 and 11 000 μm .

25. Iron ore pellets resulting from an induration process applied on the layered agglomerated iron ore balls as claimed in claim 10.
26. Iron ore pellets as claimed in claim 25, wherein the iron ore pellets have a CCS above 350 kg/pellet.
27. Iron ore pellets as claimed in claim 25, wherein the layered agglomerated iron ore balls are fired in one of a moving grate furnace and a grate-kiln furnace.

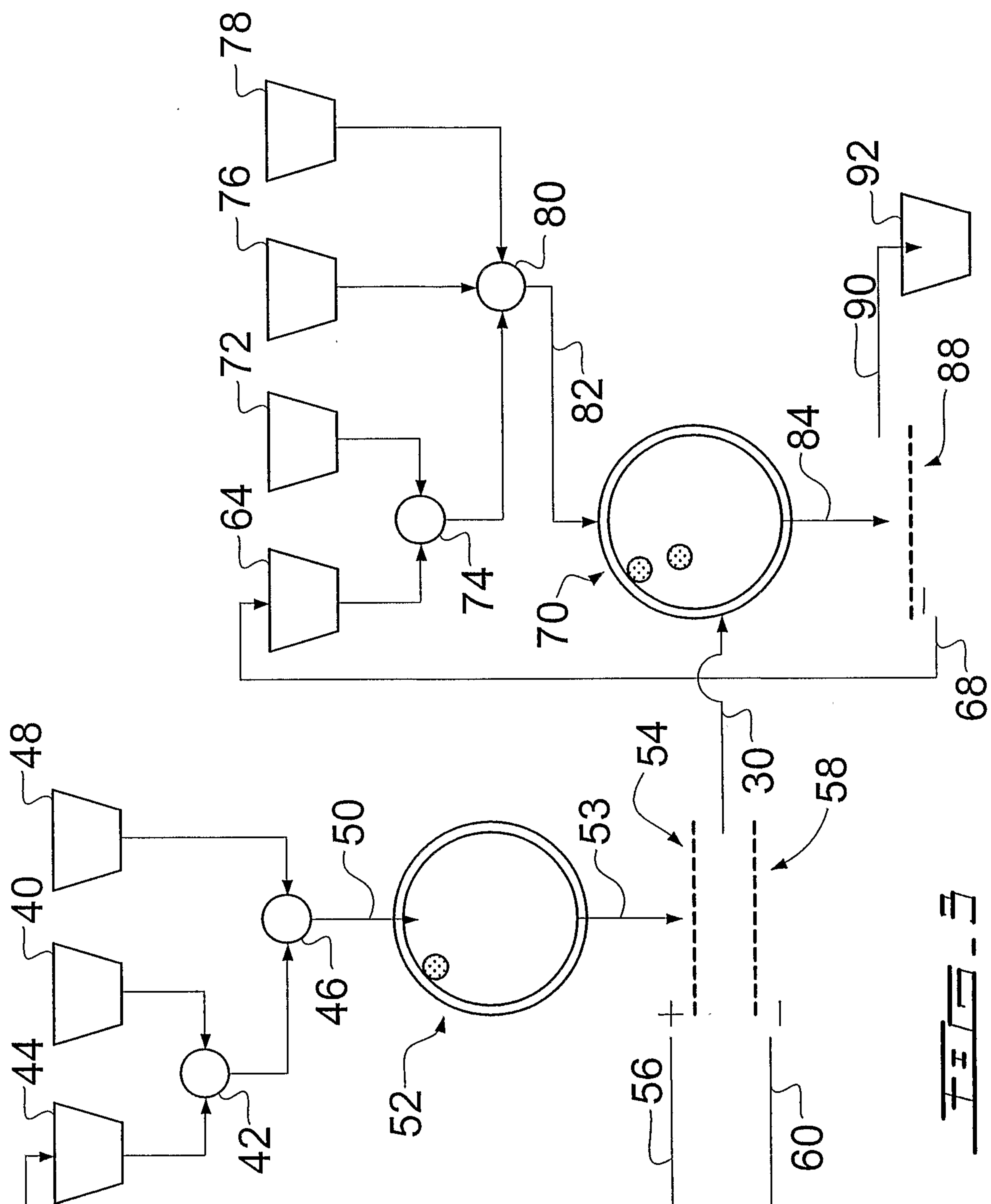
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FIG. 1 (PRIOR ART)

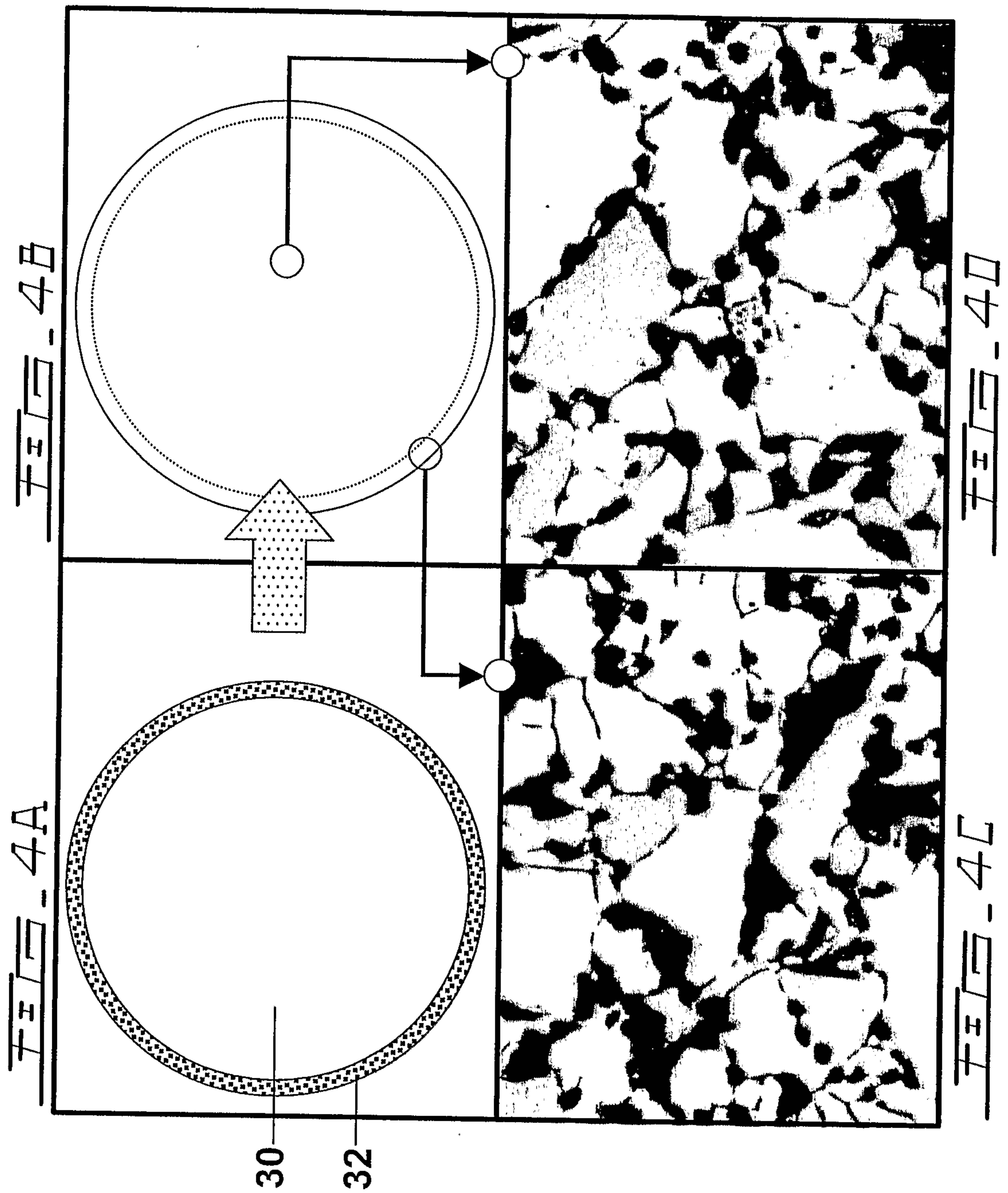
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4/8



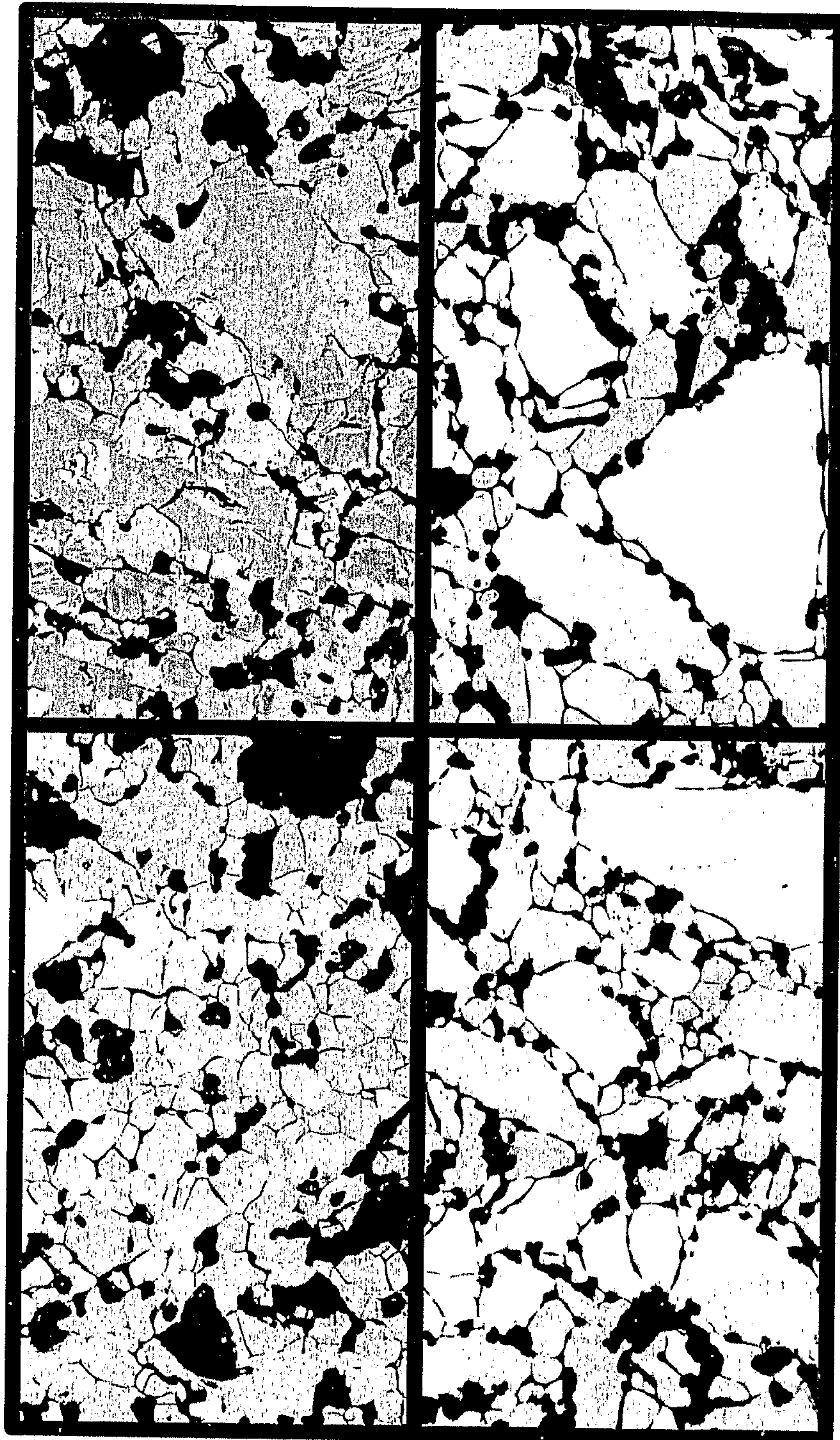
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FIG. 5B

Core

FIG. 5A

Shell portion



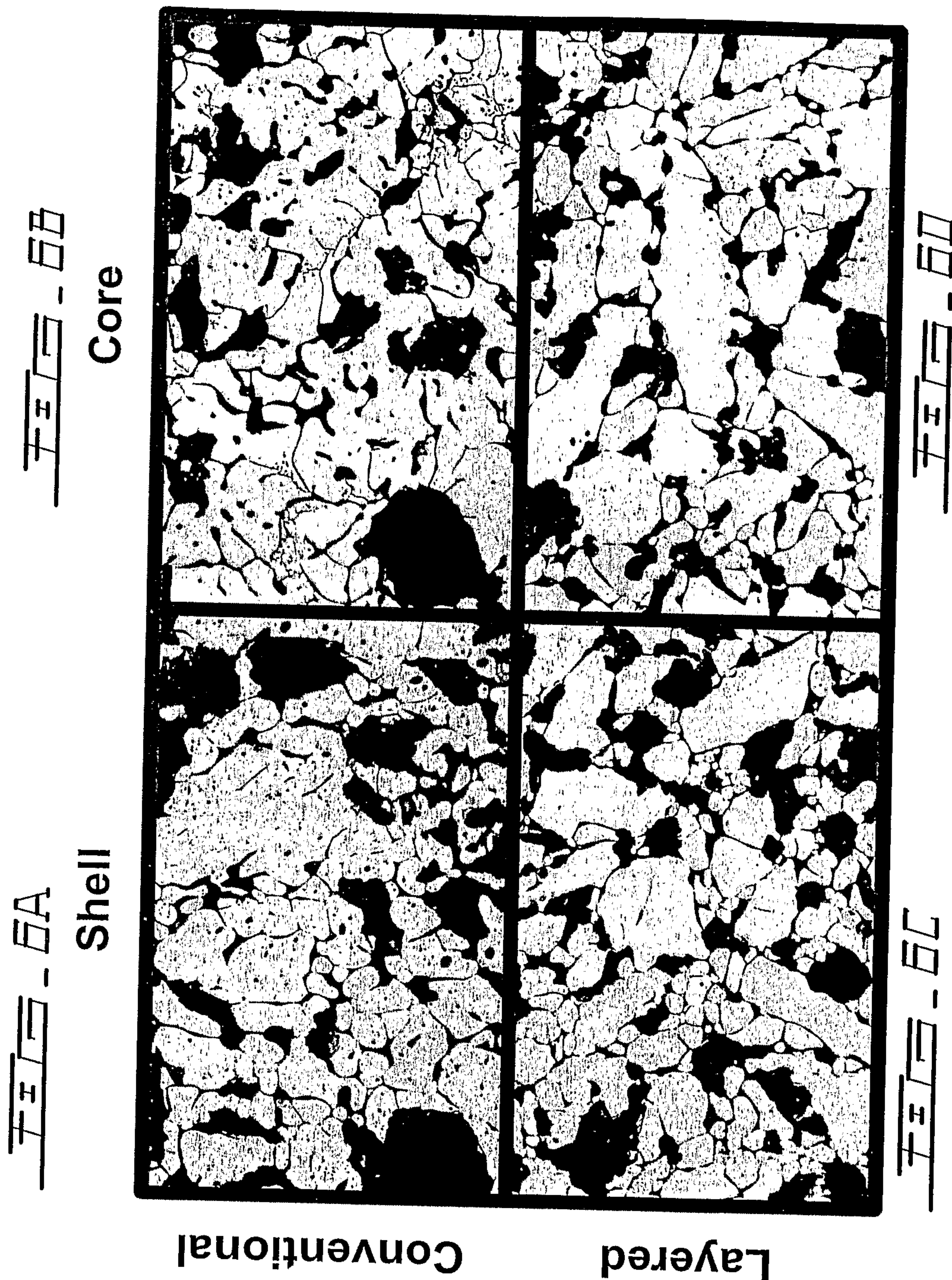
Conventional

Layered

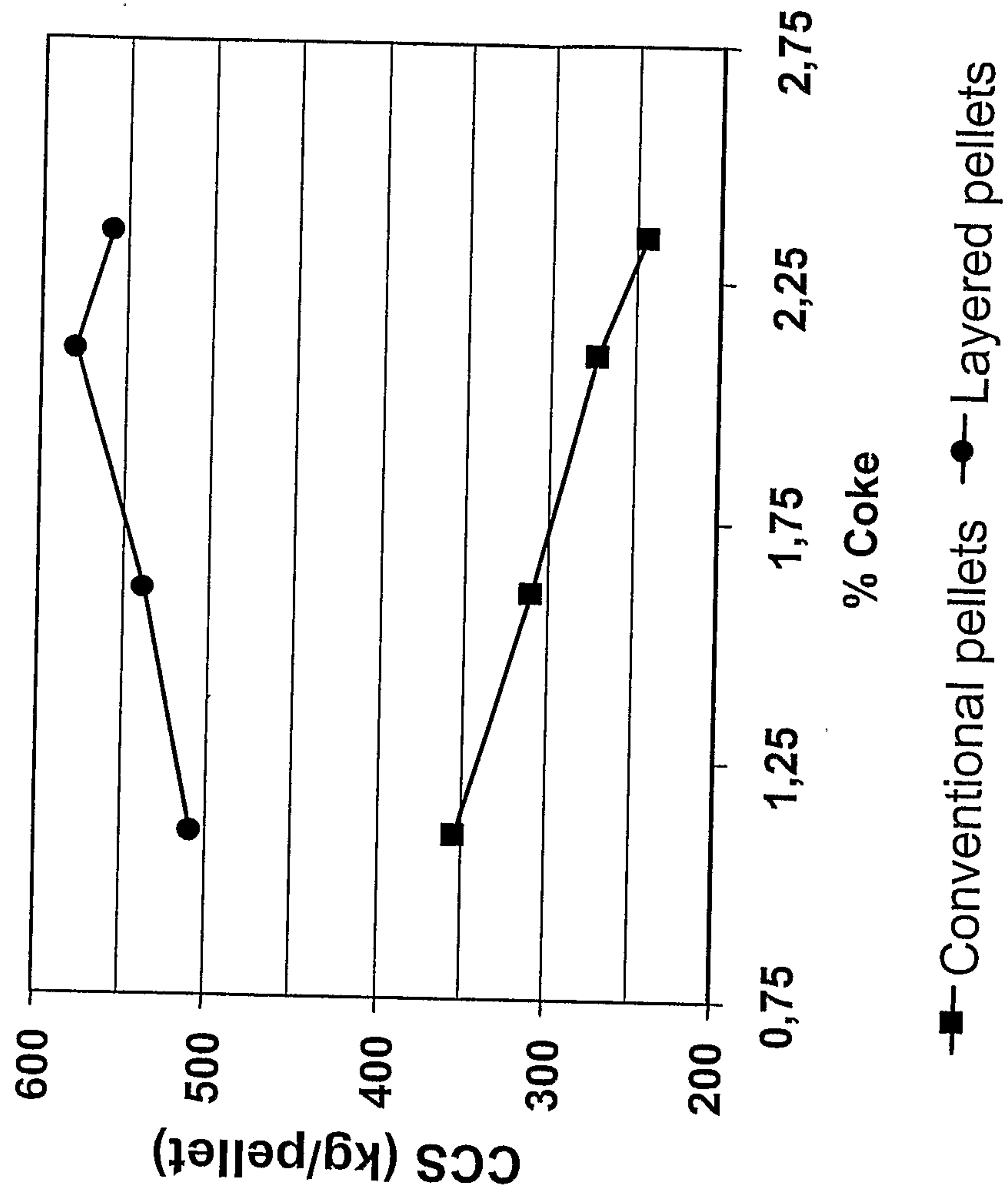
FIG. 5B

FIG. 5A

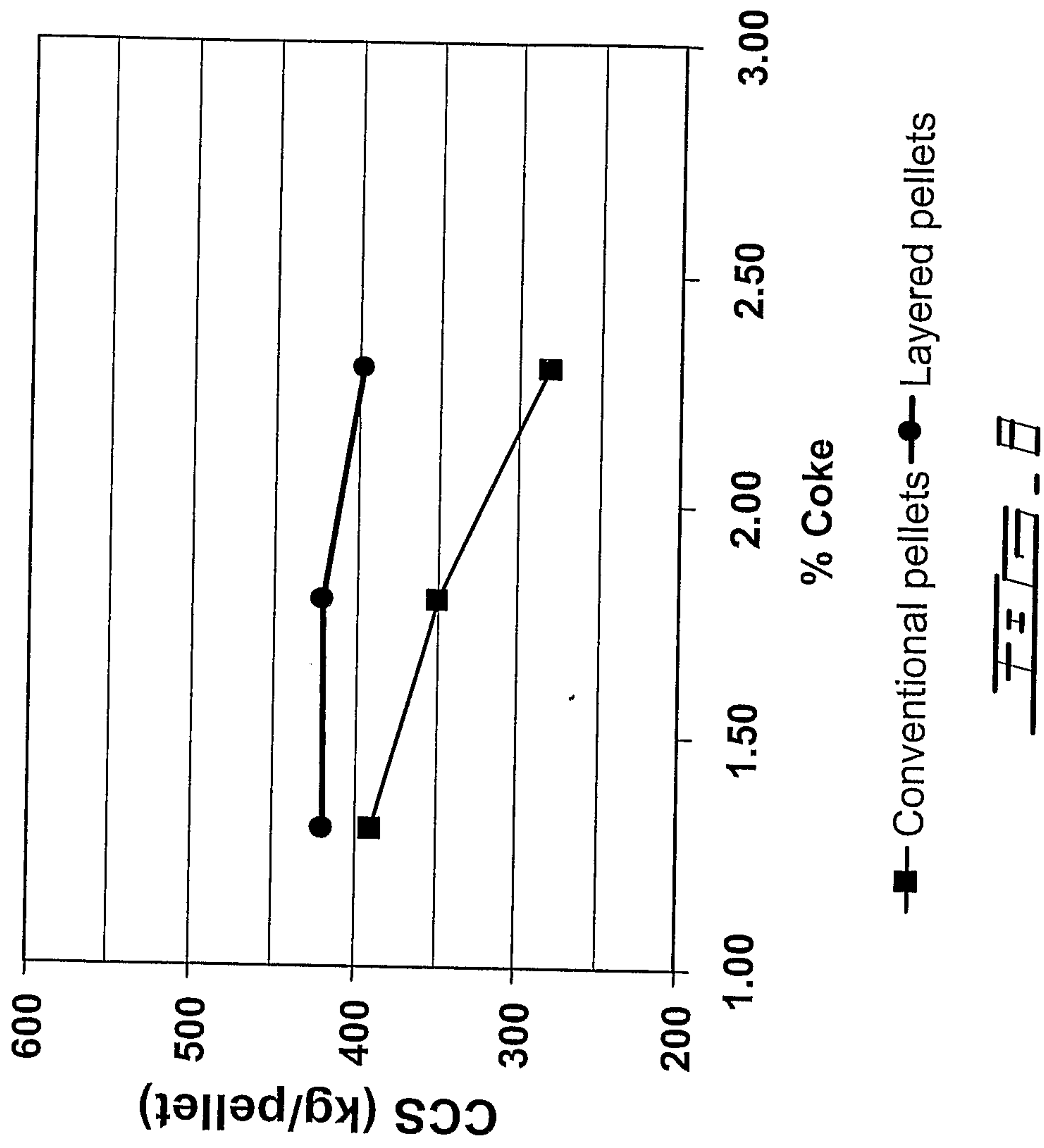
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FIG. 7

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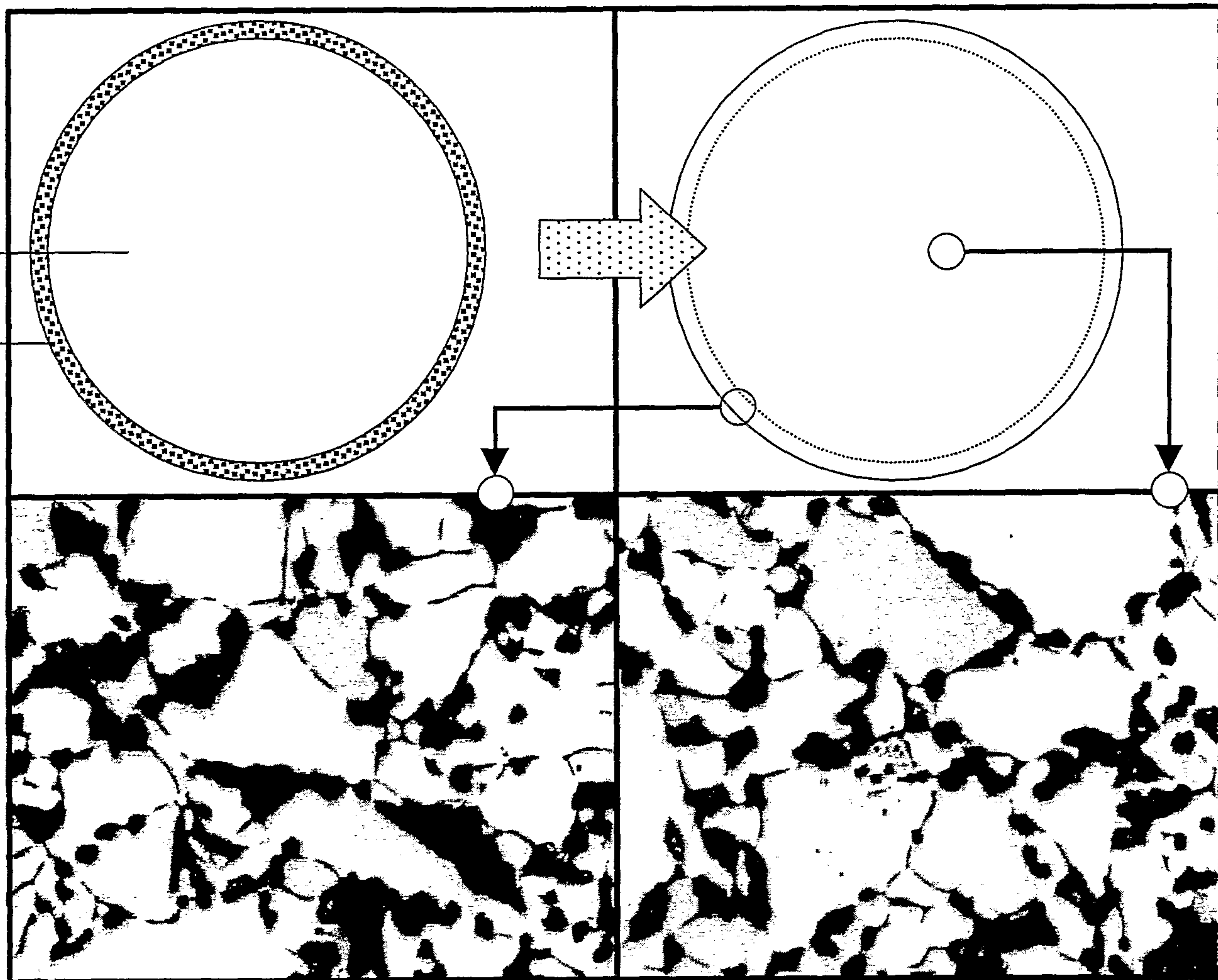


A

B

30

32



C

D