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Stadler

(54) ROTARY PLOUGH FOR GASIFIERS

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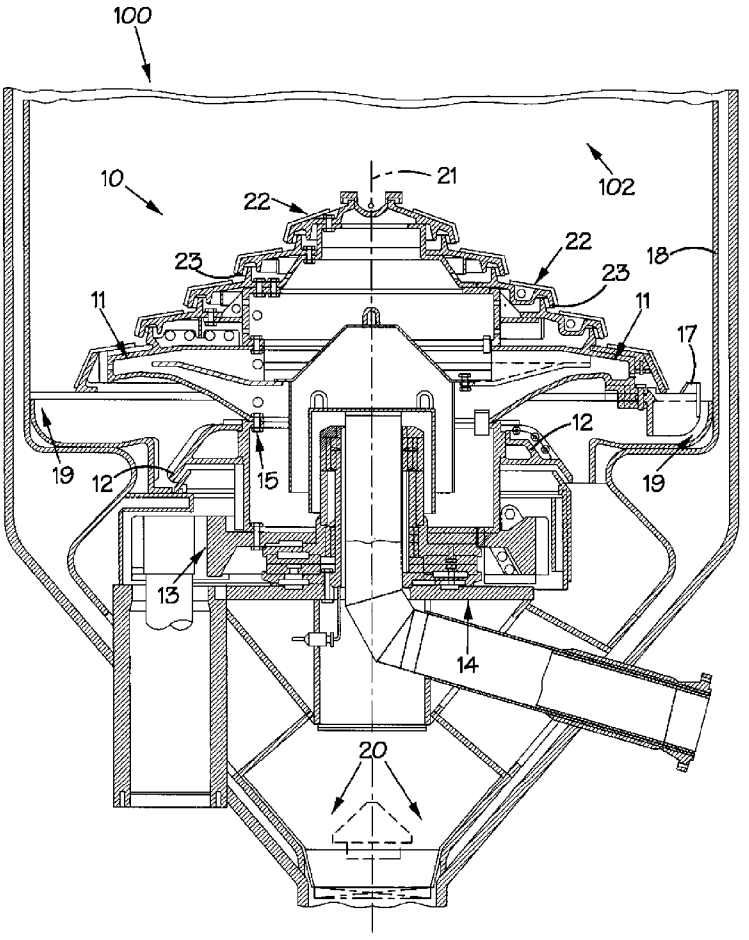
(57) **ABSTRACT**

A solids handling equipment rotary plough (**200**) includes an elongate metal body (**201**) with a leading face (**210**) and a trailing face (**212**). The body (**201**) is configured to be mounted to a rotary component for rotation about an axis of rotation at least in one direction which is an operative forward direction such that the leading face (**210**) leads the trailing face (**212**). At least the leading face (**210**) has at least two major operatively upwardly and outwardly extending surfaces (**202.1**, **204.1**) which are not coplanar. A first major surface (**202.1**) is angled operatively rearwardly and upwardly relative to the forward direction of rotation at an angle of at least 1° to the vertical. A second major surface (**204.1**) is angled operatively forwardly and outwardly at an angle of at least 1° relative to a radius of a circle described in use by the rotary plough (**200**) when rotating in the operative forward direction.



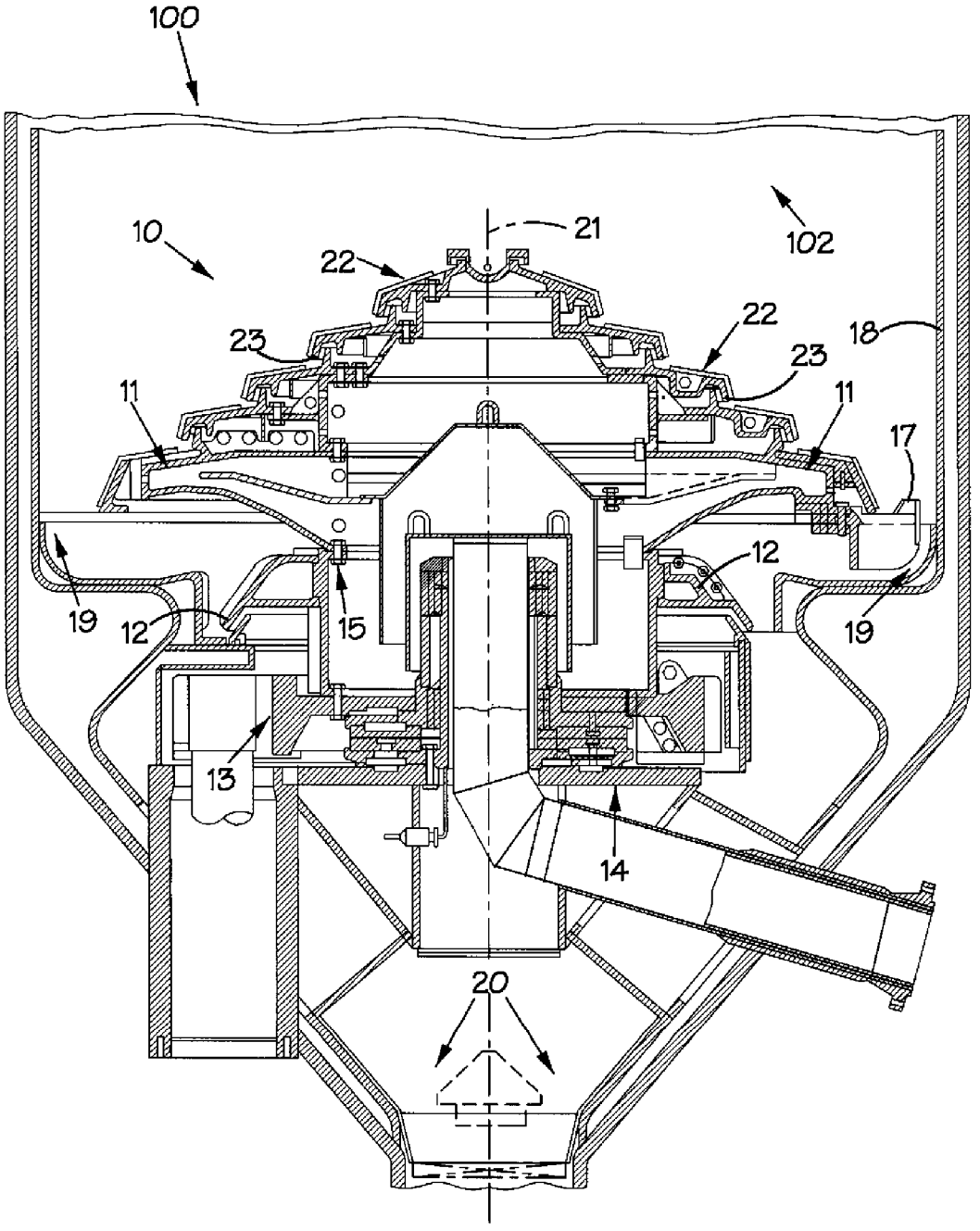


FIG 1

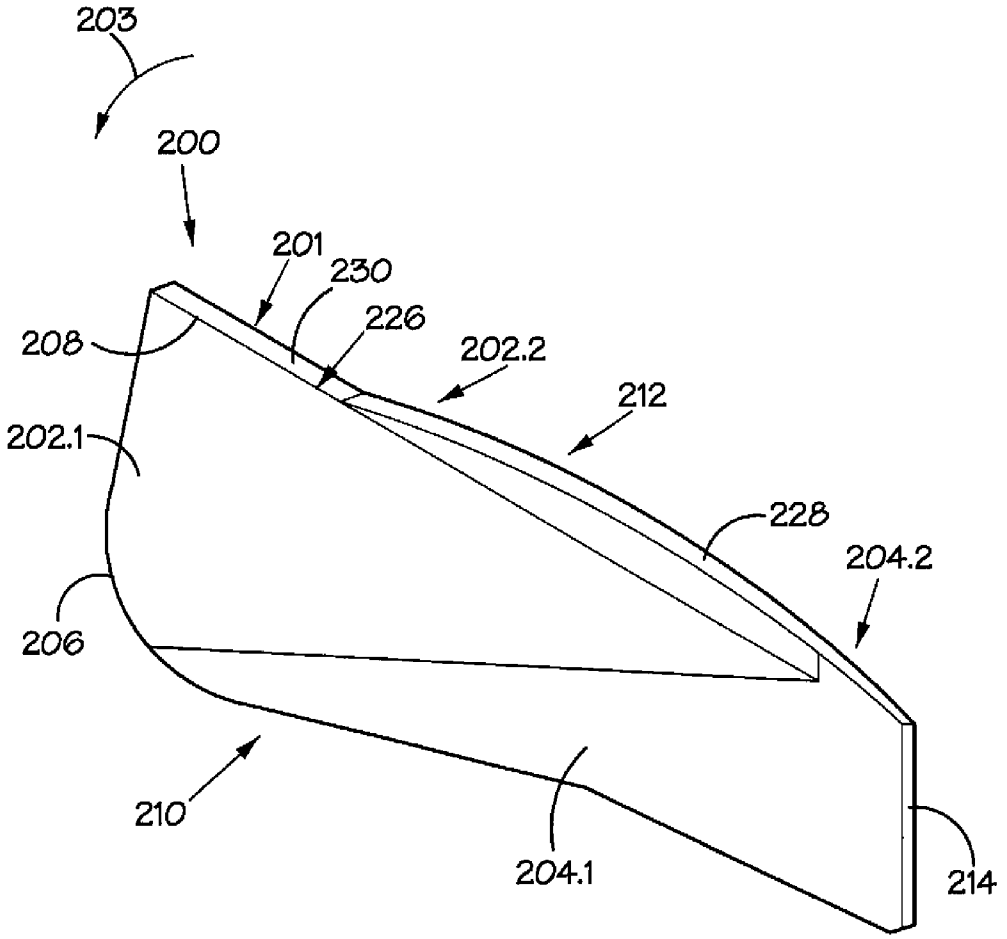


FIG 2

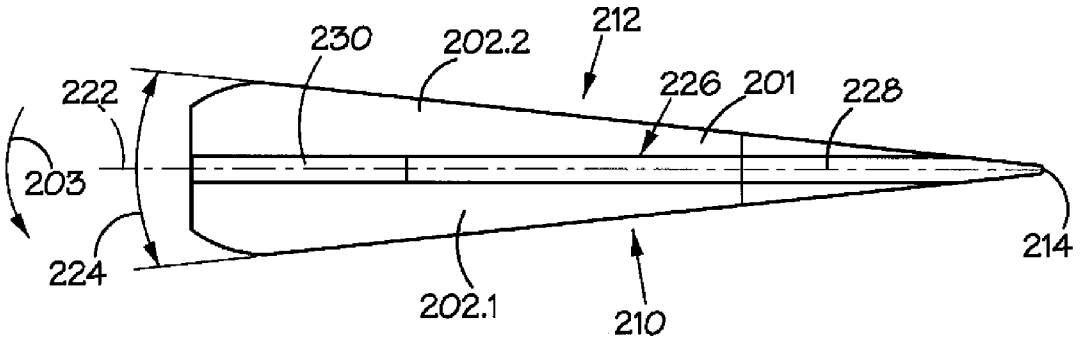

230
202.2
212
222
226
201
228
203
214
224
202.1
210

FIG 3

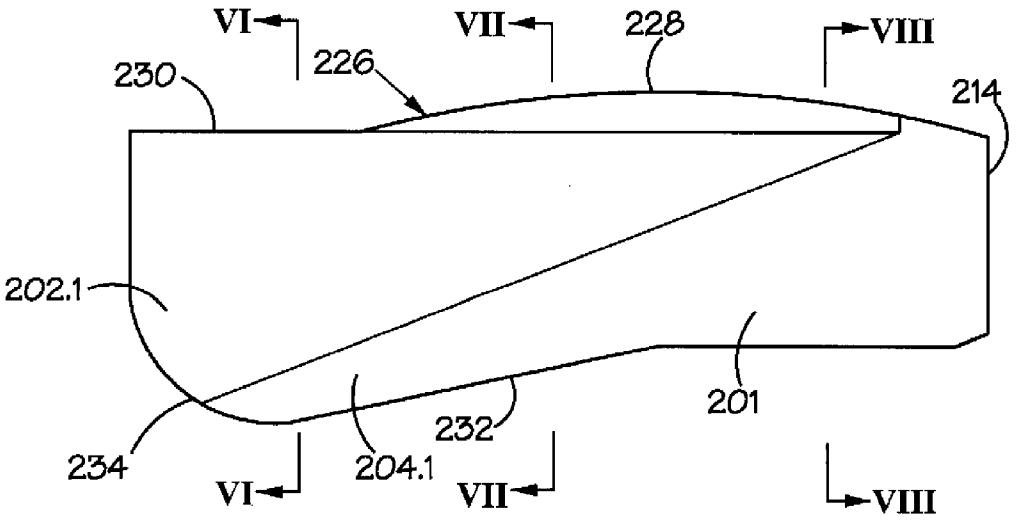

VI
VII
228
VIII
230
226
214
202.1
201
232
234
204.1
VI
VII
VIII

FIG 4

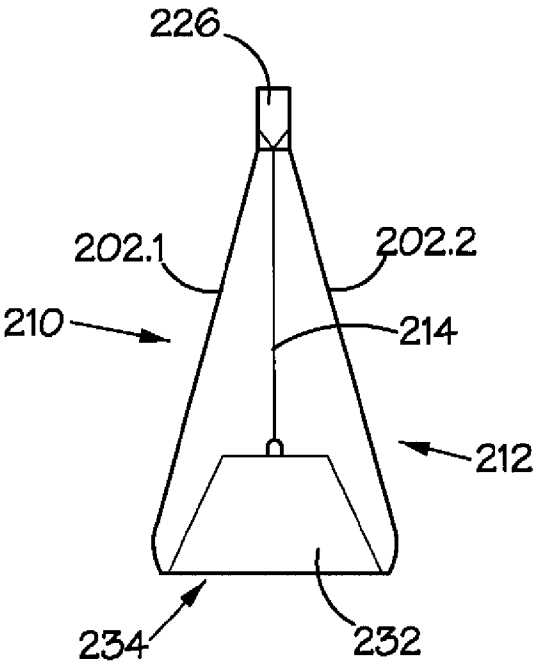
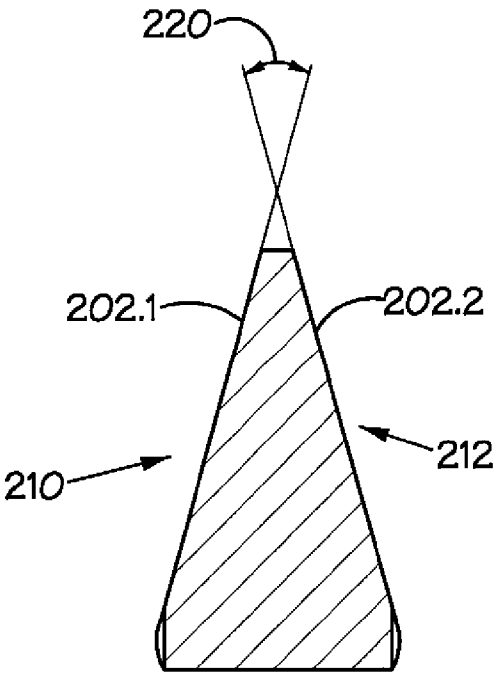
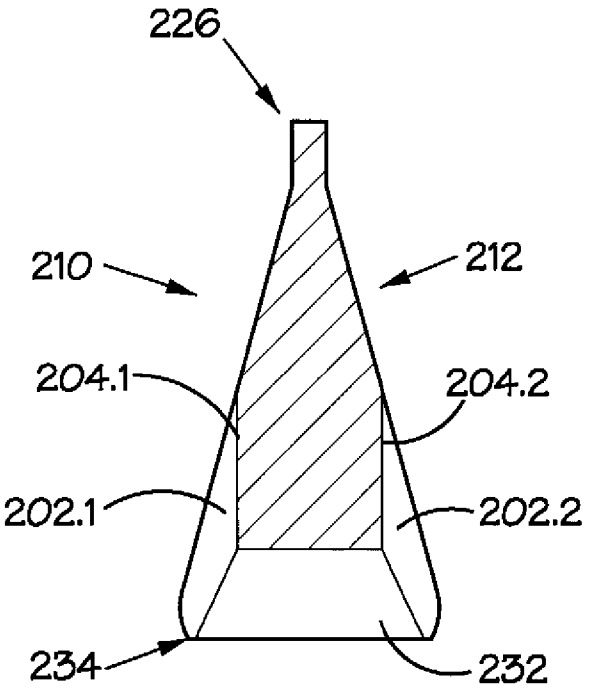


FIG 5



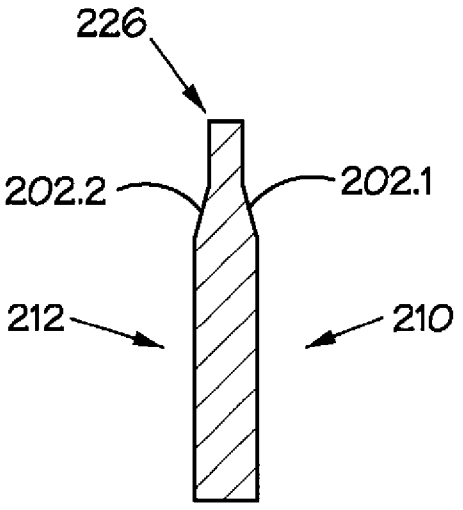
Section VI–VI

FIG 6



Section VI–VI

FIG 7



Section VI–VI

FIG 8

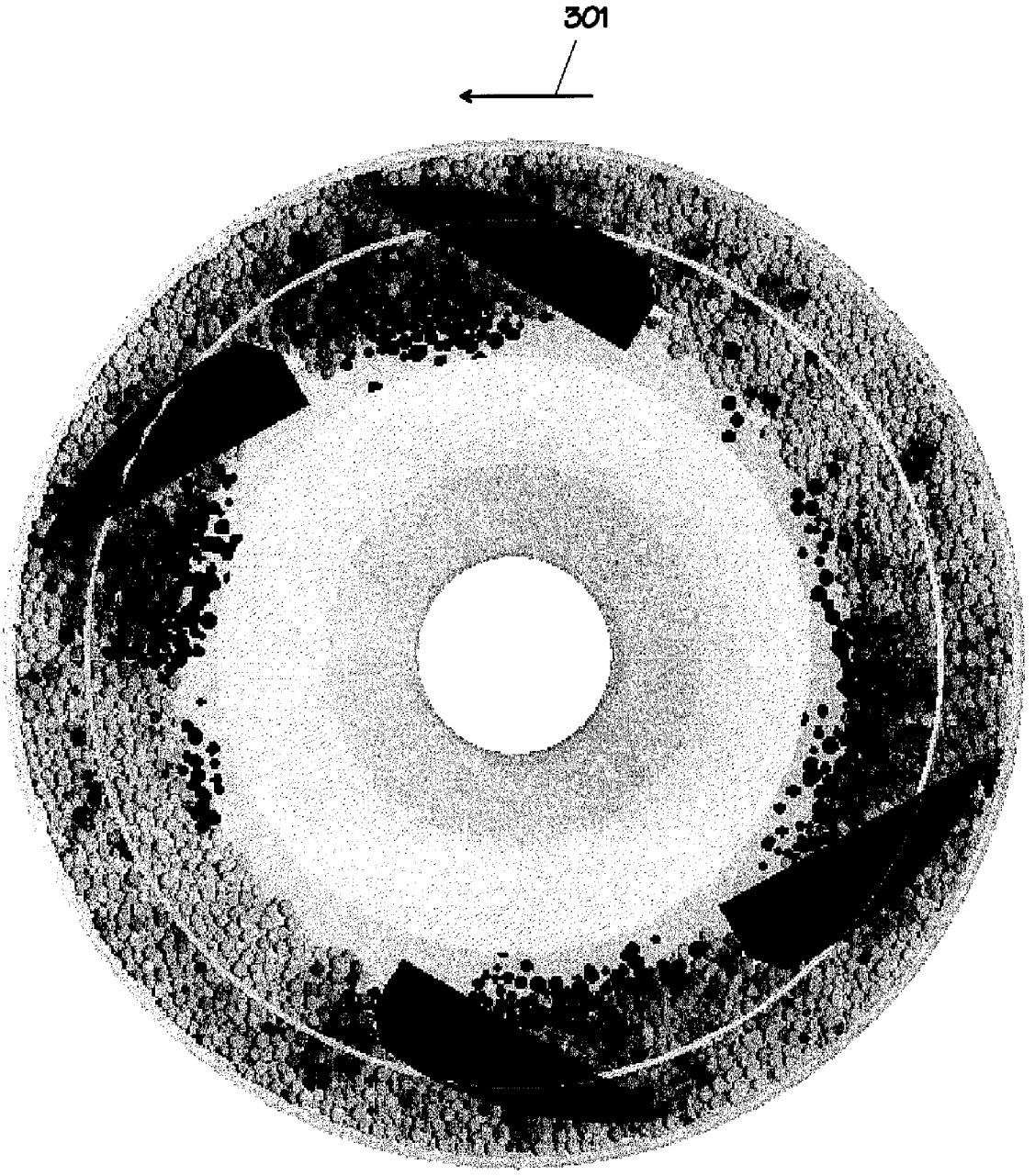


FIG 9A

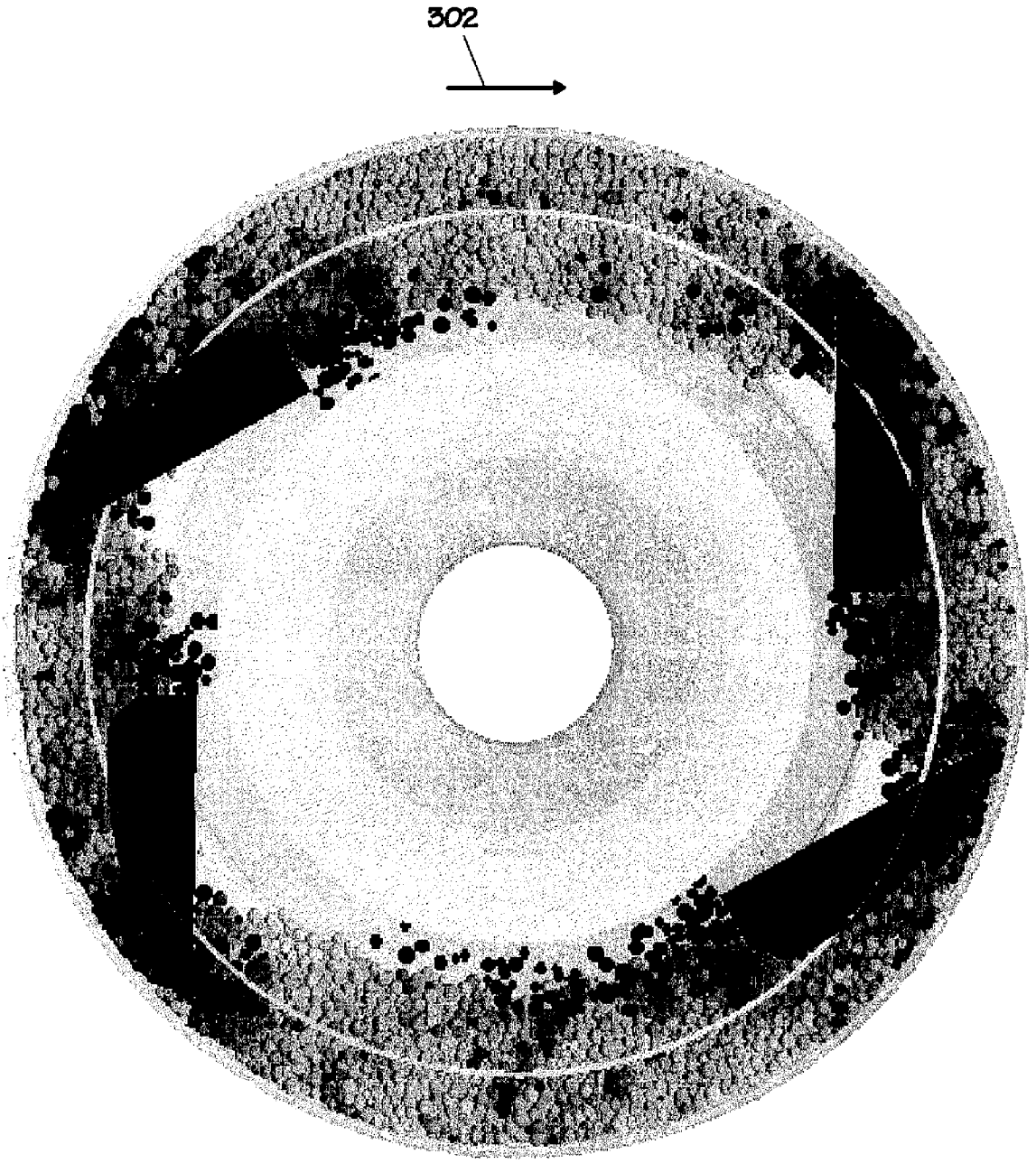


FIG 9B

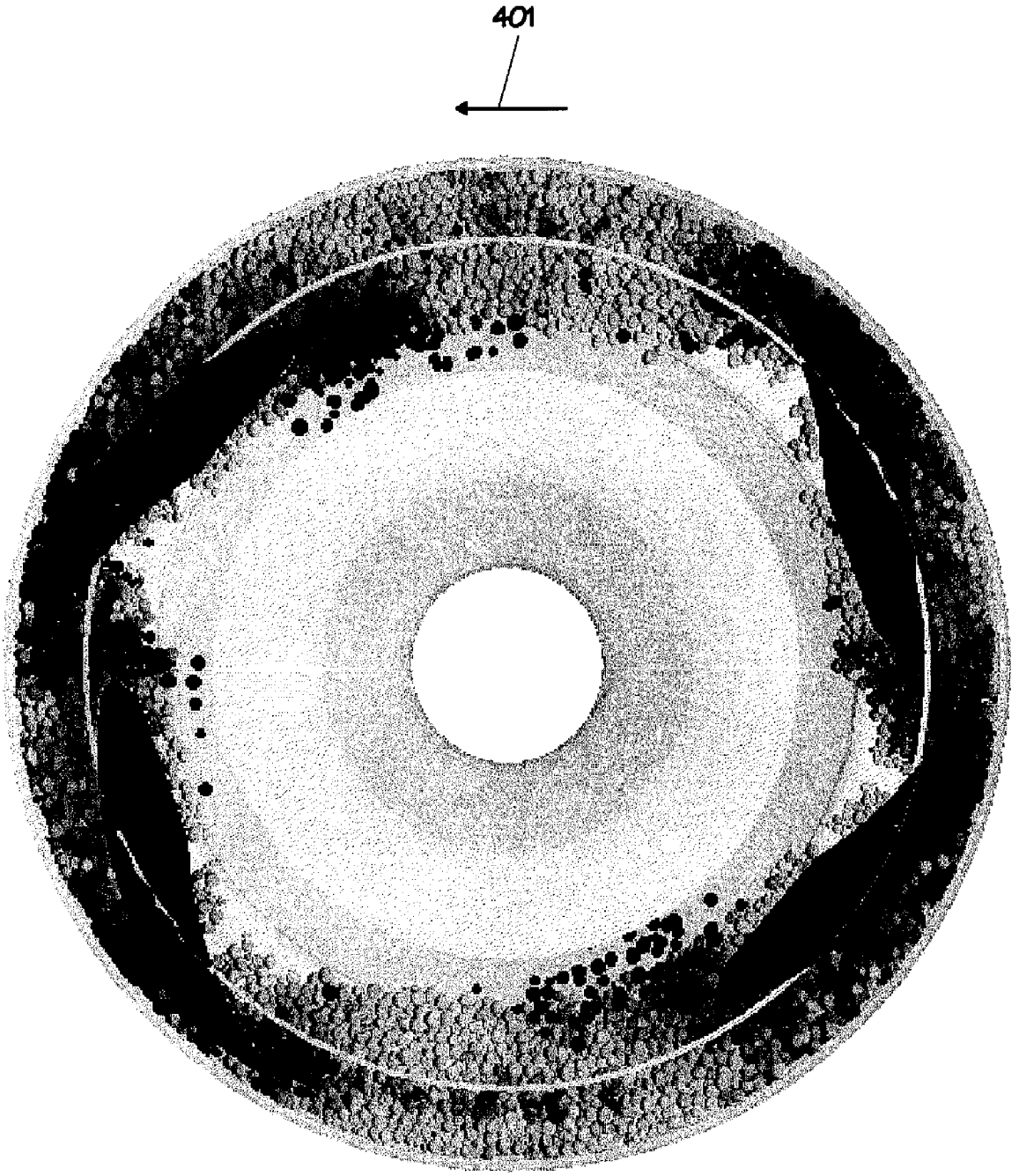


FIG 10A

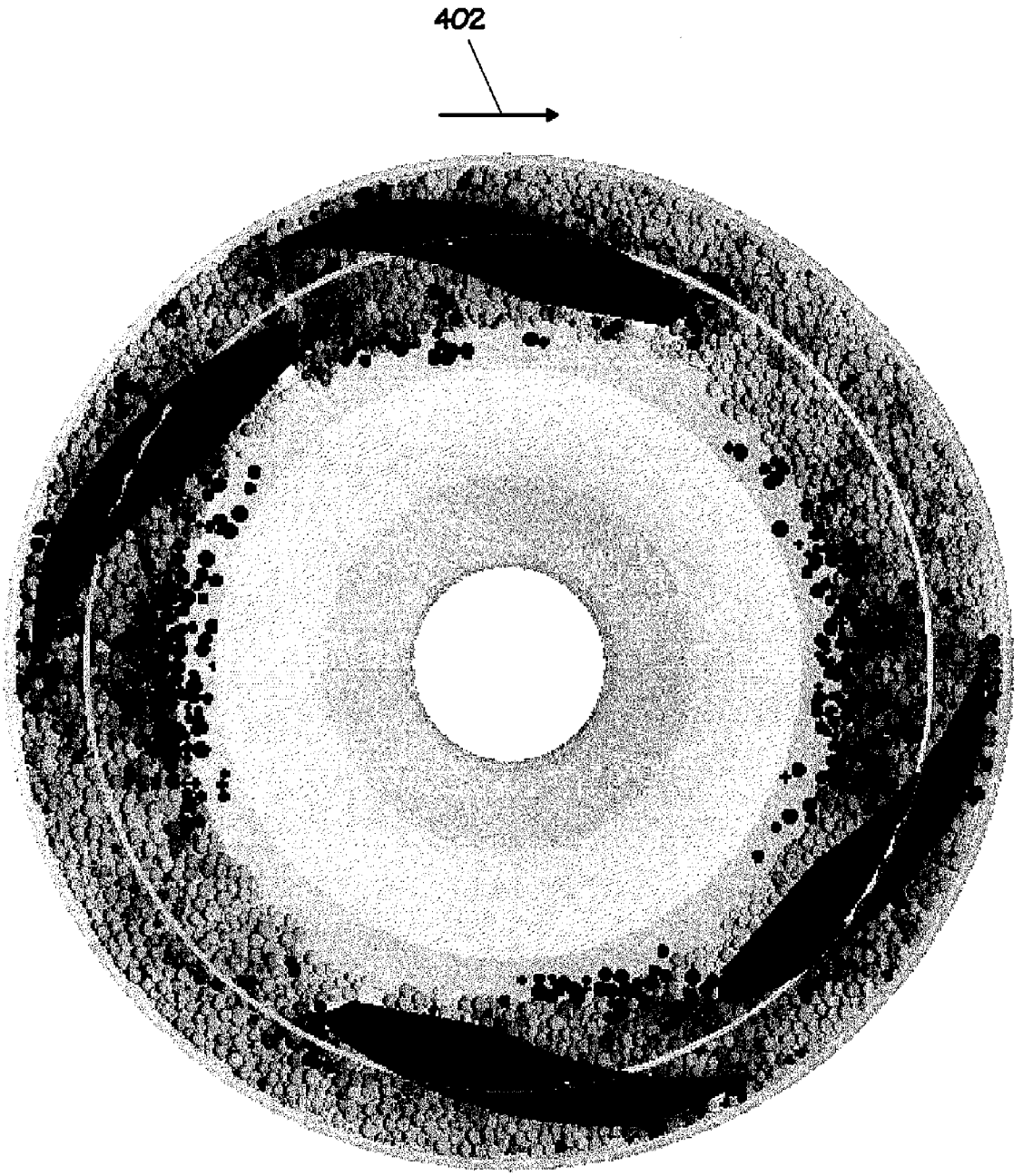


FIG 10B

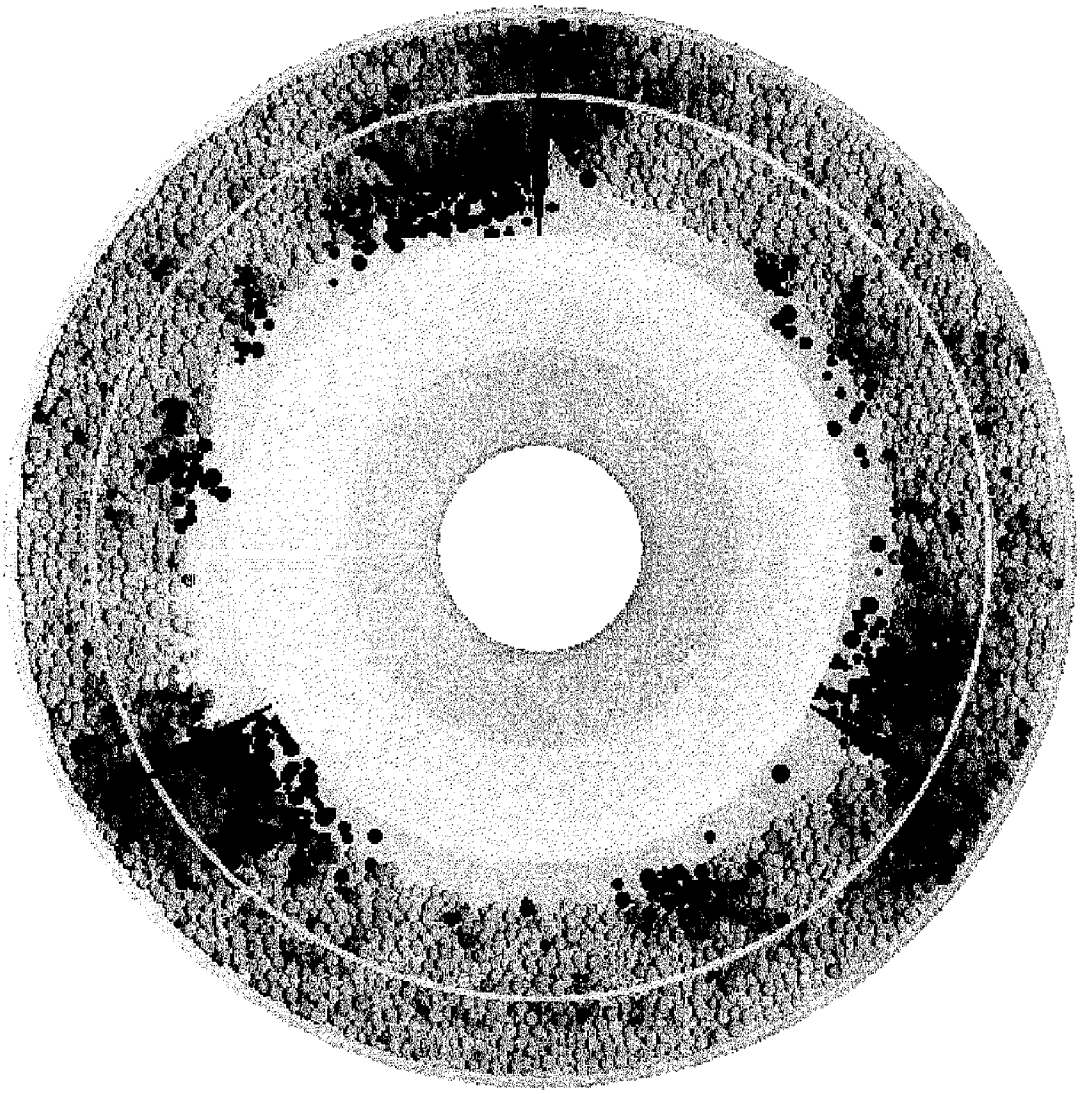


FIG 11

ROTARY PLOUGH FOR GASIFIERS

FIELD OF THE INVENTION

[0001] THIS INVENTION relates to gasifiers. In particular, the invention relates to a solids handling equipment rotary plough, to a rotatable grate assembly for a gasifier for gasifying carbonaceous material producing ash and to a gasifier for gasifying carbonaceous material.

BACKGROUND OF INVENTION

[0002] For some gasifiers, such as the Sasol® FBDB™ gasifier, it is necessary intermittently or continuously to load and unload particulate material, such as particulate carbonaceous material (e.g. coal) and ash. Thus, for example, in the case of a pressurized gasifier (e.g. a fixed bed dry bottom gasifier), particulate carbonaceous feedstock, e.g. coal, is loaded into a pressurised gasification chamber of the gasifier to form a bed (in the case of a fixed bed gasifier), and gasified at elevated temperatures and pressures, and after gasification any remaining ungasified material is removed from the gasifier as ash via a rotatable grate assembly and an ash lock.

[0003] The rotatable grate assembly has two main mechanical functions. Primarily it is used to extract ash from the bottom of the gasification chamber, but it is also used to crush and remove any ash agglomerates (clinkers) that may be formed in the gasification process. The rotatable grate assembly is also used to distribute gasification agent (typically a mixture of steam and oxygen) into the bed of carbonaceous material.

[0004] Typically, a conventional rotatable grate assembly comprises of a number of components, principally an upper roughly conical-shaped rotatable grate component, a lower rotatable support structure rigidly connected to the upper rotatable grate component at an upper periphery of the rotatable support structure so that the rotatable grate component and the rotatable support structure rotate together about a common axis of rotation and a ring gear connected at a lower periphery of the rotatable support structure. A lowermost stationary support structure is provided on which the rotatable components are supported. In use, the rotatable grate assembly is rotated when the ring gear which is drivingly connected to the lower rotatable support structure is driven via a motor and gearbox assembly which turns the rotatable components of the rotatable grate assembly.

[0005] As the rotatable grate assembly is rotated, one or more symmetrically circumferentially spaced ploughs which are rigidly connected to an outer periphery of the upper rotatable grate component act to remove the ash from the bottom of the gasifier. Ash consists of dry coarse ash and clinkers, which are by-products of the gasification process. Clinkers are solid agglomerates of particles of melted ash. Clinkers need to be crushed in order efficiently to be removed from the gasifier. The ploughs continuously scrape the ash through an ash discharge passageway which is defined between the upper rotatable grate component of the rotatable grate assembly and a wall of the gasifier. As the rotatable grate assembly rotates, the clinkers are crushed between shield plates mounted on the upper rotatable grate component and wear bricks mounted on the wall of the gasifier. The ash and clinkers fall under force of gravity from the ash discharge passageway into an ash lock which is in communication with the ash discharge passageway, to exit the gasifier.

[0006] The operation of and the removal of ash from a fixed bed gasifier are well known in the art and described in detail in WO 2006/061738.

[0007] The inventor has experience with two existing plough designs. The first is a conventional "short straight plough" and the second is the Sasol® Banana Plough™ which is currently in commercial use in South Africa in the Sasol® FBDB™ gasifier.

[0008] The major differences between the short straight plough and the Sasol® Banana Plough™ is that the short straight plough has planar leading and trailing faces, whereas the Sasol® Banana Plough™ has curved leading and trailing faces, with the leading and trailing faces curving in the same direction, resembling to some extent a banana. Both the short straight plough and the Sasol® Banana Plough™ are mounted on the upper rotatable grate component of the rotatable grate assembly at an angle to the direction of rotation, such that the leading face of the plough functions to scrape ash particles from an ash bed in a gasification chamber radially inwardly via a central ash discharge passageway or annulus into an ash chamber disposed below the rotatable grate assembly. Usually a number of ploughs, e.g. four ploughs, are symmetrically mounted on the rotatable grate assembly. Thus, during forward rotation of the rotatable grate assembly, the leading faces of each plough remove ash and crushed clinker particles from the gasifier by a scraping and cutting motion which causes the ash particles to follow a radially inward pathway from the wall of the gasifier to the central ash discharge annulus and into the ash chamber.

[0009] In the operation of the short straight plough, severe erosion on the ploughs and other components of the rotatable grate assembly has been observed. This lead to the making of improvements in the materials of construction of the rotatable grate assembly, e.g. by introducing custom made hard-facing to mitigate erosion, as well as by introducing a number of changes in the geometry of the plough and other wear surfaces exposed to ash particles. These changes, amongst others, lead to the development of the Sasol® Banana Plough™ which is in current commercial operation and has been for about 40 years.

[0010] The inventor has subsequently learned that the mode of ash removal with the Sasol® Banana Plough™ causes erosion of certain components of the rotatable grate assembly, ploughs and gasifier walls exposed to ash. Discrete element modelling has shown surprisingly that the forward rotation of a rotatable grate assembly on which the Sasol® Banana Plough™ is mounted causes the leading face of a trailing plough to force ash particles onto the trailing face of a preceding plough. Thus, ash particles become compressed between the trailing face of a leading plough, the gasifier wall and the leading face of a trailing plough. This causes an accumulation and compression of ash particles between the two ploughs, which leads to outward forces on the gasifier walls. Ash particles wedged between the ploughs and the gasifier wall cause erosion patterns on the gasifier walls and on the components of the grate assembly.

[0011] In an attempt to free the wedged ash particles, a grate may temporarily be operated in the reverse mode. This action however induces high torque loads on the drive systems which may eventually lead to mechanical equipment failure. Furthermore, erosion is increased during periods of reverse operation and ash extraction rates are also vastly reduced. Erosion leads to increased maintenance costs, equipment downtime and production loss. These are major

operational inefficiencies caused by the inability of the ploughs of the prior art to remove ash in both the forward and the reverse operational modes of a rotatable grate assembly.

[0012] WO 2006/061738 describes the components and the operation of a fixed bed coal gasifier. It discloses the use of the Sasol® Banana Plough™ in a fixed bed gasifier and its reverse mode of operation. The state of the art Sasol® Banana Plough™ is attached to a rotatable grate component such that the Sasol® Banana Plough™ passes with limited clearance over an ash collection surface. Ash is continuously withdrawn from the bottom of a gasification zone by rotation of the rotatable grate component and the Sasol® Banana Plough™ continuously discharges ash through an ash discharge passageway. WO 2006/061738 discloses the location and use of the Sasol® Banana Plough™ but is silent on the functional design of the Sasol® Banana Plough™. WO 2006/061738 also does not disclose any operational problems associated with the Sasol® Banana Plough™ or methods to solve them.

[0013] WO 1999/10094 specifically focuses on the grate component of a fixed bed coal gasifier and discloses information on the operation of the ash extraction assembly. It also discloses the use of the Sasol® Banana Plough™ which is operational in the reverse mode but does not disclose any information on its method of functioning.

[0014] U.S. Pat. No. 4,014,664 describes the components and operation of a rotary grate component assembly for a fixed bed coal gasifier, and the assembly appears to be similar to the grate assembly described in WO 2006/061738 and WO 1999/10094. U.S. Pat. No. 4,014,664 discloses that the scrapers are located on the periphery of the grate component and that the scrapers are operational in the reverse mode.

[0015] GB 389251 describes improvements in the mechanism of ash discharge in a Kerpely gas producer (Kerpely gas producers were often used for under firing coke ovens). GB 389251 discloses that scrapers are located at the periphery of a grate component and are arranged at an angle to the radius so that their rotation sweeps ash towards the centre of the grate component and into an ash discharge hopper.

[0016] U.S. Pat. No. 5,230,716 describes the components and operation of a reversible rotary grate component for a fixed bed coal gasifier. U.S. Pat. No. 5,230,716 discloses that scoops (ploughs) are located on an upper surface and near an apex of a conical grate component. In addition, each scoop is positioned at an angle to the radius of the gasification chamber and discharges ash from the central region of a gasification zone in the gasification chamber towards the peripheral region of the grate component to the ash discharge passageway. The location and operation of the scoop is therefore different to the state of the art Sasol® Banana Plough™ hereinbefore described.

[0017] U.S. Pat. No. 5,138,957 describes a bottom feed biomass gasification system that does not recirculate gases through a fixed bed. The gases are directed to a secondary heating chamber to maintain the desired operating temperature in a primary heating chamber. U.S. Pat. No. 5,138,957 discloses that the ash discharge system has four symmetrically spaced paddles that are mounted on the periphery of a rotary band which rotates in a clockwise direction. The paddles comprise "generally radial front walls" which appear to be vertical. The paddle surface (radial front walls) sweeps the ash forwardly to an ash discharge passageway located between the chamber wall and ash discharge system. When clinkers are formed, they are broken down between the rear walls of the paddles and the walls of the reaction chamber. There is no mention of ash being lodged between the ploughs or erosion of the paddles or chamber walls in U.S. Pat. No. 5,138,957.

[0018] JP 2011083773 describes a process for the removal of melted ash produced in a biomass gasification process. A rotary scraper spans the horizontal surface of a floor of a reaction chamber. A "scratching finger" is connected to ends of the rotary scraper. Slag is directed forwardly by the "scratching finger" and after a single revolution of the rotary scraper; the slag is discharged through a discharge outlet located between the wall of the reaction chamber and the rotary scraper. The design of the "scratching finger" is undisclosed, however, a top view of the "scratching finger" leads to the conclusion that it is rectangular in shape with vertical faces.

[0019] GB 548082 describes a mechanism for keeping a rotating plough in a rotatable gas generator stationary. In normal operation the plough rotates with an ash pan and gas producer and does not turn out ash. When the mechanism is engaged and the plough is held stationary, ash will be removed from the producer. The ash plough itself is not shown nor is its design or specific functioning described.

[0020] CN 2518061 describes the extraction of block-shaped lime from a vertical lime kiln. The extraction device is rotatable and reversible and has six scrapers that are symmetrically located around its circumference. CN 2518061 discloses that the scrapers are "triangle" in shape and "scrapes the ash inwardly to an ash discharge tube". The reverse mode of operation is required to "break the furnace conditions".

[0021] CA 2188736 describes a fixed bed biomass gasification system, of which a primary chamber has a raised table for supporting the bed of biomass. The waste removal system consists of four ploughs that are symmetrically located at the periphery of a ring member on a rotating table and removes ash and waste from the chamber to accumulate in a channel that spans the chamber wall. The ash and waste material are then pushed to a waste aperture located in the floor of the chamber. Two of the ploughs are formed with scraping members that extend inwardly towards an apex of the table to scrape ash from the annular zone to the waste aperture. The scraping members also break up clinkers that form on the edge of the table. From a top view of the waste disposal system, it appears that the ploughs are fin-shaped and the scraping members are rectangularly shaped. CA 2188736 however does not provide any actual description of the design or shape of the ploughs. CA 2188736 is also silent on the reversibility of the waste disposal system.

[0022] GB 141056 relates to improvements to rotary grates employed in gas producers. The ash grates disclosed are conical in shape and attached to a top surface of the grate are radial projections with the leading surface of the projection rising rearwards from the leading edge. The front surfaces of the projections are convex and when the grate rotates will raise the combustible material and ash above the grate to prevent clinkering. These projections do not remove ash from the ash bed. The conical shape of the grate also causes ash to move to the sides where an annulus is provided with stationary scrapers attached to the inside of vessel wall of the gas producer for ash removal. The ash grate projections in GB 141056 serve for clinker breaking and mixing above the grate. GB 141056 is silent on the functional design of the scraper itself. As ash is removed toward the periphery in GB 141056, no surface is provided for displacing ash radially inward.

[0023] EP 0159420 describes the gasification of solid fuel in a fixed bed system. There are two different sets of scrapers in the fixed bed gasifier for the extraction of ash. Radially extending walls continue downwards and extend inwardly into the chamber above a grate component to form "upper scraper members". These scrapers are fixed to the chamber walls. In addition, there are a set of scrapers attached below the grate component that are described as "vertically reciprocable scrapers". From the longitudinal section view of the gasification system, each "vertically reciprocable scraper" appears to span the left and right bottom surface of the grate and extends to the apex of the grate and central portion. The oscillating rotary motion of the grate component and the "vertically reciprocable scrapers" is controlled to be slightly more or less than the circumferential angle of 30°. The "vertically reciprocable scrapers" sweep ash over the periphery of the grate component to the ash discharge tube. The design aspects of the scrapers are undisclosed in EP 0159420.

[0024] A plough that at least ameliorates the problems associated with the ploughs of the prior art and is preferably able effectively to remove ash in both the forward and reverse operational modes of a rotatable grate assembly would be desirable.

SUMMARY OF THE INVENTION

[0025] According to one aspect of the invention there is provided a solids handling equipment rotary plough, the rotary plough including

[0026] an elongate metal body having a leading face and a trailing face and being configured to be mounted to a rotary component for rotation about an axis of rotation at least in one direction which is an operative forward direction such that the leading face leads the trailing face, at least the leading face having at least two major operatively upwardly and outwardly extending surfaces which are not coplanar, a first major surface being angled operatively rearwardly and upwardly relative to the forward direction of rotation at an angle of at least 1° to the vertical and a second major surface being angled operatively forwardly and outwardly at an angle of at least 1° relative to a radius of a circle described in use by the rotary plough when rotating in the operative forward direction.

[0027] By "major surfaces" of a face is meant that there are no other surfaces on the face which are larger than the major surfaces. Each major surface is typically planar.

[0028] In this specification, unless clearly intended otherwise in the context used, the term "radius" or "radially" is used to describe a direction or position relative to or coinciding with the radius of a circle in use described by the rotary plough when rotating in a plane through which said axis of rotation extends. Thus, a radially outer or radially outward object or part is further away from said axis of rotation of the metal body of the rotary plough than a radially inner or radially inward object or part. It is however to be noted that "outwardly" means outwardly away from said axis of rotation, although not necessarily along a radius of said circle, unless so specified, with the term "inwardly" having an opposite meaning.

[0029] Typically, in use, said plane through which said axis of rotation extends is a horizontal plane.

[0030] The metal body may be of hardened steel. Alternatively, the metal body may be of casting steel, e.g. a specially modified heat resistant iron-chromium-nickel alloy of ASTM A297 Grade HF. The major surfaces may be clad in a specially hardened material, e.g. a hardfacing such as PRO 100 (trade name) hardfacing.

[0031] The trailing face may have at least two major surfaces which are not coplanar, a first major surface being angled forwardly and upwardly relative to the forward direction of rotation at an angle of at least 1° to the vertical and a second major surface being angled rearwardly and outwardly at an angle of at least 1° relative to a radius of a circle described in use by the rotary plough when rotating in the forward direction.

[0032] The first and second major surfaces of the leading face may share a common periphery or edge between them. In other words, the first and second major surfaces may be adjacent to and bordering each other.

[0033] The common periphery or edge of the first and second major surfaces of the leading surface may be linear and may extend downwardly in an outward direction.

[0034] The common periphery or edge of the first and second major surfaces of the leading surface may be angled forwardly relative to a radius of a circle described in use by the rotary plough when rotating in the forward direction.

[0035] The common periphery or edge of the first and second major surfaces of the leading surface may define at least a portion of a top periphery of the second major surface.

[0036] The common periphery or edge of the first and second major surfaces of the leading surface may define at least a portion of a bottom periphery of the first major surface.

[0037] The first and second major surfaces of the trailing surface may share a common periphery or edge between them.

[0038] The common periphery or edge of the first and second major surfaces of the trailing surface may be linear and may extend downwardly in an outward direction, and may be angled rearwardly relative to a radius of a circle described in use by the rotary plough when rotating in the forward direction.

[0039] The angle of the first surface to the vertical may be in the range of from about 1° to about 35°, e.g. about 15°.

[0040] The angle of the second surface relative to said radius of said circle described in use by the rotary plough when rotating in the forward direction may be in the range of from about 1° to about 18°, e.g. about 6°.

[0041] The second surface may extend operatively vertically.

[0042] The trailing face of the body of the rotary plough may be a mirror image of the leading face of the body of the rotary plough. Thus, the trailing face and the leading face may be mirrored about a radius plane defined by the rotary plough in use.

[0043] The body may have a linear centre line, or may be configured to be mounted such that it extends radially outwardly from where it is mounted to a rotary component. A spine may be defined between the leading and trailing faces. The spine may be planar and the spine may coincide in use with a radius of said circle described by the rotary plough when rotating in the operative forward direction. The spine may have a curved upper periphery over at least a portion of the length of the spine. In one embodiment of the invention, a radially outer portion of the upper periphery of the spine is flat and a radially inner portion of the upper periphery of the spine is convexly curved.

[0044] A radially outward portion of the body may have an increased height compared to a radially inward portion of the

body. Preferably, a bottom surface of the body drops down radially outwardly to end in a rounded upwardly curved toe.

[0045] According to another aspect of the invention, there is provided a rotatable grate assembly for a gasifier for gasifying carbonaceous material producing ash, the grate assembly including

[0046] a rotary component configured for rotation about an upwardly extending axis of rotation, the rotary component being configured for rotation at least in one direction which is an operative forward direction; and

[0047] a plurality of rotary ploughs as hereinbefore described, the rotary ploughs being mounted to the rotary component for rotation together with the rotary component about said axis of rotation and the rotary ploughs extending outwardly away from said axis of rotation.

[0048] The rotary component may be an upper rotatable grate component, the rotatable grate assembly further including a lower rotatable support structure fastened to the upper rotatable grate component for rotation together with the upper rotatable grate component, the lower rotatable support structure being configured to be drivingly rotated about an axis of rotation which coincides with said axis of rotation of the upper rotatable grate component.

[0049] Typically, said axis of rotation of the upper rotatable grate component is vertical.

[0050] The rotary component may be configured for rotation in both said operative forward direction and an operative reverse direction. Thus, the grate assembly may be operable in both said forward direction and said reverse direction.

[0051] The rotary ploughs may extend radially away from said axis of rotation. Thus, an end of a rotary plough where the rotary plough is mounted to the rotary component may be radially in line with a free end of said rotary plough.

[0052] In this specification, the term "component" is intended to include an assembled component including more than one part, such as a rotatable grate component comprising a number of parts assembled to form the grate component.

[0053] The rotatable grate component may have an upwardly inwardly tapering outer surface. The upwardly inwardly tapering outer surface may be staggered or stepped when seen in vertical cross-section, defining vertically and radially spaced terraces. The terraces may be covered by shield plates to protect the rotatable grate component from abrasive material, e.g. ash.

[0054] The rotary ploughs may be equiangularly spaced. Thus, for example, when only two rotary ploughs are present, they may be about 180° apart, when three rotary ploughs are present, they may be about 120° apart, when four rotary ploughs are present, they may be about 90° apart, and when six rotary ploughs are present, they may be about 60° apart. It may however be that the arrangement of the rotary ploughs is not symmetrical due to construction constraints (other components in the way, etc.), particularly when the rotary plough of the invention is retrofitted to an existing rotatable grate assembly. Large variations in spacing between rotary ploughs, e.g. up to 60° variation, may be employed.

[0055] It is expected that up to six rotary ploughs may be mounted to the rotary component.

[0056] According to a further aspect of the invention, there is provided a gasifier for gasifying carbonaceous material, the gasifier including a rotatable grate assembly as hereinbefore described, the rotatable grate assembly being mounted within a gasification chamber defined by a gasification vessel with the lower rotatable support structure of the grate assembly being connected to drive means.

[0057] The gasifier may be a fixed bed gasifier, in particular a fixed bed dry bottom gasifier.

[0058] The gasifier may be a coal, waste or biomass gasifier, or a gasifier configured to gasify a combination of two or more of coal, waste and biomass. Typically however, the gasifier is a coal gasifier operating at a pressure of between 5 bar(g) and 100 bar(g) and a temperature of between 400° C. and 1600° C.

[0059] The rotatable grate component typically has a vertical dimension and a radial direction and is rotatable about a vertical axis of an ash discharge outlet of the gasification chamber, with a lower periphery of the rotatable grate component being below an apex or upper end of the rotatable grate component.

BRIEF DESCRIPTION OF THE DRAWINGS

[0060] The invention will now be further described, by way of example, with reference to the accompanying diagrammatic drawings in which:

[0061] FIG. **1** shows a vertically sectioned view of a rotatable grate assembly, installed in a fixed bed dry bottom coal gasifier;

[0062] FIG. **2** shows a three dimensional view of a rotary plough in accordance with the invention;

[0063] FIG. **3** shows a plan view of the rotary plough of FIG. **2**;

[0064] FIG. **4** shows a side view of the rotary plough of FIG. **2**;

[0065] FIG. **5** shows an end view of the rotary plough of FIG. **2**;

[0066] FIG. **6** shows a vertical section through the rotary plough of FIG. **2**, taken at VI-VI in FIG. **4**;

[0067] FIG. **7** shows a vertical section through the rotary plough of FIG. **2**, taken at VII-VII in FIG. **4**;

[0068] FIG. **8** shows a vertical section through the rotary plough of FIG. **2**, taken at VIII-VIII in FIG. **4**;

[0069] FIG. **9** shows the velocity of ash particles displaced by a short straight plough in (A) the forward and (B) the reverse direction;

[0070] FIG. **10** shows the velocity of ash particles displaced by a Sasol® Banana Plough™ in (A) the forward and (B) the reverse direction; and

[0071] FIG. **11** shows the velocity of ash particles displaced by a rotary ash plough in accordance with the invention having mirror image leading and trailing faces, in both the forward and reverse directions.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0072] With reference to FIG. **1** of the drawings, reference numeral **10** generally refers to a grate assembly installed in a gasification vessel **100** of a fixed bed dry bottom coal gasifier. The gasification vessel **100** defines a gasification chamber **102** (a pressure vessel) within which the grate assembly **10** is located. The gasification chamber **102** has a wall **18**.

[0073] The grate assembly **10** comprises an upper rotatable grate component **11**, connected to a lower rotatable support structure **12** by a plurality of connecting bolts **15**. The lower rotatable support structure **12** is drivingly connected to a ring gear **13** which is in turn connected through a gearbox to an electric motor (not shown). In use, the electric motor and

gearbox are used to rotate the rotatable components **11**, **12** and **13** of the grate assembly **10**.

[0074] The rotatable components **11**, **12** and **13** are supported by a stationary support structure **14** above an ash discharge outlet or passageway **20** of the gasification vessel **100**. One or more rotary metal ash ploughs **17** are connected to a radially outermost periphery of the upper rotatable grate component **11**. The ploughs **17** are used to scrape ash from an ash bed within the gasification chamber **102** through an ash discharge annulus **19** which is defined between the outer periphery of the upper rotatable grate component **11** and the wall **18** of the gasification chamber **102**. The ploughs **17** may be of the short straight type or the Sasol® Banana Plough™ as hereinbefore described, or an improved rotary ash plough according to the present invention. Conveniently, the upper rotatable grate component **11** is configured to allow the ploughs **17** to be readily interchangeable.

[0075] The upper rotatable grate component **11** is provided with shield plates **22**, arranged in terrace fashion.

[0076] In use, the grate assembly **10** is rotated about a vertical axis of rotation **21**, which corresponds with the centre line of the ash discharge passageway **20** which is also the centre line of the grate assembly **10**. Coal is fed batch-wise into the top of the gasifier (not shown) and gasification agent is fed into a lower portion of the gasification chamber **102** through gasification agent outlets **23** underneath lower edges of outer shield plates **22**, thereby to gasify coal located in a slow moving bed within the gasification chamber **102**. Ash is continuously withdrawn from the bottom of the gasification chamber **102** through the ash discharge annulus **19** provided between the wall **18** of the gasification chamber **102** on the one hand and the upper rotatable grate component **11** on the other hand, and through the ash discharge passageway **20**. The ploughs **17** rotate with the upper rotatable grate component **11** thereby discharging ash by scraping it through the ash discharge annulus **19**. As the upper rotatable grate component **11** rotates, clinker crushing is performed between the shield plates **22** of the upper rotatable grate component **11** and the wall **18** of the gasifier chamber **102**.

[0077] With reference to FIGS. **2** to **8** of the drawings, reference numeral **200** generally indicates a rotary ash plough in accordance with the present invention. The plough **200** has an elongate hardened, wedge-shaped in plan view, steel body **201** defining an operative leading face **210** and an operative trailing face **212**. The trailing face **212** is a mirror image of the leading face **210**.

[0078] Although not shown in the drawings, the plough **200** typically includes mounting formations, e.g. bolt receiving apertures, towards the right hand end of the body **201** as shown in FIG. **4**, to allow mounting of the plough **200** to the rotatable grate component **11**.

[0079] Each of the leading face **210** and the trailing face **212** defines two angled or sloped major planar surfaces **202.1**, **202.2** and **204.1**, **204.2**. The surfaces **202.1**, **202.2** are constructed at an angle to the vertical, such that a bottom leading edge **206** of the leading face **210** is radially in front of a top leading edge **208** in an operative forward direction of rotation **203**, which in this embodiment is counter-clockwise. The surface **202.1** is thus angled rearwardly relative to the forward direction of rotation **203**, and upwardly away from a horizontal plane in which the plough **200** in use rotates. For the trailing face **212**, the opposite is true in respect of the surface **202.2** when the plough **200** is rotated counter-clockwise as indicated by the arrow **203**.

[0080] The faces **202.1**, **202.2** are typically formed by a 30° angled cut **220** (see FIG. **6**), i.e. a 15° cut to the vertical each (when the plough **200** is viewed in an operative condition). However, the angle **220** may be anywhere in the range of from about 2° to about 70°. The angle **220** can thus be decreased to approach about 2° or increased to approach about 70°; however, ash extraction efficiency may be negatively impacted by a too narrow or a too wide angle **220**.

[0081] The second surface **204.1** is in use a vertical planar surface which is angled forwardly and outwardly at an angle relative to a radius **222** (see FIG. **3**) of a circle (not shown) described in use by the rotary plough **200** when rotating in the forward direction **203**. Being a mirror image of the surface **204.1**, the opposite is thus true for the surface **204.2** when the plough is rotated in the forward direction **203**.

[0082] The surfaces **204.1**, **204.2** are typically cut by a 12° radial cut, indicated by an angle **224** (see FIG. **3**), such that the body **201** of the plough **200** widens in a direction away from a radially inner edge **214** of the body **201**. The radial cut or angle **224** of the surfaces **204.1**, **204.2** may be anywhere in the range of from about 2° to about 36°. The angle **224** can thus be decreased to approach about 2° or increased to approach about 36° but the ash extraction efficiency may also be negatively impacted by a too wide or a too narrow angle **224**.

[0083] The body **201** has a centre plane coinciding with the radius **222**, defining a spine **226** between the leading and trailing faces **210**, **212**. The spine **226** is planar and has a curved upper periphery **228** in a radially inner portion of the body **201** and a flat periphery **230** in a radially outer portion of the body **201**.

[0084] As can be seen in FIG. **4** of the drawings, a radially outer portion of the body **201** has an increased height compared to a radially inner portion of the body **201**, with a bottom surface **232** of the body **201** dropping radially outwardly before curving upwardly again to define a rounded or curved toe **234**.

[0085] In use, one or more ploughs **200** are bolted to the upper rotatable grate component **11** of the grate assembly **10** by fastening means (not shown) near said radially inner edge **214** of the body **201**. As the grate assembly **10** and thus the plough or ploughs **200** are rotated in a forward direction **203** through the ash particles in the ash bed of the gasification chamber **102**, the angled surfaces **202.1** and **204.1** result in forces on the ash particles of which the contact vectors are axially upward and inwards towards the axis of rotation.

[0086] Discrete element modelling surprisingly identified a problem not previously identified in the operation of a grate assembly fitted with ploughs of the prior art. During rotation of the grate, a compression of particles between two successive ploughs occurs, resulting in erosion of the components of the grate assembly and the gasifier walls. The inclusion of two angled surfaces **202.1** and **204.1** on the leading face **210** of the plough **200** surprisingly overcomes this problem and reduces the compressive effect discovered in the operation of the short straight plough or the Sasol® Banana Plough™ of the prior art. The angled surface **202.1** lifts ash particles vertically upwards to fill void spaces in the ash bed which are caused by variable ash particle sizes. The surface **204.1** induces an inward displacement of the ash particles towards the axis of rotation relative to the normal (i.e. 90°) contact vector, thus ensuring removal of the particles via the ash discharge annulus **19**. By lifting and displacing the ash particles inwardly towards the axis of rotation, the angled surfaces **202.1** and **204.1** enable ash particles to have particle-to-particle contact

surfaces, thus minimizing wear on the plough **200** and on other surfaces, e.g. the shield plates **22** or the gasifier wall **18**. The number of ploughs **200** employed will be determined by the required ash extraction rate. Typically, up to six ploughs **200** would be utilized.

[0087] Modelling has also shown that extraction efficiency of the plough **200** is increased over ploughs of the prior art, in both the forward direction **203** and in a reverse direction of operation.

[0088] The plough **200** is designed such that the leading face **210** (comprising both angled surfaces **202.1** and **204.1**) and the trailing face **212** (also comprising angled surfaces **202.2** and **204.2**) are mirror images of each other. This enables the plough **200** effectively to remove ash when rotated in the forward direction **203** or in a reverse direction, without a reduction in the ash extraction efficiency or a change in the erosion characteristics. This extends the working life of the plough **200** greatly and prevents high wear and loss of extraction when operating the grate assembly **10** and plough **200** in a reverse mode.

Example

[0089] The inventor has conducted modelling studies to determine the solids flow characteristics of the short straight plough and the Sasol® Banana Plough™ of the prior art as well as the plough **200**. The results are reflected in FIGS. **9**, **10** and **11**. In these figures, the shade indicates the velocity of the ash particles at a point, with the light grey shades representing slow moving or stationary ash particles, and the darker shades representing particles which have a faster velocity.

[0090] Referring in particularly to FIG. **9**A (short straight plough) and FIG. **10**A (Basal® Banana Plough™), it can be seen that in forward operation (indicated by reference numerals **301** and **401**) the ash particles at the leading face of the plough move the fastest and are therefore also responsible for the greatest degree of wear on the plough and the gasifier walls. When the short straight plough is operated in reverse mode (indicated by reference numeral **302** in FIG. **9**B), almost all of the ash particles remain stagnant, which clearly shows the inability of the short straight plough to operate in reverse mode.

[0091] As shown in FIG. **10**B, the Sasol® Banana Plough™ operated in reverse mode along the direction of arrow **402** causes ash to be displaced outwardly towards the gasifier wall. This results in an increase in the degree of wear or erosion on the gasifier wall.

[0092] Referring to FIG. **11** of the drawings, the velocity of ash particles is shown when displaced by a plough **200** in accordance with the invention. FIG. **11** represents operation of the plough in either the forward or the reverse direction. The contrasting factor in the operation of the plough **200** when compared to the Sasol® Banana Plough™ (FIG. **10**) and the straight short plough (FIG. **9**) is that the plough **200** has a constant moving layer of ash on the leading face. This is because the plough **200** creates a stagnant layer of ash particles ahead of it, as it is mounted on the grate in a direction perpendicular to the direction of rotation, i.e. radially extending. With a constant stagnant layer built up ahead of the plough **200**, ash-on-ash friction ahead of the plough improves and promotes solid flow and thus prevents erosion on the plough **200**.

[0093] During the modelling exercise, the performance of the plough **200** was compared with the short straight plough and the Sasol® Banana Plough™ of the prior art. The results are reflected in the table hereunder.

	Short straight plough	Sasol ® Banana Plough ™	Plough 200
Forward Operation			
Extraction rate (m^3/rev)	1.6	1.2	0.93
Torque (kN · m)	62.0	76	70
Reverse Operation			
Extraction rate (m^3/rev)	0.6	0.2	0.93
Torque (kN · m)	99.0	120	70

[0094] The extraction rate of the plough **200** in the reverse direction is higher than that of the short straight plough or the Sasol® Banana Plough™ and at a much reduced torque. It is also clear from the data that the ploughs of the prior art show severe drop-off in performance when the rotational direction is reversed, whereas performance of the plough **200** remains unchanged.

[0095] Similar torque and extraction rates are achieved in the forward or reverse operational modes of the plough **200**, which is a notable improvement over those achieved by the Sasol® Banana Plough™ and the short straight plough. The major distinguishing factor in the operation of the plough **200** when compared to the Sasol® Banana Plough™ and the short straight plough is that the plough **200** has a constant moving layer of ash on the plough face. This is because the plough **200** creates a stagnant layer of particles ahead of it as it is mounted normal to the contact direction. Solids flow is thereby promoted and improved.

[0096] A grate assembly **10**, as illustrated, incorporating one of more ploughs **200**, as illustrated, will yield benefits in respect of reduced erosion on the ploughs, wear plates, grate components and gasifier walls, which will improve the life of the mechanical equipment. Furthermore, ash and clinker particles are more efficiently extracted from the gasifier as the plough **200** can operate in both the forward and reverse directions without a reduction in the extraction efficiencies or any noticeable increase in equipment wear. The reduced torque associated with operation in both the forward and reverse operating modes is beneficial in that equipment failure is mitigated.

1.-**12**. (canceled)

13. A solids handling equipment rotary plough, the rotary plough including an elongate metal body having a leading face and a trailing face and being configured to be mounted to a rotary component for rotation about an axis of rotation at least in one direction which is an operative forward direction such that the leading face leads the trailing face, at least the leading face having at least two major operatively upwardly and outwardly extending surfaces which are not coplanar, a first major surface being angled operatively rearwardly and upwardly relative to the forward direction of rotation at an angle of at least 1° to the vertical and a second major surface being angled operatively forwardly and outwardly at an angle of at least 1° relative to a radius of a circle described in use by the rotary plough when rotating in the operative forward direction.

14. The solids handling equipment rotary plough according to claim **13**, in which the angle of the first surface to the

vertical is in the range of from 1° to 35° and the angle of the second surface relative to said radius of said circle described in use by the rotary plough when rotating in the forward direction is in the range of from 1° to 18°.

15. The solids handling equipment rotary plough according to claim **13**, in which the second surface extends operatively vertically.

16. The solids handling equipment rotary plough according to claim **13**, in which the first and second major surfaces of the leading face share a common periphery or edge between them.

17. The solids handling equipment rotary plough according to claim **16**, in which the common periphery or edge of the first and second major surfaces of the leading surface is linear and extends downwardly in an outward direction, and in which the common periphery or edge of the first and second major surfaces is angled forwardly relative to said radius of said circle described in use by the rotary plough when rotating in the forward direction.

18. The solids handling equipment rotary plough according to claim **13**, in which the trailing face of the body of the rotary plough is a mirror image of the leading face of the body of the rotary plough.

19. The solids handling equipment rotary plough according to claim **13**, in which the body is configured to be mounted such that it extends radially outwardly from where it is mounted to said rotary component.

20. The solids handling equipment rotary plough according to claim **13**, in which a radially outward portion of the body has an increased height compared to a radially inward portion of the body.

21. The solids handling equipment rotary plough according to claim **20**, in which a bottom surface of the body drops down radially outwardly to end in a rounded upwardly curved toe.

22. A rotatable grate assembly for a gasifier for gasifying carbonaceous material producing ash, the grate assembly including

a rotary component configured for rotation about an upwardly extending axis of rotation, the rotary component being configured for rotation at least in one direction which is an operative forward direction; and

a plurality of rotary ploughs according to claim **13**, the rotary ploughs being mounted to the rotary component for rotation together with the rotary component about said axis of rotation and the rotary ploughs extending outwardly away from said axis of rotation.

23. The rotatable grate assembly according to claim **22**, in which the rotary component is configured for rotation in both said operative forward direction and an operative reverse direction, and in which the rotary ploughs extend radially away from said axis of rotation.

24. The rotatable grate assembly according to claim **22**, in which the rotary component is an upper rotatable grate component, the rotatable grate assembly further including a lower rotatable support structure fastened to the upper rotatable grate component for rotation together with the upper rotatable grate component, the lower rotatable support structure being configured to be drivingly rotated about an axis of rotation which coincides with said axis of rotation of the upper rotatable grate component, and in which said axis of rotation of the upper rotatable grate component is vertical.

25. A gasifier for gasifying carbonaceous material, the gasifier including a rotatable grate assembly according to claim **24**, the rotatable grate assembly being mounted within a gasification chamber defined by a gasification vessel with the lower rotatable support structure of the grate assembly being connected to drive means.

26. The gasifier according to claim **25**, which is a fixed bed gasifier or a fixed bed dry bottom gasifier.

27. The gasifier according to claim **25**, which is a coal gasifier operating at a pressure of between 5 bar(g) and 100 bar(g) and a temperature of between 400° C. and 1600° C.

28. A rotatable grate assembly for a gasifier for gasifying carbonaceous material producing ash, the grate assembly including

a rotary component configured to rotate about a vertical axis of rotation in at least one direction; and

a plurality of rotary ploughs mounted to the rotary component to rotate together with the rotary component in a horizontal plane about said axis of rotation to describe a circle,

said plurality of rotary ploughs each including

an elongate wedge-shaped in plan view metal body extending away from and widening in plan view away from said axis of rotation and having opposed longitudinally extending faces, at least one of said faces having at least two major surfaces which are not coplanar, a first, upper, major surface being angled towards the other of said faces to slope upwardly towards the other of said faces at an angle of at least 1° to the vertical and a second, vertical, lower, major surface being angled in a horizontal plane at an angle of at least 1° relative to a radius of said circle described by the rotary ploughs.

29. The rotatable grate assembly according to claim **28**, in which the rotary component is configured for rotation in two directions, and in which the rotary ploughs extend radially away from said axis of rotation.

30. The rotatable grate assembly according to claim **28**, in which the rotary component is an upper rotatable grate component, the rotatable grate assembly further including a lower rotatable support structure fastened to the upper rotatable grate component for rotation together with the upper rotatable grate component, the lower rotatable support structure being configured to be drivingly rotated about an axis of rotation which coincides with said axis of rotation of the upper rotatable grate component.

31. The rotatable grate assembly according to claim **28**, in which the angle of the first surface of said one of said faces to the vertical is in the range of from 1° to 35° and the angle of the second surface of said one of said faces relative to said radius is in the range of from 1° to 18°.

32. The rotatable grate assembly according to claim **28**, in which the first and second major surfaces of said one of said faces share a common periphery or edge between them.

33. The rotatable grate assembly according to claim **32**, in which the common periphery or edge of the first and second major surfaces of said one of said faces is linear and extends at an angle to the horizontal.

34. The rotatable grate assembly according to claim **28**, in which said other of said faces is a mirror image of said one of said faces.

35. The rotatable grate assembly according to claim **28**, in which a distal end of the body of a rotary plough remote from said axis of rotation has an increased height compared to an end of the body of the rotary plough closer to said axis of rotation.

36. The rotatable grate assembly according to claim **35**, in which a bottom surface of the body of the rotary plough drops

down towards said end of the body of the rotary plough remote from said axis of rotation to end in a rounded curved toe.

37. A gasifier for gasifying carbonaceous material, the gasifier including a rotatable grate assembly according to claim **30**, the rotatable grate assembly being mounted within a gasification chamber defined by a gasification vessel with the lower rotatable support structure of the grate assembly being connected to drive means.

38. The gasifier according to claim **37**, which is a fixed bed gasifier or a fixed bed dry bottom gasifier.

39. Use of a gasifier according to claim **37**, to gasify coal at a pressure of between 5 bar(g) and 100 bar(g) and a temperature of between 400° C. and 1600° C.

40. The rotatable grate assembly according to claim **29**, in which the rotary component is an upper rotatable grate component, the rotatable grate assembly further including, a lower rotatable support structure fastened to the upper rotatable grate component for rotation together with the upper rotatable grate component, the lower rotatable support structure being configured to be drivingly rotated about an axis of rotation which coincides with said axis of rotation of the upper rotatable grate component.

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