United States Patent

Gillies et al.

[15] **3,698,697**

[45] **Oct. 17, 1972**

[54] **ROTARY KILNS**

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[73] Assignee: **United Kingdom Atomic Energy Authority,** London, England

[22] Filed: **April 9, 1971**

[21] Appl. No.: **32,649**

[30] **Foreign Application Priority Data**

April 23, 1970 Great Britain..........19,664/70
May 11, 1970 Great Britain..........22,749/70

[52] **U.S. Cl.** ....**263/32 R**
[51] **Int. Cl.**..**F27b 7/20**
[58] **Field of Search** ....263/33 R, 32 R

[56] **References Cited**

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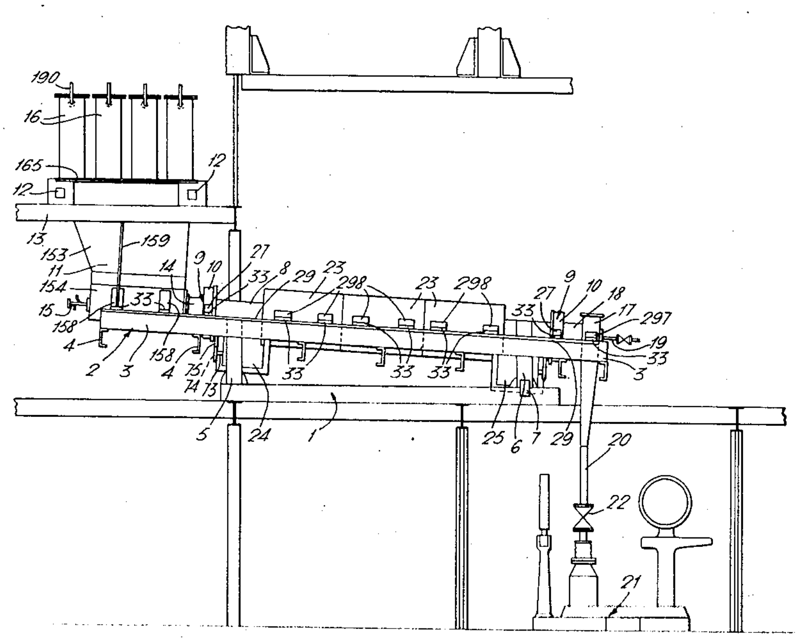
Primary Examiner—John J. Camby
Attorney—Larson, Taylor & Hinds

[57] **ABSTRACT**

A rotary kiln comprises an inclined kiln barrel mounted on a supporting framework by upper and lower bearing members at the ends of the kiln barrel. The supporting framework is fitted with longitudinal bed plates and the upper and lower bearing members for the kiln barrel have support brackets which are fitted with bearing pads sealing on the bed plates through intermediate support members which lie in longitudinal grooves in the bed plates below the bearing pads of the support brackets for the bearing members. In the case of the lower bearing member the intermediate support members are in the form of rods lying in the longitudinal grooves of the bed plates below the bearing pads of the support brackets which are rigidly bolted to the bed plates. In the case of the upper bearing member the intermediate support members take the form of ball bearings running in the longitudinal grooves of the bed plates below the bearing pads of the support brackets. Thus the upper bearing member is free to move longitudinally with respect to the bed plates to accommodate for longitudinal thermal expansion of the kiln barrel. An inlet hopper is similarly mounted on the bed plates at the upper end of the kiln barrel by a movable support bracket at its other end. The inlet hopper connects with the kiln barrel through a slidable sealing means to accommodate for relative thermal expansion between the inlet hopper and the kiln barrel.

8 Claims, 11 Drawing Figures



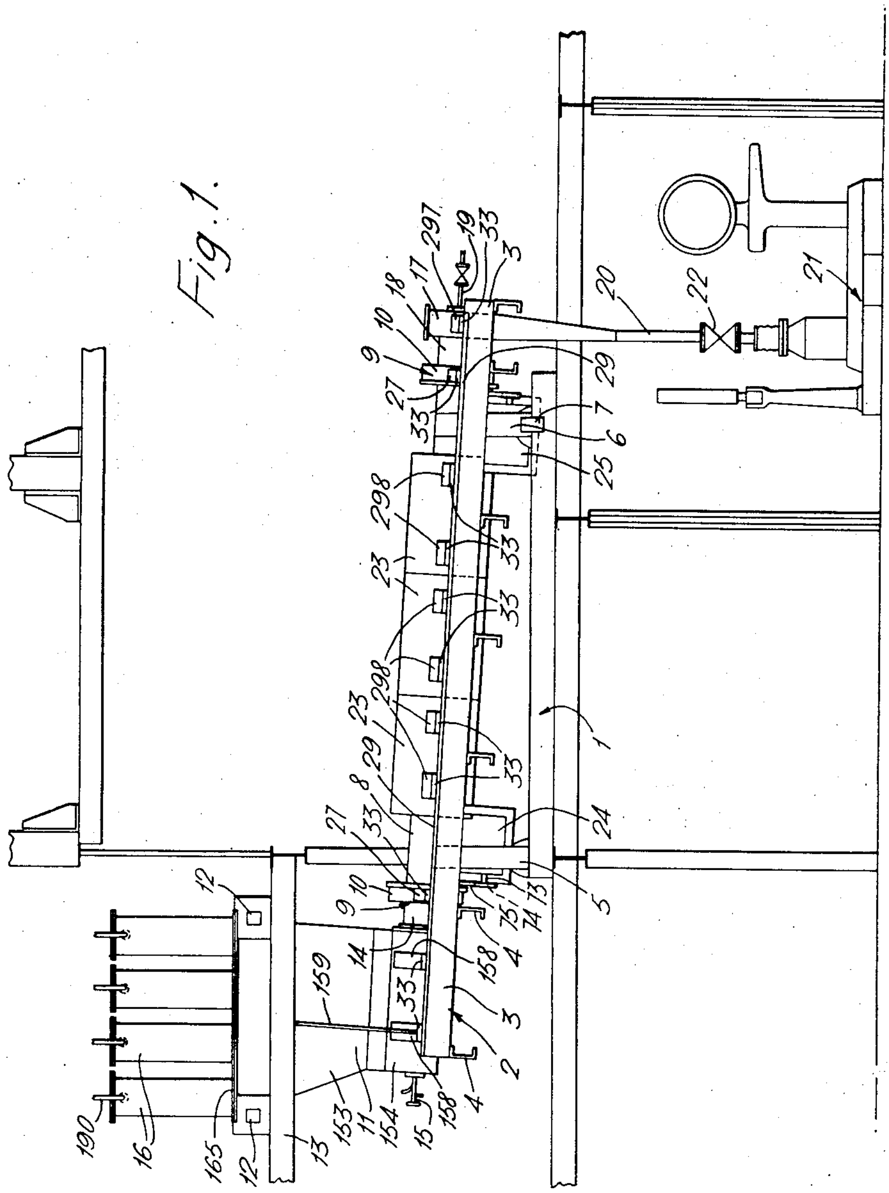


Fig. 1.

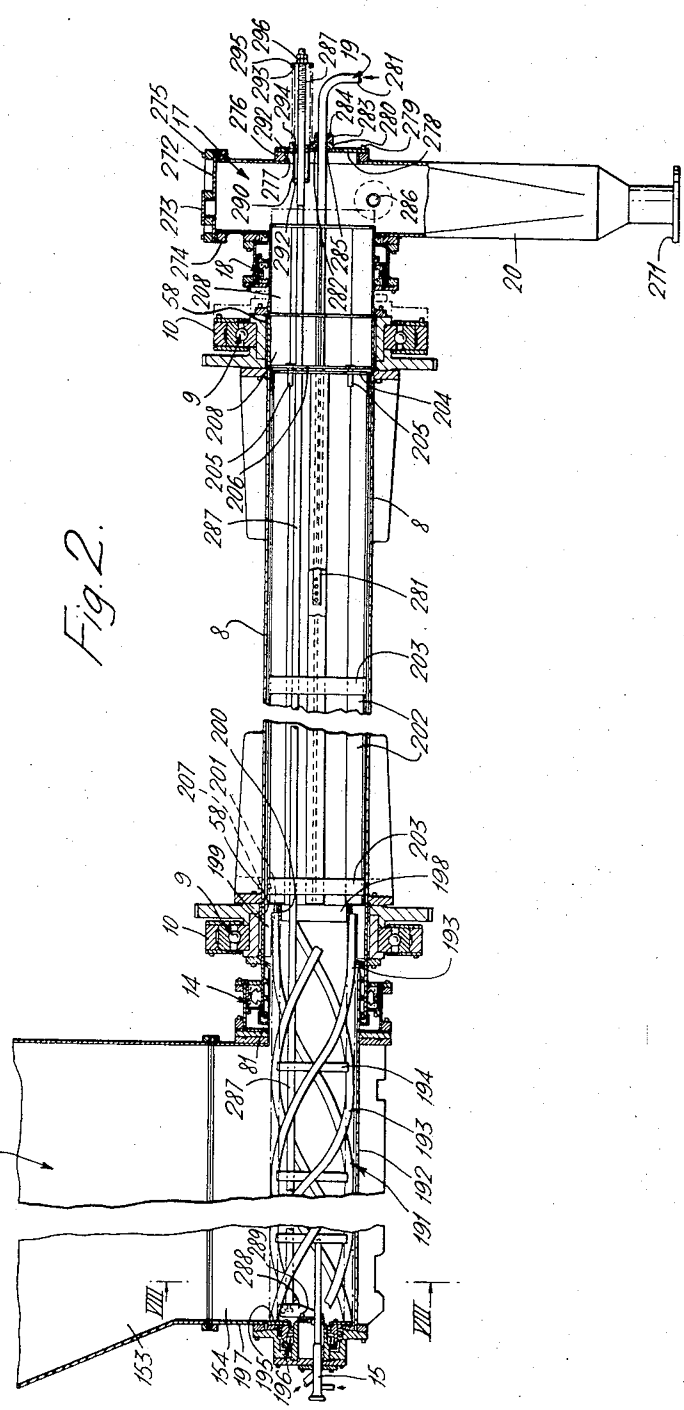


Fig. 2.

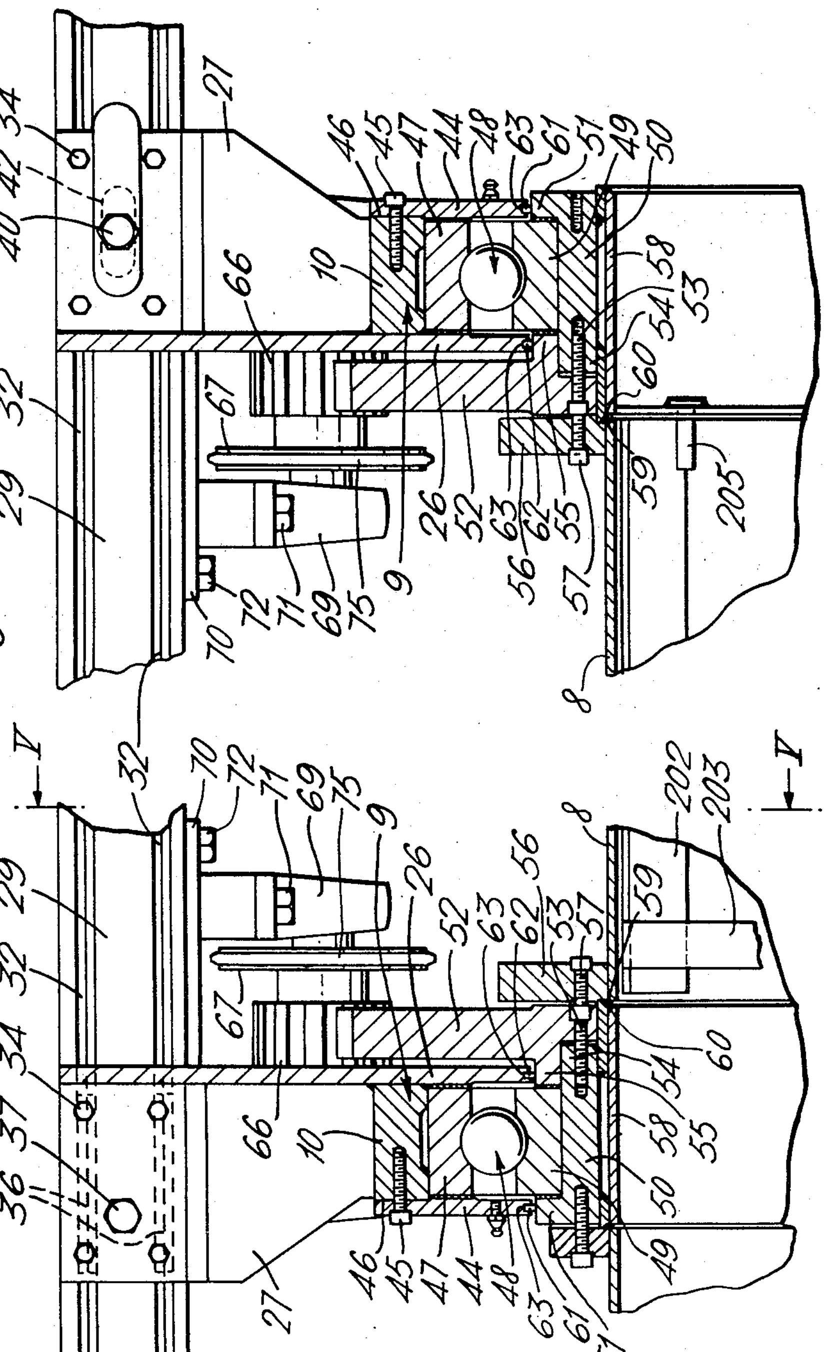
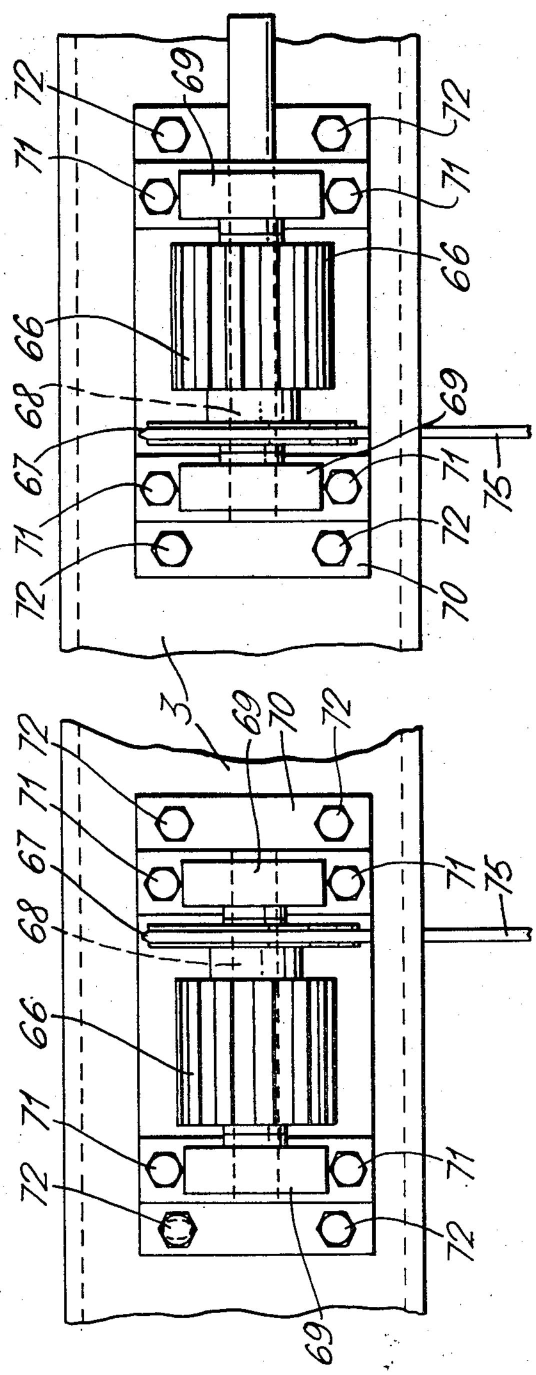


Fig. 3.

Fig. 4



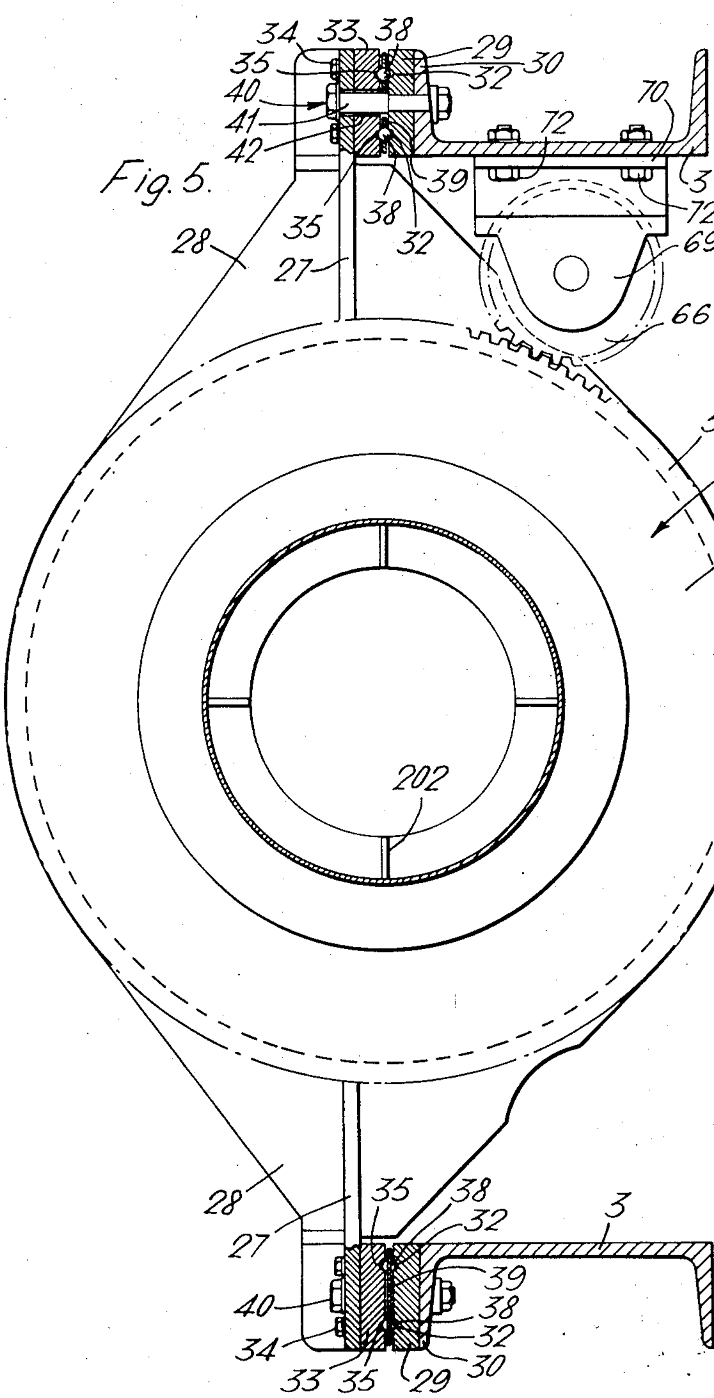

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Fig. 5.

Fig. 6.

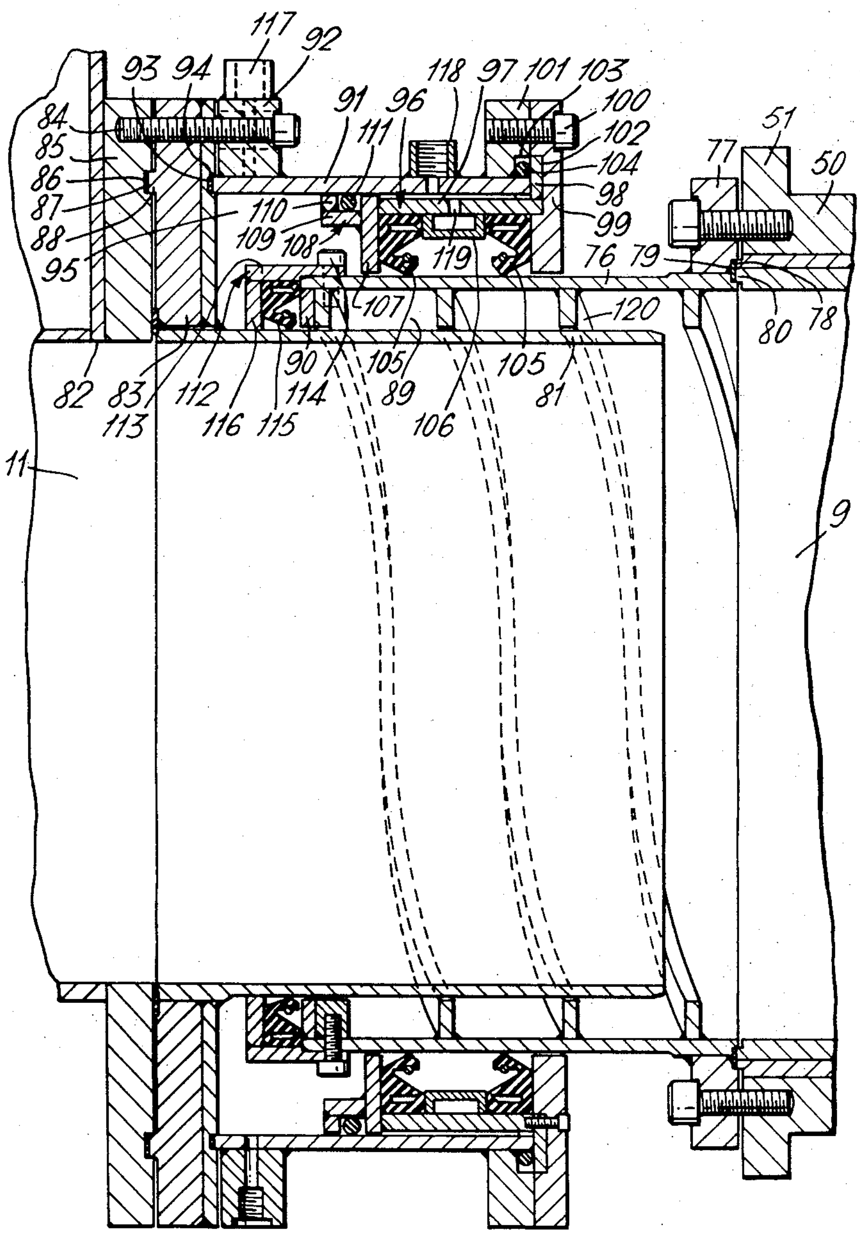
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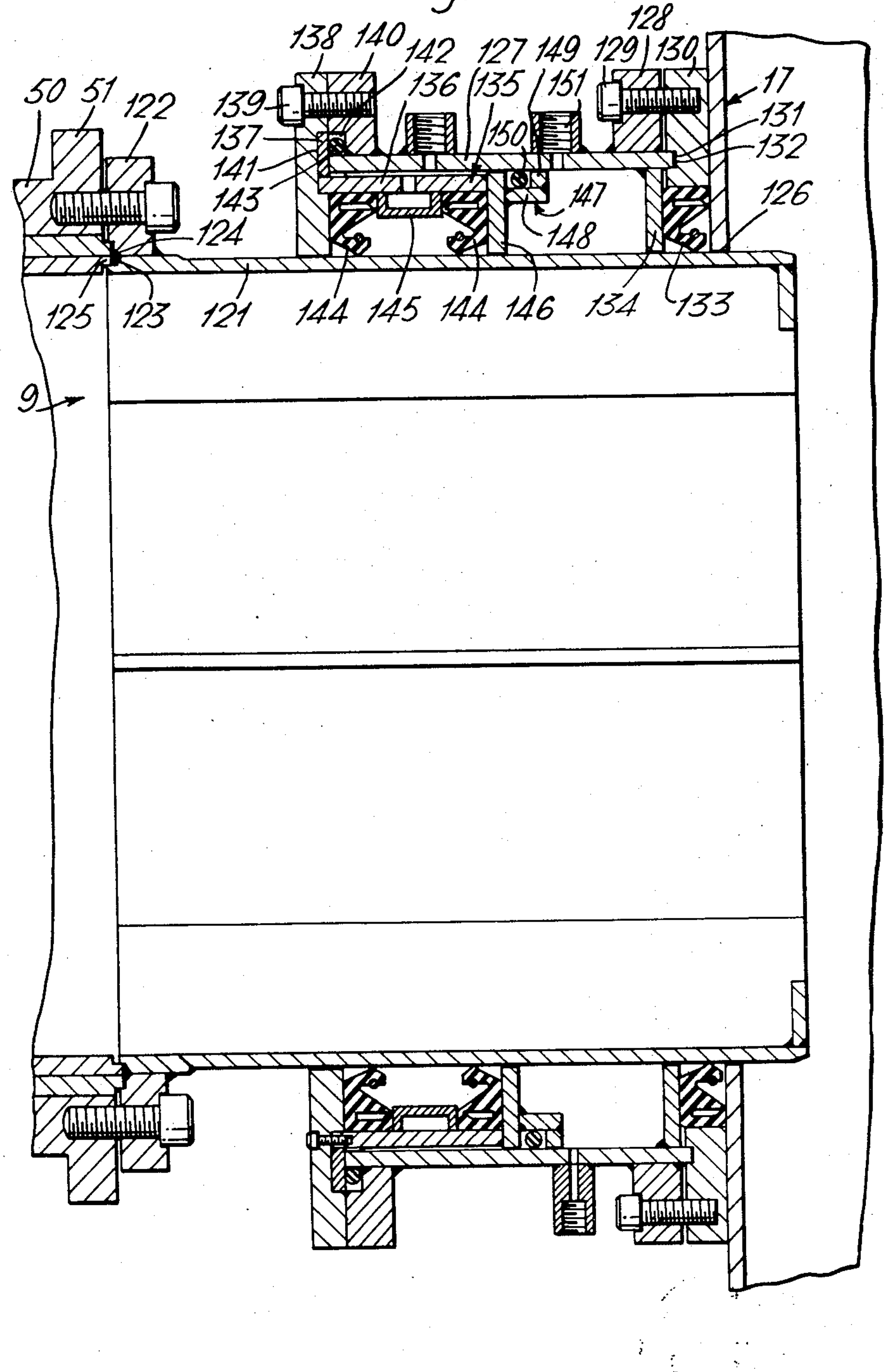
Fig. 7.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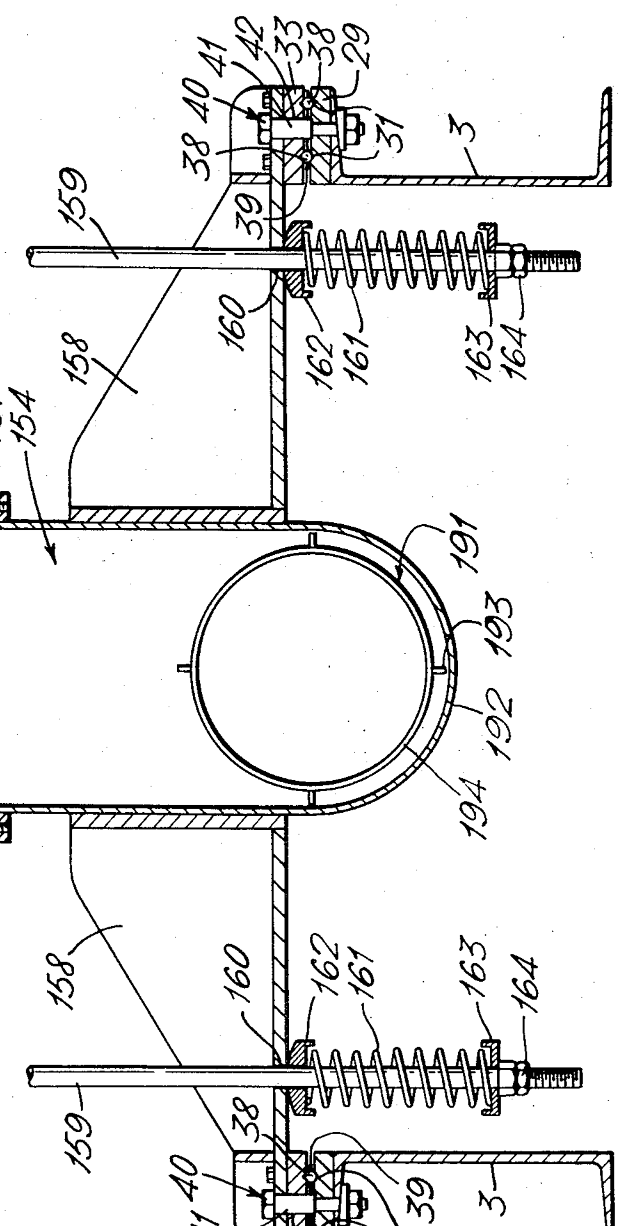
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Fig. 8

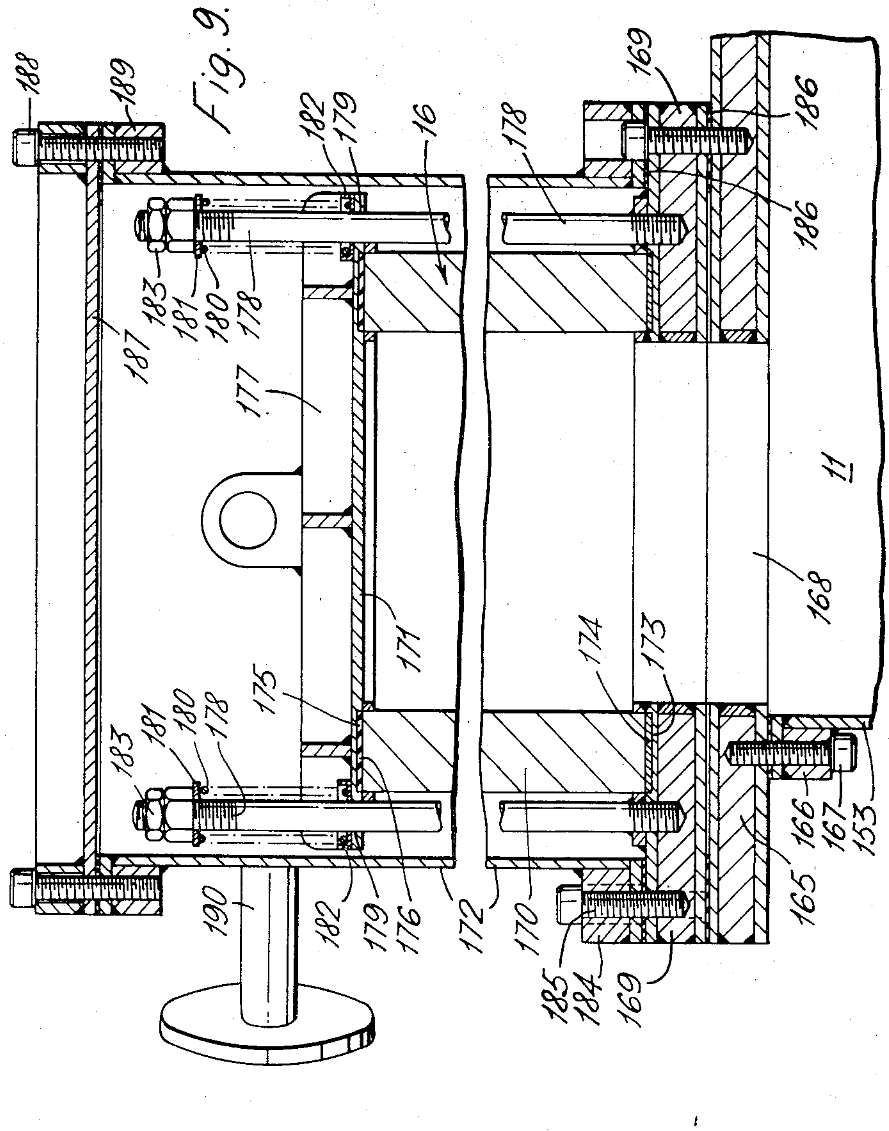
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Fig. 9.

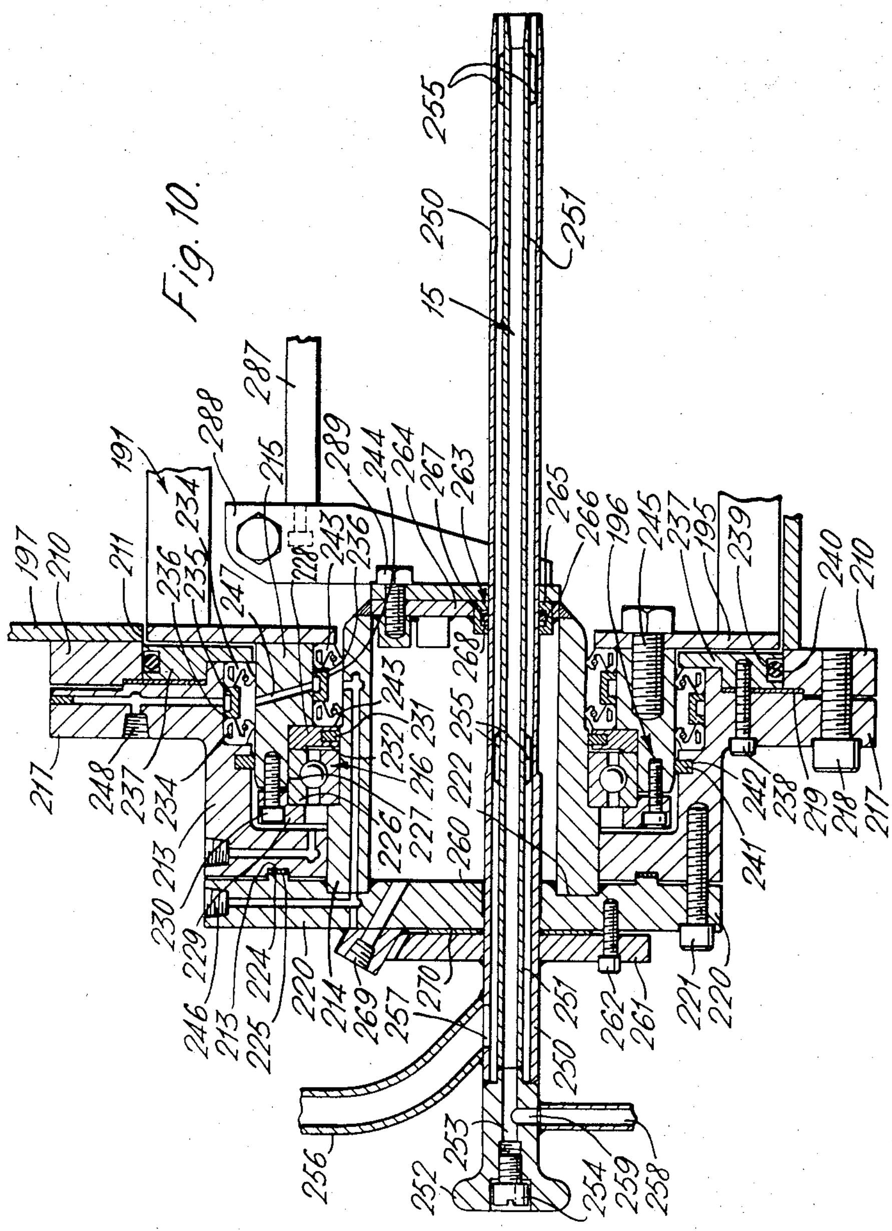
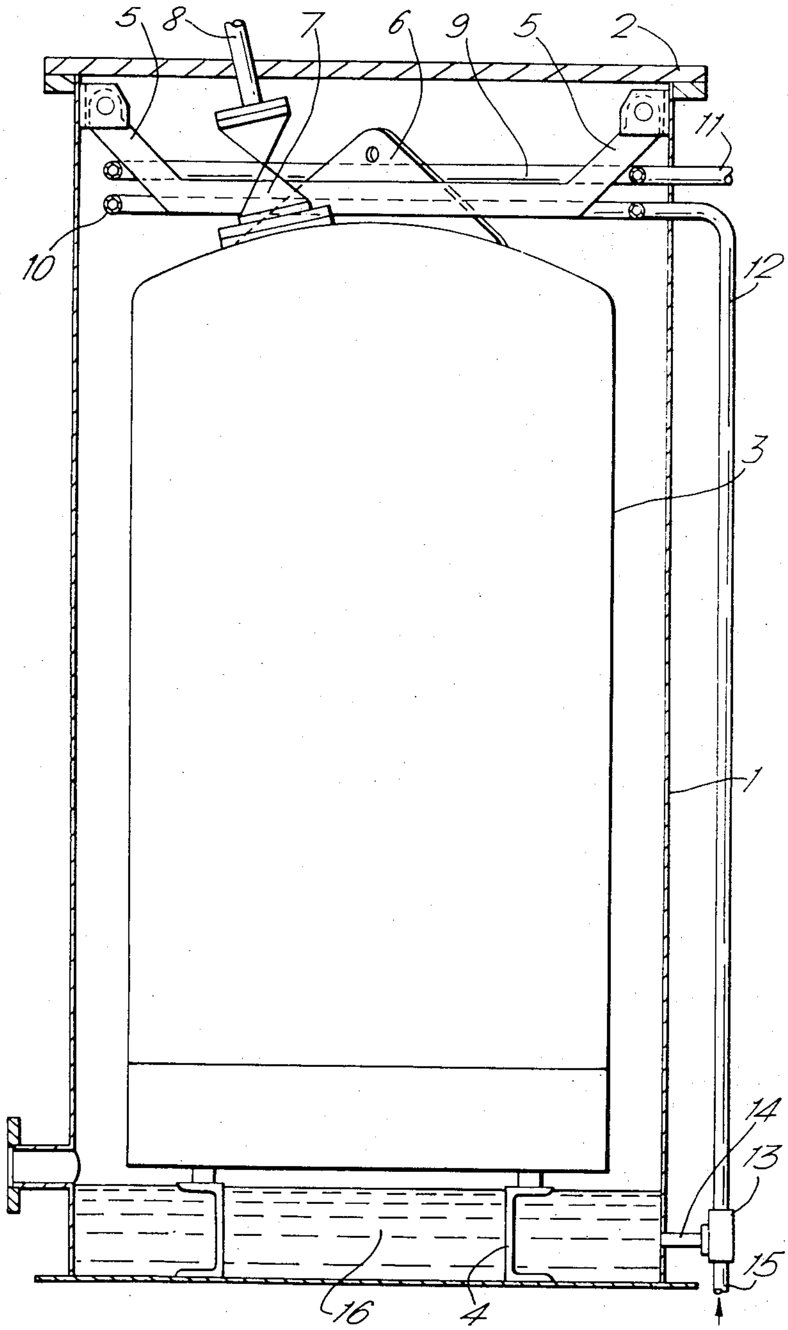


Fig. 10.

Fig. 11.



ROTARY KILNS

BACKGROUND OF THE INVENTION

This invention relates to rotary kilns and in particular relates to an improved form of rotary kiln for carrying out gas/solids reactions.

SUMMARY OF THE INVENTION

According to the invention a rotary kiln comprises a cylindrical kiln barrel rotatably mounted on a supporting framework by a bearing member at each end of the kiln barrel, an inlet hopper being mounted on the supporting framework at one end of the kiln barrel, a discharge hopper being mounted on the supporting framework at the other end of the kiln barrel, slidable sealing means connecting the inlet hopper with the adjacent end of the kiln barrel, slidable sealing means connecting the discharge hopper with the other adjacent end of the kiln barrel, the inlet hopper being mounted on the supporting framework by supports adjacent to each end of the inlet hopper, the supports at one end of the inlet hopper being rigidly fixed to the supporting framework, the supports at the other end of the inlet hopper being movably mounted on the supporting framework so as to allow for longitudinal thermal expansion of the inlet hopper relative to the supporting framework on rise of the inlet hopper from ambient to operating temperature, the bearing member at one end of the kiln barrel being mounted on the supporting framework by supports which are rigidly fixed to the supporting framework, the bearing member at the other end of the kiln barrel being mounted on the supporting framework by supports which are movably mounted on the supporting framework so as to allow for longitudinal thermal expansion of the kiln barrel relative to the supporting framework on rise of the kiln barrel from ambient to operating temperature, the discharge hopper being mounted at least at one point on the supporting framework by supports which are rigidly fixed to the supporting framework, relative longitudinal movements between the kiln barrel and the inlet and discharge hoppers due to thermal expansion being accommodated by the slidable sealing means between the inlet and discharge hoppers and the ends of the kiln barrel.

The supporting framework may be fitted with bed plates, the supports for the inlet hopper, the outlet hopper and the bearing members for the kiln barrel comprising support brackets fitted with bearing pads seating on the bed plates through intermediate support members. Where the supports are to be movably mounted on the supporting framework, as in the case of the supports at the one end of the inlet hopper and the supports for the bearing member at one end of the kiln barrel, the intermediate support members between the bed plates and the bearing pads on the support brackets may be in the form of rolling bearing members such as ball bearings lying in longitudinal grooves in the bed plates, the bearing pads having corresponding longitudinal grooves in their underfaces seating on the ball bearings. In the case where the supports are rigidly fixed to the supporting framework, the intermediate support members between the bed plates and the bearing pads may be in the form of rods lying in the longitudinal grooves in the bed plates, the bearing pads having corresponding longitudinal grooves in their underfaces seating on the rods and means being provided for clamping the support brackets rigidly to the bed plates with the intermediate rods clamped between the bed plates and the bearing pads on the support brackets.

Also according to the invention one form of slidable sealing means for connecting either the inlet or the discharge hopper with the adjacent end of the kiln barrel comprises a cylindrical member mounted coaxially from the end of the kiln barrel and extending longitudinally into the annular interspace between inner and outer coaxial sleeves mounted around an aperture in the wall of the related hopper, a lip seal assembly being located in the annular interspace between the outer sleeve and the cylindrical member and sealing with the outer surface of the cylindrical member, a second lip seal assembly being located closing the annular interspace between the cylindrical member and the inner sleeve at the end of the cylindrical member remote from the kiln barrel. In the above arrangement a helical scroll member may be fitted in the annular interspace between the cylindrical member and the inner sleeve on the side of the second lip seal assembly open to the kiln barrel, the scroll member being mounted on the inner surface of the cylindrical member so that rotation of the cylindrical member with rotation of the kiln barrel results in the removal of any powdered material which infiltrates into the annular interspace between the cylindrical member and the inner sleeve.

A scroll assembly may be fitted in the base of the inlet hopper to move any powdered material which deposits in the base of the inlet hopper into the kiln barrel, said scroll assembly being mounted from one end at the end of the inlet hopper remote from the kiln barrel by a bearing and seal assembly, the other end of the scroll assembly being coupled with the end of the kiln barrel so that the scroll assembly is rotated with rotation of the kiln barrel.

DESCRIPTION OF THE DRAWINGS

One form of rotary kiln in accordance with the invention will now be described by way of example with reference to the accompanying drawings in which:

FIG. 1 is a general elevation of the kiln,

FIG. 2 is an overall longitudinal sectional elevation of the kiln,

FIG. 3 is a longitudinal sectional detail of bearings for the kiln barrel,

FIG. 4 is an elevation of drive pinion assemblies for the bearings of FIG. 3,

FIG. 5 is a transverse cross section along the line V—V in FIG. 3,

FIG. 6 is a longitudinal sectional detail of a rotating seal assembly at the upper end of the kiln barrel in FIG. 2,

FIG. 7 is a longitudinal sectional detail of a rotating seal assembly at the lower end of the kiln barrel in FIG. 2,

FIG. 8 is a cross section along the line VIII—VIII in FIG. 2 showing details of the inlet hopper at the end of the kiln barrel,

FIG. 9 is a longitudinal sectional detail of one of a member of filter assemblies mounted on the inlet hopper shown in FIGS. 2 and 8,

FIG. 10 is a longitudinal sectional detail of a bearing and seal assembly supporting a scroll member in the inlet hopper shown in FIGS. 2 and 8. FIG. 10 also shows a longitudinal sectional elevation of a reactants inlet jet for the inlet hopper,

FIG. 11 is a cross section elevation of apparatus ancillary to the rotary kiln of FIGS. 1 to 10.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in the general arrangement of FIG. 1 the components of the kiln are supported on structural steelwork comprising a base assembly 1 carrying a framework 2. The framework 2 comprises two longitudinal girders 3 joined by cross girders 4. The framework 2 slopes downwards from one end to the other and is pivoted near its upper end on vertical legs 5 of the base assembly 1. The framework 2 is supported near its lower end by vertical legs 6 of the base assembly 1. The lower end of the framework 2 is adjustable in height on the legs 6 of the base assembly 1 so that the angle of inclination of the framework 2 can be adjusted. Jacking means 7 are provided for mechanical raising and lowering of the lower end of the framework 2.

Referring also to FIG. 2 the kiln has a cylindrical barrel 8 which is rotatably supported on the framework 2 by bearings 9 at each end of the barrel 8. Each bearing 9 has a fixed housing 10 which is mounted on the longitudinal girders 3 of the framework 2.

An inlet hopper 11 is mounted at the upper end of the framework 2. The hopper 11 is additionally supported by spring suspensions 12 from an elevated girder framework 13. The hopper 11 is connected with the adjacent upper end of the kiln barrel 8 by a rotating seal assembly 14.

An inlet jet 15 for reactants is provided at the base of the hopper 11 which is also fitted with four outlet filter assemblies 16.

A discharge hopper 17 is mounted at the lower end of the framework 2. The discharge hopper 17 is connected with the adjacent lower end of the kiln barrel 8 by a rotating seal assembly 18. A reactant inlet jet 19 is provided passing through the back face of the discharge hopper 17, into the kiln barrel 8. The discharge hopper 17 has an outlet pipe 20 extending downwards to a product discharge station 21 below the floor level of the kiln. The outlet pipe 20 of the discharge hopper 17 has a solids discharge valve 22 at its lower end.

The kiln barrel 8 is fitted with three individual heater units 23 which are mounted on the longitudinal girders 3 of the framework 2 and which can be independently controlled to provide a required temperature profile in the kiln barrel 8. The kiln barrel 8 is rotated by a drive unit 24 comprising an electric motor and reduction gear box. The drive unit 24 is suspended from the framework 2 below the bearing 9 at the upper end of the kiln barrel 8. A similar emergency drive unit 25 is suspended from the framework 2 below the bearing 9 at the lower end of the kiln barrel 8.

FIGS. 3, 4 and 5 show details of the kiln barrel 8 and the bearings 9. The housing 10 of each of the bearings 9 is cylindrical and is welded to an annular end plate 26. Side mounting brackets 27 are welded to the housing 10 and the end plate 26 has side extensions 28 forming stiffening webs for the brackets 27. The housings 10 of the bearings 9 are supported from the longitudinal girders 3 of the framework 2 by the side mounting brackets 27.

As shown in FIG. 5 a longitudinally grooved bed plate 29 is fitted along the upper web 30 of each girder 3 of the framework 2. The bed plates 29 run the full length of the girders 3 and are attached to the girders 3 by bolts (not shown). Each bed plate 29 has two parallel V-Section grooves 32 along the length of its upper face. A bearing pad 33 is fitted to each of the mounting brackets 27 of the bearing housings 10 by bolts 34. The under faces of the bearing pads 33 have parallel V-section grooves 35 corresponding to the V-section grooves 32 of the bed plates 29.

In the case of the left hand bearing 9 in FIG. 3, that is the bearing 9 at the upper end of the kiln barrel 8, the grooves 35 in the bearing pads 33 of the bearing housing 10 seat on cylindrical rods 36 which lie in the grooves 31 of the bed plates 29. The bearing housing 10 is rigidly fixed, at its mounting brackets 27, to the bed plates 29 by shouldered retaining bolts 37.

In the case of the right hand bearing 9 in FIG. 3, that is the bearing 9 at the lower end of the kiln barrel 8, the grooves 35 in the bearing pads 33 of the bearing housing 10 seat on ball bearings 38 which as shown in FIG. 5 lie in the grooves 31 of the bed plates 29 below the bearing pads 33. There are eight ball bearings 38 underlying each bearing pad 33, four in each of the two grooves 35 in the bearing pad 33. The eight ball bearings 38 associated with each bearing pad 33 are held in a ball retaining cage 39 comprising a flat plate with holes in which the ball bearings 38 are a clearance fit. The bearing housing 10 is held at its mounting brackets 27, on the bed plates 29 by shouldered bolts 40 such that the bearing housing 10 can move longitudinally to a limited extent on the bed plates 29. The bolts 40 have plain shanks 41 which extend through corresponding longitudinal slots 42 in the mounting brackets 27 of the bearing housing 10 and the bearing pads 33. The shanks 41 of the bolts 40 are a sliding fit in the slots 42 so that the bearing housing 10 is free to move longitudinally on the bed plates 29 to an extent determined by the length of the slots 42.

As shown in FIG. 3 each of the bearings 9 has an annular end plate 44 fixed by bolts 45 to the end face 46 of the bearing housing 10. The outer race 47 of a ball bearing 48 is fitted inside the bearing housing 10 between the end plates 26 and 44. The inner race 49 of the bearing 48 is fitted on an inner bearing support sleeve 50. The inner bearing support sleeve 50 has an external end flange 51 and a gear wheel 52 fitted by bolts 53 to the other end 54 of the bearing support sleeve 50. The gear wheel 52 has a center boss 55 which fits over the end 54 of the bearing support sleeve 50. The inner race 49 of the bearing 48 is located on the bearing support sleeve 50 between the end flange 51 and the boss 55 of the gear wheel 50.

The kiln barrel 8 has an external flange 56 at each end by means of which the kiln barrel 8 is attached to the gear wheels 52 of the bearings 9 by bolts 57. A linear sleeve 58 of the same diameter as the kiln barrel 8 is welded inside the inner bearing support sleeve 50 of each bearing 9.

The ends of the kiln barrel 8 are sealed with the adjoining ends of the liner sleeves 58 by aluminum sealing rings 59 which fit in V-grooves 60 in the ends of the liner sleeves 58.

Felt sealing rings 61 and 62 are fitted in grooves 63 respectively around the inner edges of the annular end plates 26 and 44 of the bearing housings 10. The felt sealing ring 61 fits around the end flange 51 of the inner support sleeve 50 of the bearings 9 and the felt sealing ring 62 fits around the boss 55 of the gear wheel 52 in the bearing 9.

Drive pinions 66 for the bearings 9 are mounted on the side face of the right hand longitudinal girder 3 of the framework 2 as shown in FIG. 5. Referring to FIG. 4 each drive pinion 66 is fitted with a V-grooved drive pulley 67 on a shaft 68 which is supported in pillow bearing blocks 69 mounted on a base plate 70. The bearing blocks are fixed on the base plate 70 by bolts 71 and the base plate 70 is fixed to the side face of the girder 3 by bolts 72 such that the pinion 66 engages with the gear wheel 52 of the corresponding bearing 9.

As shown in FIG. 1 the drive unit 24 and the emergency drive unit 25 each have a drive shaft 73 fitted with a V-grooved drive pulley 74. V drive belts 75 are fitted between the pulleys 67 of the pinions 66 and the drive pulleys 74 of the drive units 24 and 25.

Referring to FIG. 6 this shows the rotating seal assembly 14 which connects the inlet hopper 11 with the adjacent upper end of the kiln barrel 8.

The rotating seal assembly 14 comprises a central cylinder 76 having a welded external end flange 77. The cylinder 76 is bolted at the end flange 77 to the end flange 51 of the bearing support sleeve 50 in the adjacent bearing 9. An aluminum sealing ring 78 is fitted in a V-groove 79 around the inner edge of the end flange 77 on the cylinder 76. The sealing ring 78 is trapped in the V-groove 79 by a raised annular land 80 on the flange 51 of the bearing support sleeve 50.

An inner cylindrical sleeve 81 is mounted in register with a circular opening 82 in the end of the inlet hopper 11. The sleeve 81 has an external end flange 83 at which the sleeve 81 is attached by bolts 84 to an annular mounting plate 85 around the opening 82 in the end of the inlet hopper 11. An annular groove 86 in the face of the mounting plate 85 contains an aluminum sealing ring 87 which is trapped in the groove 86 by a raised annular land 88 on the face of the end flange 83 of the sleeve 81. The inner sleeve 81 which extends coaxially inside the cylinder 76 is of smaller diameter than the cylinder 76 so that an annular interspace 89 is defined between the cylinder 76 and the inner sleeve 81. An internal flange 90 welded in the end of the cylinder 76 extends to the inner sleeve 81 and closes the end of the interspace 89 between the cylinder 76 and the inner sleeve 81.

An outer sleeve 91 is mounted coaxially around the cylinder 76. The outer sleeve 91 has an external end flange 92 at which the outer sleeve 91 bolted to the end flange 83 of the inner sleeve 81. An annular groove 93 in the face of the end flange 83 of the inner sleeve 81 contains an aluminum sealing ring 94 which is trapped in the groove 93 by the end face of the outer sleeve 91. The outer sleeve 91 is of larger diameter than the diameter of the cylinder 76 so that an annular interspace 95 is defined between the outer sleeve 91 and the cylinder 76.

An outer seal housing 96 is contained in the interspace 95 between the outer sleeve 91 and the cylinder 76. The seal housing 96 comprises a cylindrical body member 97 of slightly smaller diameter than the internal diameter of the outer sleeve 91. The body member 97 has an external end flange 98. An annular seal retaining plate 99 is attached by bolts 100 to an external end flange 101 on the outer sleeve 91. An annular groove 102 in the face of the seal retaining plate 99 houses the external end flange 98 of the body member 97. An annular groove 103 in the face of the end flange 101 on the outer sleeve 91 contains a rubber 'O' ring 104. The 'O' ring 104 is trapped in the groove 103 by the external end flange 98 of the body member 97. Two lip seals 105 separated by a lantern ring 106 are fitted in the body member 97 of the seal housing 96 between the seal retaining plate 99 and an annular end plate 107 welded to the inner end face of the body member 97. The ring seals 105 bear on the outer surface of the central cylinder 76. A channel member 108 comprising a cylindric ring 109 having an annular rim 110 is welded to the face of the annular end plate 107 on the body member 97 of the seal housing 96. The channel member 108 is fitted with an 'O' ring 111 which seals with the inner surface of the outer sleeve 91.

An inner seal housing 112 mounted on the end of the central cylinder 76 comprises a cylindrical body member 113 which is counterbored to fit over the end of the central cylinder 76. The body member 113 is attached to the end of the cylinder 76 by bolts 114. A lip seal 115 is fitted inside the body member 113 of the inner seal housing 112 between an internal end flange 116 in the body member 113 and the internal end flange 90 in the end of the central cylinder 76. The ring seal 115 bears on the outer surface of the inner sleeve 81. A nitrogen purge inlet 117 is provided in the external end flange 92 of the outer sleeve 91. A further nitrogen purge inlet 118 is provided in the wall of the outer sleeve 91 in the region of the outer seal housing 96. Drillings 119 in the body member 97 of the outer seal housing 96 provide for bleeding of nitrogen into the space between the two ring seals 105.

A helical scroll 120 is welded inside the central cylinder 76 extending across the interspace 89 between the central cylinder 76 and the inner sleeve 81.

Referring to FIG. 7 this shows the rotating seal assembly 18 which connects the lower end of the kiln barrel 8 with the discharge hopper 17.

The rotating seal assembly 18 comprises a cylinder 121 having a welded external end flange 122. The cylinder 121 is bolted at the end flange 122 to the end flange 51 of the bearing support sleeve 50 in the adjacent bearing 9. An aluminum sealing ring 123 is fitted in a V-groove 124 around the inner edge of the end flange 122 on the cylinder 121. The sealing ring 123 is trapped in the V-groove 124 by a raised annular land 125 on the flange 51 of the bearing support sleeve 50. The cylinder 121 extends through an aperture 126 in the discharge hopper 17. An outer sleeve 127 has an external flange 128 at which the sleeve 127 is attached by bolts 129 to an annular mounting plate 130 around the aperture 126 in the discharge hopper 17. An annular groove 131 in the face of the mounting plate 130 contains an aluminum sealing ring 132 which is trapped in the groove 131 by the end face of the outer sleeve

127. A lip seal 133 is fitted inside the annular mounting plate 130 bearing on the cylinder 121. An annular retaining plate 134 for the ring seal 133 is welded inside the end of the outer sleeve 127.

A seal housing 135 is contained in the interspace between the cylinder 121 and the outer sleeve 127. The seal housing 135 comprises a cylindrical body member 136 of slightly smaller diameter than the internal diameter of the outer sleeve 127. The body member 136 has an external end flange 137. An annular seal retaining plate 138 is attached by bolts 139 to an external end flange 140 on the outer sleeve 127. An annular groove 141 in the face of the seal retaining plate 138 houses the external end flange 137 of the body member 136. An annular groove 142 in the face of the end flange 140 on the outer cylinder 127 contains a rubber 'O' ring 143. The 'O' ring 143 is trapped in the groove 142 by the external end flange 137 of the body member 136.

Two lip seals 144 separated by a lantern ring 145 are fitted in the body member 136 of the seal housing 135, between the seal retaining plate 138 and an annular end plate 146 welded to the inner end face of the body member 136. The lip seals 144 bear on the surface of the cylinder 121. A channel member 137 comprising a cylindrical ring 148 having an annular rim 149 is welded to the face of the annular end plate 146 on the body member 136 of the seal housing 135. The channel member 147 is fitted with an 'O' ring 150 which seals with the inside of the outer sleeve 127. A nitrogen purge inlet 151 is provided in the wall of the outer sleeve 127 in the region to the side of the seal housing 135.

As shown in FIGS. 1, 2 and 8 the inlet hopper 11 has an upper section 153 and a lower section 154. Referring to FIG. 8 the upper and lower sections 153 and 154 of the hopper 11 have mating flanges 155 and 156 at which the sections 153 and 154 are fixed together by bolts 157. Mounting brackets 158 are welded to the lower section 154 of the hopper 11. The brackets 158 support the hopper 11 on the bed plates 29 of the framework 2. Similarly to the side mounting flanges 27 of the bearing 9 at the lower end of the kiln body 8, the mounting brackets 158 at the left hand end of the solids disentrainment hopper 11 are fitted with longitudinally grooved bearing pads 33 which seat on ball bearings 38 lying in the grooves 31 of the bed plates 29 below the bearing pads 33. The ball bearings 38 below each bearing pad 33 are held in a ball retaining cage 39. The brackets 158 are held on the bed plates 29 by shouldered bolts 40 having plain shanks 41 which extend through corresponding longitudinal slots 42 in the brackets 158 and the bearing pads 33 so that the brackets 158 can move longitudinally on the bed plates 29 to a limited extent determined by the length of the slots 42. The brackets 158 at the right hand end of the solids disentrainment hopper 11 are also fitted with bearing pads 33 but in this case, as in the case of the bearing 9 at the upper end of the kiln body 8, the bearing pads 33 bear on cylindrical rods which lie in the grooves 31 of the bed plates 29 below the bearing pads 33 and the brackets 158 are rigidly bolted to the bed plates 29.

Further support for the hopper 11, in addition to the support afforded by the spring suspensions 12, is provided by spring loaded tie bars 159 which connect with the brackets 158 at the rear end of the hopper 11. As shown in FIG. 8 the tie bars 159 extend through holes 160 in the brackets 158. Below the brackets 158 the tie bars 159 are fitted with a coil spring 161 extending between upper and lower spring retaining washers 162 and 163. The upper spring retaining washer 162 has a domed top and the lower spring retaining washer 163 is held by retaining nuts 164 on the lower threaded end of each tie bar 159. As shown in FIG. 1 the upper ends of the tie bars 159 are connected with the elevated girder framework 13.

As shown in FIG. 1 and particularly in FIG. 9 the upper section 153 of the hopper 11 has a top cover plate 165 which is attached to a top flange 166 of the upper section 153 of the hopper 11 by bolts 167. The four outlet filter assemblies 16 of the hopper 11 are mounted in register with apertures 168 in the top cover plate 165 of the hopper 11. Each filter assembly 16 comprises an annular base plate 169, a cylindrical porous carbon filter element 170, a cover plate 171 for the filter element 170 and an outer casing 172 enclosing the filter element 170. The filter element 170 seats in an annular groove 173 in the face of the base plate 169 and is sealed in the groove 173 by jointing compound 174. The upper end face of the filter element 170 seats in an annular groove 175 in the underface of the cover plate 171 and is sealed in the groove 175 by jointing compound 176. The cover plate 171, which has radial stiffening webs 177, is held by four tie bars 178. The tie bars 178 are screwed into the annular base plate 169 and extend alongside the filter element 170. The upper ends of the tie bars 178 pass through apertures 170 in the cover plate 171 and the end of each tie bar 178 above the cover plate 171 is fitted with a coil spring 180 extending between upper and lower spring retaining washers 181 and 182. The coil springs 180 are held in compression by a nut 183 fitted on the upper threaded end of each tie bar 178. The outer casing 172 of each filter assembly 16 has an end flange 184 at its bottom end. Bolts 185 extending through the end flange 184 of the casing 172 and through the annular base plate 169 of each filter assembly 16 attach the filter assemblies 16 to the top cover plate 165 of the hopper 11 in register with the apertures 168. Sealing rings 186 are provided between the end flanges 184 of the casings 172 and the annular base plates 169 of the filter assemblies 16. Sealing rings 186 are also provided between the annular base plates 168 and the top cover plate 164 of the hopper 11. The outer casing 172 of each filter assembly 16 has a lid 187 which is attached by bolts 188 to a flange 189 at the top end of the casing 172. The casing 172 of each filter assembly 16 has an outlet branch pipe 190 near its upper end.

As shown in FIG. 2 the lower section 154 of the inlet hopper 11 contains a longitudinally arranged scroll 191. The lower section 154 of the hopper 11 has a semicircular base 192 conforming to the scroll 191. The scroll 191 comprises four helical blades 193 welded to supporting rings 194. At the rear end of the scroll 191 the blades 193 are welded to an annular end plate 195 by means of which the scroll 191 is supported from a bearing and seal assembly 196 mounted on the rear end wall 197 of the lower section 154 of the hopper 11.

The forward end of the scroll 191 extends through the inner sleeve 81 of the rotating seal assembly 14 and the liner sleeve 58 of the adjacent bearing 9. A supporting ring 198 is welded to the forward ends of the blades 193 of the scroll 191. Short helical scroll blades 199 are welded inside the liner sleeve 58 of the bearing 9 co-extensive with the ends of the scroll blades 193. The supporting ring 198 at the ends of the scroll blades 193 fits in a coupling ring 200 welded to the ends of the scroll blades 199 in the liner sleeve 58 of the bearing 9. Catch plates 201 are welded to the ends of the scroll blades 199 engaging with the ends of the scroll blades 193 of the scroll 191.

An assembly of straight lifting flights 202 is fitted in the kiln barrel 8. The lifting flights 202 which are of 'T' cross section are welded to supporting rings 203. An annular mounting plate 204 is welded to the flights 202 at the lower end of the kiln barrel 8. The mounting plate 204 is attached by dowels 205 to an annular end flange 206 in the liner sleeve 58 of the bearing 9 at the lower end of the kiln barrel 8. The supporting ring 203 for the flights 202 at the upper end of the kiln barrel 8 is attached by bolts 207 to the kiln barrel 8. Straight lifting flights 208 co-extensive with the flights 202 in the kiln barrel 8 are welded inside the liner sleeve 58 of the bearing 9 at the lower end of the kiln barrel 8 and inside the inner cylinder 121 of the adjacent rotating seal assembly 18.

As shown in FIG. 10 the bearing and seal assembly 196 for the scroll 191 is fitted on an annular mounting flange 210 surrounding an opening 211 in the rear end wall 212 of the hopper 11. The bearing and seal assembly 196 comprises a fixed cylindrical body member 213, a fixed cylindrical bearing support member 214 located coaxially in the body member 213 and a cylindrical bearing housing 215 rotatably mounted on the bearing support member 214 inside the body member 218 by a ball bearing assembly 216.

The cylindrical body member 213 has an end flange 217 at which the body member 213 is fixed to the mounting flange 210 of the hopper 11 by bolts 218, an aluminum joint ring 219 being trapped between the corresponding end faces of the end flange 217 of the body member 213 and the mounting flange 210 of the hopper 11. The cylindrical bearing support member 214 is supported from the body member 213 by an end plate 220 which is fixed to the end of the body member 213 by bolts 221. The bearing support member 214 is welded at one end in an annular groove 222 in the face of the end plate 220. The end face of the body member 213 has an annular groove 223 and an aluminum joint ring 224 is trapped in the groove 223 by an annular land 225 on the face of the end plate 220. The ball bearing assembly 216 has an outer race 226 which is fitted in a counterbore 227 in the bearing housing 215. An annular locating ring 228 is fitted at the inner end of the counterbore 227 in the bearing housing 215. The outer race of the bearing assembly 216 is trapped in the counterbore 227 of the bearing housing 215 between the annular locating ring 228 and an annular locking ring 229 which is fixed to the rear end face of the bearing housing 215 by bolts 230. A felt ring 231 seals between the inner edge of the annular locating ring 228 and the bearing support member 214, the felt ring 231 being fitted in an annular groove 232 around the inner edge of the annular locating ring 228. Two lip seals 234 separated by a lantern ring 235 are fitted in a counterbore 236 in the body member 213. The lip seals 234 seal against the surface of the bearing housing 215 and are trapped in the counterbore 236 of the body member 213 by an annular end plate 237 which is fixed to the end flange 217 of the body member 213 by bolts 238. The annular end plate 237 fits inside the mounting flange 210 of the hopper 11. An annular groove 239 around the outer edge of the annular end plate 237 houses an 'O' ring 240 which seals with the inner edge of the mounting flange 210 of the hopper 11. A felt ring 241 fitted in an annular groove 242 around the inside of the body member 213 seals about the bearing housing 215 adjacent the left hand ring seal 234.

Two lip seals 243 separated by a lantern ring 244 are fitted in the bearing housing 215 to the right of the annular locating ring 228. The lip seals 243 seal against the surface of the bearing support member 214 and are trapped between the annular locating ring 228 and the annular end plate 195 of the scroll 191 which is fixed to the bearing housing 215 by bolts 245. A nitrogen purge inlet 246 is provided through the end plate 220 and the bearing support member 214 leading to the region between the lip seals 243. A cross drilling 247 in the bearing housing 215 leads from the lantern ring 244 between the lip seals 243 to the region between the lip seals 234. A nitrogen purge outlet 248 in the end flange 217 of the body member 213 leads from the lantern ring 235 between the lip seals 234.

As also shown in FIG. 10 the inlet jet 15 for reactant gases comprises two coaxial tubes 250 and 251. An adaptor knob 252, having a longitudinal bore 253, is welded to the end of the outer tube 250, the corresponding end of the inner tube 251 being welded in connection with the bore 253. A screwed plug 254 is fitted in the bore 253 at the end of the adaptor knob 252. Two groups of circumferentially spaced lugs 255 are welded to the inner tube 251 to maintain the inner tube 251 coaxially located in the outer tube 250.

An inlet branch 256 for feed of reactant gas through the annular interspaced between the tubes 250 and 251, is welded in connection with an aperture 257 in the outer tube 250. An inlet branch 258 for feed of another reactant gas through the inner tube 251 is welded to the adaptor knob 252 in connection with a cross drilling 259 connecting with the bore 253 in the adaptor knob 252.

The outer tube 250 of the jet 15 is fitted through an aperture 260 in the end plate 220 of the bearing and seal assembly 196. A mounting flange 261 is welded to the outer tube 250 of the jet 15, the flange 261 being fixed to the end plate 220 of the bearing and seal assembly 196 by bolts 262.

The outer tube 250 of the jet 15 also passes through a seal 263 in an end plate 264 which is welded closing the inner end of the bearing support member 214 in the bearing and seal assembly 196. The seal 263 comprises a bush 265 which is welded in an aperture 266 in the end plate 264. The bush has an internal circumferential groove 267 which houses an 'O' ring 268 sealing about the outer tube 250 of the inlet jet 15. A nitrogen purge inlet 269 for the seal 263 is provided in the end plate 220 of the bearing and seal assembly 196. Sealing between the mounting flange 261 of the jet 15 and the end plate **220** of the bearing and seal assembly **196** is by means of an interposed joint ring **270**.

Referring again to FIG. **2** the discharge hopper **17** is of rectangular cross section, the outlet section **20** of the hopper **17** being tapered and having an end coupling flange **271** by means of which the outlet section **20** of the hopper **17** is connected with the solids discharge valve **22** in the product discharge station **21** (See FIG. **1**). A lid **272** having an access port **273** is attached to a top flange **274** on the hopper **17** by bolts **275**. An annular flange **276** is welded around an aperture **277** in the back face of the hopper **17**. A cover plate **278** is fixed to the flange **276** by bolts **279**. The cover plate **278** has a welded flange plate **280**. The reactant inlet jet **19** comprises a tube **281** which passes through apertures **282** in the flange plate **280** and the cover plate **278** and extends through the rotating seal assembly **18** and the adjacent bearing **9** into the lower end of the kiln body **8**. The tube **281** has a mounting flange **283** which is fixed by bolts **284** to the flange plate **280** on the cover plate **278**. The tube **281** is sealed in passage through the aperture **282** in the cover plate **278** by an 'O' ring seal **285**. A further reactant inlet jet **286** is fitted through the side wall of the hopper **17**.

A thermocouple tube **287** is located passing longitudinally through the kiln barrel **8** from the rear end of the inlet hopper **11** to the discharge hopper **17**. The end of the thermocouple tube **287** in the inlet hopper **11** is fixed to a bracket **288** which is attached by bolts **289** to the end plate **264** closing the inner end of the bearing support member **214** in the scroll bearing and seal assembly **196**. The other end of the thermocouple tube **287** passes out of the rear end face of the discharge hopper **17** through a sleeve **290** set in an aperture **291** in the flange plate **280** and the cover plate **278** of the hopper **17**. 'O' ring seals **292** at each end of the sleeve **290** seal the thermocouple tube **287** in passage through the sleeve **290**. The end of the thermocouple tube **287** extending outside the sleeve **290**, is fitted with a coil spring **293** extending between a seating **294** in the flange plate **280** and a spring retaining washer **295** fitted on the outer threaded end of the thermocouple tube **287**. The spring retaining washer **295** is held by nuts **296** fitted on the threaded end of the thermocouple tube **287**. The spring **293** holds the thermocouple tube **287** under tension which remains under tension to prevent sagging of the thermocouple tube **287** on longitudinal thermal expansion of the components of the kiln on heating up.

As shown in FIG. **1** the discharge hopper **17** is mounted on the bed plates **29** of the framework **2** by side mounting brackets **297**. Similarly to the brackets **27** which mount the housing **10** of the bearing **9** at the upper end of the kiln body **8**, the mounting brackets **297** of the discharge hopper **17** are rigidly fixed to the bed plates **29** of the framework **2**. The brackets **297** are fitted with bearing pads **33** which bear on cylindrical rods lying in the grooves **31** of the bed plates **29** and the brackets **297** are rigidly bolted to the bed plates **29**.

The heater units **23** fitted to the kiln body **8** are each mounted on the bed plates **29** of the framework **2** by side mounting brackets **298**. In the case of the center and left hand heater units **23** in FIG. **1** the brackets **298** are movably mounted on the bed plates **29** by bearing pads **33** and ball bearings in the manner in which the housing **10** of the bearing **9** at the lower end of the kiln body **8** is mounted. In the case of the right hand heater unit **23** in FIG. **1** the right hand pair of brackets **298** are movably mounted in a similar manner on the bed plates **29** but the left hand pair of brackets **298** are rigidly bolted to the bed plates **29**.

Reiterating with regard to the mounting of the various components of the kiln on the framework **2** and referring to FIG. **1** the mounting brackets **158** at the right hand end of the solids disentrainment hopper **11** are rigidly bolted to the bed plates **29** of the framework **2** and the mounting brackets **158** at the left hand end of the solids disentrainment hopper **11** are longitudinally movable on the bed plates **29**. This allows longitudinal thermal expansion of the hopper **11** to occur during rise of the equipment from ambient to operating temperature.

The brackets **27** mounting the housing **10** of the left hand bearing **9** at the upper end of the kiln body **8** are rigidly bolted to the bed plates **29** of the framework **2**, whereas the brackets **27** mounting the housing **10** of the right hand bearing **9** at the lower end of the kiln body **8** are longitudinally movable on the bed plates **29**. This allows for longitudinal thermal expansion of the kiln body **8** again during the rise of the equipment from ambient to operating temperature. Such longitudinal thermal expansion of the kiln body **8** is accommodated by sliding of the cylinder **121** of the rotating seal assembly **18** in the lip seals **133**, and **144** of the seal assembly **18** (See FIG. **7**).

In the case of the heater units **23** as the left hand pair of mounting brackets **298** on the right hand heater unit **23** are rigidly bolted to the bed plates **29** of the framework **2** and the other pairs of mounting brackets **298** of the heater units **23** are movably mounted on the bed plates **29** this allows for longitudinal thermal expansion of the heater units **23** on rise from ambient to operating temperatures.

By way of example the kiln may be used for carrying out an integrated process such as that in which uranium hexafluoride (UF_6) is reacted with steam to produce uranyl fluoride (UO_2F_2) and the uranyl fluoride produced by this reaction is then further reacted with steam and/or hydrogen to produce uranium dioxide.

In use of the kiln for carrying out such a process uranium hexafluoride vapor and dry steam are fed together into the inlet hopper **11** through the jet **15**. The uranium hexafluoride vapor is fed into the jet **15** through the inlet branch **258** and passes through the inner tube **251** of the jet **15**. The dry steam is fed into the jet **15** through the inlet branch **256** and passes through the annular interspace between the tubes **250** and **251** of the jet **15**. The uranium hexafluoride and dry steam issuing together from the nozzle of the jet **15** react together (at a temperature of 150°–250° C) in the form of a plume which is directed towards the upper end of the kiln barrel **8**. Thus the uranyl fluoride which is produced by the reaction is mainly deposited in the upper end of the kiln barrel **8**, although some of the uranyl fluoride falls to the bottom of the inlet hopper **11** or is driven back into the inlet hopper **11** by gases emerging from the kiln barrel **8**. The uranyl fluoride passes down the kiln barrel **8** which is rotated by the drive unit **24**.

In passing down the barrel 8 of the kiln the uranyl fluoride is reacted at a higher temperature (500°–800° C) with a steam/hydrogen mixture to produce uranium oxide powder. The required temperature is maintained in the barrel 8 of the kiln by the heater units 23. The use of a series of heater units 23 enables the establishment of a required temperature gradient along the length of the kiln barrel 8. Steam is fed into the lower end of the kiln barrel 8 through the inlet jet 19 and hydrogen is passed through the inlet jet 286 in the discharge hopper 17.

The lifting flights 202 in the kiln barrel 8 tumble the uranyl fluoride powder and cause it to move in a downwards spiral path in countercurrent flow to the steam/hydrogen mixture passing upwards through the kiln barrel 8. The lifting and tumbling motion of the uranyl fluoride powder ensures efficient solids/gas contacting and rapid and efficient conversion of the uranyl fluoride powder to uranium oxide powder. The tumbling of the uranyl fluoride powder in passing down the barrel 8 of the kiln also achieves the necessary agglomeration and densification of the powder so that the finally produced fluoride free uranium oxide powder is free flowing and thereby capable of being easily handled in conventional powder handling equipment.

The uranium dioxide produced tumbles into the discharge hopper 17 and is discharged from the hopper 17 at the discharge station 21 into containers coupled with the discharge valve 22 at the lower end of the outlet pipe 20 of the discharge hopper 17. The annular end flange 206 in the liner sleeve 58 of the bearing 9 at the lower end of the kiln barrel 8 which provides for mounting of the assembly of lifting flights 202 in the kiln barrel 8, also acts as a spill ring controlling the flow of powder out of the kiln barrel 8 into the discharge hopper 17.

The scroll 191 in the inlet hopper 11 is driven by rotation of the kiln barrel 8 and feeds any uranyl fluoride powder which is deposited in the base of the inlet hopper 11 into the upper end of the kiln barrel 8. Also the reaction gases entering the inlet hopper 11 from the kiln barrel 8 are extracted through the filter assemblies 16 on the top cover plate 165 of the inlet hopper 11. The reaction gases are extracted through the outlet branch pipes 190 of the filter assemblies 16, passing through the carbon filter element 170 of the filter assemblies 16 from the inside. Any fine uranyl fluoride powder carried over from the kiln barrel 8 by the emerging reaction gases is deposited on the inside of the filter elements 170 of the filter assemblies 16. Blow back facilities are provided for the filter assemblies 16 for removal of accumulated uranyl fluoride powder which when dislodged from the filter elements 170 falls to the bottom of the inlet hopper 11 and is fed back into the barrel 8 of the kiln by the scroll 191.

Finally, the design of the rotating seal assembly 14 is such that the lip seals 105 are fully protected from damage by ingress of powder from the kiln barrel 8. Access of powder to the lip seals 105 from the kiln barrel 8 is prevented by the third lip seal 115 which is fitted at the end of the interspace 89 between the cylinder 76 and the inner sleeve 81 of the rotating seal assembly 14. Nitrogen purging of the seal housing 96 through the purge inlet 118 and of the interspace 95 between the outer sleeve 91 and the cylinder 76 through the purge inlet 117 also prevents access of powder to the lip seals 105. Any powder infiltrating into the interspace 89 between the cylinder 76 and the inner sleeve 81 is removed away from the lip seal 115 by the helical scroll 120 which is fitted inside the cylinder 76.

FIG. 11 shows apparatus for the solid to gaseous conversion of uranium hexafluoride for supply of gaseous uranium hexafluoride to the rotary kiln in carrying out the process for production of uranium dioxide as described above.

Referring to FIG. 11 a vertically orientated tank 1 is shown having a removable lid 2. Located in the tank 1 is a cylindrical transport container 3 containing solid phase uranium hexafluoride. Location for the container 3 in the tank 1 is provided by an annular upstand 4 fitted in the base of the tank 1 and by locking bars 5 pivotably attached to the walls of the tank 1 immediately below the lid 2 and bearing on the top of the container 3. The top of the container 3 is provided with a lifting attachment 6 and a filler/outlet valve 7. The valve 7 is connected into a line 8 for supply of gaseous phase uranium hexafluoride to the rotary kiln. Located immediately above the container 3 are two annular pipes 9 and 10, the internal diameters of which allow the container 3 to be loaded into or removed from the tank 1 without difficulty. Both of the annular pipes 9 and 10 have equidistantly spaced apertures in their inner surfaces which allow water supplied in the pipes to be sprayed onto the top of the container 3. The upper annular pipe 9 is connected to a cold water supply line 11 whilst the lower annular pipe 10 is connected into a hot water supply line 12 which extends down towards the base of the tank 1 where it connects into a steam ejector 13. A pipe 14 connects the ejector 13 into the bottom of the tank 1. A line 15 supplies steam to the ejector 13. The supply of steam to the ejector 13 is controlled by means of an air controlled valve located in the line 15 which is actuated by an air signal from a pressure transducer located in the line 8. Thus the steam supply to the ejector 13 is controlled by the pressure of gaseous phase uranium hexafluoride in the line 8. When the valve 7 is in the open position the pressure of gaseous phase uranium hexafluoride in the line 8 will be the same as in the cylinder 3.

In operation a container 3 containing uranium hexafluoride in the solid phase is loaded into the tank 1 and located in position by means of the upstand 4 and the locking bars 5. The line 8 is then connected to the valve 7 which is then opened. Steam is supplied by the line 15 to the ejector 13 causing it to draw water 16 from the base of the tank 1 via the pipe 14 and pass it mixed with steam up the line 12 into the annular pipe 10 from which it emerges as a hot water spray which is directed onto the top of the container 3. The water from the hot spray runs down the outside of the container 3 and collects in the base of the tank 1 where it is available for recirculation by the ejector 13. The hot water spray heats the walls of the container 3 and converts the solid phase uranium hexafluoride contained therein into the gaseous phase which passes out of the cylinder 3 via the valve 7 into the line 8.

The pressure of the gaseous uranium hexafluoride controls the amount of steam supplied to the ejector 13 and hence controls the volume of hot water sprayed on to the top of the container 3 from the annular pipe 10. In this way the heat supply to the container 3 and thus the rate of conversion of the uranium hexafluoride from the solid to the gaseous phase is automatically controlled.

The cold water spray from the annular pipe 9 is used to cool down the container 3 when it is required to stop the conversion of uranium hexafluoride from the solid to the gaseous phase.

We claim:

1. A rotary kiln comprising a cylindrical kiln barrel rotatably mounted on a supporting framework by a bearing member at each end of the kiln barrel, an inlet hopper mounted on the supporting framework at one end of the kiln barrel, a discharge hopper mounted on the supporting framework at the other end of the kiln barrel, slidable sealing means connecting the inlet hopper with the adjacent end of the kiln barrel, slidable sealing means connecting the discharge hopper with the other adjacent end of the kiln barrel, the inlet hopper being mounted on the supporting framework by supports adjacent to each end of the inlet hopper, the supports at one end of the inlet hopper being rigidly fixed to the supporting framework, the supports at the other end of the inlet hopper being movably mounted on the supporting framework so as to allow for longitudinal thermal expansion of the inlet hopper relative to the supporting framework on rise of the inlet hopper from ambient to operating temperature, the bearing member at one end of the kiln barrel being mounted on the supporting framework by supports which are rigidly fixed to the supporting framework, the bearing member at the other end of the kiln barrel being mounted on the supporting framework by supports which are movably mounted on the supporting framework so as to allow for longitudinal thermal expansion of the kiln barrel relative to the supporting framework on rise of the kiln barrel from ambient to operating temperature, the discharge hopper being mounted at least at one point on the supporting framework by supports which are rigidly fixed to the supporting framework, relative longitudinal movements between the kiln barrel and the inlet and discharge hoppers due to thermal expansion being accommodated by the slidable sealing means between the inlet and discharge hoppers and the ends of the kiln barrel.

2. A rotary kiln as claimed in claim 1 wherein the supporting framework is fitted with longitudinally extending bed plates, the supports for the inlet hopper, the outlet hopper and the bearing members for the kiln barrel comprising support brackets fitted with bearing pads seating on the bed plates through intermediate support members, said intermediate support members, in the case where the support brackets are movably mounted on the supporting framework, comprising rolling bearing members lying in longitudinal grooves in the bed plates, the bearing pads having corresponding longitudinal grooves in their underfaces seating on the rolling bearing members, said intermediate support members, in the case where the support brackets are rigidly fixed to the supporting framework, comprising rods lying in the longitudinal grooves in the bed plates, the bearing pads of the support brackets having corresponding longitudinal grooves in their underfaces seating on the rods and means being provided for clamping the support brackets rigidly to the bed plates with the intermediate rods clamped between the bed plates and the bearing pads on the support brackets.

3. A rotary kiln as claimed in claim 1 wherein said slidable sealing means for connecting either the inlet or the discharge hopper with the adjacent end of the kiln barrel comprises a cylindrical member mounted coaxially from the end of the kiln barrel and extending longitudinally into the annular interspace between inner and outer coaxial sleeves mounted around an aperture in the wall of the related hopper, a lip seal assembly being located in the annular interspace between the outer sleeve and the cylindrical member and sealing with the outer surface of the cylindrical member, a second lip seal assembly being located closing the annular interspace between the cylindrical member and the inner sleeve at the end of the cylindrical member remote from the kiln barrel.

4. A rotary kiln as claimed in claim 3 wherein a helical scroll member is fitted in the annular interspace between the cylindrical member and the inner sleeve on the side of the second lip seal assembly open to the kiln barrel, the scroll member being mounted on the inner surface of the cylindrical member so rotation of the cylindrical member with rotation of the kiln barrel results in the removal of any powdered material which infiltrates into the annular interspace between the cylindrical member and the inner sleeve.

5. A rotary kiln as claimed in claim 1 wherein a scroll assembly is fitted in the base of the inlet hopper to move any powdered material which deposits in the base of the inlet hopper into the kiln barrel, said scroll assembly being mounted from one end at the end of the inlet hopper remote from the kiln barrel by a bearing and seal assembly, the other end of the scroll assembly being coupled with the end of the kiln barrel so that the scroll assembly is rotated with rotation of the kiln barrel.

6. A rotary kiln as claimed in claim 5 wherein the scroll assembly is of skeletal form comprising helical scroll blades mounted on a series of annular support rings.

7. A rotary kiln as claimed in claim 6 wherein the scroll assembly has a cylindrical end support ring at its end adjacent the kiln barrel, the end support ring fitting in a cylindrical extension of the kiln barrel, the kiln barrel having catch plates which engage with and drive the scroll assembly on rotation of the kiln barrel.

8. A rotary kiln as claimed in claim 5 wherein the bearing and seal assembly for the scroll assembly comprises a cylindrical bearing housing mounted on the end of the scroll assembly and extending longitudinally into the annular interspace between inner and outer coaxial sleeves mounted from the end wall of the inlet hopper, a bearing member being fitted in the annular interspace between the cylindrical bearing housing of the scroll assembly and the inner of the coaxial sleeves, a lip seal assembly being located sealing across the annular interspace between the outer of the coaxial sleeves and the cylindrical bearing housing of the scroll assembly, a second lip seal assembly being located sealing across the annular interspace between the interior of the cylindrical bearing housing and the inner of the coaxial sleeves on the side of the bearing member towards the scroll assembly.

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