April 20, 1971 A. F. JOHNSON 3,575,827

SYSTEM FOR REDUCTION OF ALUMINUM

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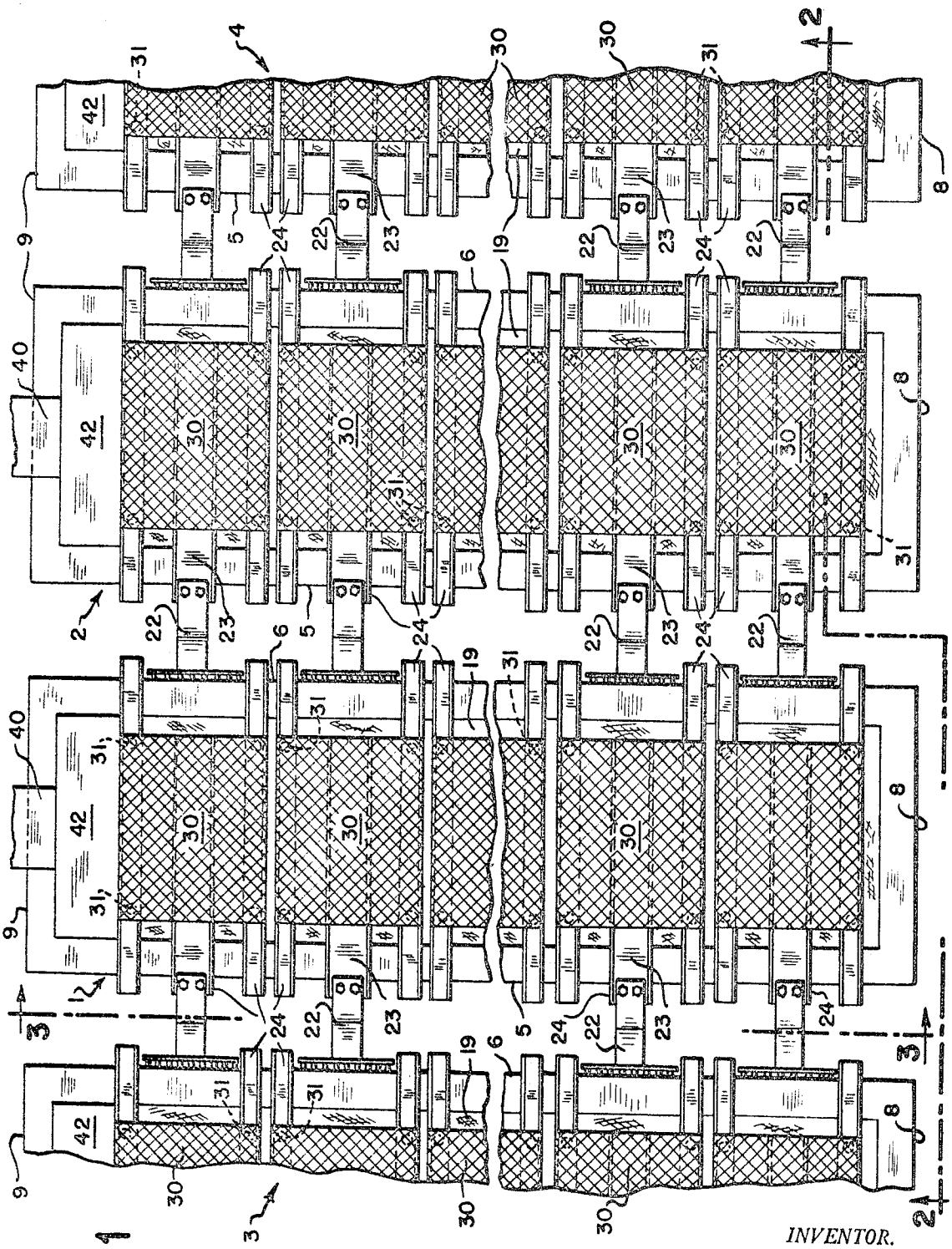


FIG. 1

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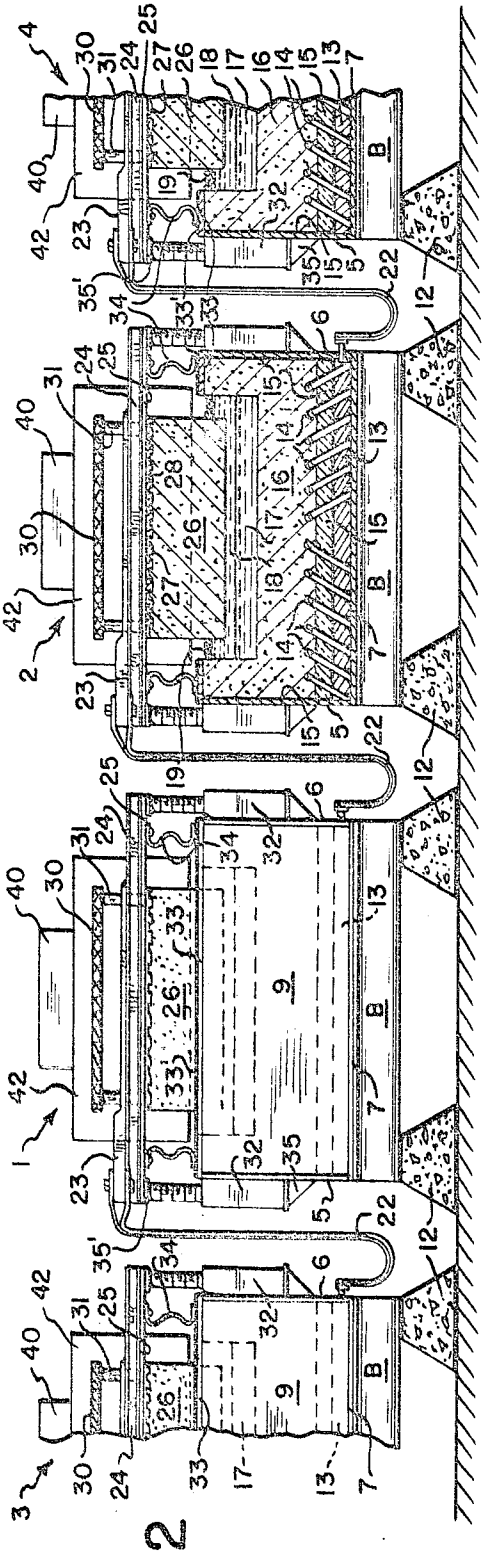


FIG. 2

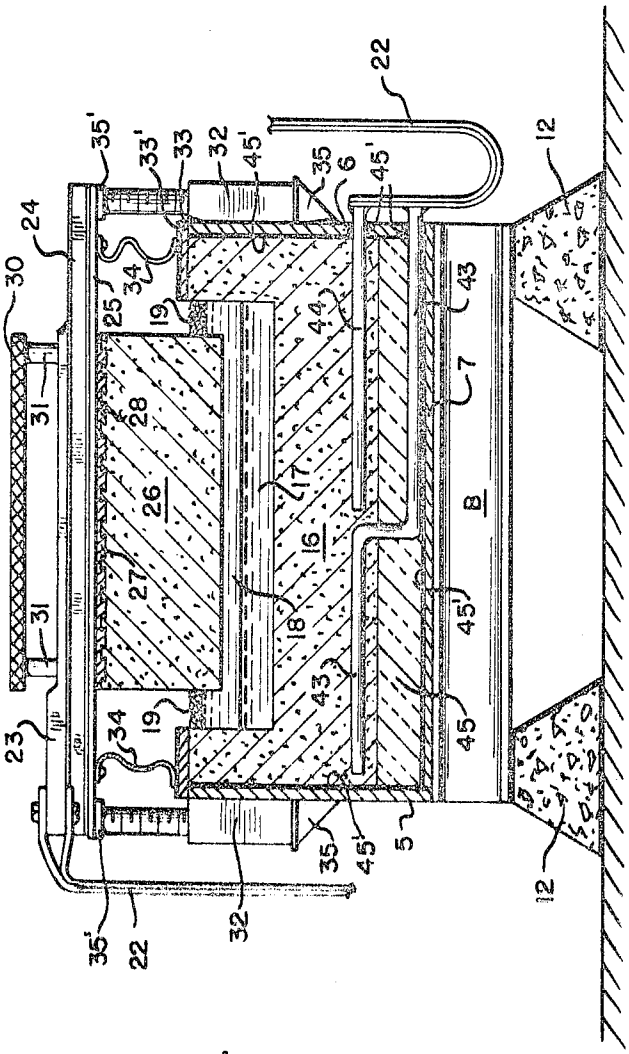


FIG. 4

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Filed Dec. 6, 1967 3 Sheets-Sheet 3

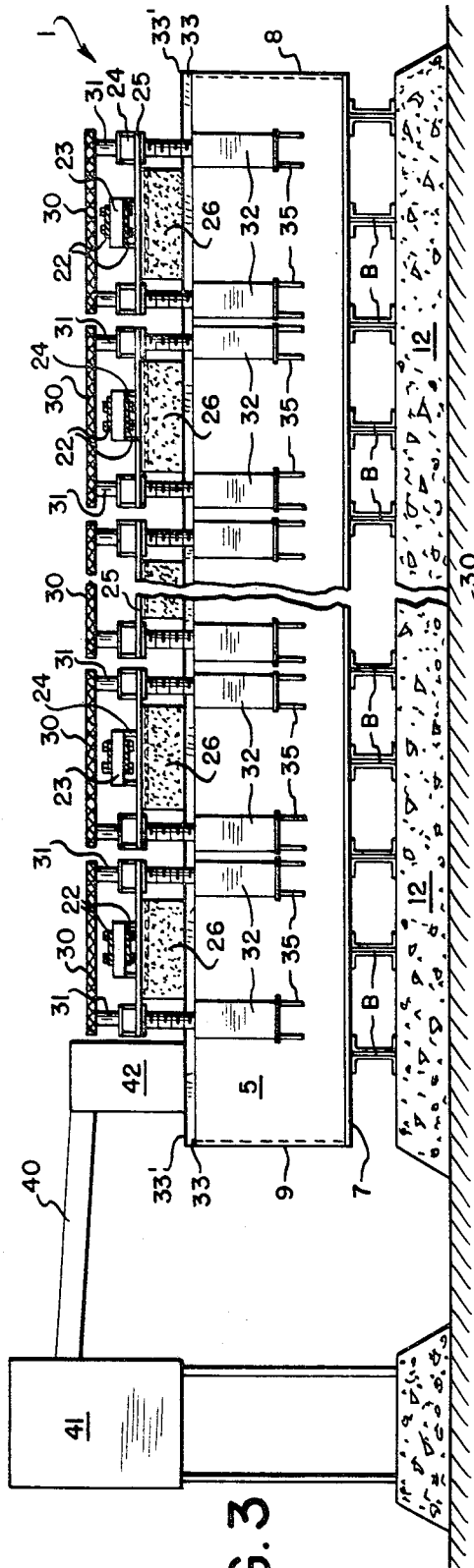


FIG. 3

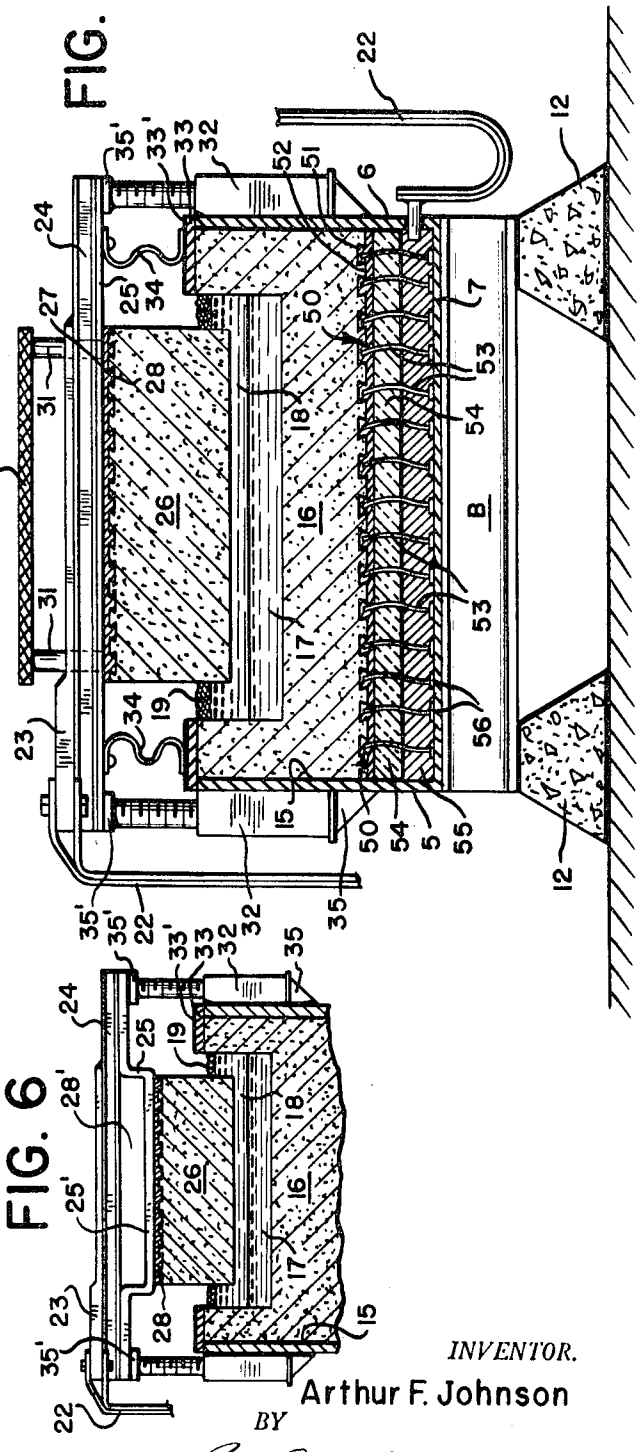


FIG. 5

FIG. 6

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Patented Apr. 20, 1971

3,575,827

SYSTEM FOR REDUCTION OF ALUMINUM

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Continuation-in-part of applications Ser. No. 528,503, Feb. 18, 1966, now Patent No. 3,434,957, Ser. No. 550,653, May 17, 1966, now Patent No. 3,501,386, Ser. No. 607,330, Jan. 4, 1967, now Patent No. 3,434,958, and Ser. No. 614,294, Feb. 6, 1967, now Patent No. 3,470,075. This application Dec. 6, 1967, Ser. No. 688,578

Int. Cl. C22d *3/12, 3/02;* B01k *3/00*
U.S. Cl. 204—67 16 Claims

ABSTRACT OF THE DISCLOSURE

A system for electrolytic reduction of aluminum, the system including a plurality of adjacent cells for effecting the electrolytic reduction of aluminum in which the cells are connected in line and each cell includes a cathode and a plurality of anodes with the cathode of one cell electrically connected to each anode of the next adjacent cell for directing the entire current from the cathode of the one cell to each anode of the adjacent cell.

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of my application, Ser. No. 528,503, filed Feb. 18, 1966, now U.S. Patent No. 3,434,957; application, Ser. No. 550,653, filed May 17, 1966, now U.S. Patent No. 3,501,386; application, Ser. No. 607,330, filed Jan. 4, 1967, now U.S. Patent No. 3,434,958; and application, Ser. No. 614,294, filed Feb. 6, 1967, now U.S. Patent No. 3,470,075.

BACKGROUND OF THE INVENTION

Field of the invention

This invention is concerned with the electrolytic reduction of aluminum from molten fusions.

Description of the prior art

It is common practice to arrange the Hall type reduction cells in rows called pot lines in which the cathode current is collected from areas of the carbonaceous cell lining by collector bars embedded in the lining and extending to the long sides of the cells. It is usual to suspend the anodes by vertical anode rods from a superstructure electrically insulated from the steel cell shell. The cathode collector bars contact cathode bus bars running parallel to and closely spaced from the longitudinal sides of the cells and thereby all cathode current is accumulated and carried to the ends of the cell in buses of increasing cross-section and thence carried transversely and upward through cell to cell cross-over buses to longitudinal anode buses above the next downstream cell and thence distributed lengthwise of said cell in buses of decreasing cross-sections to vertical anode rods. In such cell arrangements 50,000 or even possibly 200,000 amperes are accumulated in the massive cross-over bus bars near the ends of the cells and in the anode and cathode buses adjoining them.

Such huge currents have given rise to magnetic stirring and locally unpredictable anode spacing between the molten aluminum on the cathode lining and the anodes suspended in the fluoride fusion overlying the reduced molten aluminum. To appreciate the precision of adjustment of anode heights necessary to preserve uniform anode current density, it must be understood that the anodes are spaced above the molten aluminum only about 1¼ to 2 inches over an area of aluminum which may be 6 to 10 feet wide and 20 or 30 feet or more long.

SUMMARY OF THE INVENTION

The construction arrangement of this invention saves much expensive bus structure, enables the cells to be arranged closer together with a substantial saving in plant area, and avoids the large magnetic effects which decrease operating efficiencies. The invention eliminates the need for the customary anode rods and superstructure by which such rods are supported.

Generally, the invention provides a combination of at least two cells one of which has a cathode electrically connected through an individual bus to each anode which is disposed transversely across the adjacent downstream cell. The cells are arranged side-by-side with their adjacent longitudinal sides parallel to each other in a construction which eliminates the customary longitudinal bus structure, the only bus structure being that which transverses the cell from one longitudinal side of one cell to the longitudinal side of the adjacent cell. Each anode is electrically connected in the shortest practical manner entirely by a flexible bus to the cathode of the adjacent cell. The anodes may be unitary or assembled in sections and are preferably provided with means for individual regulation so that the current density of the anodes of each cell are at least as uniform as in the present practices. The invention makes possible cells of great length and the amount of amperage unlimited except for supply considerations. Anodes may be composed of prebaked electrodes or be of Soederberg or other massive type built up of baked blocks electrically and mechanically cemented together with resulting electrical efficiency and minimizing of magnetic stirring.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustraate various constructions and arrangements of apparatus for the electrolytic reduction of aluminum of the invention.

FIG. 1 is a plan view of several electrolytic reduction cells arranged in parallel side-by-side position;

FIG. 2 is sectional view at 2—2 of FIG. 1;

FIG. 3 is a side view at 3—3 of FIG. 1;

FIG. 4 is a vertical sectional view of a modified cell for arrangement with another similar cell as in FIGS. 1 and 2;

FIG. 5 is a vertical sectional view of another modified cell for arrangement with another similar cell as in FIGS. 1 and 2; and

FIG. 6 is a vertical sectional view of a modified anode supporting structure.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The apparatus of the invention illustrated in FIGS. 1, 2 and 3 comprises at least two adjacent similar cells **1** and **2** and portions of cells **3** and **4**, all arranged in side-by-side position with their longitudinal sides **5** and **6** parallel. Each cell has a steel shell consisting of bottom **7**, sides **5** and **6** and ends **8** and **9**. The bottom rests on supporting channel bar steel beams B which support the cell above the concrete support foundations **12** and provide spaces for the circulation of cooling air under the cell bottom and upward along its sides. Steel upright plates (not shown) may be sandwiched between the channels and extended upward to stiffen the cell sides. Any suitable side stiffening bars may be used. The bottom **7** of the steel shell has an overlying cast slab of aluminum **13** in which cathode collector bars **14** are set when casting the aluminum as more completely described in my copending applications Ser. No. 528,503 filed Feb. 18, 1966, now U.S. Pat. No. 3,434,957 and Ser. No. 607,330 filed

Jan. 4, 1967, now U.S. Pat. No. 3,434,958. The inner sides of the steel shell and the upper surface of the slab of aluminum **13** are covered with a thin chemically resistant and electrically insulating refractory **15** to compel the cathode current to travel through the collector bars **14** rather than flow directly to the sides and bottom via the conducting carbonaceous cell vessel or pot lining **16**. The upper portions of the collector bars **14** are embedded in the carbonaceous vessel **16** and the lower portions extend through the aluminum slab **13** and are mechanically and electrically joined to a steel bottom plate **7**. Above the aluminum slab the heat insulation **15** may be of refractory brick or pulverized alumina through which the collector bars **14** project upward into the carbonaceous lining **16**. The vessel **16**, of course, contains the reduced molten aluminum layer **17**, and the overlying fluoride fusion **18** which has a crust **19**. As is well known, the carbonaceous lining **16** and the aluminum are cathodic. The current collected by the bars **14** passes into the aluminum slab and the botton steel plate **7** and via conducting pins or lugs to the flexible buses **22** which extend to the anode buses **23** of the adjacent cell.

The anode buses **23** are attached to steel bars (channels or I beams) **24** extending transversely of the cell, which are in turn attached to the underlying steel plates **25**. However, when using an aluminum bus it is desirable to leave a space for ventilation of at least several inches between the bus **23** and the plate **25** to avoid melting the aluminum bus. The flat-topped anodes **26** which may be unitary or assembled in sections are suspended in the fluoride fusion at a distance about 1.5 to 2.0 inches above the molten aluminum cathode layer **17**. The anodes are mechanically and electrically joined by a layer or slab of cast iron **27** having roughened, indented or grooved surfaces **28** which secure the anodes to the steel plates **25**. Alternately the anodes may be secured to the steel plates by graphite cement (not shown).

The anode assemblies consisting of the flat-topped anodes **26**, the steel plates **25** and the channel or I beams **24** to which the anode bus **23** is connected is cooled by radiation and convection to the atmosphere to which it is outwardly exposed. Steel gratings **30** on which potmen may work may be superimposed a few inches above the anode bus **23** on steel legs **31** attached to the steel anode plates **25**. These gratings may be made of steel bars turned edgewise and preferably enameled or coated with low heat conducting material to permit workmen to use it as a walkway. The anode assemblies are adjusted upward or downward by the jacks **32** on which they rest. The jacks are supported on brackets **35** and may be manually or mechanically operated. The jacks are electrically insulated from the plates **25** by refractory insulation **35'**. As is best shown in FIG. 3, the various anodes are at the same elevation. However, as a result of adjustment by the jacks due to the anode consumption they are usually in various stages of elevation above the steel plates **33** which extend over the top of the cathode side lining and have a coating of refractory insulation **33'**. The anode assemblies are sealed along the sides and ends by thin flexible electrically insulated steel sheets **34** which extend from the insulation over the steel cover plates **33** to the plates **25** and do not electrically short circuit these plates. These seals prevent the escape of gases or vapors from the cell and enable the gases to be removed by a suction pump (not shown).

As best shown in FIG. 3 the air-slide closed duct conveyor **40** set at an angle of about 2% slope is connected to a bin **41** for carrying the alumina in a fluidized state. The duct connects to a small feed bin **42** at the end of each cell. This bin is in closed connection with the duct **40** which also makes a gas-tight connection to the enclosed spaces over the fusion crust. The vapors from the cells are sucked through the duct **40** and into the bin **41** which may be equipped with apparatus as shown in my application Ser. No. 614,294 filed Feb. 6, 1967, now U.S. Pat. No. 3,470,075, for the recovery of fluorides carried along in the vapors or gas passing through duct **40**. The small bin **42** is for emergency purposes when the air-slide conveyor is inoperative. Normally the conveyor distributes the alumina feed to the spaces between the anodes. The fluoride crust **19** is broken to add alumina to the fluoride fusion **18** by moving the anode or assembly of anodes vertically relative to the adjacent cell side lining or by moving the anodes relative to each other by means of the jacks **32**. The fluoride crust is necessarily sheared between most anodes to permit alumina on top of the crust to fall into the fusion when an anode effect results from a depletion of alumina in the fusion. In between anode effects the alumina need only be added periodically every 5 to 50 minutes near the ends of the cells where electromagnetic stirring of the fusion is a maximum and thus readily dissolves alumina.

The construction of anodes shown in FIGS. 1 and 2 are as disclosed in my said patent application Ser. No. 550,653, now U.S. 3,501,386. The construction of cathodes in FIGS. 1 and 2 is similar to that disclosed in my patent application Ser. No. 528,503, filed Feb. 18, 1966, now U.S. Pat. No. 3,434,957, and may also be similar to that disclosed in my patent application Ser. No. 607,330 filed Jan. 4, 1967, now U.S. Pat. No. 3,434,958.

The collector bars may be of any suitable or known type or as illustrated in my said patent applications or as shown in FIGS. 4 and 5. I may use about six or more collector bars of the horizontal type connected together by flexible buses and likewise connected to the anode bus **23** as described above.

FIG. 4 illustrates in cross-section a modification of cell of the invention characterized by an arrangement of horizontal collector bars **43** and **44**. The remaining parts of the cell are as described in FIGS. 1 and 2. The collector bars **43** and **44** issues from the same longitudinal side **6** whereas in conventional cells, bars similar to these issue from opposite longitudinal sides and are attached by flexible buses to the respective longitudinal accumulator buses located on the side where the bar issues. The cell bottom plate **7** is relatively cool due to the layer of heat insulating brick or pulverized alumina **45** which is 2 to 12 inches thick between the cell bottom **7** and the carbonaceous potlining **16**. The bars **43** run partly through the cathode lining and partly through the refractory **45**. The downstream (right) half of bars **43**, therefore, stay cool. The collector bars **43** and **44** are embedded in the electrically conductive lining **16**. Near the center of the potlining the collector bars may reach a temperature of 900° C. or more whereas the steel bottom may be only 100° to 200° C. For this reason, the construction of bars **43** allows current to be withdrawn across the width of the cell without being choked off by the high electrical resistance of such a long bar above red heat (500° C.) for so much of its length. Without such construction of bars nearly all the current from the anode on the downstream (left) side would move horizontally in the molten aluminum layer and then travel vertically downward into the bars underlying it. The thin refractory electrical insulation **45'** is also used around bars **43** and **44** where they issue through the steel shell so current in the potlining will not travel horizontally sideways to the steel shell directly from the molten aluminum layer since this can cause unpredictable metal circulation and concentrations of currents in cracks in the potlining and burnouts through the steel shell through which both molten aluminum and fluoride fusion could then empty onto the floor.

The cell illustrated in FIG. 5 is generally similar to the cell of FIG. 4 and comprises a poured cast iron plate **50** which may be from ¼ inch to 1 inch thick in a waffle plate or corrugated type of construction. As shown, the upper surface has dovetail ribs **51** and intervening thin sections **52** which contact the carbonaceous potlining **16** and is, therefore, secured thereto. The thickest sections **51** of the cast iron contact and cover the upper ends of a multi-

plicity of flexible iron straps **53** which are cast into the cast iron and carry the cathode current downward through the heat insulating layer **54** to the attached end plates **56** and into an aluminum layer **55** which is cast on the steel shell bottom **7**. The cast iron layer **50** serves as a means of electrical contact between the cell lining **16** and also protects the heat insulation **54** from absorbing fluoride fusion which may eventually permeate the carbonaceous lining and then the insulation and destroy heat insulating properties. Enough flexible iron straps are used so that the current density therein usually ranges from about 100 to 300 amperes per square inch. When the current in any area of the cell and potlining thereunder becomes higher than in another area, the current in the iron straps there increases; but the increased resistance of the overloaded straps and overloaded thin sections in the cast iron waffle pattern keep currents in any such area from being excessive.

The modification of anode supporting means shown in FIG. 6 comprises anode buses **23** attached to steel beams **24** which are attached to steel plates **25** as described above. In this modification the steel plates **25** have a U-shaped depression or depending portion **25'** to which the cast iron grid **28** is attached. This construction enables the anode **26** to be lowered to a position so that the top of the carbon anode is near the crust **19**, whereby substantially all of the anode can be consumed. Another advantage is the provision of a space **28'** which facilitates the cooling of the beams **24** to which the anode buses are attached.

In the operation of the apparatus of the invention, each anode assembly is raised or lowered by the jacks **32** supporting the steel anode plates **25** at their four corners above the cell until the amperage taken by this anode assembyy is about the same as the amperage taken by the other similar anode assemblies which feed the electrolyzing current to any cell in the potline. Anode current density which is usually suitable varies between 3.5 to 9 amperes per square inch of horizontal anode cross-section in the fluoride fusion with 4 to 7 ampres per square inch being more common. This invention makes it possible to carry somewhat higher anode current densities than on conventional cells without detrimental effect such as rapid loss of ampere efficiency and overheating and air burning of the anodes above the fluoride crust because the absence of longitudinal buses carrying high amperage currents avoids the excessive and almost unpredictable metal heaping and electromagnetic stirring of the molten aluminum cathode layer experienced in conventional cells and extensively discussed in the prior art. It should be understood that the workmen who set conventional anodes are only able to estimate by many molten metal level measurements the proper height to set new anodes in a cell in order to give such new anodes the same anode-molten metal cathode spacings as others. Absence of significant local metal heaping attained by this invention makes original anode setting more uniformly correct. Advantageously, this invention employs anodes with flat tops (as distinguished from bell-shaped top anodes) and makes electrical connection as between **22**, **23**, **24**, **25** and **26** to at least a major part of anode top. Both of these features reduce the electrical drop from anode bus to anode to a fraction of the conventional practice where a 2 inch to 4 inch or more diameter vertical steel rod ordinarily contacts only the center of the anode carbon to a depth of about 4 inches. Thus, this feature of the invention may reduce the conventional voltage loss from anode-bus-to anode of from 0.15 to 0.20 down to from 0.10 to 0.14 volt.

The above feature of providing flat-top anodes cooled by outward radiation due to contact with the atmosphere is not merely an improvement in voltage saving in the metal to anode contact but an improvement in preserving anode cross-section (and hence low anode current density) by decreasing anode top air burning. Heretofore, the high metal-anode voltage drop has by the heat of RI^2 (resistance and square of amperage) acted to make the top of the anode red hot with consequent oxidized periphery since it lay above the fluoride crust. It has, therefore, not been practical to use prebaked anodes much higher than 14 inches without coating them with expensive impervious coatings since the tops burned up. Especially has this been true in cells which used hoods over the anodes to collect the gases issuing from the fusion as the hoods prevented outward radiation of heat. This invention permits the steel top of the anodes to remain relatively cooler by atmospheric radiation and convection, and permits prebaked anodes even 2 feet or more high to be used which eliminates the necessity of changing anodes for three weeks or more instead of as frequently as once per week as presently often necessary.

When an anode carbon is consumed by electrolysis where only about 6 inches of its height remains, the anode plate **25** will almost rest on the deck plate **33** but be insulated against shortcircuiting thereon by the thin refractory layer **33'**. At this time the anode is raised by the jacks **32** enough so that the amount of current taken by it is greatly reduced. Then the cross-over flexible bus **22** is unbolted or otherwise detached from the anode bus **23** and the anode **26** removed from the furnace by a crane and hooks gripping the transverse reinforcing beams **24**. The carbon anode **26** is mechanically broken off the cast iron **27** and the brittle cast iron is mechanically broken off the steel plate **25** and a new anode of 1½ or 2 feet or more in height is attached as by pouring cast iron between the steel plate **25** and the new anode **26** to sandwich their indented or otherwise roughened surfaces together. One or more pieces of anode **26** may be used to attach to each anode plate **25** with a cast iron layer **27** to form one anode assembly. Thus, the size of individual anodes may be limited by the size of the hydraulic press to form them but this need not limit anode assembly size. In any case enough anodes are required to span the width of the cell which may be 8 to 12 feet or wider. The total length of the multiplicity of anode assemblies in the longitudinal dimension determines the overall length of the cell. Anode carbons of 1.5 tons or more may be attached to a single steel plate and carry from 10,000 to 30,000 amperes current or more.

When a cell needs to be taken out of service for repairs, air-operated cylinders may be used to simultaneously pull all thin insulation out from between switch plates which "dead head" or short out that cell in the conventional manner after voltage on it has been reduced by lowering the anodes to or near the metal layer.

Soederberg anodes may be used with this invention. In this case the anode pins of each typically similar cross-section are electrically connected together only by a transverse anode bus spanning the cell transversally and this in turn is flexibly connected in the shortest practical manner to the cathode of the adjacent electrically upstream cell in a manner similar to that described above. One or more Soederberg anodes may be used per cell.

By this invention the necessity for massive longitudinal cathode and anode buses is eliminated since huge currents are not respectively accumulated longitudinally or distributed longitudinally towards or away from the ends of the cell. In this way much expensive bus is saved and the cells are more free of magnetic effects which decrease efficiencies.

Although carbonaceous potlinings are generally used, this invention may advantageously use electrical connection to the cathode molten metal other than such potlinings.

I claim:

1. The combination of cells for the electrolytic reduction of aluminum from molten fusions which comprises at least two adjacent cells arranged side-by-side the longitudinal adjacent sides of which are close together, each cell having a cathode at the bottom in electrical contact with electrically conductive cell lining, each cell having a plurality of anodes disposed transversely across the cell

and being supported on means providing for upward and downward movement whereby each anode is adjustable to unify current distribution, and a separate flexible bus connecting the cathode of one cell in the shortest practical distance to each anode of the other cell, said flexible buses being the entire effective means for conducting current from the cathode of one cell to the anodes of the adjacent cell with the elimination of longitudinal anode bus structures.

2. In the combination of claim 1 the flexible buses being formed of sheets of aluminum or copper connected at one end to current collector bars in the cathode of one cell and to an anode bus for each anode which spans the other cell, each anode being supported on adjustable means for raising or lowering it individually to balance the current flow.

3. The combination of claim 1 which comprises flat top anodes, a transverse beam having an attached steel plate, a cast iron slab connecting the anode to the steel plate, the anode bus being connected to the transverse beam.

4. The combination of claim 1 which comprises a solid aluminum slab beneath the carbonaceous cell lining which is in electrical contact with conductive cell lining and the flexible buses.

5. The combination of claim 1 which comprises cells in excess of twenty feet in length, one cell having a continuous unitary and approximately equipotential cathodic bottom portion.

6. The combination of claim 1 which comprises an anode assembly comprising an anode bus connected to the flexible bus, a ferrous metal structure connecting the anode bus to the anode, said ferrous metal structure being supported at the sides of the cell on upward and downward adjusting means and having an area to which the anode is attached which depends towards the cell fusion whereby the anode can be lowered into the cell to an extent permitting practical consumption of the entire anode.

7. The combination of cells for the electrolytic reduction of aluminum from molten fusions which comprises at least two adjacent cells arranged side-by-side the longitudinal sides of which are parallel to and close together, said cells being over twenty feet in length and each having a unitary cathodic bottom portion, a plurality of anodes in the cells, a plurality of flexible buses separately connected to the cathodic bottom portion of one cell, each anode of one cell being separately and entirely connected to one of the flexible buses, each anode having a flat top connected to a steel plate, said steel plate being connected to the flexible bus.

8. The combination of claim 7 in which each anode is supported on individual adjusting means to raise or lower the anode to balance the current flow in the several anodes.

9. The combination of claim 7 which comprises vapor confining means above the cell fusion, a duct operating under reduced pressure for carrying away the gases and vapors emanating from the cells, and means for feeding alumina in a fluidized state through said duct whereby fluorides in the gases are absorbed by the alumina.

10. The combination of claim 7 which comprises an anode assembly comprising an anode bus connected to the flexible bus, a ferrous metal structure connecting the anode bus to the anode, said ferrous metal structure being supported at the sides of the cell on upward and downward adjusting means and having an area to which the anode is attached which depends towards the cell fusion whereby the anode can be lowered into the cell to an extent permitting practical consumption of the entire anode.

11. The combination of at least two cells for the electrolytic reduction of aluminum which comprises at least two cells arranged side-by-side and having their longitudinal sides close together, one cell having a cathodic bottom portion, the adjacent cell having a plurality of flat top anodes arranged side-by-side and transversely spanning to cell, bus means connecting each anode across the space between the longitudinal sides to the cathodic bottom which is the entire current conducting means to the anode, and a superstructure above the andoes having a grating on which workmen can walk.

12. The combination defined in claim 11 which comprises means to seal the upper portion of the cell to prevent the escape of gases and vapors from the cell, a duct operated under reduced pressure for removing the gases and vapors from the cell, and the means to feed alumina through the duct countercurrent to the gases whereby fluorides in the gases are absorbed by the alumina.

13. The combination defined in claim 11 in which the anodes have flat tops secured to a cast iron slab and means for connecting the cast iron slab to the bus means.

14. In an operation for the electrolytic reduction of aluminum in a plurality of cells arranged in series the improvement which comprises passing current from a plurality of anodes of one cell through a fusion and to a conducting cathode of said one cell, and passing all the cathode current from said one cell in a plurality of separate electrical paths to each of a plurality of anodes of the next adjacent cell with a material reduction of electromagnetic effects on the molten aluminum cathode layer.

15. An operation for the electrolytic reduction of aluminum as defined in claim 14 wherein all of the cathode current from the one cell is fed in separate electrically parallel paths to each anode of the next adjacent cell.

16. A combination of at least two cells for the electrolytic reduction of aluminum which comprises at least two cells arranged side by side and having their longitudinal sides close together, one cell having a cathode at the bottom, the adjacent cell having a plurality of anodes arranged side by side and transversely spanning the cell, and a plurality of bus means separately connecting the cathode of said one cell to each anode of the adjacent cell, said bus means being the entire effective means for conducting current from the cathode of the one cell to the anodes of the adjacent cell.

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U.S. Cl. X.R.

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