United States Patent [19]

Anderson et al.

[11] **3,715,299**

[45] **Feb. 6, 1973**

[54] **ELECTROPLATING APPARATUS INCLUDING MEANS TO DISTURB THE BOUNDARY LAYER ADJACENT A MOVING ELECTRODE**

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[73] Assignee: **Future Systems, Inc.,** Los Gatos, Calif.

[22] Filed: **Oct. 12, 1970**

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[52] **U.S. Cl.** **204/212,** 204/109, 204/281, 204/286, 204/289

[51] **Int. Cl.** **C23b 5/68**

[58] **Field of Search**.....204/109, 212, 272, 289, 281, 204/286

[56] **References Cited**

UNITED STATES PATENTS

2,536,912	1/1951	Corbett	204/212
3,477,926	11/1969	Snow et al.	204/109
3,560,366	2/1971	Fisher	204/212

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Assistant Examiner—W. I. Solomon
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[57] **ABSTRACT**

Apparatus for transfer of mass, e.g. metallic ions to or from a relatively stationary body from or into a moving fluid. Means are included for continuously disturbing the fluid about the surface of the body to discourage the establishment of a steady state boundary layer of the fluid.

8 Claims, 10 Drawing Figures

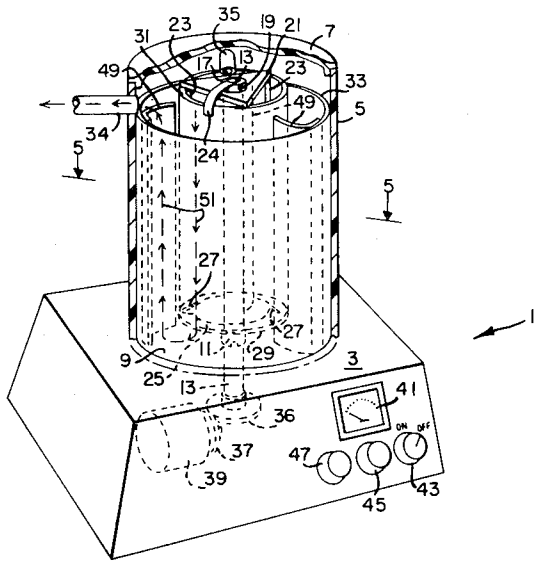


FIG. 1

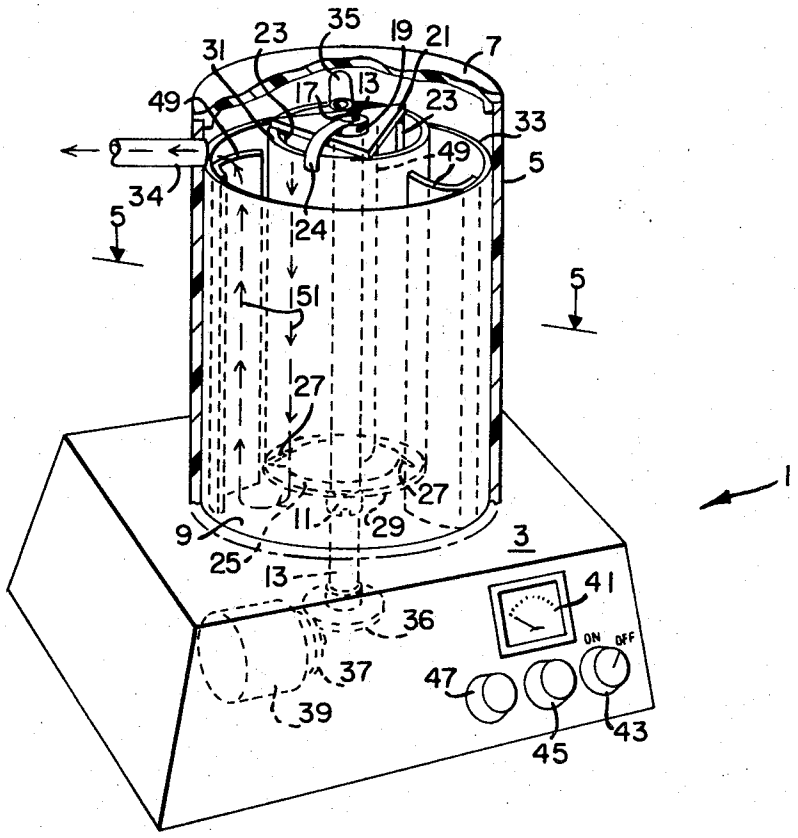
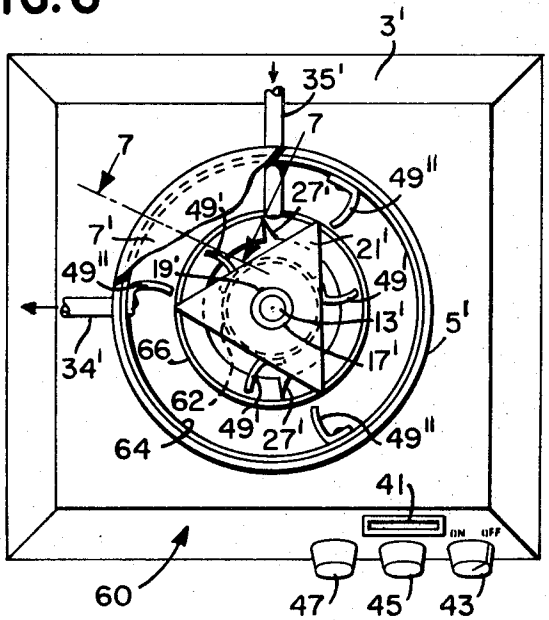


FIG. 6



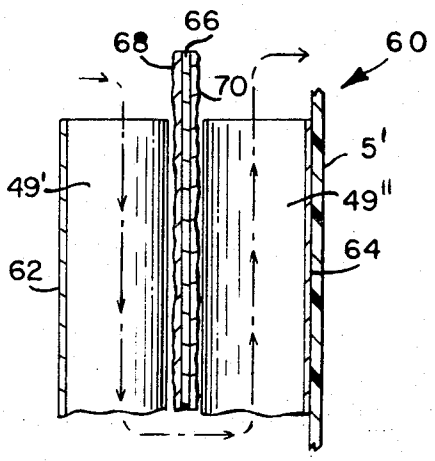


FIG. 7

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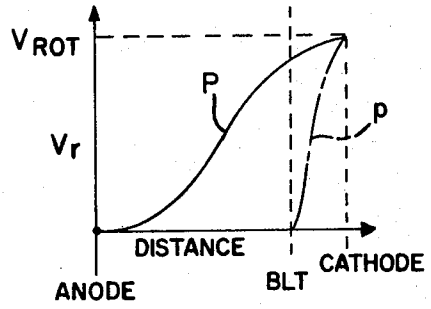

FIG. 2

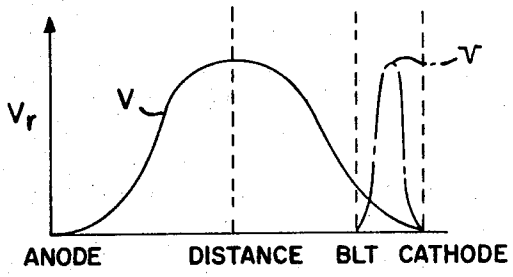

FIG. 3

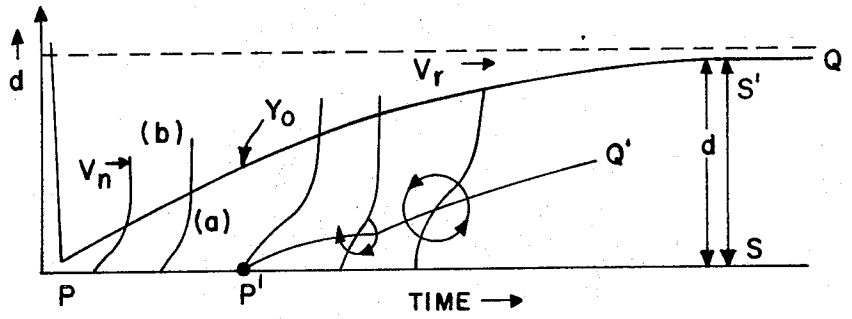

FIG. 4

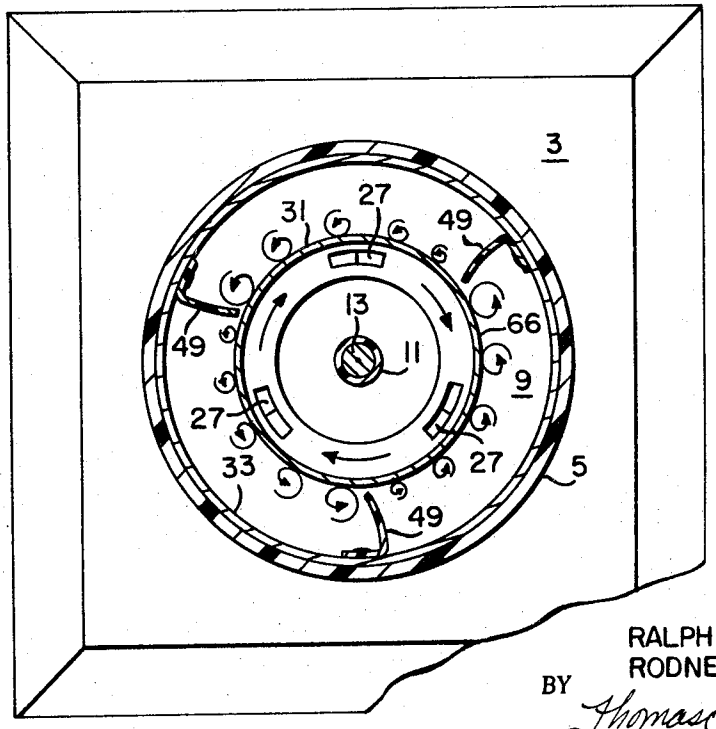

FIG. 5

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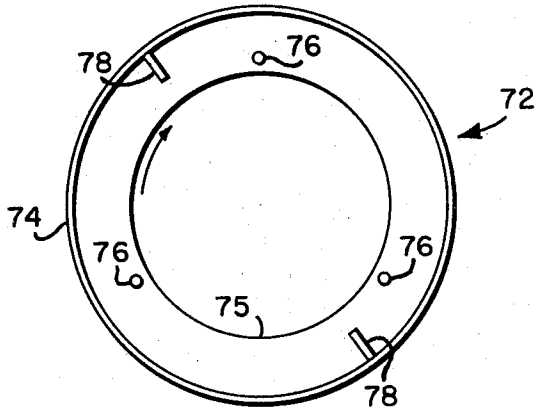

FIG.8

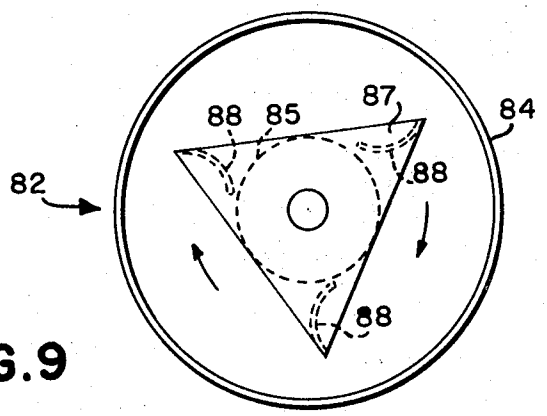

FIG.9

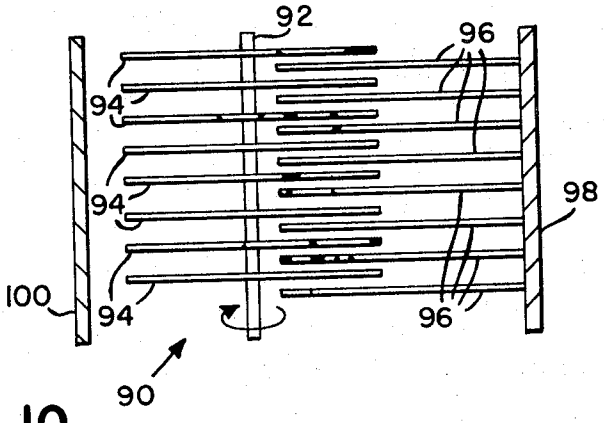

FIG. 10

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ELECTROPLATING APPARATUS INCLUDING MEANS TO DISTURB THE BOUNDARY LAYER ADJACENT A MOVING ELECTRODE

BACKGROUND OF THE INVENTION

The transfer of mass between a selective stationary body and a moving fluid is of prime concern in numerous chemical, electrochemical and heat transfer controlled processes. For example, in photographic film development, the process is controlled by transfer of silver bearing species and other ions to and from the film surface. Also, in electrodeposition processes for extracting metal from a metal bearing solution to a collecting electrode, the metal ion is transferred from the solution to the collecting electrode. Electrodeposition structures heretofore available commonly include an anode, a cathode and means for circulating the solution intermediate and past the cathode and anode. A voltage difference is established across the electrodes such that the metal is attracted and deposited on the cathode and extracted from the solution. The collected metal may then be removed from the cathode. It has been found that the efficiency and success of transfer of the metal from the solution to the collecting electrode is dependent on the boundary layer of fluid established about the relative stationary body of the electrode.

There are presently various electrodeposition structures available. Commonly, as the metal content is depleted the impedance and the current through the solution varies. Frequently, the potential value between the electrodes is controlled as the concentration of metal within the solution varies to effect certain separations. A common approach is to install a sensor cell to sense the metal concentration within the solution. The potential across the electrodes is controlled responsive to the sensor.

It has also been found that as the solution is transferred across the face of the collecting electrode, a boundary layer of relatively motionless solution tends to form adjacent the cathode. The metal ions within this layer, commonly referred to as a boundary layer, are substantially depleted. The boundary layer, being relatively motionless retains its position and impedes the transfer of metal from the solution outside the layer to the surface of the collecting electrode. Thus, to overcome the boundary layer and reach the collecting electrode, the metal ions need be of sufficient velocity to penetrate said layer. To realize the higher velocity, increased electrical potential need be established across the electrodes.

Electrodeposition apparatus is widely used in the recovery of silver metal from silver bearing solutions such as that commonly used in photographical fixing baths. The recovery of silver serves two key functions — to recover silver for further use and to regenerate the fixer for further use. With prior art electrodeposition silver recovery systems it has been found that as the laminar flow of the silver bearing fixer (hypo) solution takes place about an electrode, the electrical current density must be controlled and varied as the silver concentration varies in order to prevent breakdown of thiosulfate ion which causes silver sulfide precipitation. As silver is depleted from the solution, the excess electrical energy is more readily available for alternate reactions to occur. The insoluable silver sulfide precipitate, in turn, renders the solution unsuitable for

further use. Thus, to preserve the collected silver and the solution for further use it is necessary to avoid silver sulfiding. This requires control of the electrical energy relative to the silver metal concentration of the solution.

Besides the use of sensors and control of the current density, another approach in the silver recovery art is to utilize a batch process. A number of recovery units are tied in cascade array and the silver bearing solution is permitted to flow from one recovery unit to another. The solution in each succeeding unit has less silver and each unit is operated at less current density relative to the preceding unit. As the solution flows from one unit to the next, the silver concentration is diluted to the level of that particular unit and then transferred to the next succeeding unit. It has been found that with the batch process, the recovery of silver becomes more time consuming in succeeding units as the silver content is decreased and the current density decreased. Consequently, it becomes necessary to sacrifice either time or the degree of extraction of silver from the solution in the terminal unit.

The prior art includes numerous various approaches to recover silver from solution and to rejuvenate hypo solution. Electrodeposition apparatus and methods are described in U.S. Pat. application Ser. No. 851,697, filed Aug. 20, 1969, and now abandoned entitled Apparatus for Silver Recovery from Silver Bearing Solutions by Lawrence R. Francom and assigned to the assignee of the present invention. The disclosed structure teaches an impeller to aid in circulating the solution about the surface of the electrodes. This structure has proven to substantially minimize difficulties with sulfiding over that of structures theretofore available. U.S. Pat. No. 2,791,555 discloses apparatus for recovery of silver from hypo solutions utilizing a plurality of disc shaped cathodes laterally spaced from a plurality of anodes. The cathodes are continuously rotated within the solution. Canadian Patent No. 491,453 describes apparatus for recovery of silver from hypo solution utilizing a stationary cylindrical cathode and a plurality of carbon anodes driven in a circular path coaxial with the cathode and radially spaced from the interior and exterior surfaces of the cathode.

A tutorial review of silver recovery methods is provided in the paper by M. L. Schrieber, entitled "Present Status of Silver Recovery in Motion-Picture Laboratories," published in the Journal of the SMPTE, June 1965, Vol. 74, pp. 505–513. A tutorial paper by K. Hickman, C. Sanford and W. Weyerts, entitled "The Electrolytic Regeneration of Fixing Baths," published in the J.S.M.P.E., Oct. 1931, pp. 568–589, discusses theoretical and practical approaches to silver recovery and the considerations of sulfiding.

A. A. Rasch and J. I. Orabree authored a tutorial paper entitled "Electrolytic Recovery of Silver From Fixing Baths at Low Current Density," published in Photographic Science and Technique, Series II, Volume 2, Number 1, pp. 15–33, Feb. 1955. This paper recognizes that a key concern with electrodeposition apparatus is sulfiding. Nicholas J. Cedrone, in a paper entitled "A Silver-Recovery Apparatus for Operation at High Current Density," published in the Journal of the S.M.P.T.E., Volume 67, pp. 172–174, Mar. 1958, recognizes the concern of sulfiding and discusses an

electrodeposition system utilizing external pump agitation and high current density.

SUMMARY OF THE PRESENT INVENTION

The present invention relates to an improved apparatus for mass transfer and control of boundary layer. The invention has proven to provide a significant improvement in electrodeposition apparatus for recovery of metals from metal bearing solutions. The invention teaches structure for facilitating the transfer of solution about the face of the body moving relative to the solution e.g. a collecting electrode, and discouraging the creation of a relative motionless boundary layer of solution adjacent to said collecting electrode. This has been found in electrodeposition embodiments to substantially decrease the tendency of sulfiding even in the presence of high current densities.

In an exemplary embodiment of an electrodeposition apparatus including a stationary electrode and a rotating electrode, the stationary electrode carries a plurality of flexible tripper arms protruding towards the collecting surface of the collecting electrode and terminating adjacent to the collecting electrode. Means are included to transfer the solution intermediate the electrodes while the rotating electrode provides radial motion to the solution. The tripper arms disturb and agitate the solution adjacent the collecting electrode thereby discouraging buildup of a boundary layer.

The exemplary embodiment may be further adapted such that the input portal of the apparatus for the solution is at a higher level than the output portal. Thus, the solution flows from the input portal to the output portal by fluid displacement in an axial direction about at least one electrode while the rotating electrode simultaneously imparts radial motion. The solution then exits at the lower level such that minimal mixing of the incoming solution with rejuvenated solution takes place.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of an electrodeposition apparatus incorporating the teachings of the present invention;

FIG. 2 is a theoretical schematic illustration of the velocity profile of solution between the cathode and anode of structures of FIG. 1 with and without boundary layer trippers;

FIG. 3 is a theoretical schematic illustration of the velocity of solution between the cathode and anode of structures of FIG. 1 with and without boundary layer trippers;

FIG. 4 is a theoretical schematic illustration of the boundary layer about the cathode of the structure of FIG. 1 with and without boundary layer trippers;

FIG. 5 is a sectional view along the line 5—5 of FIG. 1 and theoretically illustrating the eddy current action of the solution about the cathode of FIG. 1 with boundary layer trippers;

FIG. 6 illustrates a partially sectioned plan view of an alternative embodiment of an electrodeposition apparatus incorporating two anodes and the principles of the present invention;

FIG. 7 illustrates a sectional view taken along the line 7—7 of FIG. 6; and

FIG. 8–10 schematically illustrate other embodiments of electrodeposition apparatus incorporating the teachings of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention has been found to be highly beneficial in apparatus for the recovery of silver from silver bearing solutions, such as fixative baths used in the photographic industry. Such solutions are commonly referred to as hypo or fixer. In standard photographic film, silver is dispersed in a gelatin material in the form of silver halides-primarily silver bromide and silver chloride. The remainder of the silver halides are believed reduced to pure silver due to exposure of light. During processing and development of the photographic film, the silver ion part of the silver halides is extracted as a complex with a thiosulfate ion in the hypo solution. As the relative silver content is increased the hypo solution may lose its effectiveness and utility for processing film. Simultaneously the silver within the hypo is a valuable commodity. Accordingly, the removal and collection of the silver from the hypo is an important concept to permit reuse of the hypo solution in processing film and recovery of the silver for reuse of the metal itself.

Various approaches have been taken to recover silver from hypo solutions. To date, electrolytic methods have been found to be overall the most efficient, economical, and cleanest. A prime concern with electrolytic systems heretofore available has been formation of silver sulfide and other compounds during the recovery process. Sulfiding decreases the purity of the collected silver and the effectiveness of the hypo for reuse. The formation of silver sulfide is a function of current density relative to the silver content within the solution. As the current relative to the silver content increases, the likelihood of sulfiding increases. At the same time, however, as the current density decreases, the time required to extract silver from the solution increases and time efficiency decreases.

Approaches heretofore available have included incorporation of sensors to sense the silver content of the hypo which hypo solution is continuously circulated through the electrodeposition apparatus. An electronic control network in turn responds to the sensor and controls the current within the solution between the electrodes. Thus, as the silver content decreases, the current is decreased. Though said approach has been found to improve the system efficiency and control of sulfiding, further improvement is desireable for still more thorough depletion and efficient use of time. Prior art electrodeposition silver recovery systems have proven that with hypo at low silver concentrations, e.g. 0.20 troy ounces per gallon and less that maximum plating current densities without sulfiding are in the order of one to two amperes per square foot of cathode plating surface area.

FIG. 1 illustrates a silver recovery electrodeposition apparatus, referred to by the general reference character 1 and incorporating the teachings of the present invention. The apparatus 1 includes a control panel-base support member 3 supporting about its top surface a retainer in the form of an enclosure 5 in which a volume of hypo or other silver bearing solution may be retained. The enclosure has a removable top 7

and an integral bottom end wall 9. Preferably, the enclosure 5 including the walls 7 and 9 comprise a non-metallic material compatible with the hypo solution. Such material may comprise a plastic, fiberglass, polyvinyl chloride, etc. Extending through the bottom surface 9 within the center of the enclosure 5 is a fixed cylindrical shaft housing 11. The housing 11 houses a cylindrical rotatable shaft 13. The shaft 13 is comprised of an electrically conductive material and rotates about its axis within the housing 11 and the enclosure 5. The exterior of the housing 11 carries a non-metallic coating compatible with the hypo, e.g. plastic, fiberglass, polyvinyl chloride, etc. The housing 11 is sealed about the bottom surface 9 with an epoxy to prevent leakage. Within the housing 11 about the shaft 13 is an axial-thrust bearing (not shown) to provide lateral and axial support and guidance to the shaft. About the upper end of the shaft 13 is an electrically conductive coupling member 17 adapted to be secured to the shaft by means of a fastener 19 such that the coupling member 17 rotates responsive to the shaft 13. A triangular shaped support member 21 comprised of a non-conductive material extends radially from the coupling member 17 and is secured to the shaft 13. A plurality of three columns 23 are joined to the support member at the apexes and extend from said support member parallel to the rotating shaft 13. A conducting strip 24 is secured to the top of the shaft 13 and extends laterally therefrom.

At the terminating end of the support columns 23 is supported an impeller 25 adapted to urge axial flow of the solution. The impeller 25 is supported above the surface of the bottom wall 9. The impeller 25 is illustrated as carrying a plurality of openings 27 in the form of arcurate slots of substantially equivalent size relative to one another. The impeller 25 carries an outer ridge 29 about the outside of the column members 23. Engaging the exterior of the column members 23 and resting on the ridge 29 is a right circular cylinder cathode 31 referred to as the collecting electrode on which the silver is to be collected. The cathode 31 is substantially coaxial with the shaft 13. The cathode 31, which is comprised of an electrically conductive material, e.g. stainless steel, is secured to the strip 24. Accordingly, application of an electrical potential on the shaft 13 places the cathode 31 at a similar potential and rotation of the shaft 13 places the cathode 31 in simultaneous rotation within the enclosure 5.

About the exterior surface of the cathode electrode and coaxial therewith is a stationary right circular cylinder anode 33 preferably comprised of a material having a high electrical conductivity and not subject to attack by the hypo solution, e.g. stainless steel. The anode 31 is substantially coaxial with the cathode 31 and is positioned flush against the interior side walls of the enclosure 5. The top of the anode 33 is preferably below the level of the top of the cathode 31. The anode 33 is desirably spaced laterally from the cathode 31 such that the cross-sectional area of the enclosed spacing between the anode 33 and the exterior surface of the cathode 31 is substantially equal to the cross-sectional area intermediate the interior surface of the cathode and shaft housing 11. This provides for substantially equal flow areas about the interior and exterior surfaces of the cathode. Joined to the enclosure 5 about the top edge of the anode 33 is an outlet 34 permitting exit of the solution from the enclosure 5. An inlet portal 35 is included to permit entering of solution about the interior of the cathode 31.

In operation, a potential difference is established across the cathode 31 and anode 33. Electrical current is forced through the hypo solution by application of electrical voltage between the cathode 31 and the anode 33 and silver tends to be plated out in metallic form on the cathode surface. In a continuous flow process with the outlet portal 34 open, entering incoming solution tends to force the solution axially downward relative to the interior of the cathode 31 and upward about the area intermediate the cathode 31 and anode 33. The solution then flows over the top edge of the anode 33 and out the outlet 34. The impeller 25 tends to facilitate the flow of the solution. This method approximates the concept of a plug flow reactor.

The drive shaft 13 extends through the bottom wall 9 of the enclosure 5. About the exposed end, is a drive means including a gear 36 engaging a drive gear 37 driven by an electric drive motor 39 within the interior of the support member 3. The panel-base support member 3 may be designed to include an ammeter 41 to indicate the current through the solution intermediate the electrodes 31 and 33. Within the panel-base support there may be a suitable d.c. power source means (not shown) for applying a d.c. voltage between the cathode 31 and anode 33. The panel-base member 3 may also include an on-off switch 43, a voltage regulator control 45 extending to the power source means (not shown) and a speed regulator 47 to control the speed of the motor 39 and the rotational velocity of the shaft 13 and the cathode 31.

Accordingly, viewing the structure of FIG. 1, a hypo solution may be retained within the enclosure 5 and enter within the interior of the cathode 31. The solution may be contained if the portal 34 is closed or there may be a continuous flow of solution if the portals 34 and 35 are open. The motor 39 drives the cathode 31 in a rotary motion and the hypo solution circulates about the interior and exterior of the cathode. As the cathode 31 rotates hypo is continuously drawn down about the interior of the cathode and upward between the cathode 31 and anode 33 area. At the same time, the rotating cathode imparts radial motion to the hypo. As the hypo is circulated, silver is plated on the surface of the cathode reducing the content of the silver ions within the hypo. After a substantial amount of silver is collected on the cathode 31, the cover 7 is removed, the strip 24 is disengaged and the entire unitary cathode may be removed by sliding it off of the column members 23. After removal of the cathode 31, the collected silver may be removed by flexing the cathode. Also, the hypo is rejuvenated and may be reused in processing film.

The structure of FIG. 1 further carries a boundary layer tripper means including a plurality of arms in the form of flexible flaps 49 longitudinally engaged to and projecting from the exterior surface of the stationary anode 33. The flaps 49 are evenly radially spaced apart about the anode. For example, in FIG. 1 the flaps 49 are spaced approximately 120° apart. The flaps 49 extend longitudinally substantially end-to-end of the cathode 31 and terminate adjacent to the exterior col-

lecting surface of the cathode **31** such that they extend substantially radially relative to said collecting surface. The flaps **49** assume a concave shape and are comprised of an electrically non-conductive material compatible with the hypo solution so as not to be corroded or deteriorated to any substantial degree by the solution. To date, flaps **49** comprised of a saturated hydrocarbon elastomer material of approximately one-sixteenth inch thickness have proven compatible. Such materials may include ethylene-propylene, rubber, neoprene rubber, n-butyl rubber, polyethylene, etc. The flaps are flexible and pivot about the point of engagement with the anode. The flaps terminate adjacent to the cathode surface within the area of the boundary layer. For example, in structures similar to FIG. **1**, the flaps **49** terminate to leave a space in the order of one-fourth to three-eighths inch between the terminal end of the tabs and the cathode surface. The drive means moves the cathode **31** relative to the flaps **49** by driving the cathode **31** about the axis of the shaft **13**.

The flaps **49** serve to disturb the hypo solution adjacent the surface of the cathode **31** and discourage establishment of a relative motionless layer of solution adjacent said cathode surface. The flaps **49** extend adjacent to the cathode within the area of this otherwise motionless layer. The theoretical explanation of the function and results of the boundary layer trippers is believed to be as follows. Theoretically, in mass transfer through liquids, a relative motionless layer of solution tends to be formed adjacent to a relative stationary surface. The liquid outside the layer, referred to as the bulk flow area, flows at a net bulk velocity. With the structure of FIG. **1** the net velocity Vr of the liquid within the bulk is dependent upon the vectorial sum of the rotational velocity component and the axial velocity component. In the absence of the boundary layer trippers **49**, the velocity profile of the solution between the anode **33** and the cathode **31** relative to the anode is shown schematically by the solid line P in FIG. **2** assuming that the anode is stationary and the cathode is rotated at a velocity V_{rot}. The velocity Vr of the fluid relative to the cathode **31** and the anode is schematically illustrated by the solid line V in FIG. **3** in the absence of the boundary layer trippers. Viewing the diagram of FIG. **4**, in the absence of the boundary layer tripper flaps **49**, as the viscous solution is transferred axially about the cathode (indicated by the line **51** in FIG. **1**) the flow fluid is retarded at and near the surface of the cathode **31** by the laminar boundary layer. The laminar boundary layer of solution tends to build up about the cathode surface and the depth "*d*" of the layer is a function of the velocity of the fluid in the bulk relative to the velocity of the relative stationary surface. For example, assuming the system is initially static and starting at a given point, as the fluid is transferred axially across the relative axially stationary surface, the thickness of the layer increases along the cathode surface as illustrated by the line Yo in FIG. **4**. Analyzing the boundary layer as consisting of an incompressible fluid, the pressure differential of the fluid within the layer of zone (a) relative to outside the layer of zone (b) is small (see FIG. **4**), as the effect of gravity is small. The force of the layer on the fluid attempting to penetrate the boundary layer may be sufficient to bring the fluid in the boundary layer to rest or cause flow in the reverse direction with the result that a turbulent eddy current is set up, also shown in FIG. **4**. A region of reverse flow then exists near the solid surface where the boundary layer has separated at the point P'. The velocity of the fluid rises from zero at the surface of the solid boundary to a maximum negative value (reverse flow) and falls again to zero along the line P'–Q'. Thus, P'–Q' may be viewed as a zero velocity line. The velocity then increases in the positive direction until it reaches the main stream velocity Vr of the bulk at the edge of the boundary layer PQ.

In the absence of the trippers **49**, the line PQ represents the development of the boundary layer adjacent a given point on the cathode from start to steady state with the enclosure **5** containing a supply of hypo. When steady state conditions are established a profile will be set up corresponding to a vertical section in FIG. **4**. This is designated as section S–S'. The thickness d depends on the rotational velocity of the cathode or solid boundary. Somewhere, in the boundary layer, the flow will separate at the point P' and induce eddy formation and flow recirculation. The induced eddy formation and flow recirculation is a normal result of high flow velocities in the absence of the trippers **49**. As Vr increases, recirculation can increase the power required to move the bulk fluid increases and there are practical limits as to power input.

Translation of a moving liquid and a stationary boundary condition (Case I) to a moving solid boundary and a stationary or stagnant fluid (Case II) are believed essentially equivalent in steady state flow conditions. However, in the pre-steady state conditions (unsteady-state boundary layer build-up) they can be different. For example, in Case I with the fluid starting from rest, the magnitude of the boundary layer thickness d decreases until steady state is reached while in Case II the magnitude of d increases until steady state is reached. This is due primarily to the fluid inertia. In both cases, however, as the velocity is increased, detachment of the fluid at the solid surface can occur which results in eddy formation and recirculation.

With the boundary layer trippers **49** attached to the anode **33**, the boundary layer at the cathode **31** is continually disturbed at the cathode surface. This is designated by the point P' in FIG. **4** and with the moving solid boundary cathode **31** and the stagnant bulk fluid, steady state is never reached. Eddy currents are induced at point P adjacent to the surface of the rotating cathode **31**. These intense eddy currents persist for a period of time and tend to dampen until the cathode has rotated around to another boundary layer tripper and the process is repeated. The induced eddy current phenomena adjacent to the surface of the cathode **31** thereby facilitates attraction to the cathode and transfer of fluid to the immediate adjacent surface of the cathode.

In regard to electrodeposition, such as silver recovery or other mass transfer to or from a solid surface, the more prevalent the formation of turbulent eddy currents, the faster the metal ions to be depleted or generated can be supplied or removed at the surface. Referring again to FIGS. **2** and **3**, incorporation of the boundary layer tripper flaps **49** as depicted in FIG. **1** effectively reduces the radial flow passage between the anode and cathode such that the profile and distribu-

tion are represented by the lines "*p*" and "*v*" respectively. The tripper flaps **49** prevent the formation of laminar boundary layer about the cathode and intensifies eddy current flow at the cathode surface. The eddy currents, at a given point on the cathode tend to persist at the surface for a substantial time period while the cathode rotates. The eddy currents at said given point tend to dampen intermediate successive trippers and are rejuvenated when the next tripper **49** is encountered. Said phenomena is illustrated schematically in FIG. **5** illustrating a cross-sectional view of the structure of FIG. **1** taken along the line **5—5**. As the cathode rotates, the boundary layer tripper flaps **49** tend to continuously disturb the solution about the cathode surface. Simultaneously, the supply of hypo is circulated adjacent to the cathode allowing ready transfer of silver ions from the circulating supply to the cathode. Accordingly, the electrical potential necessary to attract the silver ions to reach the cathode is substantially decreased thereby decreasing the necessary electrical power between the electrodes to realize electrodeposition. As the electrical potential is decreased the tendency of silver sulfide at the cathode for a given current is deminished.

The boundary layer tripper flaps **49** have been found to provide improved efficiency in electrodeposition in various ways. First, the boundary layer is decreased thereby facilitating transfer of silver ions from the bulk solution to the cathode surface. Second, the solution is circulated immediately adjacent to the cathode surface thereby facilitating transfer of the silver ions from the circulating solution to the cathode. Third, the continuous circulation has been found to virtually eliminate the tendency of sulfiding thus permitting increased current densities, even as the silver ion content decreases. Embodiments of silver recovery units incorporating boundary layer tripper flaps **49** have been found to accommodate current densities in the order of 100 amperes per square foot of cathode surface area with hypo solutions of silver concentration in the order 0.1 troy ounces per gallon without detectable sulfiding of the silver.

The incorporation of the boundary layer trippers have been found to permit units similar to the unit **1**, to perform similar to a batch process without the reaction times necessary in batch processes. With the unit **1** as the solution transfers axially, the concentration of succeeding increments of solution of axial movement have less silver concentration. At the same time, the high degree of agitation has been found to permit a uniform potential across the electrodes not withstanding the changing concentrations along the axial plane.

FIG. **6** illustrates a plan view of a further embodiment of a silver recovery unit incorporating the teachings of the present invention and referred to by the general reference character **60**. The unit **60**, exteriorally is similar to the unit **1** of FIG. **1** such that elements common to those of the unit **1** carry the same reference with a prime designation. The unit **60** is designed to incorporate a pair of stationary right circular cylinder anodes **62** and **64**. A rotatable right circular cylinder cathode **66** is positioned intermediate the anodes **62** and **64** such that each of the anodes is adjacent a collecting surface of the cathode **66**. The anode **62** carries a plurality of evenly spaced boundary layer tripper flaps 49^{1} and the anode **64** carries a plurality of evenly spaced boundary layer tripper flaps 49^{11}. The support member 21^{1} is comprised of an electrically conductive material such that the cathode **66** is at the same electrical potential as the shaft 13^{1}. FIG. **7** illustrates a cross-sectional segment of the structure **60** taken along the line **7—7**. Each of the anodes **62** and **64** carry a positive potential relative to the cathode **66** such that silver is plated on both exterior surfaces of the cathode **66** as illustrated by the layers of collected silver **68** and **70**. In the embodiment **60** the boundary layer tripper flaps 49^{1} and 49^{11} simultaneously disturb the solution adjacent both exterior surfaces of the cathode to facilitate plating on both of said surfaces as the cathode is rotationally driven about the shaft 13^{1}. The eddy currents are intensified at both surfaces of the cathode. The plating on both surfaces of the cathode is desired to be uniform. In units heretofore available, the spacing between the cathode and the anodes was critical for uniform plating. The boundary layer trippers 49^{1} and 49^{11} aid in uniform plating because the electrical resistance at the surface of the cathode is decreased, due to decrease or elimination of the boundary layer. Consequently, the spacing between the cathode and anodes has been found not to be as critical as heretofore known.

FIG. **8** schematically illustrates a plan view of a further embodiment of an electrodeposition apparatus incorporating the teachings of the present invention and referred to by the general reference character **72**. The apparatus **72** includes a stationary right cylindrical anode **74** and a rotating right cylindrical cathode **75**. Suspended intermediate thereof and adjacent the cathode are a plurality of arms in the form of stationary flexible tubes or rods **76**. The rods **76** are positioned immediately adjacent to the surface of the cathode and function as the boundary layer trippers. There may also be included impeding vanes **78** to impede rotational flow of the solution and to agitate the solution. As the cathode **75** rotates, the tubes or rods **76**, which are stationary, create eddy currents adjacent to the cathode to discourage the establishment of a boundary layer.

FIG. **9** schematically illustrates a further embodiment of an electrodeposition apparatus incorporating the teachings of the present invention and referred to by the general reference character **82**. The apparatus **82** includes a stationary right cylindrical anode **84** and a stationary right cylindrical cathode **85**. A rotating member **87** supports a plurality of arms in the form of flexible, concave boundary layer trippers **88** similar to the flaps **49**. The flaps **88** are rotated coaxially about the area intermediate the anode **84** and cathode **85**. The flaps **88** terminate immediately adjacent to the surface of the cathode and functions to discourage the establishment of a boundary layer about the cathode **85**.

A further embodiment of electrodeposition apparatus incorporating the teachings of the present invention and referred to by the general reference character **90** is illustrated in FIG. **10**. The apparatus **90** includes a drive shaft **92** supporting a plurality of disc cathodes **94**. A plurality of arms in the form of flexible members **96** protrude to within the area intermediate adjacent the discs **94**. The members **96** serve as boundary layer trippers to disturb the solution about said

discs and discourage the establishment of boundary layers about the disc surfaces. The members **96** are supported by a column **98**. An anode **100** is included. The cathodes **94** are moved relative to the boundary layer trippers **96** by maintaining the trippers **96** stationary while the cathodes are rotated by the shaft **92**.

We claim:

1. Apparatus for the electrodeposition of a metal from a body of solution comprising:

a retainer for retaining a volume of a solution bearing a metal to be recovered;

a first electrode member within the retainer and having a first collecting surface to receive and collect said metals;

a second electrode member within the retainer and disposed in spaced apart relationship with said first electrode member, the space between said first collecting surface and second electrode defining a chamber for passage of a body of said solution;

means for establishing an electrical potential difference between said first electrode member and said second electrode member;

means for moving said first electrode member in a first direction, such movement tending to establish proximate said first collecting surface a laminar boundary layer of fluid having a substantial component of motion in said first direction responsive to movement of said first electrode; and

boundary layer tripper means disposed within said chamber and stationary relative to said second electrode member, said boundary layer tripper means extending into said boundary layer of fluid for creating eddy currents of fluid within said boundary layer as said first electrode member is moved.

2. The apparatus of claim **1** wherein said first and second electrodes are in the form of a right circular cylindrical body disposed in coaxial relationship, and wherein said boundary layer tripper means includes at least one elongated member having a longitudinal dimension extending substantially parallel with said first collecting surface.

3. The apparatus of claim **1** in which

the boundary layer tripper means includes a plurality of arms positioned within said chamber, each of said arms having a longitudinally extending end, each of said arms positioned with its respective longitudinal dimension extending substantially parallel with said first collecting surface.

4. The apparatus of claim **3** in which

said arms are in the form of a plurality of flaps each comprised of a flexible material compatible with the solution to be retained within the retainer.

5. Apparatus for electrodeposition of a metal from a solution comprising, in combination:

a retainer for retaining a volume of solution bearing a metal to be recovered;

a first electrode member within the retainer and having a first collecting surface and a second collecting surface, said first and second collecting surfaces being positioned to be exposed to the solution within the retainer to receive and collect said metal;

a second electrode member within the retainer and spaced from the first collecting surface of the first electrode, the first and second electrodes positioned relative to one another to permit said solution to circulate intermediate the first and second electrodes;

a third electrode member within the retainer and spaced from the second collecting surface of the first electrode with the first electrode positioned intermediate the second and third electrodes, the first and third electrodes positioned relative to one another to permit said solution to circulate intermediate the first and third electrodes;

electrical power means for establishing an electrical potential on the first and second electrodes relative to one another and on the first and third electrodes relative to one another;

boundary layer tripper means intermediate the first and second electrode members and intermediate the first and third electrode members for disturbing the solution adjacent the first and second collecting surfaces, the boundary layer tripper means including at least one arm positioned within the retainer intermediate the first and second electrodes and projecting toward said first collecting surface and at least one arm positioned within the retainer intermediate the first and third electrodes and projecting toward said second collecting surface; and

drive means for providing relative motion between the boundary layer tripper means and said first and second collecting surfaces.

6. The apparatus of claim **5** in which

said arms are comprised of a flexible non-conductive material compatible with the solution, said arms terminating adjacent to the respective first and second collecting surfaces.

7. The apparatus of claim **6** in which

the boundary layer tripper means includes a plurality of said arms with the second and third electrodes each being engaged to a plurality of arms, the arms engaged to the second electrode being substantially uniformally spaced relative to one another about the first collecting surface of the first electrode, and the arms engaged to the third electrode being substantially uniformally spaced relative to one another about the second collecting surface of the first electrode.

8. The apparatus of claim **5** in which

the first, second and third electrode members are in the form of right circular cylinders coaxial about a common axis with the first electrode member positioned intermediate the second and third electrodes, the first electrode member being engaged to the drive means, the drive means being adapted to rotate the first electrode about said common axis;

the boundary layer tripper means includes a first set of boundary layer trippers and a second set of boundary layer trippers, said first set of boundary layer trippers being positioned intermediate the first and the second electrode members and adjacent said first collecting surface for disturbing the solution adjacent to said first collecting surface, and said second set of boundary layer trippers being positioned intermediate the first and the third electrode members and adjacent said second

collecting surface for disturbing the solution adjacent to said second collecting surface, each of the first set and each of the second set of boundary layer tripper means extending substantially normal to said first and second collecting surfaces of the first electrode;

an inlet portal means to permit a solution to enter the retainer intermediate the first and third electrodes about an axial terminal end of the second collecting surface of the first electrode; and

an outlet portal means to permit said solution to exit from the retainer about an axial terminal end of the second collecting surface of said first electrode; whereby solution displacement may force the solution from said inlet portal to said outlet portal axially across the first and second collecting surfaces.

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