The Complete Technology Book on Electroplating, Phosphating, Powder Coating And Metal Finishing
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Electroplating and Metal Finishing concerns itself with the development and applications of composites and non-metallic coatings. These coatings are used for decorative, protective and functional application. Some of the other common metal surface finishing technologies are phosphating, pickling, electroforming, powder coating etc. Electroplating is the process of applying a metallic coating to an article by passing an electric current through an electrolyte in contact with the article, thereby forming a surface having properties or dimensions different from those of the article. Metal finishing has now come to be known as surface engineering. Surface engineering techniques are generally used to develop a wide range of functional properties. In addition to the decorative aspects, metal finishing aids the protection of metals and alloys from corrosion and rusting. A great potential exists for development of new materials involving, for example, coatings of metals composites particle incorporated anodic coatings and even films of sapphire like materials, porous files of niobium etc. and coating of refractory metals like molybdenum and tungsten. Phosphate coatings have a wide field of application in manufacturing industry, both as an aid to mechanical production operations and in surface finishing. The major applications for phosphate treatments fall into four areas; pre treatment prior to organic coatings, protection against corrosion, anti wear coatings and phosphating as a production aid. Powder coating of aluminium, extrusions in particular, has become an important feature in the finishing of aluminium. There are several advantages of powder; powder coating overspray can be recycled and thus it is possible to achieve nearly 100% use of the coating, powder coating production lines produce less hazardous waste than conventional liquid coatings, capital equipment and operating costs for a powder line are generally less than for conventional liquid lines. Surface finishing is a broad range of industrial processes that alter the surface of a manufactured item to achieve a certain property. Currently, the trend is towards surface treatments. Industries in developing countries like India have to be increasingly aware of the need not only for upgradation of existing technologies but also for indigenization of new technologies on a time bound basis. The content of the book includes information about technology involved in surface engineering of metals; some of them are electroplating plant, barrel planting plant, electroplating equipment, cleaning, pickling and dipping, equipment for hot alkaline cleaners, electrolytic and chemical processes for the polishing of metals, canning stainless steel electro-polishing solution, electroforming in gramophone record production, silver plating, fluoborate plating, gold plating (gilding), cadmium plating, zinc plating, chemical finishing of aluminium, powder coating of aluminium, bright nickel electro plating, copper plating, etc. This book covers an intensive study of technology of electroplating, phosphating, powder coating and metal finishing. The first hand information on these technologies is dealt in the book and can be very useful for those looking for entrepreneurship opportunity in the said industry.
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**Electroplating Plant**

**Automatic Equipment**

Mechanization has been applied to the electroplating process since the 1920s, but until the 1960s its use was restricted to those organizations having massive quantities of components of similar type and which required an identical finish. In the last decade there has been a complete change in the situation with mechanization or automation being applied on an ever extending scale. Today, any electroplating production or output requirement from the mass production demands of the automobile industry to the small scale needs of the electronics manufacturer may be met and variations in the components to be processed and in the specification requirement are no longer an obstacle to the employment of automatic handling techniques.

An automatic electroplating plant is essentially a line of process tanks with a transfer system, which enables the articles to be electroplated to be immersed in each tank for the appropriate time and in the sequence necessary to produce the required finish.

Automatic electroplating equipment may be divided into two groups:

- **Fixed sequence plant**, which is the subject of the next section of this chapter, is employed where large volumes of work of a similar type are processed.
- **Variable programme plant**, which incorporates one or more independent transporters (lift/traverse units) operating under the instruction of a programmed controller.

### Fixed Sequence Automatic Plating Plant

The first automatic plant was essentially a development of the conveyor system in order to provide:

1. Immersion times in different tanks over a wide time scale.
2. Rapid inter-tank transfer to avoid staining of the work.

In the early 1950s, the conventional automatic plating plant developed on the basis of a return type design with a centre lifting carriage around which the tanks were arranged in a U formation. For large outputs and for the most effective use of floor space, this type of equipment is still to be preferred. It is however, subject to limitations in that, these designs can only be considered when there is a fairly narrow range of components to be processed and there is a common specification requirement. In general, the equipment is restricted to the single process sequence for which the plant was designed and whilst the speed of operation can be varied, such a change will introduce a proportional change in the immersion times at every other stage in the process sequence.

Within the well proven designs of the fixed sequence automatic electro-plating plant, efforts have been made to introduce a degree of variability so that this type of equipment could be employed where there are alternative specification requirements, for example, differing types of passivation on zinc deposits; a number of deposit thickness requirements or differing types of coating to be applied.

Equipment of this type includes the **Trojan, Gem, Titan, Vulcan and Digit** ranges of automatic plant.

A number of different mechanical transfer systems are employed which may be hydraulic or electromechanical in operation. The choice of system is dependent upon the output, the jig load and the process requirements.

The majority of automatics are of the return type with the load and unload positions adjacent. This arrangement makes economical use of the lifting mechanism and also enables the plant to be operated from a single position.

### Trojan and Gem Type Automatic Plant

With these automatics hydraulic power is employed to operate both the lift and traverse movements, and the use of unit type construction permits plant modification should it be necessary to alter the process sequence at a later date.
The plant is made up of a series of tanks. For processes requiring a short immersion time, e.g. water rinses and acid dips, single station tanks which will accommodate one work arm are used. For processes requiring a longer immersion time, e.g. electroplating, multi-station tanks are used which will accommodate a number of work arms. On these tanks, the jigs carried by the work arms progress through from one end of the tank to the other, remaining immersed for the required process time.

The basic sequence of movement is:
Lift
Upper traverse
Lower
Bottom traverse
Dwell.

During the "dwell" period, the plant is stationary. The "dwell" time is generally 30 to 60 seconds, which, with the normal transfer time of 30 seconds, would give an average throughput of 40 to 60 work arms per hour. On the Gem type plant, one jig per work arm is the usual, whilst on the Trojan automatic each work arm carries two jigs. The "dwell" period is controlled by means of an electronic timer and can thus be readily adjusted.

The tracks on which the work arms are carried are divided into fixed and lifting sections. On single station tanks, the track is a lifting section attached to the carriage. On multi-station tanks, the initial and final sections of the track lift, but the centre section is fixed so that on this section the jigs remain in the solution during the lifting cycles, and are progressed forward at each lower traverse movement.

The lift to the carriage is provided by a number of single acting hydraulic cylinders base mounted and synchronized by means of racks and pinions linked by a line shaft. The cylinders provide the support for the lifting carriage, thus avoiding the need for an overhead framework.

The traverse movement is by means of reciprocating pushers operated by two or four hydraulic cylinders. The pushers are pivoted on the reciprocating traverse bars so that they may be lifted clear of the work arms on the return stroke and also during the lower traverse movement at single station tanks where no forward movement is required.

**Vulcan Lattice Arm Type Automatic Plant**

The lattice arm type automatic is used where the loads on the work arm are high and also where deep process tanks are employed, which necessitate a long lifting movement.

The transfer system consists of a number of vertical slides, in which the work arms are carried, the slides being linked by upper and lower driving chains. The vertical lift movement is by means of an internal carriage provided with hydraulic or mechanical lifting gear. Lattice arm type plant may be fitted with "delayed set-down" to permit very short immersion times at selected process stages and also "skip" by which a particular stage or stages can be missed with the work carriers held above solution level, whilst the carriage descends. This permits process variation and also the storage of plating jigs on the plant. The incorporation of a storage track at the upper level enables jigs to be loaded on to the plant at the end of a shift in preparation for the next production run.

**Titan Type Automatic Plant**

This type of automatic differs from the Trojan and Gem in that separate upper and lower traverse mechanisms are provided, with the upper traverse gear curried on overhead framework. The Titan may be used where the jig loading is greater than that permissible with the Trojan.

**Digit Pivoted Arm Type Automatic Plant**

This represents the simplest form of transfer system with the lifting movements being provided by a cam track along which the work arms travel. The Digit type plant is suitable for light work and small area jigs. See illustration opposite which shows a typical plant employing jigs 250mm (10 in) wide by 450 mm (18 in)
The ability of the Digit to handle components individually (each on a separate work arm) makes it particularly suitable for use on automated transfer type production lines and the application of robotics. A further production advantage with the Digit is that by processing components as they pass down the production line, the need to provide interstate storage of batches of work awaiting processing is avoided.

**Straight-through Type Automatic Plant**

In this type of plant, a number of lifting carriages are used at the transfer points between tanks to raise and lower the work. Traverse in the raised position is achieved by means of pusher rods whilst traverse in the lowered position is achieved by means of continuously moving conveyor chain. Straight-through type plants are used for specialized large output requirements.

**The Glydo System**

Simple hoist systems have been in use for many years for handling work which was too heavy for manual processing but the hoists were difficult to control and the need to accurately locate the work load in a succession of tanks made it a tedious operation. From this basic system, the transporter type of plant was developed where the lift and traverse movements were provided by transporters running on tracks mounted on either side of the tank line. Plants of this type are known as the Glydo system.

The subsequent development of programme control units made it practical to control and automate the movement of these transporters in a predetermined pattern. This type of equipment is far more versatile than automatic plant previously available, it can be applied economically to situations where the work load is insufficient to justify conventional automatic equipment and in addition it can be employed for the handling of plating barrels and other heavy loads.

Development of cross transfer units permitted the introduction of multi-line plants thus enabling the equipment to be arranged most effectively in the space available and also in relation to the work flow pattern of the factory. There are now in use plants having a variety of tank line arrangements, multiple lines with two or three tank lines linked by cross transfer system; in-line plants with the load and unloading at the same end and the main plating tanks, e.g. nickel at the far end of the line, thus reducing traverse distances to a minimum and at the same time providing for the possibility of simple expansion of the line should it be necessary to add an additional plating stage. A modification of the cross transfer unit is the side loader, which enables work carriers to be brought out of the tank line in order to permit access to either side of the work load when loading and unloading the jigs or barrels.

Since Glydo plants were originally introduced into the plating industry, there have been a variety of transporter designs employed. The simplest arrangement is to have the tracks mounted along the tank line and supported by brackets attached to the tanks themselves. Raising the track level so that it is above the tank line has an advantage in that the centre of mass of the transporter load particularly on barrel lines is at the track level and this greatly improves the stability of the system and also enables high transfer speeds to be employed. The mounting of the transporters from an overhead rail system has the advantage that complete accessibility to the tanks can be provided and in addition this arrangement can be employed where extremely wide tanks are in use. A further possibility is mounting the track alongside the tank line with a cantilever type of transporter. This provides accessibility to the tank on one side but is limited to barrel lines and to fairly narrow rack lines.

The range of equipment available extends from small light weight systems for processing, for example, printed circuit boards, to large heavy duty installations with transporters capable of handling loads in excess of 2000 kg.

The provision of process variation is an advantage in that it enables a number of differing finishes to be produced from one plant and also permits changes in specification to be made without heavy expense on plant alteration. The provision of the facility for programme variation may, however, result in a reduction in...
the overall efficiency of the plant, in that there will be occasions when the equipment is not fully utilized.
To meet differing process and production requirements, a number of variants on the Glydo system have been developed.
These include:
- Model 2 Glydo with transporters on raised tracks.
- Model 3 Glydo with cantilever type transporters.
- Model 5 Glydo with transporters on tank mounted tracks.
- Glydair with transporters carried from an overhead runway.
- Glydette with transporters on tracks just above tank level.

**Model 2 Glydo**
In the Model 2 Glydo, the positioning of the transporter tracks at eye level provides a number of distinct advantages: the traverse system is in line with the centre of gravity of the load, it provides a more stable system, and as a consequence permits the use of higher traverse speeds than are permissible with either tank mounted or overhead rail type systems.
The process tanks are more readily accessible for solution preparation and maintenance, and they can also be easily removed should they need to be replaced without affecting the track structure. Tank widths up to 10 metres (33 ft) can be accommodated.

**Model 3 Glydo**
In the Model 3 Glydo, the transporters are of a cantilever design and carried from tracks mounted on a framework along the rear of the tank line. This design permits complete accessibility to the working side of the plant, and is employed for specialized applications, as for example, the etching of turbine blades in the aerospace industry.

**Model 5 Glydo**
In the Model 5 Glydo, a tank mounted track assembly is employed to provide a simple "low capital cost" electroplating line. The transporters may be controlled manually, or automatically by means of a programmed controller incorporating a photoelectric cell type reader.
The Model 5 Glydo design meets the need in certain areas and developing countries for equipment at an intermediate technology level.

**Glydair**
In the Glydair design, the transporters are mounted from an overhead track, which may be supported from the building structure, or carried from a free-standing framework. The use of the Glydair design permits free access to the process tanks and in addition the system can be applied to very wide tanks.

**Glydette**
The Glydette was originally introduced as a low cost, versatile transfer system, which employed a hand propelled transporter having a powered lift thus removing the effort but retaining the simplicity and versatility of manual operation. The special mounts for transporters enable them to be moved at the touch of a hand and a simple and positive station location is provided to ensure that the transporter is correctly positioned for the lifting and lowering operations.
The Model C Glydette is a development on the original design. As with the Model A, the tracks on which the transporters operate are mounted just above the tank line, but instead of being carried from the tanks themselves they are mounted on a coated steel framework which also supports the process tanks. The tank/track support frames are of a modular design and each unit normally holds three tanks. The plant is made up by linking together the necessary number of frame units and to permit alignment on site, jacking points are provided. In addition, to simplify plant installation, electrical, water and drainage services may, if required, be prefabricated in the frame units. The Glydettes incorporate many important features such as completely enclosed track wheels, safety guards and smooth speed change and braking, preventing undue
work swing and workload shock; these all reduce maintenance and add to operator safety.

**Special Transporter Designs**

**Combined Barrel and Ruck Transporters**
Transporter type equipment is now in use for handling work mounted on racks, or enclosed in barrels or baskets. By the use of barrels in tandem it is possible to arrange for both rack and barrel work to be carried through the same process line without the need to modify the anode arrangements when changing from rack to barrel processing.

**Transporters with Integral Drip Tray**
In mechanized plating plants, it is usual for a water rinse to follow each treatment stage to avoid the danger that cross contamination might occur if unrinsed loads were taken over other process tanks. One possibility for reducing the number of these tanks is to have rinses between alternate process tanks and where necessary to move back down the line to the rinse rather than continue in a forward direction. Another approach is to fit the drip tray to the transporter so that any solution dripping from the load is collected in the tray rather than allowed to fall into another tank. While such an arrangement permits a reduction in the number of rinse tanks and hence the total length of the process line there are limitations to the practical reduction in view of the need to separate certain of the rinses and also to provide sufficient rinsing on the line to handle the total work flow.

**Dual Lift Transporters**
To reduce the number of traverse movements, which the transporter has to undertake, a transporter with two independently operated hoists may be used. In operation, the transporter would, for example, pick up a load with the rear hoist, move to the required station, lift out the work with the front hoist and then move forward to deposit the load on the rear hoist into the now vacant tank. Thus, the two steps of unloading a tank and putting in a new load may be undertaken with a single transporter movement rather than with the two movements, which are required with the standard transporter.

**Methods of Transporter Control**
Glydo transporters may be controlled automatically by means of a programmed controller as described on the next page, alternatively, the plant may be controlled manually by means of a simple control panel on the side of each transporter. Where a very simple transfer system is required, then the push-along Glydette may be considered. With this unit, a power lift is provided but the transporters are traversed manually from tank to tank.

Manual control can be at the individual transporters themselves or at a central control desk. On each transporter a Joy-stick™ type control lever is provided and the stick moved in the direction of movement required, inter-locking being provided to prevent mal-operation of the units. For example the Joy-stick™ may be pulled forward and then moved to the right to initiate a vertical lift followed by a right-hand horizontal traverse. At the conclusion of the lifting operation, the transporter automatically moves to the right until the Joy-stick™ is moved to the neutral position. The transporter then travels on until it reaches the next process station and stops in the correct position for the next movement.

**Programmed Controllers**
With automatic transporter type processing plant, e.g. the Glydo range, a programmed controller is employed which issues instructions to the transporter or transporters to lift, lower, traverse left or right, in order that the work loads may be taken through the required treatment sequence. The programmed controller may also control the operation of ancillary equipment such as rectifiers, cross transfer units, centrifugal dryers, and monitor the process solutions so that they may be kept at the optimum operating parameters.

**Programme Preparation**
Before any instruction can be issued to the programmer, it is necessary to prepare a list of the movements required and normally this is in the form of a time/movement graph. To prepare this type of information it is necessary to know:

(a) The process tanks in order of use.
(b) The physical order in which the tanks are arranged. This will vary dependent on whether the plant is loaded and unloaded the same end or opposite ends.
(c) The immersion times for each process together with an indication as to the degree of variation in time which is acceptable.
(d) The output required.

From the time-movement graph prepared on the basis of this information it is possible to establish:

1. The number of transporters required.
2. The area over which each transporter needs to operate.
3. The number of barrels or flight bars, (work carriers required).
4. The precise immersion time for each process.
5. The times to lift, traverse left or right and where to stop.

This information is then converted into a form in which it may be read by a programmer as it moves through the processing sequence.

Fig. 1. Typical Transport Time/Distance Graph.

In the graph, the solid line shows movements of the transporters whilst carrying work loads, the broken lines show movement of the transporters when unloaded, and the breaks in the lines indicate periods when the Glydo transporters are awaiting instructions.

**Programming Systems**

Developments in programmers has paralleled that of communications systems; starting with electromechanical relays and unit-selectors; moving to solid state switching and the use of integrated circuits in the controller, and most recently micro-processor/computer control.

The choice of system will be influenced by the number of activities and parameters, which need to be monitored and controlled; the information, which must be provided, and the level of technology, which is appropriate to the plant and its situation.

Today a control system based upon a microprocessor with the peripheral equipment, and suitably programmed, would be the first choice. Electromechanical systems with, for example, a photoelectric reader taking instructions stored upon a perforated tape or sleeve, may however be used where an advanced electronic device would not be appropriate.

**Photoelectric Cell Type Reader**

The programmed controller in which the programme of transporter movements is recorded as holes in a plastic tape which is read by a photo-electric cell system is typical of the equipment employed prior to the introduction of the microprocessor. The perforated tape or sleeve is traversed between a light source and a series of photoelectric cells. Where the sleeve is perforated, electrical impulses are generated and these are employed to control the operation of the transporters initiating the required lift and traverse movements.

The reader incorporates a number of tracks which collectively control the lift/lower; traverse left and right movements of the transporter; the stop positions at the various process tanks, and the monitoring system to check the operation of the transporter to ensure that each movement instructions has been correctly carried out. Where more than one reader is used, all the tapes or sleeves are synchronized at the start of each cycle.

For stages where the immersion time exceeds the single cycle time, e.g. at the electroplating stages, multi-station tanks are provided. The programmed controller directs the transporter to the multi-station tank and
an additional relay system selects the particular station into which the work is to be lowered. To change the programme, it is merely necessary to insert a fresh tape or sleeve into each reader, the points at which a programme change can be made being indicated by the illumination of the “programme change” pilot light on the panel. It is generally necessary to “run out” one batch of work before changing the programme.

**Microprocessor and Computer Control**

The term programmable electronic system (PES) is perhaps the most descriptive of the types of microprocessor (microcomputer) control which are now being employed with transporter type processing plant. These controllers differ from previous generations of conventional relay and electronic systems in that they do not have to be built individually to the specific requirements of each process line but can be interfaced with a wide range of plant and process sequences.

Microprocessor based systems provide extremely reliable performance and their very large capacity for the storage and handling of information makes it practical to extend control to a wide range of process parameters, and also to provide management and production information.

The most important single advantage of microprocessor control is the flexibility, which the system provides. The same hardware (electronic equipment) can be employed for a variety of plant/process control requirements or information handling, with only a modification to the software.

**Control of the transporter movements**

The logic system checks the positions of the transporters, and also where required the individual work carriers, from information provided by proximity switches mounted on the transporters themselves also at appropriate positions along the transporter tracks. This information is compared with that given in the programme stored in the memory and the appropriate instructions are issued to the transporters to undertake the necessary hoist/traverse operations.

A mimic LED display may be incorporated to indicate the transporter and flight bar positions and can also indicate the positions required for plant start up or change in programme. A number of alternative programmes can be stored in the memory to be called up when required, and fail-safe facilities incorporated to prevent start-up or change in programme, should any of the transporters or work carriers be out of position.

In addition to fully automatic control, the transporters may also be controlled manually via a joystick or pendant switch with the controller monitoring the movements so that when the plant is returned to automatic operation, the normal processing cycle can be continued. There is also provision for emergency manual control with the programmed controller inoperative.

**Additional Plant operation Functions**

The controller may also be employed to initiate and monitor the operation of cross transfer units, automatic work loading and unloading equipment, and also dryers, so that these are synchronized with the operation of the transporters on the plant line.

**Process Control**

The large capacity of the new types of controller permit the incorporation of a number of facilities which enable the various treatment processes themselves to be monitored, controlled and adjusted so that they operate under optimum conditions, for example:

The temperatures of the various solutions on the process line may be monitored using contact type thermometers, or alternatively thermocouples or resistance thermometers in order that the actual temperatures may be recorded. Proportional integral differential loop control may be incorporated and used in conjunction with modulating control on the heating or cooling system in order to give very fine temperature control.

Automatic control of rectifiers may be provided in order to reduce the voltage before unloading, followed by
adjustment to a specified value when the tank is reloaded. In addition, constant current, constant voltage, constant current density control can be incorporated. For example, the controller can accept an analogue signal from a shunt, which is proportional to the current flow, compare this with a reference level, and initiate an adjustment of the rectifier output so that the correct current is applied to the load. The reference level is computed from information fed in via switches or a keyboard when the work is loaded on to the plant. It may represent, the required plating current; voltage; ampere hours required per load; current density or work area.
Solution levels may be monitored and appropriate instructions issued to circulating pumps and control valves to make the necessary adjustments.
Chemical additions may be made automatically by the control of dosing pumps or control valves on the basis of process usage or change in composition. For example, electroplating additives may be added on an ampere hour basis, and acid/alkali for control of solution acidity on the basis of regular pH determinations.

**Fault Indication**
With microprocessor control, facilities are provided to simplify fault location. Error checking facilities are built into the programming and an alphanumeric display can be incorporated in the control panel to indicate the type and location of faults which might develop or any error in plant operation.

**Performance and Production data preparation and handling**
The controller may incorporate facilities for the numerical display of solution temperatures, operating currents and voltages, power and water consumption and also store this information for subsequent processing on a mainframe computer. Information on each load of work processed can be tabulated, presented to the plant controller by way of a visual display unit or printer and stored for subsequent processing.

**Entering the Programme**
The programme or series of programmes may be entered into the memory of the programmed controller in a number of ways:
The programmes may be contained within a replaceable memory chip prepared by the plant supplier. In the event of a major change in programme requirements a new chip would be plugged in.
it may be keyed in directly, step by step, using a teletype or a keyboard. To simplify this operation, a translator may be incorporated in the controller to enable the instructions to be entered in plain language or by the use of specially designated keys.
it may be prepared as a perforated tape or magnetic tape which is fed into a reader attached to the equipment.
Where the plant incorporates process or sequence selection on individual loads, an additional keyboard or set of switches is provided in order that the necessary information can be keyed in for each batch of work.

**Random Selection Control**
With the development of microprocessor control, it is no longer possible to classify systems as Mixed programmeTM or random selectionTM, as a whole range of facilities can he incorporated by the use of appropriate software (programmes).
An example of the facilities which microprocessor control can provide is given by the plant for the hard chromium plating of piston rings illustrated on this page. The plant enables the plating requirements for each mandrel to be selected.
The microprocessor provides pre-set control of the transporter movements and of the ancillary equipment and in addition, a random selection facility which directs the hard chromium plating operation. Information on over 100 batches of work or mandrels can be stored in the memory to enable individual thickness requirements to be met. Each plating station takes two mandrels each of which is provided with
independent rectifier control. Plating times can vary from 3 to 15 hours depending upon the individual thickness requirements. The current and voltage outputs from each of the 32 rectifiers on the plant is sequentially monitored, and where necessary adjusted to the preselected values. The system “knows” which is the next plating cell to be unloaded and arranges for the current to be switched off before the load is lifted out by the transporter. At the unload station, full details on each mandrel are recorded and automatically printed on to the work ticket.

**Semi-Automatic Plating Plant**

The term semi-automatic may be applied to process lines, which are manually controlled but employ mechanized systems of work transfer. This arrangement enables heavier workloads to be processed, as their weight and size are no longer limited to that which can be conveniently lifted by hand. At the same time, much of the versatility of manual processing is retained.

For work transfer, overhead hoists are often employed, particularly for large components, with either a single or twin track system depending upon the width of the process tanks. Equipment of this type is widely used for the processing of large components such as in the aircraft industry, and for the anodizing of aluminium extrusions. Hoist type plant is, in many instances being replaced by transporter type equipment e.g. manually controlled Glydo and Glydette, in view of the greater ease of control and the positive station location, which these systems provide.

**Barrel Planting Plant**

Barrel plating is widely employed for the bulk processing of small to medium sized components. Recent improvements in plant and processes have greatly increased the range of components which can be electroplated in barrels and now permit the application of heavier deposits, thus enabling specification finishes to be produced.

Barrel plating equipment can consist of multi-station units in which the plating, pre- and post-plating sections are combined in one plant, or single station units where the plating barrel is fed from an independent and usually manually operated cleaning line.

**Suitability of Articles for Barrel Plating**

The selection of articles for barrel plating is limited by their size, shape and weight. Massive or sharp cornered parts are liable to damage one another during the process and also result in abrasion of the barrel itself.

Flat articles, especially thin discs, washers, and light gauge sheet metal parts, tend to stick together when wet through surface tension of the solution, and some small pressings are apt “nest” one inside another.

**Barrel Types**

Barrel plating units may be divided into two main types:

- Perforated barrels, which are immersed in the plating solution.
- Open-ended solid barrels in which the solution, the anode and the work are contained inside the barrel.

The choice of barrel is dependent upon the shape, size, density and the quantity of articles to be plated. For large outputs, particularly where specification thickness requirements have to be met, it is now usual to employ immersed barrels. Very small parts, however, such as fine screws and rivets may be plated in an open-ended barrel, e.g. a Typhon.

The particular plating solution to be employed can also collect the choice of plating barrel, and further information on this is given under the appropriate process headings.

The barrel plant may be arranged as a production line with mechanical transfer of the barrels from one stage to the next, e.g. the Glydette, or may consist of single station plating units, e.g. Electrominik barrell. With barrels such as the Electrominik, the articles to be plated are cleaned on a separate line and then transferred to the barrel for the plating process.
Immersed barrels range in sizes from 1070 by 400 mm (42 by 16 in) for large scale production down to small 180 by 100 mm (7 in by 4 in) diameter barrels for experimental and small applications. A number of different methods of transfer are available for immersed barrels. On multi-station plant, the Glydette, an overhead hoist, may be used, and for single station barrels, equipment such as Electrominikis employed. The open ended type barrel is still used for small outputs, and it has the advantages of low initial cost, and the use of a relatively small volume of solution. It is suitable for processing a wide range of components, including those too small to be treated in small perforated barrels; it has, however, a lower efficiency than the immersed type of barrel, and the present trend is for this type of equipment to be replaced by immersed barrel plating units.

**Immersed Perforated Plating Barrels**

For the majority of applications horizontal barrels are employed but for certain high output requirements, oblique perforated barrels are employed. These have the advantage that they can be more easily provided with automatic loading and unloading facilities as part of a fully automatic process line.

**Glydo/Glydette Barrel Plating Equipment**

The articles to be plated are loaded into the barrels, which are then taken through the various pre-plating, electroplating and post-plating processes by means of a transporter system. The Glydoplant is built up as a series, of process tanks, with the transporters mounted on tracks alongside the tanks. A Glydo plant may consist of only two or three tanks for a simple loading, plating, rinsing and unloading sequence, whilst large installations may be of thirty or more tanks involving differing cleaning sequences and a number of plating stations. The unit method of construction permits modification or extension of the plant to meet changing production requirements.

**Horizontal Barrels**

The size of the barrels employed is dependent upon the output required. Where small batches of work are to be processed, a compartmented barrel can be employed. The barrel container has a vertical partition providing two separate sections, each with its own cathode contact. Alternatively, a twin barrel unit can be used consisting of two barrels mounted on a single carrier with single or separate double motor drive. Barrels may be cylindrical with internal work breaks, or hexagonal using single sheet wrap-around construction.

**Constructional Materials**

The majority of plating barrels are now made in polypropylene and are suitable for continuous operation at solution temperatures up to 75° C (167° F). Barrels fabricated in the G 76 type of polypropylene can be supplied with special interior surface finishes which prevent the articles from sticking to the barrel walls; protect the perforations against damage and can give an improvement in the throwing power of the plating process. For barrels, which have small perforations (e.g. 3 mm) the dimpled waffle type material is used whilst for barrels having perforations (up to 6 mm), the Polydomesurfaced polypropylene is preferred.

**‘Câ€” Series Barrels**

The ‘Câ€” Series range of barrels is a development of the conventional horizontal transportable cylinder units which have been used on hoist and transporter type barrel plating plants for a number of years. Developed initially for use on the Model C Glydette, the ‘Câ€” Series range of barrel units, incorporate a patented design of cathode connection, which eliminates the need for the traditional brass cathode horn and saddles. The 50 volt 3 phase pick-up blocks for the barrel drive supply, the mild steel guides for barrel location and all other fittings are mounted directly on the framework, which supports the tank and transporter.

The barrels are constructed from a new type of material, G76 polypropylene, and also feature patented
self-sealing bearings which prevent the ingress of swarf and small work, thus extending bearing life.

**Barrel Perforations**
The standard perforation is a series of cylindrical holes. Where the holes are small (i.e. below 3 mm, in) the holes are counter bored from the outside to increase solution circulation and reduce the internal electrical resistance. For plating of small diameter articles such as pins, which would pass through the normal perforations, a herringbone or mesh type barrel may be used.

The herringbone barrel is used for the plating of pins and similar articles. As indicated in the diagram, the perforations in the plastic walls of the barrel are drilled at an angle in a herringbone formation so that even small pins cannot pass through. At the same time, the holes are sufficiently large to ensure good solution circulation.

Herringbone barrels are available in Cub Major, Electrominik, Glydette and Glydosizes. The Electromesh barrel is employed for small work, particularly where precious metals are to be deposited on precision watch, instrument and electronics components. The fine 0.8 or 0.4 mm perforations enable very small components to be processed including those with delicate wire leads.

**Cathode Contacts**
The normal form of cathode contact consists of a length of heavy insulated flexible cable terminated with a steel cathode knob. (This is often known as a dangler contact.) Two contacts are provided entering through the stationary bearings at either end of the container. For certain types of work, a shaft may be fitted to the barrel to carry the cathode contacts or, alternately, other contacts may be provided.

**Current Control**
Where the barrel is operated off an individual rectifier, off-load or on-load voltage control can be provided, depending upon the situation. Where a number of barrels for the same plating process are operated off a single low voltage supply, then it is advisable to provide individual off/on control.

**Voltage**
The voltage necessary for barrel plating is dependent upon the type of barrel and the electrolyte used, but in all cases is somewhat higher than that required for still vat plating with a similar type of solution. With a self-contained open-ended barrel using a highly conductive electrolyte, such as acid tin solution, the internal resistance is small, hence, a pressure of 3 volts may be sufficient. Generally speaking, however, a minimum of 6, and an average of between 8 and 16 volts, is necessary for barrel deposition, and in some cases as much as 20 volts may be required.

**Speed of Barrels**
The correct speed of rotation is governed by the diameter of the barrel and the nature of the articles that are to be plated. Small barrels are usually driven at 10 to 15 revolutions per minute, and large at 6 to 12 revolutions per minute, but a reduction of speed below these limits may be necessary in special cases. For bright zinc and bright cadmium plating, it is advisable to use a speed of 5 to 6 r.p.m., even with barrels of medium size whilst for phosphating the usual speed is ½ r.p.m.

**Anodes**
In view of the fact that a barrel load of small articles usually presents a very big surface area, it is desirable to provide as large an anode surface as possible, in order to maintain the metal content and general balance of the solution.

With the self-contained, open-ended type of barrel, all that is necessary is for the operator to replace the anode whenever it becomes thin and much reduced in diameter. In some instances, these anodes are cast with a heavily ridged or corrugated face, so as to increase the effective surface area for a given diameter. With the other types of barrel, namely those in which the solution is contained in a tank, the anodes must be examined regularly and new ones introduced from time to time to maintain the necessary surface area. To prevent corrosion and poor electrical contact, the rods on which the anodes hang should be protected
against splashing by the solution. The anode hooks must be of the same metal as the anodes or one that does not dissolve in the solution, and should be long enough to permit suspension of the anodes at the proper depth.

Electroplating Equipment

Process Tanks
For electroplating and allied processes, chemically resistant containers are generally necessary for the solutions employed.

Welded Steel Tanks
Welded steel tanks, suitably lined if required, are used for the majority of electroplating processes, but other types of container may be used when operating conditions permit. The steel tank in its usual form consists of an open rectangular box with welded joints and an angle stiffener on the top edge. For cleaning and rinse tanks the outlet can be fitted to the bottom of the tank. For plating tanks it is usual to fit the outlets to the end of the tank.

Steel tanks are also available provided with a sloping bottom. This form of construction greatly simplifies emptying and cleaning out. The extra cost of this type of tank is more than justified by the simplification of plant and process maintenance, which it permits.

Unlined steel tanks, preferably double welded, are employed as containers for alkaline cleaning and plating solutions, also cyanide dips and sulphide bronzing baths.

Plastic Tanks
Plastics tanks have a wide range of application in electroplating and other solution treatments in view of their inherent resistance to corrosion and chemical attack, light weight as compared with metal, and good electrical insulation properties.

A number of differing types of tank construction are available including

- Polypropylene welded tanks
- Polythene moulded tanks
- Glass fibre (GRP) tanks
- PVC and polypropylene GRP reinforced tanks.

The choice will depend upon the specific application, and in particular - the solution to be contained, the operating temperature, the tank size and situation.

Polypropylene welded tanks are constructed from sheet material and provided with reinforcement bands to prevent distortion of the tank when full of solution. They are suitable for the majority of solutions used in electro-plating and can be operated at temperatures up to 70° C.

Tanks moulded in rigid high density polythene are available in a wide range of sizes up to about 1250 litres (275 gal) capacity. They are suitable for the majority of solutions used in electroplating and pickling, and when made from the rigid grade of polythene are effective for use up to the boiling point of water with suitable tank support.

Plastic Tanks Reinforced with Glass Fibre

These tanks are fabricated in rigid PVC or polypropylene and then covered on the outside with a glass fibre plastic laminate (GRP) in order to provide the required mechanical strength. The standard range of tanks has capacities from 102 litres (22 gallons) up to 1860 litres (410 gallons) and they are suitable for the majority of plating and pre-treatment solutions. The PVC is suitable for use up to about 70° C (160° F) and the polypropylene up to boiling point 100° C (212° F).

Glass Fibre (GRP) Tanks

Tanks of polyester GRP construction are now used extensively for rinses and dilute acid dips. It is not advisable to use the tanks for any plating solutions except cool working, mildly acidic or neutral solutions.
which are not sensitive to the organic compounds which may be leached from the tank. The tanks should not be used to contain strong acids, alkalis or cyanide solutions. At elevated temperatures, even dilute solutions can attack the resins used and it is particularly important therefore to mix substances like sulphuric acid, which heat up on dilution, in a separate metal or plastic lined vessel and then transfer to the fibreglass tank when cool. The chemical resistance of GRP tanks depends upon the type of resin employed in the moulding and on the way in which it is layed up and cured.

**Stainless Steel**

Stainless steel (18 per cent nickel and 8 per cent chromium) containers can be used for nitric acid and other oxidizing acids, e.g. chromic acid/ sulphuric acid pickling solutions. Stainless steel is not suitable for use in hydrochloric or sulphuric acid solutions or for alkaline solutions where the stainless steel may become anodic or bipolar. Stainless steels of widely differing compositions are available. It is therefore important when ordering stainless steel tanks that the process and operating temperature be specified.

**Tank Lining Materials**

**Rubber**

Rubber is the most widely used material for tank lining. For this purpose, it is available in two main grades soft and hard. Whilst the soft grade of rubber can be specified for water rinse tanks and for hydrochloric acid containers, it is more usual to supply the same hard grade for all tanks, in order to simplify plant layout and modification. The hard grade is used for electroplating solutions. For this purpose it is essential that a suitable quality of rubber be employed which is free from any constituents such as fillers or accelerators, which may have a detrimental effect on the plating solution.

The rubber quality is of particular importance with bright nickel and acid copper plating solutions; for these, an approved grade of high temperature cured rubber, e.g. *Vulcron*, should be specified.

With rubber-lined tanks, a maximum operating temperature of 70° C (160° F) is advised. For bright nickel and also acid copper plating solutions, it is recommended that the linings be pre-treated with hot dilute acid as described below.

Tanks for cyanide plating solutions should be pre-treated with hot caustic soda solution as described on the next page.

Natural rubber is not suitable for use with strong oxidizing solutions, such as nitric acid and chromic acid.

**Treatment of Rubber Linings**

**For Bright Nickel and other Acid Plating Solutions**

Before use, new rubber-lined tanks and equipment should be treated with hot dilute acid for a period of at least 8 hours. Where stainless steel components are included in the pumps or filtration system, dilute sulphuric acid is employed. Where the system is entirely of rubber or plastic, dilute hydrochloric acid may be used.

Using sulphuric acid, the plating tank is filled to about three quarters of its capacity with clean cold water, the sulphuric acid is then added slowly and carefully with stirring, care being taken to ensure that the concentrated acid does not come into direct contact with the rubber.

Sufficient acid should be added to raise the concentration of solution to 10 ml/l (1½ ft oz/gal). When the necessary quantity of sulphuric acid has been added and the solution thoroughly mixed, the temperature is raised to 60° C (140° F) and maintained at this value for at least 8 hours. To treat any associated rubber-lined equipment, e.g. filter units and pumps, the acid should also be circulated through these. It is important that the cloths be removed from the filtration unit prior to this treatment, otherwise the fabric may be damaged. After treatment with dilute acid, the tanks should be washed out with water before use.
Where there are no metallic parts in contact with the solution and the equipment is wholly of rubber or plastic, hydrochloric acid solution having a concentration of 50 ml/1 (8 fl oz/gal) may be used in place of the sulphuric acid described above.

**Acid Cleaning of Rubber Lined Tanks fitted with Titanium Coils**

Where titanium steam coils are used, anodic protection of the titanium is necessary during the sulphuric acid cleaning period. A temporary graphite or lead plate having a minimum surface area of 80 cm² (12 in²) should be hung from the cathode rod and a 3 to 4 volt DC supply connected between the cathode rod and the titanium coil, the coil being connected to the positive. The plating rectifier may be used for the DC supply or alternatively two cells from a car battery can be employed. The current required is quite small and rapidly falls to a few hundred milliamps. A 1 ohm (5 ampere rating) resistance should, however, be included in the circuit to afford protection against accidental short circuit and to restrict the current surge.

An alternative method which, can be adopted is to carry out the acid cleaning process before the titanium coils are fitted and to arrange for the dilute sulphuric acid to be heated by independent means. One method sometimes used is to heat the solution by injecting live steam directly into it. Where this method is employed it is essential that suitable steam injectors be used and that a pressure reducing valve be fitted. Care must be taken to avoid damage to the rubber lining by direct impingement of the steam on to the rubber.

**For Cyanide Plating Solutions**

With cyanide plating solutions, it is advisable to pre-treat new rubber linings with a hot caustic soda solution. The solution is retained in the tank for at least eight hours and where possible the temperature maintained at 50 to 70° C (120-160° F). After treatment the tank should be well washed out with water, the rubber lining then slightly scoured with a fibre or bristle brush and again washed out before being put into use.

A suitable concentration for the caustic soda (sodium hydroxide) is 100 g/1 (16 oz/gal) or 25 to 40 g/1 (4 to 6 oz/gal) where the solution can be heated. The material should be carefully dissolved, with stirring, in cold water in a separate steel tank and then transferred while still hot to the plating tank, (sodium hydroxide evolves heat upon dissolution.)

**Key to Table**

R = Recommended Å = Suitable

1. Å Å Å With, preferably, a loose inner lining of rigid plastic sheets or reinforced glass sheets.

2. Å Å Å Antimonial lead alloy with a loose inner lining of rigid plastic sheets or reinforced glass sheets.

When starting up new chrome plating tanks or re-commissioning re-lined tanks, it is important that the temperature of the chromium plating solution be brought up as rapidly as possible to 60 to 65° C (140 to 150° F). In this way a protective film is formed on the surface of the lead. Under no circumstances should cold chrome solution be left in contact with alloy lead, until the above treatment has been applied.

3. Å Å Å Vulcron, pre-treated with hot dilute acid.

4. Å Å Å Vulcron, pre-treated with hot dilute alkali.

5. Å Å Å Stainless steels of widely differing compositions are available. It is, therefore, important when ordering stainless steel tanks that the process and operating temperature be specified.

6. Å Å Å When preparing dilute sulphuric acid or dissolving up caustic alkalis, in plastics or plastics lined tanks, care must be taken to ensure that the solution temperature does not rise above 70° C (160° F) or with polypropylene 100° C (112° F). These substances evolve heat on dilution with water and can produce local areas of heat well in excess of 100° C (212° F).

7. Å Å Å In the case of sulphuric acid, the concentrated acid should be added slowly and carefully to cold water whilst the solution is continuously mixed. If there is an excessive rise in temperature, then the acid additions should be suspended until the solution has had time to cool.
8. With potassium and sodium hydroxide and other caustic mixtures, the alkali should be added slowly to cold water with thorough mixing. Great care must be taken to avoid the accumulation of any quantity of solid alkali on the bottom of the tank.

7. A band of rigid PVC should be bonded to the Ilex at the solution/air interface and should extend 152 mm (6 in) above and below the optimum solution level.

8. With a sprayed PTFE lining or a loose plastic liner.

**Polyvinyl Chloride**

Polyvinyl chloride (PVC) is resistant to almost all solutions employed in electroplating, provided the operating temperature is below 70 C° (160° F.) For chromium plating and other solutions, tanks lined with a special grade of soft plasticised PVC may be used. This coating is supplied under the name Ilex.

For other linings and exhaust ducts, a laminated material is used consisting of layers of rigid and plasticised PVC firmly bonded together. The rigid PVC surface is in contact with the solution or fumes, and the softer plasticised PVC provides a surface, which can be bonded to the tank and also prevents cracking developing in the rigid PVC layer.

The table gives general recommendations and reference should be made to the appropriate process section for more detailed information upon plant requirements.

**Ilex Grade Plastic Lined Tanks**

These tanks are lined in a special grade of soft plasticised PVC, which has a number of advantages over rigid type PVC linings. The flexibility of the coating enables it to accommodate differences in thermal expansion between the plastic and the steel and absorb any stresses, which may be produced. The high flexibility of the coating also permits it to be applied to complex structures and greatly simplifies the internal lining of tanks and other containers. The coating is firmly bonded to the steel and can be used at temperatures up to 70° C (160° F).

By careful selection of the plasticisers in the PVC film, a very high chemical resistance is obtained, this being only slightly less than that provided by rigid PVC. The coatings do not age rapidly, neither are they susceptible to degradation by oxidizing agents.

These PVC lined tanks are suitable for all types of plating solution, including bright and hard chromium, acid dips and pickling solutions, alkaline solutions, and for the storage of a wide range of chemicals. Nitric acid based solutions are the exception however and a rigid PVC lining is recommended rather than Ilex, which should not be used. On steel tanks a laminate is used consisting of layers of rigid and plasticised PVC. The rigid surface is in contact with the nitric acid and the plasticised PVC provides a resilient surface, which can be bonded to the tank.

**Lead**

Chemical lead is used for the lining of tanks for sulphuric acid, dull nickel and acid copper plating solutions. For chromium plating solutions, and also where a higher mechanical strength is required, antimonial lead alloy is employed. Lead-lined chromium plating tanks should be pre-treated before use.

Lead must not be used for holding nitric acid, or any alkaline cleaning or plating solution (other than silver and certain copper solutions). It is attacked by hot hydrochloric acid, and is not recommended for cold hydrochloric acid or aqua fortis.

**Materials of Construction—Containers, Hooks, Dipping Baskets**

Resistance to corrosion is influenced by many factors, such as the temperature and concentration of the liquid, and in the case of metals those which may be affected by galvanic action and the presence of impurities in the solution, some of which will accelerate and others inhibit attack. The recommendation as to the suitability of a material does not imply that it is entirely resistant and will withstand corrosive liquids.
Aluminium
High purity aluminium hooks and dipping baskets are suitable for use in strong nitric acid and in aqua fortis bright dips. Wire and jigs are used for the suspension of aluminium articles undergoing anodic oxidation, and aluminium tanks are satisfactory containers for nitric acid at high concentrations. Aluminium must not be employed in caustic or strongly alkaline solutions, and is unsuitable for sulphuric, hydrochloric and hydrofluoric acids.

Glass
Chemical glassware and apparatus including measures, containers and pipe work are suitable for all solutions employed in electroplating and allied processes with the exception of those containing hydrofluoric acid or other acid fluorides. Fluoboric acid solutions are satisfactory in glass containers provided excess boric acid is present in the solution. Where glass is used in contact with hot highly alkaline solutions, then there may be some surface attack, which could result in contamination of the solution.

Brass, Bronze and Copper
Copper wire is generally used for the suspension of small articles during plating, and brass strip and rod for the construction of jigs. Acid-resisting phosphor bronze hooks are suitable for handling heavy work in sulphuric or hydrochloric acid pickles, although not entirely resistant to the latter if hot. Brass and copper hooks may be similarly employed, and brass wire baskets for small articles. These metals are also used in alkaline cleaning solutions, but should not be made anodic in the circuit.

These metals will not withstand the action of nitric acid, aqua fortis and chromic acid dips. Brass is unsuitable for use in hot hydrochloric acid.

Monel Metal
This nickel alloy is highly resistant to sulphuric acid and is used for hooks and dipping baskets. It is also used for cold dilute hydrochloric acid, but is attacked by the hot acid according to the temperature and degree of concentration. Monel metal may be put through alkaline degreasing solutions.

Monel metal is unsuitable for use in aqua fortis and nitric acid.

Nichrome ('Chrome™ Wire)
Nichrome hooks and wire baskets are suitable for use in nitric acid, aqua fortis and chromic acid dips. Nichrome is resistant to alkaline solutions but the metal must not be made anodic in an electrolytic cleaning bath.

Nichrome should not be used for hydrochloric acid.

Rods & Connections for Process Tanks
 Electroplating tanks are fitted with suitable anode and cathode connections. For the suspension of the anodes and articles in the plating solution, brass or copper tubes or solid rods are used; for heavy currents or for carrying greater loads of work, solid or 'D™ section or hollow or 'U™ section bars are employed.

Fixed bars are supported on porcelain, polyethylene or phenolic insulators which are either screwed to a wooden or plastic capping on top of the tank, or fastened directly to the tank lip. In automatics of the Glydotype where generally the heavy section rods are used, the fixed supports are of cast metal, which are fastened to the tanks or support framework. If these rods are carrying current they should be suitably insulated from the main structure. Because the work bar is movable in this type of equipment, the cathode contacts are of a specially designed or 'V™ shape to provide both a good contact and to guide the flight bar into position.

Round tubes or rods can be jointed together by means of the various rod connectors shown in the illustration or can have clip-ends when there is a need for regular adjustment. If tanks have more than one
anode or cathode bar, the rods are extended just beyond the tank and cross connections fitted so that all bars of like polarity are joined together.

**Solution Heating**

For many of the processes associated with electroplating it is necessary to heat the solution. The available methods of heating include steam, hot water (medium or high pressure), liquid phase, gas and electricity. The most satisfactory methods of heating are steam, hot water, and liquid phase, but where these services are not available and the size of the plating plant does not justify the installation of a boiler, then gas or electricity can be employed. The capacity of the boiler should be such that the solutions can be heated from cold to the operating temperature within the time required. This time is usually 3 to 4 hours.

**Steam Heating**

Fig. 1. Steam Heating.

Steam can be raised using any of the available means of heating, e.g. solid fuels, gas, oil and electricity. The steam pressure for heating can vary over a wide range; the extremes should, however, be avoided, and it is either advantageous or economic to generate super-heated steam for plating process heating. The usual pressure range is 1.5 to 4 bar (20 to 60) lb/in². It should be noted that the higher the steam pressure, the greater the temperature difference that will exist between the steam and solution. This, in turn, reduces the size of the heating equipment required.

The efficient use of steam depends upon properly sized and maintained steam traps and control valves. The steam trap ensures that condensate is discharged with the minimum loss of 'liveâ€™ steam. The correct type and size of control valve will permit the accurate regulation of the solution temperature. Electrolytic process tanks must have steam coils provided with insulated flanges to prevent low voltage D.C. leakage currents between the tanks by way of the steam lines.

With steam heated tanks, it is now usual to return the condensate to the boiler hot well in order to conserve energy. It is however essential that conductivity or pH control is fitted to the return line to detect the presence of contamination as a result of a leak in a steam coil.

Four main methods are available for using steam for the heating of solutions:

- Steam heating coils or plates submerged in the tank.
- Heat exchangers external to the tank.
- Water jackets surrounding tank.
- Live steam injectors in the tank or jacket.

**Steam Coils**

Steam coils immersed in the solution are the most widely used method of heating. The coils should be made of, or clad with, a metal, which is chemically resistant to the solution in which they are to be immersed.

The following materials are used for steam heating coils:

- Plain or galvanized steel,
- Mild steel lead covered, or solid lead/lead alloy,
- Titanium,
- Zirconium,
- Tantalum,
- Incoloy 825,
- Stainless steel,
- Fluocarbon, e.g. Dupont Teflon.

**Plain Steel Coils**

These may be used in alkaline and alkaline-cyanide solutions for example, hot alkaline cleaners, cyanide plating solutions such as copper, zinc and cadmium, also stannic tin.
Galvanized Steel Coils
Galvanized steel coils are suitable for use in galvanized hot swill tanks. They should not be used in alkaline, acid or cyanide solutions.

Lead and Lead Alloy Coils
Lead covered or solid lead heating coils may be used for dull nickel and acid copper plating solutions, sulphuric acid pickles, regular chromium plating solutions and chromic acid etches for plastics.
For chromium plating solutions containing fluoride or silico-fluoride, Tellurium lead heating coils can be used whilst for phosphoric acid based electro polishing solutions such as Electro polishing Solution C 24201 for aluminium, pure lead coils can be employed.
Where high pressure steam is used for heating, the lead coil must have an inner strengthening tube of steel. The lead covering can be wrapped or bonded to the inner coil, the latter method will increase the rate of transfer heat to the solution and is known as homogeneous lead covering.
Solid lead heating coils are only advised for steam and hot water pressures below 2 bar (30 lb/sq in) at a temperature not exceeding 135° C (275° F). The provision of a reducing valve is necessary to ensure that this pressure is not exceeded.

Titanium Coils
Titanium coils are now widely used for solution heating and cooling, particularly in nickel and chromium plating solutions.
Two grades of titanium are now in general use for solution heating and cooling coils, these are commercially pure titanium (IMIdesignation 125); titanium/palladium alloy (minimum 0.15% Pd.) (IMI designation Titanium 260).
Titanium 260 has a much higher resistance to acidic conditions than the normal c.p. Titanium so that it can be used in dilute sulphuric or hydrochloric acid solutions without the necessity for an applied current to maintain the anodic film. Titanium 260 is also of advantage in phosphoric acid and in organic acid solutions such as citric acid and formic acid. The small proportion of palladium ensures the retention of the passive layer. For high temperatures and also high acid concentrations it will, however, still be necessary to apply anodic protection.
Commercially pure titanium is still the grade generally employed, particularly for the heating of nickel plating solutions, chromium plating solutions, and phosphating solutions.
Titanium coils in electrolytic process tanks must be placed where they cannot be touched by the anodes or suffer mechanical damage from work or jigs falling on to them. The most suitable position is generally behind, but well clear of, the anodes.
All heating coils should be fitted with air boxes at solution level in order to reduce the possibility of attack at the solution interface.
Where there is the possibility that titanium coils may become cathodic or bi-polar in electroplating solutions, it is recommended that they be connected electrically with the anode circuit. With high chloride nickel solutions, the titanium coils should not be connected to the anode circuit and special care should be taken in the positioning of the titanium coils so that there is no possibility of bi-polar effects occurring.

Anodic Protection
Anodic protection is necessary where commercially pure titanium is used for dilute sulphuric acid solutions. This takes the form of the continuous application of an anodic potential to the titanium coil. The low voltage D.C. required must be obtained from a 24-hour supply, transformed and rectified to the correct voltage with a trickle charged battery on standby to provide current in the event of mains or equipment failure. Where anodic protection is used, the temperature of the heating medium should be limited to 134o C (273o F). At higher temperatures there may be breakdown of the anodic film formed on the surface of the titanium, and this would result in the eventual failure of the coil.
Applications of Titanium

A summary of the uses of titanium in electroplating and other solutions is given below. These recommendations also apply to titanium immersion heaters, heat exchangers and plate coils.

**Nickel Plating Solutions:** Titanium has proved to be entirely satisfactory for heating and cooling coils in solutions based on nickel sulphate or nickel chloride, e.g. Nivo, Niflow and Gemini solutions. Titanium is not to be advised for solutions containing nickel fluoborate. It is important to note that where rubber-lined nickel tanks are fitted with titanium heating coils and are cleaned with dilute sulphuric acid, the titanium coil should be anodically protected during the cleaning. If these instructions are not followed, damage to, and eventual failure of the coil, is to be expected.

**Chromium Plating Solutions:** Titanium 125 heating and cooling coils are suitable for use in conventional types of sulphate catalyst chromium plating solutions such as Zonax Bright and Zonax Hard. Where fluoride and silicofluoride catalysts are used in chromium plating solutions such as Hycrome 80, then titanium can still be used for heating provided certain precautions are taken and certain limitations accepted. For hard chromium plating solutions such as Chrome fast and Catalyte Hard, where very high currents and high temperatures are employed, titanium is not recommended.

The tank for chromium plating should be mild steel lined with Ilex or for small volumes of solution, polypropylene/GRP. The titanium coils should be positioned between the anodes and the tank wall within the anode envelope, i.e. not extending below the bottom of the anodes or on either side of the last anodes on the rail. The anodes should be spaced evenly along the anode rail and when they are removed for cleaning or replacement they should be re-arranged to cover the titanium coil. Should the anodes be allowed to wear out or lose contact due to corrosion of the hook or if the anodes are frequently taken out to plate small items, then the coil may corrode.

The risers of the coil or coils should be positioned midway, 64 mm (2.5 inches), from the anodes and the tank wall (the recommended tank wall to anode distance is 128 mm (5 inches), and at least 152 mm (6 in) from either end of the tank). The bottom row of the heating coil should be at least 306 mm (12 in) from the tank bottom. Where steam or hot water are used, these should not exceed a temperature of 135° C (275° F) or a pressure of 2 bar (30 lb/in2). Where high pressure, high temperature water must be used, tantalum coils are the only alternative.

If an extended service life is expected then, coils of tantalum or Teflon should be used.

For cooling in both lead lined and Ilex lined tanks, Titanium 125 can be used but the limitations as to the position of the coils in the tank must still be observed.

**Acid Copper-Sulphate Plating Solutions:** Titanium 125 heating and cooling coils are suitable for use in this solution; with heating coils, protection to the coil at solution level should be provided in the form of an air box.

**Sulphuric Acid Anodizing Solutions:** For solution cooling, Titanium 260 coils may be used, if, however, commercially pure titanium is employed than, continuous anodic protection is required. In hard anodizing solutions continually at 0o C (32o F), commercially pure titanium cooling coils have been proved satisfactory without the necessity for anodic protection, but if the temperatures may on occasion rise above 10° C (50°F) then anodic protection will be required.

For heating coils in sulphuric acid, anodizing solution with an operating temperature of 20° C (70° F) Titanium 260 heating coils may be used in view of the small temperature rise and relatively short heating period.

Titanium cooling coils should preferably be positioned behind the cathode plates and not connected electrically either to the cathode or anode circuit, preferably rubber or plastic lined tanks should be used.
employed.

**Sulphuric Acid Pickles for Copper and Copper Alloys:** Titanium heating coils are satisfactory in these solutions e.g. 10 per cent w/w sulphuric acid solution operated at 70° C (160° F), providing copper is present in the solution c.p. Titanium is suitable. If, however, there is any possibility that the sulphuric acid pickle would be left for a period before use, then either a copper addition should be made to the solution on preparation, or Titanium 260 coils should be employed. A suitable copper addition to inhibit the attack on titanium is 1 gramme per litre of copper (4 g/l - oz / gal of copper sulphate).

Titanium coils are also suitable for use in sulphuric acid/chromic acid pickling solutions.

**Sulphuric Acid Pickles for Steel:** For these solutions the use of zirconium heating coils is recommended in preference to titanium.

**Sulphuric Acid Etch Solutions:** For sulphuric acid etches solutions, the use of zirconium cooling coils is advised as an alternative to lead.

**Cyanide Plating Solutions:** Titanium heating and cooling coils are satisfactory for Cupraxe copper and Kadamax cadmium solutions. They are not satisfactory for solutions containing more than 10 percent (16 oz/gal=100 g/1) sodium hydroxide; e.g. Hylite 80 zinc solutions.

**Hydrochloric Acid:** Titanium is not advised for heating or cooling coils in this solution unless cupric or ferric ions are present in the solution, or the solution is at low concentration and temperature.

**Nitric Acid:** Titanium can be used for heating and cooling coils for this solution, with the exception of red fuming nitric acid.

**Hot Alkaline Cleaners:** Titanium heating coils are suitable for use in alkaline solutions containing not more than 10 per cent (100 g/l) of sodium hydroxide.

**Acid Tin Plating Solutions, e.g. Stannolyte:** The use of Titanium 260 heating and cooling coils is advised for these solutions. The coil should be made anodic, not to provide protection but merely to prevent it becoming cathodic.

**Phosphating Solutions:** Titanium heating coils are satisfactory for use in phosphating solutions. With the majority of solutions of this type, the deposit formed on the coil is easy to remove and thus titanium has a considerable advantage over other materials.

**Zirconium Coils**

Zirconium is recommended for heating coils in sulphuric acid pickling solutions. It is resistant to sulphuric acid solutions up to 65 per cent concentration at temperatures up to boiling point, and for this purpose it provides an alternative to lead. Zirconium coils are considerably lighter than lead coils and are not subject to creep. In addition, zirconium coils have a much higher thermal efficiency so that a lead covered coil can be directly replaced by a zirconium coil of less than half the heating surface area. As indicated previously, zirconium cooling coils may also be used in sulphuric acid etch solutions.

**Tantalum Coils**

Tantalum sheathed copper and solid tantalum heating and cooling coils are recommended for the heating of silico-fluoride and fluoride based chromium plating solutions, e.g. Chromefast C, where high temperatures and very high currents are employed. Tantalum has an extremely high chemical resistance and in many ways its properties are similar to those of glass, it is thus not suitable for use in hot highly caustic solutions or in those containing free hydrofluoric acid. Solid tantalum can be used with high pressure, high temperature hot water heating.

**Incoloy 825 Coils**

Coils in Incoloy alloy 825 may be used for heating and cooling nickel plating solutions. This alloy which is a titanium stabilised nickel-chromium-iron-molybdenum-copper alloy has been developed to meet corrosive conditions of unusual severity and in general has a high resistance to oxidising conditions and stress corrosion cracking.
Stainless Steel Coils

Stainless steel coils are used for heating sealing solutions for anodic oxidation coatings and for hot water rinses, particularly where de-ionized water is used. Stainless steel coils are also specified for certain electrolytic polishing solutions.

Fluorocarbon Coils (Dupont Teflon Heat Exchangers)

Fluorocarbon plastics being chemically inert are resistant to all metal finishing solutions, and are thus of particular value for the heating and cooling of highly corrosive solutions such as hydrochloric and hydrofluoric acids and nitric acid mixtures. Major applications in the metal finishing field are for the heating and cooling of fluoride type chromium plating solutions, particularly where these are used for hard chromium deposition.

Special Teflon coils can be used for electroless nickel solutions where canalization and excessive build-up of deposit must be kept to a minimum. The large number of tubes means that there are no ‘hot-spots’, as in other types of immersion heaters and the coil can be easily cleaned by immersion in nitric acid with no fear of contamination or degradation of the coil. The Teflon coated weights are replaced by PVDC bolts and nuts and the end fittings made of Teflon PTFE to allow complete immersion.

To provide the large surface area necessary, in view of the low thermal conductivity of the plastics, the heating coils are made up from a great number of small diameter, thin walled tubes. The flexible thin tube structure with its inherent anti-stick properties discourages fouling and scale build up, and the insulating nature of the material eliminates the possibility of short circuits, bi-polar effects and corrosion due to stray currents.

Teflon heating and cooling coils are available in a number of configurations:
- **Super coils** which employ thin Teflon tubes made up into multiple braids separated by polyvinylidene chloride spacers and provided with Teflon coated weights to prevent the coil from floating and to ensure that it takes up the required ‘U’ form.
- **Slimline Coils** in which the support and protection, for the Teflon tubes is provided by a Teflon coated stainless steel frame.
- **Mini coils** for use in small tanks that consist of a single or double wound Teflon spiral supported on a polypropylene sheet.

Teflon coils should be used with low pressure saturated steam or hot water at a pressure not greater than 2 bar (30 p.s.i.) on large coils and down to 1 bar (15 p.s.i.) on the smaller coils.

For solution cooling, a range of wide bore (8mm - ¼ in dia.) is available. Cooling coils may be used for initial steam heat-up providing sufficient time is allowed for the coil to cool before starting water flow (approx. 15 min.)

External Heat Exchangers

External heat exchangers provide an effective method of heating and cooling solutions used for electroplating and can be manufactured in a wide variety of materials to suit the solution to be heated or cooled, for example, carbon block, stainless steel, mild steel, titanium.

Use of an external heat exchanger requires that the solution be circulated. Whilst in certain filtration system the heat exchanger can be incorporated in the solution circulation system, it is preferable to have a separate circulating system for the heat exchanger to ensure that the solution is circulated at a constant velocity.

To prevent damage to the heat exchanger, it is also advisable that a safety device be included in the temperature control circuit to prevent the heating medium being applied or maintained without solution being circulated.

Where heat exchangers are used for cooling, the solution should be circulated at a constant velocity. The flow of cooling medium should be controlled by either a straight through or three-way diverting valve, the
latter being required where a re-circulating system for the cooling medium is used.

**Water Jackets**
The use of water jackets for heating solutions is restricted because of the relative inefficiency of the method, but for highly corrosive solutions, it is often the most convenient method. Hot water jackets are widely used for the heating of lead-lined chromium plating tanks; they are not, however, normally advised with rubber or plastic lined inner tanks, since the rate of heat transfer is low and there is the possibility that the surface temperature of the inner tank may be raised above the maximum safe operating temperature of the tank lining material. Where this method of heating is used with lined tanks, it is important that thermostatic control of the solution with an overriding thermostat for the water jacket should be employed. This will ensure that both the temperature of the solution and the water jacket will be controlled within safe limits.

When maintaining water jackets at high temperatures, for example, in Electroless Nickel tanks, higher boiling point materials can be added to prevent excessive evaporation from the water jacket.

To maintain the level of water in the jacket at all times, it is necessary to fit a water box with a ball valve controlled water supply.

Four methods of heating the water jackets are in general use:

- **Steam heating coils**: immersed in the jacket are fitted to a removable plate under the main tank. The removable plate enables the coils to be taken out for inspection or servicing.
- **Steam Injection**: The steam injector is submerged in the jacket to inject live steam directly into the water. Provision must be made on the jacket for the water overflow.
- **Immersion heaters**: of the screw in type fitted in the bottom of the jacket and under the main tank.
- **Gas heating**: preferably the treble cased type, should be used with lagged outer casing, the hot gases circulating between the water jacket and outer casing. Suitable baffles are included in the casing to allow the spent gases to circulate round the tank before finally going to the atmosphere.

**High and Medium Pressure Hot Water Heating**
The advantages of this method of heating as compared with steam include cleanliness of operation, lower water and fuel costs. For plating solution heating, the system may be operated at either medium or high pressure. Pressure raises the boiling point of the water and enables it to be heated to above 100°C (212°F). The higher the water temperature needs to be, to provide the necessary heat energy input to the tank, the higher the pressure that must be applied to suppress boiling. Therefore when using high pressure hot water for heating, larger bore and stronger coils have to be used. These, together with the use of heavier gauge flanges and larger control valves are the important variations between hot water and steam heating.

Low pressure hot water heating is not normally effective because the amount of heat energy that can be carried through normal coils by water below 100°C (212°F) is not sufficient to heat large volumes of solution or to maintain steady high temperatures.

Using hot water for heating, three main methods are available:
- Coil submerged in the tank.
- Coil submerged in the jacket,
- Heat exchanger.

**Liquid Phase Heating**
In liquid phase heating, a liquid heating medium other than water is used, for example oils and glycols or mixtures of glycol and water. Because of the much higher boiling point of these materials and mixtures, they can be circulated at high temperatures but at normal atmospheric pressure.

A number of special media have been developed for this application, which can be employed at temperatures well above 100°C (212°F).

The equipment and heating methods are similar to those used with hot water heating but it should be noted
that these materials generally have a greater mass than water.

**Gas Heating**

With the more general availability of natural gas, there is now a greater interest in the use of gas as a heating medium for plating solutions. In the past, gas has been considered as a convenient method of heating small plating shops and individual tanks, where low capital cost was more important than high thermal efficiency. Today, the emphasis is on the use of gas as a highly economical form of heating, with the use of efficiently designed burners to give high thermal efficiencies. Flame failure control is now generally provided, often with the provision of thermostatic control.

On large installations, particularly with automatic plating equipment, the most effective system is the use of a gas fired boiler for the provision of steam, high pressure hot water or liquid phase heating.

Plain steel tanks can be gas heated with burners directly beneath the tank, the tank being supported on an angle iron stand which incorporates the burner, or it may be supported on a brick plinth and have separate burners. A baffle plate should be placed under the burners to reduce the heat reflected on to the floor, and a baffle should also be placed between the burners and the tank.

For solution heating, gas-fired immersion heaters are now available as an alternative (in suitable solutions) to the use of external burners.

**Electric Heating**

The usual method for the electrical heating of solutions is by means of immersion heaters, but on unlined tanks plate type heaters which are clamped to the sides of the tank can be used.

The immersion heaters used may be of the metal. Teflon or silica cased types, and are usually vertically mounted with the upper section of the heater unit above solution level. Where heaters are fitted in plastic or rubber lined tanks, sufficient space must be allowed between the heaters and the tank wall to prevent any possibility of the lining overheating.

To secure efficient service from electric immersion heaters, it is important that the surface of the heaters be kept clean and free from any surface scale or film, which might result in local overheating.

In suitable cases screw-in type immersion heaters may be used. These permit the heater to be positioned in the lower part of the tank and are thus of advantage with deep tanks which could not be effectively heated using heaters mounted on the top of the tank. The use of screw-in type heaters is usually restricted to hot water jackets.

**Metal Cased Heaters**

Metal cased heaters may be of the mineral insulated hair-pin™ type with the heating element positioned within a narrow tube, or the tubular type where the heating element is mounted on a ceramic former and enclosed within a metal tube of larger diameter.

The tube or casing must be made from or covered with a metal which is resistant to the solution in which it is to be used.

All these types of heaters are provided with a 128 mm (5 in) horizontal section adjacent to the junction box to permit the heater to be mounted on the tank flange by means of a fixing cleat.

For use in shallow tanks, metal cased heaters can be provided with the lower part of the casing bent horizontally to lie along the tank bottom.

The heated section begins 305 mm (12 in) down the vertical length of the heater and it is essential that the solution level does not drop below this point. The minimum safe working solution level is 250 mm (10 in) from the top of the heater casing.

<table>
<thead>
<tr>
<th>Casing</th>
<th>Suitable Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel</td>
<td>Cyanide and alkaline solutions.</td>
</tr>
</tbody>
</table>
Lead rolled Dull nickel, acid zinc, hot swills.

Stainless steel Hot swills, dye tanks, phosphoric acid and chromic acid solutions.

Titanium Nickel and chromium plating solutions.

**Teflon Immersion Heaters**

Teflon cased electric immersion heaters are suitable for all types of solution including electroless copper and nickel. The electric heating resistance wire of the immersion heater is double sheathed with Teflon fluocarbon plastic. Between the two Teflon sheaths, there is a spirally wound tinned copper ribbon providing earth protection. The fitting of an automatic earth leakage circuit breaker is strongly recommended.

The Teflon heaters which are available in ratings up to 4 kW (single phase) and 6 to 12 kW (3 phase); with heat dissipations of 1 watt/cm² (normal type) or ½ watt/cm² (heavy duty).

The heaters are insensitive to mechanical and thermal shock. The normal type may be operated up to 100°C and the heavy duty type up to 150°C. The average power requirement is 1.5 kW per 100 litres of solution, this will however be influenced by the solution volume, the required operating temperature and the required heating up time.

**Silica Cased Heaters**

For bright nickel solutions and for other solutions where metal cased heaters are unsuitable, the fused silica cased type may be used. These heaters incorporate a non-metallic sheath of fused silica and are suitable for all types of acid solutions with the exception of hydrofluoric acid, solutions containing fluorides and concentrated phosphoric acid. They are unsuitable for use with caustic solutions. Silica cased heaters are suitable for use in phosphating solutions, in phosphoric acid based chemical and electrolytic polishing solutions and in pyrophosphate copper solutions providing the silica sheaths are cleaned regularly to keep them free from surface film. Where heaters are used in chemical polishing solutions or other extremely corrosive solutions the heaters can either be positioned so as to limit the possibility of damage, by fume, to the heater caps and cables or special heaters with PVC caps can be employed.

Every heater is clearly marked with an encircling black line at the minimum safe immersion depth and it is essential that the solution does not fall below this level.

Silica sheaths are strong but will not stand up to sharp impacts so it is recommended that Teflon Heater Guards are fitted round the heaters in the tank to protect against accidental damage caused by careless handling of anodes or loaded jigs. Outside the vat silica cased heaters should be carefully and individually stored, and not be dropped or subjected to rough handling.

**Earthing of Electrically Heated Tanks**

Where electric immersion heaters are used, it is essential they be effectively earthed to ensure safety to operatives in the event of failure of the medium insulating the heater elements from the metal sheath or solution.

**Metal Sheathed Heaters**

With non-electrolytic tanks the heaters may be connected directly to earth.

With electroplating or other electrolytic process tanks the method of earthing is dependent upon the type of low voltage circuit employed. In the case of a single tank, or of tanks supplied from individual D.C. power sources, earthing is direct. Where, however, two or more tanks with metal sheathed heaters are supplied from a single D.C. source, direct earthing to the heaters could result in the flow of low voltage direct current between the individual tanks by way of the earth connection. This may result in erosion or a build-up of
deposit on the heaters. The possibility of such a low voltage D.C. current leakage is greatly increased when the tanks are regulated by individual resistance boards.

On automatic plants, e.g. Trojan, where the cathodic work carriers (negative) are linked to the steelwork frame and hence effectively earthed, there is also the possibility that current may flow from the anodes (positive) via the heater cases to earth and hence to the cathode (negative) connection of the power supply. These D.C. currents can be sufficiently high to cause failure of the heater earth leads thus leaving the heaters unprotected.

Appropriate provision must be made to block low voltage D.C. current flows in the heater earth leads and at the same time provide effective protection in the case of failure of the heater. This would generally require the use of a current operated earth leakage circuit breaker.

To present the possibility of current leakage between the tanks themselves, the normal precautions advised for plating tanks operated from a common low voltage source should be taken. The tanks should be mounted on insulated supports, insulated couplings fitted to the connecting pipe work and thermostat bulbs provided with insulated sheaths.

**Teflon and Silica Cased Immersion Heaters**

The earthing terminal on the heater must be connected direct to the system earth. This will apply whether one or more tanks are supplied from a single low voltage source. These immersion heaters incorporate an internal earth wire, and as the heater case itself effectively isolates both this and the live element from the solution, inter-tank circulating currents are automatically prevented.

In order to ensure absolute electrical safety in the event of sheath breakage, particularly where the heaters are used in water or other low conductivity solutions, an earth leakage circuit breaker should be included in the electrical circuit, in addition to the normal fuse protection.

Where a thermostat is included, this must also be earthed direct and in addition the metal bulb must be electrically insulated from the solution by enclosing it in a container of material such as Pyrex. Heat conduction is maintained by filling the space between the bulb and sheath with a non-corrosive liquid such as distilled water or glycerol.

**Electric Heating of Plastic or Plastic Lined Tanks**

With electrically heated plastic or plastic lined tanks it is important that solution level control or a level operated safety cut-out be provided in order to avoid the risk of overheating or of fire in the event of the solution level falling and exposing the heaters.

**Solution Level Control**

A typical liquid level control consists of three stainless steel probes of differing lengths together with a control unit. When the liquid level is above the high probe the relay will energize and operate the supply to A.C. contactors controlling immersion heaters or the coil of solenoid operated valves or motors for steam, gas or high pressure hot water systems. When the solution level falls below the low probe the relay will then de-energize breaking the supply to the controlled circuit. The circuit cannot be re-made again until the level of the solution is brought above the high probe; this effectively prevents hunting. A further application is to safeguard the loss of expensive solutions as well as providing a warning of the loss of solution, which would affect the effluent discharge particularly overnight when plant is not manned.

**Lagging and Heat Conservation**

The lagging of the exteriors of heated tanks and pipe-work will result in a considerable heat saving.

With tanks the normal procedure is to fit to the tank sides panels of insulation material for example Marinite or plastic foam sheet with an outer layer of glass-fibre plastic laminate.

Before fitting external thermal insulation to plastic or rubber lined steel tanks, it is advisable to determine whether a reduction in the rate of heat transfer, and a subsequent rise in the temperature of the steel is likely to result in damage to the lining or to the bond between the lining and the steel tank.
Chroffles

Heat losses from the surface of static solutions can be reduced by covering with one or more layers of Polypropylene Chroffles. A single layer of these Chroffles will reduce the heat losses from the surface of the solution by as much as 60-75 per cent. Polypropylene Chroffles are plastic spheres which float on the surface of solutions and act as an insulating layer. Jigs and anodes can be inserted into the processing solutions through the blanket of Chroffles without difficulty. When certain components are treated i.e. hollowware, on removal from the tank they can retain a few Chroffles within them but usually these float to the surface of subsequent swills where they can be easily collected and returned to the hot processing solution.

The evaporation rate from the surface of hot solutions is also reduced by a layer of Chroffles. Tests carried out show an 88 per cent reduction in the weight of water evaporated from an open free surface when a layer of Chroffles were used.

The other important use that Chroffles have is the reduction of spray from the surface of solutions. It should be noted that in chromium plating, the use of Chroffles will reduce spray as well as heat losses from the surface of the solution but efficient fume extraction or an appropriate spray suppressant, e.g. Minimist is still required.

Chroffles are obtainable in three different sizes: 45 mm (1¾ in) this is the standard size and the most universally useful; 20 mm (¾ in), these are suitable for small tanks or for components where the standard size would block and jam in a cavity or angle; 150 mm (6 in) are used for very large tanks and to prevent any entry of Chroffles down wider cavities.

**Calculation of Heating Requirements**

In order to estimate the capacity of the heating unit required (either steam boiler, hot water boiler, electrical or gas heaters), it is necessary to determine the requirements of the various heated tanks expressed in watts, British thermal units or kilo calories per hour. This figure is then divided by the number of hours which has been decided will be required to heat up the tanks (normally this is 3 to 4 hours).

In calculating the heat requirements, it is usual to assume that the density of the solution \( \times \) the specific heat = 1, thus:

\[
\text{kcal/h} = \frac{\text{1 Btu/h}}{0.252 \text{ kcal}} = \frac{\text{1 kWh}}{3,412 \text{ Btu}}
\]

<table>
<thead>
<tr>
<th>1 Btu</th>
<th>0.252 kcal</th>
<th>1 kWh</th>
<th>3,412 Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Btu</td>
<td>1.055 kJ</td>
<td>1 kWh</td>
<td>860 kcal</td>
</tr>
<tr>
<td>1,000 Btu</td>
<td>2.93 kWh</td>
<td>1 kWh</td>
<td>3.6 MJ</td>
</tr>
<tr>
<td>1 kcal</td>
<td>3.968 Btu</td>
<td>1 MJ</td>
<td>948 Btu</td>
</tr>
<tr>
<td>1 kcal</td>
<td>4.186 kJ</td>
<td>1 MJ</td>
<td>239 kcal</td>
</tr>
<tr>
<td>1,000 kcal</td>
<td>1.163 kWh</td>
<td>1 MJ</td>
<td>0.2788 kWh</td>
</tr>
</tbody>
</table>

**Allowance for Heating Losses**

To the figure obtained as described in the previous paragraph for heating up the solution must be added an allowance for heat loss from the surface and also from the sides of the tank during the heating up period. This heat loss will be dependent upon the final temperature of the solution, the ambient temperature and also the heating up time allowed. The use of air agitation or fume extraction will result in a considerable increase in heat loss.

With electrolytic tanks, heat will be generated when these are in operation, and thus heat losses may be balanced by the heat input due to the passage of the electric current. With processes such as chrome plating, sulphuric acid anodizing and electrolytic polishing, it may be necessary to provide for solution cooling.
Cleaning, Pickling and Dipping

The importance of perfect cleaning cannot be over-emphasized, since upon the efficiency of this operation depends the adhesion of the deposited metal. Of the various processes, designed to give a clean surface suitable for plating none is more important than the removal of grease, oil and other soils, whether left from machining, stamping, spinning, pressing, or polishing. Plating on to a dirty or greasy surface inevitably leads to blistering or peeling of the deposit.

The various cleaning and pre-treatment processes through which an article must pass before it may be successfully electro-plated can be classified under the following headings:

- Preliminary Cleaning or Degreasing.
- Pickling or Bright Dipping.
- Hot Alkaline Cleaning.
- Final Cleaning and Surface Activation.

Preliminary cleaning or degreasing involves the removal of heavy oils, greases and soils, and is necessary before a component can be pickled or bright dipped for the removal of oxide and scale. After this, the component is ready for polishing or other mechanical finishing. Even where an article is not mechanically finished prior to plating, it is still good practice to carry out initial degreasing and pickling before components pass to the primary cleaning stages.

Hot Alkaline Cleaning.
Final Cleaning and Surface Activation.

These stages will remove all traces of grease and any passive film to give an active surface to which the electro-plated deposit will adhere.

The pre-treatment processes immediately prior to plating generally take the form of hot alkali cleaning, possibly followed by acid dipping to remove slight oxide films, then final cleaning to ensure that the component is perfectly clean. Where the final cleaning is carried out in alkaline solution and the components are to be plated from an acidic solution such as nickel. They are given a dip through dilute acid followed by swilling before they are placed in the plating tank.

**Routine Operations in Cleaning**

The chart does not cover metals such as aluminium or stainless steels, which require special treatment, but is applicable to the general run of work and assumes that the articles are in a dirty or ‘rough’ condition to begin with, as, for example, castings, forgings, hot stampings and heat treated parts. In most instances it is necessary to pickle to remove scale, but before this operation can be attempted, the article must be degreased so that the acid can wet the surface and act uniformly and effectively. Some annealed articles taken straight from the muffle will, of course, be free from grease and may be put directly into the pickle, whereas many small parts, such as sheet metal pressings, being oily, will require careful degreasing but no more than a dip in acid to remove ‘temper’ colours or incipient rust.

Pickling processes for the removal of scale, rust and corrosion, are dealt with later in the chapter, but it is necessary to consider first the cleaning operations. The term ‘cleaning’ refers primarily to the removal of oil, grease or extraneous dirt from the surface of the article, but some of the cleaners serve a dual purpose and will also remove tarnish and thin films of oxide.

**Preliminary Cleaning and Degreasing**

**Solvent Cleaning**

Cold solvents such as paraffin and white spirit were formerly used widely for the removal of heavy grease and oil from components to be electro-plated. After treatment in the solvent, the components were dried in sawdust before being given a final clean in a hot alkaline solution. These solvents possessed a low toxicity but they were flammable. Their use was time-consuming and not altogether effective as they had a low solvent-power.

These methods have now been largely replaced by the use of solvent vapour cleaning methods. The solvents generally used are: trichloroethylene, perchloroethylene, 1,1,1-trichloroethane or trichloro-
Trifluoroethanes. These solvents are all non-flammable but only trichloroethane is safe enough to be used as a solvent for hand wiping, the rest need to be used in specially designed equipment to avoid inhalation as they have anesthetic and toxic properties.

Trichloroethylene has the highest solvent-power but has the lowest TLV. Perchloroethylene has a similar TLV and is used where high melting point waxes are to be removed. 1,1,1-trichloroethane has a solvent-power almost as good as trichlorethylene but has a much higher TLV making it a safer solvent. The trichloro/trifluoroethanes have the highest TLV and will dissolve fluxes and silicone oils but not polishing compositions or fingerprints on metals, thus making them more suitable for the electronic and instrumentation industries.

The solvent is contained in a special unit which is provided with heating elements in the base and cooling coils round the top edge. The boiling solvent is condensed by the cooling coils and thus retained within the unit. When a component is immersed in the degreaser, the vapour condenses on its cool surface as clean distilled solvent, washing off the grease and oil, which are carried into the sump. The cycle of distillation and condensation of clear liquor continues until the component attains the temperature of the vapour.

Where components carry particles of compacted polishing composition, it is advisable that they be immersed initially in the boiling liquor in order to secure mechanical removal of the solids. Components can then be allowed to cool slightly before being immersed in the vapour to obtain final cleaning. If this procedure were to be reversed and the polishing composition exposed initially to the vapour, the grease present in the composition would be dissolved out, leaving a solid residue which could be extremely difficult to remove.

Multi-compartment degreasing units are available in which this sequence of cleaning, where the components are immersed initially in the hot liquor and then later in the vapour, can be carried out. Another variation is to use special grades of trichloroethylene or trichloroethane, which form stable water/solvent emulsions. These emulsions are used cold and are circulated by a pump at high velocity to create vigorous turbulence in the tank. Components are not only degreased but solid particulate material is removed, which is not always the case with solvent vapour as explained above. After this emulsion treatment, the components are transferred to a conventional type of vapour degreaser to finish the cleaning process.

Several safety points should be considered: vapours of trichloroethylene should not be allowed to come into contact with red-hot surfaces as toxic gases, including phosgene, may be produced.

When components are withdrawn from trichloroethylene vapour degreasers, any residual solvent, which may be retained in cavities, should be allowed to evaporate completely before immersion in an alkaline cleaner. Carry-over of trichloroethylene into caustic soda containing cleaners may result in the production of dichloroacetylene gas, which is highly toxic and spontaneously flammable in air. Products of its combustion may include phosgene. No such reaction occurs between perchloethylene and caustic soda.

Where metals such as aluminium are to be cleaned, the use of stabilized forms of the solvents is advised, in order to avoid the possibility of decomposition of the solvents to form acids which will attack the metal surface to be cleaned.

Table of common solvents used in metal cleaning, with comparisons

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Flammability</th>
<th>TLV p.p.m</th>
<th>Solvent Power (KB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethylene</td>
<td>Non flammable</td>
<td>100</td>
<td>132</td>
</tr>
<tr>
<td>Perchloroethylene</td>
<td>Non flammable</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td>Nonflammable</td>
<td>200</td>
<td>124</td>
</tr>
<tr>
<td>Trichloro/ Trifluoroethanes</td>
<td>Non flammable</td>
<td>1000</td>
<td>Various</td>
</tr>
</tbody>
</table>
Aqueous Neutral Detergent Pre-Cleaners

Aqueous neutral detergent pre-cleaners, e.g. Mersol Soak Cleaner, are employed for the removal of polishing residues and heavy soiling prior to normal cleaning before electro-plating and also for inter-stage cleaning of articles during manufacture. Their action is to (1) modify the soils so that they can be easily removed by the subsequent alkaline cleaning stage, or (2) dissolve oils and greases.

Mersol Soak Cleaner

Mersol has been developed for the pre-cleaning of components prior to the usual cleaning and plating sequence. It is extremely effective for the removal of oils, greases and impacted polishing residues. These are quickly removed by simple immersion in the Mersol solution, and in many cases the use of solvent degreasing can be completely eliminated.

Mersol is suitable for the treatment of most metals, including steel, copper and copper based alloys, aluminium, and also zinc base die-castings. In addition to its use for the removal of polishing residues, Mersol is also recommended for the general degreasing of components in engineering works.

Solution Composition

| General purpose use. Mersol Soak Cleaner | 30 ml/1 | 5 fl oz/gal |
| For Aluminium Components, Mersol Soak Cleaner | 10 ml/1 | 2 fl oz/gal |
| For Ultrasonic Cleaning, Mersol Soak Cleaner | 20 ml/1 | 3 fl oz/gal |

Solution Preparation

For the Mersol solution a welded mild steel tank is used. The solution is prepared by filling the tank to two-thirds its capacity with clean water, at 36-45°C (95-110°F), and then adding the Mersol Soak Cleaner concentrate slowly with stirring. The tank is finally topped up to working level with water.

Operating Conditions

Temperature. 70 to 99°C (160 to 210°F). For ultrasonic cleaning temperature should not exceed 70°C (160°F).

Treatment Time. 1 to 5 minutes.

Agitation. Mechanical, manual or ultrasonic.

Operating Procedure

From the Mersol Cleaner the articles are thoroughly swilled and then transferred to a hot alkaline soak solution. This solution is maintained at a temperature of not less than 60°C (140°F) and is prepared by the use of 10 to 25 g/1 (2 to 4 oz/gal) of the normal hot cleaner employed in the plating line (e.g. Activax or Multiklense).

After treatment in the alkaline soak for a few seconds, the articles are transferred to a hot electrolytic alkaline cleaner and then passed through the remainder of the cleaning line (secondary cleaner, acid dip, etc.).

After immersion in the MersolCleanera thin surface film may remain which can result in water-breaks™ being apparent, particularly on unpolished surfaces. This effect is removed by a hot alkaline
soak and is in no way detrimental to the cleaning cycle, however Mersol should only be used as an off-plant cleaning operation.

**Ultrasonic Cleaning**

In ultrasonic cleaning, the penetrating power of the solvent or aqueous cleaner is accelerated by employing the high frequency energy of sound waves. Microscopic cavities are progressively created and collapsed in the cleaning medium, producing a powerful and penetrating scrubbing action. Any stubborn soils present on the components being cleaned are efficiently removed even from deeply recessed areas. The main applications of ultrasonic cleaning are in the manufacture of small precision components, such as watch parts and for the cleaning of intricate jewellery. For these applications equipment is of small capacity, generally of the order of 20 litres (5 gal).

In the pre-treatment of articles to be electro-plated, the main field is in connection with zinc base diecastings, particularly, where impacted polishing composition has to be removed.

Ultrasonic are principally of advantage where sensitive metals have to be cleaned. For the cleaning of steel, more active cleaners can be employed and this is generally a more economical approach than the application of ultrasonic.

Ultrasonic can be applied to solvent degreasing with cold and warm solvents and also to aqueous cleaners, such as Mersol. Ultrasonic equipment can produce audible harmonics, especially if it is not tuned correctly. Operatives may need to wear ear protectors to ensure comfortable working conditions and avoid possible hearing reduction.

**Alkaline Cleaners**

Aqueous alkaline cleaners, e.g. Active. Nuvax, 10-15 and Anodax may be used for initial soak or electrolytic degreasing, as well as final cleaning prior to plating. These cleaners are fully discussed under each individual cleaner section. When large quantities of oil need to be removed, the use of an oil separation unit, is recommended.

Where spray or power wash degreasing is required, e.g. for the removal of oil, cutting lubricants and swarf from all metal groups in machine shop inter--stage cleaning operations, the 1100 Spray Cleaner is particularly effective. This cleaner is easily soluble and incorporates a blend of the most recent surface active materials together with agents to disperse scum, obviate hard water precipitates, and inhibit oxidation of the cleaned metal surface. Bactericides are also incorporated into 1100 cleaner. This spray cleaner is caustic free, non-toxic and incorporates bio-degradable surfactants.

Solvent degreasing is still recommended, where a dry article is required immediately after the degreasing operation.

**Hot Alkaline Cleaners**

Hot aqueous alkaline cleaners are used for the removal of grease and soils from components to be electro-plated. Choice of metal cleaner to be employed is influenced by the material to be cleaned, and also by the type of soil or grease to be removed. A range of cleaners is available to meet these varying requirements. The various cleaners may be classified in order of alkalinity. As a general rule, the higher the alkalinity the more rapid will be the cleaning. Recent developments in cleaner formulation and the use of modern surfactants do, however, enable effective cleaning to be obtained with solutions having much lower free alkalinities than those formerly employed. In modern cleaner formulations soil suspending and anti-redeposition agents are also incorporated together with sequestering agents to enable the cleaner to be used effectively in hard water areas.

The effect of an alkaline cleaner is influenced by:

- The type of basis metal.
- The type and concentration of the cleaner.
- The cleaner temperature.
The time of immersion is important. The condition of use, i.e. immersion; electrolytic (cathodic or anodic); spray. Increasing the cleaner concentration, temperature, time of immersion, and the use of electrolytic cleaning will all accelerate the rate of cleaning. It is, however, important that the recommended concentrations given for the various cleaners are not exceeded. Strongly alkaline cleaners may be used for steel, but for the non-etch cleaning of zinc and aluminium, a solution having a low free alkalinity must be used. The common metals may be classified in the following groups:
1. Steel.
2. Copper, brass, nickel, silver and other copper based alloys, magnesium and its alloys.
3. Zinc base alloy, tin, tin alloys such as pewter, Britannia metal, lead and lead alloys.
4. Aluminium.

The alkaline cleaning stage is generally one part of a pre-treatment system used to prepare the surface for electro-plating.

Electrolytic and Chemical Processes for the Polishing of Metals
There is considerable interest in the electrolytic and chemical processes for the polishing of metallic surfaces. Their main commercial applications are for components of aluminium, stainless steel and iron, brass and nickel silver, in particular for those, which are difficult or expensive to polish mechanically. In the engineering industry, electro-polishing processes are being employed for super-finishing and for the removal of stressed surfaces. While it may not always be possible to eliminate mechanical polishing completely, a saving can sometimes be effected on suitable components by a combination of mechanical and electrolytic or chemical processes.

These electrolytic or chemical processes do not "flow" the surface, as happens in mechanical polishing, and surface defects such as deep scratches, draw marks and flaws in the metal, will not be removed from the polished surfaces. It is therefore essential, if a satisfactory finish is to be obtained, that the components to be treated are made from high quality material which has a uniform structure, a small grain size, freedom from inclusions, and a good surface finish. The single phase alloys are most suitable. With multi-phase alloys preferential dissolution often occurs with etching of the surface.

The effectiveness of a polishing process may be judged from an examination of the reflected image. With some alloys, electro-polishing and chemical polishing processes give a reflected image of improved clarity as compared with the un-treated surface. On other alloys, while a finish of equal lustre may be produced, there is little improvement in quality to the reflected image.

Electro-polishing Solutions
The electro-polishing process may be likened to electro-plating in reverse, in that it requires similar equipment, e.g. tanks, solution and low voltage direct current provided by a rectifier. The essential difference between the two processes is that the articles to be polished are made the anode in the circuit, and not the cathode as in electro-plating.

In electro-polishing, the cathodes, which may be of copper, lead, or stain- less steel, serve merely to conduct the current to the solution. A suitably lined tank is required, fitted with exhaust equipment for the
removal of spray or fume. For successful operation, the majority of processes require the use of a low voltage current of the order of 15 to 80 amp/dm² (1 to 5 amp/in²). The high current density employed can create problems with regard to the jiggling of the article, particularly where light gauge articles of substantial area are to be processed.

These solutions are phosphoric acid based and are available in prepared form ready for use. Solutions containing perchloric acid, such as those advised for the polishing of metallurgical specimens, should not be used on an industrial scale. Perchloric acid reacts with organic matter with explosive violence. The use of such solutions is dangerous on any but the smallest laboratory scale with experienced control.

**Aluminium and Aluminium Alloys**

For aluminium components, solution polishing followed by an anodised and dyed finish is almost universally used. Today, many items from fashion jewellery to kitchen utensils in many beautiful colours and patterns are made from aluminium which has been electro-polished or chemically polished, anodised, and then dyed or printed to give customer appeal.

While it is possible to electro-polish a wide range of aluminium alloys of the low silicon type, the necessity for employing an alloy which will anodise without loss of brilliance restricts the choice of material for most purposes to high purity aluminium and its magnesium alloys. Where it is necessary to employ an alloy which is unsuitable for bright anodising, a reasonable degree of protection may be given to the polished surface by lacquering.

**Aluminium Electro-polishing Solution**

Aluminium Electro-polishing Solution provides an effective and economical method of electro-polishing aluminium and aluminium alloys prior to anodising. It is now widely used for the electro-polishing of aluminium automobile trim, holloware, door furniture, and domestic equipment.

**Equipment**

For this solution a tank lined with antimonial lead is employed. Where cathodes or work are likely to come into contact with the tank lining, loose, rigid plastic sheets or re-enforced glass should be fitted. The tank should be fitted with fume extraction, and for heating, tellurium lead coils provided. As an alternative to steam heating, silica-cased immersion heaters may be used; these should be anchored to prevent them from floating out of position.

To provide maximum solution movement on the surfaces being processed both mechanical anode movement and air agitation are employed. For large articles the air agitation should be vigorous, twin row agitation coils being fitted under each work rod. The mechanical anode movement is in the vertical plane with a stroke of 50 to 75 mm (2 to 3 in).

For cathodes, antimonial lead or stainless steel plates are employed. The cathode area should be as large as possible.

**Jigs**

The use of aluminium, aluminium magnesium alloy or titanium jigs is advised.

**Solution Composition**

The solution is made up from a liquid acid base and a solid activator and they must be mixed together in exactly the way described below.

<table>
<thead>
<tr>
<th>Aluminium Electro-polishing Acid Base</th>
<th>As supplied</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Activator Salts</td>
<td>37.5 g/l</td>
<td>6 oz/gal</td>
</tr>
</tbody>
</table>

**Solution Preparation**
To prepare a working solution, it is necessary to add the *Activator Salts* to the *Acid Base* Solution. The Activator Saltshavelimited solubility in the Acid Base and so they should first be dissolved in water at the rate of 750 g Activator Saltsper litre of water (120 oz/gal). 50 ml of the solution made up in this way should be added to every litre of the Acid Base, (8 ft oz/gal or 80 fl. oz/carboy of Acid Base) with vigorous stirring to ensure complete mixing. The Aluminium Electro-polishing Solution is then ready for use.

**Operating Conditions**

<table>
<thead>
<tr>
<th>Anodic Current Density.</th>
<th>10 amp/dm² (90 amp/ft²) initially, falling to half this value after 45 seconds. Generally higher solution temperatures give higher current densities. As the solution â€œagesâ€ these values will fall.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage.</td>
<td>14 to 20 Volts.</td>
</tr>
<tr>
<td>Temperature.</td>
<td>60 to 65°C (140 to 150°F).</td>
</tr>
<tr>
<td>Time.</td>
<td>5 to 10 minutes depending on initial surface condition and the quality of finish required. For some castings a processing time of 2 minutes is sufficient.</td>
</tr>
<tr>
<td>Solution Density.</td>
<td>The solution density should be between sp. gr. 1.70 to 1.75 (60° Be - 62° Be).</td>
</tr>
</tbody>
</table>

**Operating Procedure**

Before electro-polishing, articles should be cleaned in a hot alkaline cleaner, e.g. Minco Aluminium Cleaner preceded if necessary be degreasing in a solvent degreaser.

Articles which have not been pre-polished may require etching for a few seconds in Kelco Aluminium Cleaner. This etching stage should follow alkaline cleaning or degreasing.

Where aqueous cleaning is employed, it is necessary to rinse well and then allow the articles to drain in order to reduce to a minimum carry-over of water into the electro-polishing solution. On work which is liable to carry over appreciable quantities of water, the use of a separate pre-dip solution is advised. Articles are immersed in this solution for 30 seconds before being transferred to the electro-polishing tank.

To ensure uniform treatment articles should be immersed in the electro-polishing solution for 7 to 10 seconds before contact is made with the anode rod. Where a pre-dip solution is used, the current can be applied to the articles immediately they are immersed in the electro-polishing solution.

Where plant is manually loaded, maximum current requirements can be limited by working round the tank, taking out one jig at a time and replacing with a new one.

After rinsing the articles are desmutted in a chromic-phosphoric acid solution. Where manual handling is employed an alternative desmutting solution is Kelcoat 25 g/l (4 oz/gal). The solution is used at room temperature and the immersion time is 12 to 15 seconds.

**Solution Maintenance**

Care should be taken to reduce the carry over of water into the solution to a minimum, and drag out losses should be replaced by fresh Aluminium Electro-polishing Solution made up from the *Acid Base* and *Activator Salts* as described.

Excess water in the solution can be removed by heating the solution for a period to a temperature of 95 to 105°C (200 to 220°F). Before heating the solution above 75°C (170°F), any plastic fitting, which may be damaged by the elevated temperature, should be removed.

If the solution fails to give effective polishing, or if etching of the aluminium surface occurs, an addition of up to 8 ml/l (1.25 fl. oz/gal) of a solution of the Activator Salts made up at the rate of 750 g/l (120 oz/gal) should be added. It is preferable, however, to regularly add a solution of the *Activator Salts* at the rate of 13.3 ml per kAh (0.47 fl. oz per 1000 ampere hours). The solution should be analysed periodically. The
solution is made up at 37.5 g/1 (6 oz/gal) of Activator Salts, but during use, the concentration rapidly falls to about 12.5 g/1 (2 oz/gal) and should be maintained at this value.

Brytal Process
For the electro-polishing of mechanically polished aluminium, the Brytal process is perhaps the best known. It is suitable for super purity or 99.8 per cent aluminium and also for super purity aluminium based magnesium alloys. The components are made anodic in a solution consisting of:

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium carbonate</td>
<td>150 g/l</td>
</tr>
<tr>
<td>Tri-sodium phosphate (crystalline)</td>
<td>115 g/l</td>
</tr>
</tbody>
</table>

In the initial preparation of the solution 80 to 95 g/1 (13 to 15 oz/gal) of tri-sodium phosphate are added, and the remaining quantity necessary to bring the solution up to the specified concentration added as the solution ages.

Equipment
For the Brytal solution, a mild steel tank, preferably lagged, is employed. This is fitted with heating, air agitation and fume extraction. The air agitation is provided as a means of equalising the solution temperature between loads and is not used during the actual polishing process. To prevent the hydrogen evolved by the cathode plates from producing local agitation of the solution in the vicinity of the components being polished, baffle plates are provided in front of the cathodes.

Operating Conditions
- **Anodic Current Density.** 5 to 10 amp/dm² (45 to 90 amp/ft²) dependent on alloy used. After 2 minutes current density falls to half this value.
- **Voltage.** Maintain at 12 to 15 volts.
- **Temperature.** 85 to 90°C (185 to 195°F).
- **Time.** 5 to 20 minutes.

Desmutting
After polishing, the components are well rinsed and then desmutted in a solution containing:

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromic acid</td>
<td>25 g/l</td>
</tr>
<tr>
<td>Phosphoric acid, sp. gr. 1.7 (Technical)</td>
<td>-40 ml/lÂ° Â Â Â Â 6 fl oz/gal</td>
</tr>
</tbody>
</table>

This solution is contained in a stainless steel tank and the components are treated for up to 5 minutes at a temperature of 80°C (180°F), and then, after further rinsing, transferred to the sulphuric acid anodising solution.

An insulated rod should be provided for the desmutting tank so that the components may be suspended away from the tank sides. It is essential that there be no electrical connection between the aluminium components and the stainless steel tank, otherwise etching of the aluminium may result.

Stainless Steels
Stainless steels and irons are electro-polished on a considerable scale. The process is particularly attractive in view of the high costs of mechanically finishing these alloys. Components treated range in size from kitchen sink units to small surgical needles, typical examples are windscreen wipers, wire work, automobile and cooker trim and surgical instruments.

Canning Stainless Steel Electro-polishing Solution
Solution Composition
The electro-polishing solution is supplied in a prepared form ready for use.
Equipment
For this solution a tank lined with chemical lead is employed. The tank should be fitted with fume extraction and mechanical anode rod movement provided. The provision of mild air agitation is necessary in order to provide solution movement during processing and to prevent layering. To prevent water being carried into the solution with the low pressure air, a separator unit should be fitted into the air line. For solution heating silica cased immersion heaters may be used, alternatively a hot water jacket may be provided. For cathodes, lead or copper strips 150 to 200 mm (6 to 8 in) wide are used. The cathodes should be of sufficient area to give a cathode current density of 5 to 8 amp/dm² (50 to 75 amp/ft²). The cathodes will require periodic brushing to remove the scale formed upon the surface.

Jigs
The use of titanium jigs is advised. Alternatively copper or brass jigs with bronze contacts may be used but these will only have a limited life. The jigs should be of adequate size in order to carry the high currents employed. The work should be angled at 20 to 45° to the direction of work rod movement, with good spacing.

Operating Conditions

<table>
<thead>
<tr>
<th>Anodic Current Density</th>
<th>16 to 45 amp/dm² (150 to 400 amp/ft²) dependent on alloy used and shape of article.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>6 to 15 volts dependent upon the size of the load, the current density applied, the anode/ cathode distance and ratio of the surface areas of the anode and cathode.</td>
</tr>
<tr>
<td>Temperature</td>
<td>60 to 90°C (140 to 195°F).</td>
</tr>
<tr>
<td>Time</td>
<td>4 to 10 minutes. To ensure maximum solution life the processing times should be kept as short as possible.</td>
</tr>
</tbody>
</table>

Process Sequence
The following sequence is advised:
1. Cleaning. Solvent degrease in a solvent degreaser or, alternatively, hot clean in Activax soak or Anodax anodic cleaner, depending upon the surface condition. Where solvent degreasing is employed, it is advisable to follow with hot alkaline cleaning.
2. Swill
1. If aqueous cleaning is employed.
2. Hot swill and dry.
3. Electro-polish for 4 to 10 minutes.
4. Swill.
5. Swill.
6. Passivate in a 5 per cent volume sulphuric acid-1 per cent sodium dichromate solution at room temperature, or in a 20 per cent volume nitric acid at 50°C (120°F) for a few minutes.
7. Swill.
8. Swill.
9. Hot water and dry.

Solution Maintenance
The solution is controlled by adjustment of the density and the iron content.

Density
As supplied the Canning Stainless Steel Electro-polishing Solution will having a density of approximately sp gr. 1.75 at 15°C (62°F). In use, the density of the solution should be maintained within the following
<table>
<thead>
<tr>
<th>limits:</th>
<th>15°C (60°F)</th>
<th>90°C (195°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density Minimum value</td>
<td>sp. gr. 1.70</td>
<td>sp. gr. 1.64</td>
</tr>
<tr>
<td>Å</td>
<td>60° Be</td>
<td>57° Be</td>
</tr>
<tr>
<td>Density Maximum value</td>
<td>sp. gr. 1.81</td>
<td>sp. gr. 1.75</td>
</tr>
<tr>
<td>Å</td>
<td>65° Be</td>
<td>62° Be</td>
</tr>
</tbody>
</table>

In use, the density of solution will normally rise. If, however, the density of the solution tends to fall, this will be due to excess carry-over of water on the work or absorption of moisture from the atmosphere. Articles should be dried before being immersed in the electro-polishing solution and the tank should be covered when not in use. Excess water may be driven off the solution by heating the solution to 95 to 105°C (200 to 220°F) for a period.

**Iron Content**

The degree of brightness will tend to fall when the iron content reaches 60 g/l (10 oz/gal) and the iron content should normally be kept below 50 g/l (8 oz/gal) by drag-out or the removal of a small proportion of the solution. As a guide, the use of the solution to the extent of four ampere hours per litre will increase the iron content by about 1 g/l. (114 ampere hours per gallon use will raise iron content by 1 oz/gal.)

Most of the nickel and some of the iron dissolved from the processed components will precipitate as a sludge. It will, therefore, be necessary for the tank to be emptied occasionally and the sludge removed.

**Copper, Brass and Nickel Silver**

The fancy goods trades electro-polish non-ferrous materials and typical uses include jewellery, cuff links, tie clips, compacts, brush backs, and engine-turned work. Many decorative items produced in copper and brass are of complex shape and do not lend themselves to mechanical polishing so electro-polishing is particularly valuable.

To obtain a mirror finish articles should, preferably, be made from special electro-polishing quality materials having a grain size of 0.015 to 0.25 mm.

High annealing temperatures or prolonged heat treatment should be avoided. Any surface imperfections or machining marks should be removed by finishing or polishing, and the metal surface should be protected from damage at all stages of manufacture.

On free cutting brasses, which contain lead, it is not possible to obtain a high lustre.

**Canning Non-Ferrous Electro-polishing Solution**

**Solution Composition**

The electro-polishing solution and the special solution rinse are supplied in prepared form ready for use.

**Equipment**

For this process a rubber lined tank is employed provided with moving anode gear and a cooling coil. As the solution is used at room temperature no heating is required. Fume extraction is not generally necessary, provided that the shop is reasonably well ventilated.

**Cathode Plates**

Copper sheet or brass cathodes are employed. Copper is deposited onto the cathode plates in the form of a powder, and to keep the plates clean they should be removed and cleaned once per day.

**Jigs**

Work may be carried on copper wires, or, alternatively, jigs may be used with stainless steel or titanium contacts. Care should be taken to avoid shadowing one article with another, and jigs should preferably be insulated with Ohmax Insulating Compound.
Operating Conditions

<table>
<thead>
<tr>
<th>Anodic Current Density</th>
<th>5 to 10 amp/dm² (45 to 90 amp/ft²).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>4 to 7 with copper and brass, higher voltages will be needed with nickel silver.</td>
</tr>
<tr>
<td>Temperature</td>
<td>15 to 25°C (60 to 75°F). Do not allow to rise above 30°C (85°F).</td>
</tr>
<tr>
<td>Time</td>
<td>5 to 15 minutes.</td>
</tr>
</tbody>
</table>

Process Sequence

The following sequence is advised:

1. Cleaning. Articles may be degreased in a solvent degreaser and then transferred directly to the electro-polishing solution; it is however preferable to employ hot alkaline cleaning as described below, preceded if necessary by solvent degreasing.
   1.a. Hot clean in Activax Cleaner or Zonax Metal Cleaner.
   1.b. Water swill.
   1.c. Pickle, if necessary on unpolished work to remove scale or discoloration, using hot 10 per cent sulphuric acid or *aqua-fortis bright dipping acid*. Over-pickling should be avoided.
   1.d. Water swill thoroughly.
   1.e. Hot swill and dry.
   1.f. Work must be clean and dry before it is immersed in the electro-polishing solution.

2. Electro-polish 5 to 15 minutes. Then drain for 20 seconds.

3. Immerse in special drag-out rinse solution (*Canning Non-ferrous Electro-polishing Solution Rinse*). This special rinse rapidly removes the viscous electro-polishing solution from the surface of the treated parts. This swill is used to top up the electro-polishing solution and thus, minimise loss of solution through drag-out.


5a. Where electro-polished articles are to be plated they should be cathodically cleaned in Activax Cleaner or Klenewell Cleaner (pages 302 and 336), well rinsed, dipped in 10 per cent dilute sulphuric acid, and then again well rinsed before being put into the plating tank.

5b. To prevent the tarnishing of components which are not subsequently plated, it is advisable that, after electro-polishing, they be immersed for one to two minutes in a solution of potassium or sodium bi-chromate (25 g/1â€”4 oz/gal), well rinsed and dried out.

5c. After immersion in the neutralising solution the articles should be well rinsed in water and then dried, using a centrifugal dryer, or hot air.

Solution Maintenance

As supplied, the electro-polishing solution will have a density of approximately sp. gr. 1.30 (33° Be). In operation, the density of the solution will rise to sp. gr. 1.39 (40° Be) and should then be maintained between sp. gr. 1.39 and 1.42 (40° and 43° Be) by the addition of solution from the drag-out rinse tank or by the additions of electro-polishing solution. To ensure thorough mixing, the solution should be stirred using a plastic stirrer, taking care not to disturb unduly any sludge on the bottom of the tank. When not in use the tank should be kept covered to prevent absorption of water or evaporation of the solution.

Providing the density is maintained, as described above, no further control of the solution is generally necessary.
Chemical Polishing of Aluminium

Chemical polishing provides an alternative to electrolytic polishing for the treatment of a wide range of articles made from low silicon alloy or pure aluminium. After polishing the articles may be anodised in order to provide protection against corrosion. A further important application is in connection with the anodising of large flat surfaces which have been mechanically polished. By the use of a preliminary chemical polishing stage, the possibility of a patchy appearance being obtained on subsequent anodising is avoided. For this application a phosphoric acid/nitric acid based solution is available.

The equipment required consists of a molybdenum stabilised stainless steel tank E.N.58J grade (e.g. Firth Vickers FMB) fitted with fume extraction using a PVC lip and hood system extending over the chemical brightening tank and also the adjacent water swill. A drip tray is provided between the tanks, and to treat the acid fumes evolved it is usually necessary to fit a scrubbing unit into the exhaust system. For solution heating either a stainless steel steam coil or silica cased immersion heaters fitted with PVC caps may be used.

Typical Operating Conditions

A typical chemical brightening solution for aluminium is used at a temperature of 95 to 105°C (203 to 220°F) and the required immersion time is from ½ to 3 min., depending upon the initial condition of the articles, the quality of surface finish required and the age of the brightening solution. Whilst being treated in the brightening solution, it is advantageous to agitate the work mechanically.

Procedure

1. Solvent degrease.
2. Alternatively hot clean in Minco aluminium cleaner for 2 to 3 minutes at 70 to 75°C (160 to 170°F). Water swill and drain.
3. Chemically brighten.
5. Desmut in 50 per cent by volume nitric acid solution, immersing for ½ to 1½ minutes at room temperature.
6. Swill.
7. Dry or transfer to anodising line.

Electroforming

Electroforming is a technique which is used to produce actual components by electroplating, using the same basic equipment and practices as in conventional decorative deposition. In its simplest form, a mandrel or former is electro-plated with a substantial layer of metal and when the mandrel is removed, the electrodeposit is left as a self-supporting component in its own right.

In conventional decorative electroplating, the deposit protects the basis metal from corrosion and gives it an attractive appearance; it must have good adhesion and is rarely plated over 25 microns (0.001 in) thick. In electroforming, however, the deposit must have low adhesion to the mandrel to ensure that the component can be removed, and the deposit can be plated to any thickness as necessary. While a good surface appearance is necessary for electroforms whose outer surface is significant, e.g. a kettle spout, and for items like foils which are plated with a thin cross section, for thick electroforms, such as are used for moulds and dies or waveguides where the inner surface is significant, the appearance of the deposit is not important.

Electroforming has many advantages, not the least of which is the ability to make components which would be difficult or in some cases impossible to produce using other methods of fabrication. Other advantages are as follows:

1. The whole manufacturing process can be simplified. A number of individual parts which would have to be cut, blanked, drilled, machined, deburred and then welded or fastened together before being finally assembled and polished, may be made at once by electroforming.
finished, could be electroformed in one single stage and then a minimum of finishing carried out.

(2) Because the electroform faithfully reproduces the surface detail, finish and shape of the mandrel, products of high dimensional accuracy, or precise surface textures such as graining or high polishes can be obtained without any other finishing.

(3) By employing re-usable mandrels, many identical items can be made for mass production with no loss of accuracy, e.g. gramophone records.

(4) The capital cost of equipment needed for electroforming is minimal.

Applications of Electroforming
There are three main areas of electroforming:

- Screens and meshes.
- Dies, moulds and press tools.
- Components.

Screens and meshes are a very important and unique application for electroforming and they are employed in many ways. Typical examples are: foils for electric razors, meshes for battery separators, filter screens for the food processing trade, seamless belts and perforated bands in widths up to 1200 mm (47 in) and in lengths of several metres.

Electroformed screens are used in many industries to print patterns, colours and images onto items as varied as fabrics, wallpapers, posters and packaging. While most of these screens are plain, there is an increasing use of screens which have the pattern already electroformed into them; these screens can be very large and are used, for example, for the mass production printing of carpets.

Another example which can be included in this list is the production of electroformed foil in nickel, copper, iron and other metals plated onto stainless steel rolls and peeled off in a continuous sheet. Millions of square metres of copper foil are produced every year for the printed circuit industry alone.

Electroformed moulds, dies and press tools are used to produce many different products, ranging from glassware, zinc based die castings and rubber products which subject the electroforms to extremes of heat and pressure, to blow moulds and rotational slush moulds for plastics where severe chemical corrosion can be a problem.

The manufacture of gramophone records is a major industry which uses electroformed dies as press tools, and the process for producing these is considered in detail as it illustrates many typical practices in electroforming. Digital sound and video disks also require electroformed masters.

Electroforming is suitable for mould and die making where the following requirements must be met:

- Extremely accurate reproduction.
- High wear resistance.
- Resistance to corrosive gases.
- Good heat conductivity.
- Precise parting lines.

It is easier to produce a positive mandrel than sink a die impression.

The final category is a very general one and covers all those hundreds of individual applications where electroforming has solved problems in fabrication or production. Examples include mirrors for precise optical instruments, bursting discs for pipeline pressure protection, Venturis for rocket motors, heat exchangers for the chemical industry, wave guides and tuning cavities for radar and lasers, flexible, seamless bellows of all sizes and many other devices. Large and heavy items can have delicate items electroformed on or separate fabrications can be joined by electroforming as an alternative to welding.

Electroforming should always be considered whenever there is a component problem to be solved or when existing methods of fabrication are complex, long or difficult.

Materials for Electroforming
Relatively, few metals are electroformed commercially but of these the most widely used is nickel. Nickel is strong, resistant to corrosive attack, erosion and abrasion; the mechanical properties such as hardness, stress and ductility may be easily varied and the nickel plating process itself is well understood and is simple to control.

Alloys of nickel and cobalt are also used extensively for electroforming moulds and dies. These materials have a great resistance to heat combined with substantial hardness.

Copper is also used as an electroforming material but is generally only employed for electronic parts, such as waveguides which need a higher conductivity than nickel can provide. Copper is more often used as a backing material to a thin nickel electroform, where the nickel forms the hard working surface of the electroform and the copper gives bulk and rigidity.

Other metals are occasionally used for electroforming purposes. An example of these small scale uses are in the production of gold and silver electroforms for use in sophisticated laboratory apparatus, in the aerospace industry and for the production of jewellery components.

**Nickel Solution**

There are three types of nickel plating solutions used for electroforming:

- The Watts solution.
- The Sulphamate solution.
- The Ni-speed solution, an ultra concentrated sulphamate solution.

**The Watts Solution**

This solution, based upon nickel sulphate and nickel chloride was the first successful commercial nickel plating solution and is still the basis of nearly all decorative bright and semi-bright nickel solutions however, it can only be used for certain non-critical electroforming applications because it has some limitations. The deposit as plated from the Watts solution is dull and highly stressed. Stress causes thin electroforms to distort, especially if they are to be used in situations where heat is applied to them. Ideally, the deposit stress should be zero. To achieve this in a Watts deposit, the solution needs to have a stress reducing agent added which is normally a sulphur containing organic compound. This compound not only breaks down to give products which further increase stress but also the problem of maintaining the concentration of the stress reducer at exactly the right amount during the long plating times used in electroforming, is very difficult.

Sulphur from the stress relieving agents is incorporated into the deposit which causes embrittlement on exposure to temperatures greater than 200Â° C (400Â° F); with solutions contaminated with breakdown products, embrittlement can occur at room temperature.

**Deposit stress in three nickel plating solutions :**

A: Watts solution.
B: Conventional sulphamate solution.
C: Ni-speed solution.

The Watts solution when operated at 60Â° C (140Â° F) and a pH of 4.0, depending on the current density will give a deposit hardness of 140-160 H.V., a tensile strength of 380 - 450 N/mm² (25 to 29 tonf/in²), an elongation in 50 mm, of 20-30% and a tensile stress of 157 to 265 N/mm² (22 to 38 103 lbf/in²).

**The Sulphamate Solution**

The conventional nickel sulphamate bath, is a very versatile solution which can be made to give zero stress when worked at lower temperatures and current densities but when worked normally to give a reasonable depositing time, the deposit has a tensile stress. This is well below that given by a Watts bath. Nickel sulphamate solutions can have low concentrations of stress reducer added which ultimately lead to the same sort of problems as with a Watts solution but generally give a low stress for much longer before
Corrective treatment is necessary. The hardness of the deposit can be varied between 150 H.V. for the simplest solution to 450 H.V. for solutions with chloride and special addition agents. These organic additions can be removed by appropriate purification treatment.

The conventional nickel sulphamate solution when operated at 60Â°C (140Â°F) and a pH of 4.0, depending on the current density will give a deposit hardness of 140 to 250 H.V., a tensile strength of 415 to 760 N/mm2 (27 to 49 tonf/in2), an elongation in 50 mm of 5 to 30% and a tensile stress from zero to 118 N/mm2 (0 to 17 103 lbf/in2).

The Ni-speed Solution

The Ni-speed process developed by Inco Europe Limited uses nickel sulphamate solution with no organic or other additions, at a concentration of 600 to 650 g/l, with the advantage that the stress in the deposit can be varied by changing the relationship of temperature and current density. Ni-speed is also capable of being worked at very high current densities.

Zero-stress conditions for the Ni-speed process

<table>
<thead>
<tr>
<th>Temperature Co</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current density amp/dm2</td>
<td>1.1</td>
<td>2.7</td>
<td>4.3</td>
<td>8.1</td>
<td>13.5</td>
<td>17.8</td>
<td>21.6</td>
<td>32</td>
</tr>
<tr>
<td>Plating rate (approx) mm/h</td>
<td>12</td>
<td>31</td>
<td>50</td>
<td>94</td>
<td>156</td>
<td>206</td>
<td>250</td>
<td>375</td>
</tr>
</tbody>
</table>

The hardness of the deposit is about 220 H.V. except at current densities below 1 amp/dm2 (10 amp/ft2), as shown in the graph. By working in this way, an electroform can have a hard working surface deposited to start with and this can be backed up at high speed with a softer nickel deposit.

The voltage of the power supply will depend on the maximum current density to be employed with the Ni-speed solution.

- Up to 16 amp/dm2 (150 amp/ft2) | 12 volt supply
- 16 to 43 amp/dm2 (150 to 400 amp/ft2) | 30 volt supply
- 43 to 86 amp/dm2 (400 to 800 amp/ft2) | 60 volt supply

The highest current densities can only be used on suitable cathode (mandrel) shapes; i.e. cylinders.

The Ni-speed solution operated at 60Â°C (140Â°F) and a pH of 4.0, will give it deposit hardness of 220 H.V., a tensile strength of 860 N/mm2 (56 tonf/in2), an elongation in 50 mm of 10%, and depending on the current density a stress from 108 N/mm2 (16 Å- 103 lbf/in2) compressive to 167 N/mm2 (24 Å- 103 lbf/in2) tensile.

Nickel/Cobalt Alloy Solutions

When cobalt sulphamate is used as an inorganic addition agent to the Ni-speed nickel sulphamate solution the hardness of the deposit can be increased to about 520 H.V., without the problems that organic hardeners bring. After heat treatment between 200 and 600Â°C, there is considerable improvement in the hardness at room temperature and at elevated temperatures over those of unalloyed nickel which makes cobalt/nickel deposits ideal for electroformed dies and moulds. As the amount of theoretical and practical knowledge of nickel/cobalt alloys increases in the trade, the use of these solutions will become increasingly important in the production of electroforms. Increasing the concentration of cobalt in the solution increases the cobalt content of the deposit, but at a decreasing rate, and at any given cobalt concentration in solution, increasing the cathode current density will reduce the cobalt content of the deposit. With lower levels of cobalt in solution, an increase in current density will reduce the deposit hardness rapidly but at high levels
of cobalt concentration, this change in hardness with current density is slight. The displacement of the two shown in this graph is constant for a current density of 5.4 amp/dm2 (50 amp/ft²). At higher current densities this relationship will change. The stress rises with increasing cobalt concentration and with the current density so that deposits with the highest values of hardness cannot be used for electroforming, but nickel cobalt alloys can still be deposited with zero stress by choosing the correct operating parameters. When plated at high current densities, the deposit has a tensile stress but this is lower than that given by a Watts solution.

Plating conditions at 60°C to give zero-stress deposits in cobalt-containing Ni-Speed solutions

<table>
<thead>
<tr>
<th>Cobalt concentration in solution g/l</th>
<th>Current density amp/dm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75</td>
<td>10</td>
</tr>
<tr>
<td>1.0</td>
<td>7.5</td>
</tr>
<tr>
<td>1.25</td>
<td>5.1</td>
</tr>
<tr>
<td>1.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Copper Plating Solution

Copper electroforming can be carried out by using Cuprax, Cuprasol Mk. 2, Super Pyrobrite or Copper Fluoboratesolution. The main advantage of using a cyanide copper such as Cupraxis is that it has very good throwing power which enables excellent coverage of intricate shapes. When plated using periodic reversing equipment rates of deposition of up to 100 mm per hour can be obtained.

Cuprasol Mk. 2 can be used to obtain a controlled hardness of deposit as explained. Copper pyrophosphate solutions can be used for electroforming using the special additive PY60. Copper fluoroborate solutions can be operated at very high current densities and no addition agents are required.

**Throwing power**

Under ideal conditions, the metal from the anodes in solution would transfer to the cathode so that every part of it received a deposit of identical thickness. In reality this does not occur and surfaces nearer the anodes, or with sharp edges or protuberances will take more current. Inevitably, this means that the recessed areas receive a thinner deposit than the prominent areas. The shape and size of the cathode and anodes and the positioning of the anode and cathode within the plating bath play a large part in determining the metal distribution. This is often considerably modified by the electrochemical characteristics of the solution, one of which is called “throwing power”. Throwing power is a measure of the extent to which a solution will produce deposits that are more uniform than those which would be produced in the absence of any effects, which reduce high current densities, such as polarisation and cathode efficiency.

Nickel solutions have throwing powers which vary with their average current density and throwing power is improved by using a low average current density. However, a reduction in current density causes an increase in electroforming time. Cyanide copper solutions have a very good throwing power and for this reason one electroforming technique is to plate an initial layer of nickel at a low current density followed by copper at a much higher current density. By so doing, an almost equal thickness of metal can be obtained in both recessed and prominent areas. Where an all nickel deposit is needed on a complex electroform, a sodium high sulphate solution should be considered instead of the copper. This dilute nickel solution has
very high throwing power but produces a highly stressed deposit therefore the use of a stress reducer is almost always required.

### Sodium High-Sulphate Nickel Solution

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel sulphate</td>
<td>30 g/l</td>
</tr>
<tr>
<td>Nickel chloride</td>
<td>38 g/l</td>
</tr>
<tr>
<td>Boric acid</td>
<td>25 g/l</td>
</tr>
<tr>
<td>Anhydrous sodium sulphate</td>
<td>180 g/l</td>
</tr>
</tbody>
</table>

Current density 0.2 to 4.3 amp/dm² (2 to 40 amp/ft²).

The maximum current density which can be safely used in any nickel or copper solution depends on the shape of the mandrel and in practice, deep recesses and high peaks on mandrels should be avoided. *Ni-speed* can be used at a higher average current density than ordinary sulphamate or Watts solutions.

### Operating Techniques

The equipment and maintenance of electroforming solutions is discussed in detail in each of the appropriate chapters for those solutions, however, there are some general points, which should be made. Sulphamate solutions should be continually "conditioned" by low current density plating out using non-activated nickel anodes at a controlled current density, "Purification Stage 6". Also, before using a sulphamate or *Ni-speed* solution, it must be purified, "solution preparation". Continuous filtration is very important.

To avoid heavy overplating on prominent areas while achieving adequate deposits in recesses, use the following techniques:

1. Shaped auxiliary anodes.
2. Radiused corners and avoidance of deep recesses.
3. Plastic shields over high current density areas.
4. Conforming anodes.

Current interruption can cause lamination, so, either a battery must be provided for emergency power, even if at a lower current density or a cut-out should be fitted which will prevent deposition when the current is restored. Under such circumstances, the electroform can be removed and reactivated in the following way:

1. Degrease in Activaxsoak cleaner.
2. Rinse.
3. Anodic etch in Watts nickel plating solution at pH 2.0 and 60°C for 15-20 minutes.
4. Rinse quickly.
5. Recomence electroforming making connection before immersion.

Because of the long periods of time usually involved in plating electro-forms, it is wise to use automatic volume level control. Always make-up with distilled or deionised water.

### Mandrels for Electroforms

The choice of preparation of the mandrel is very important to the success of the electroforming process. The dimensional accuracy and the surface finish of the final components are only as good as those on the mandrel that is used.

A wide variety of materials can be employed for mandrels or formers on which the electro-deposited coating is applied. These can be considered in two groups:

1. Permanent mandrels.
2. Expendable mandrels.

Permanent mandrels can be employed where the shape is such that the electroform can be removed after electro-deposition, i.e., there are no re-entrant angles; their main application is for long production runs.
Materials which can be employed are:
Stainless steel.
Mild steel.
Copper and Brass.
Electroformed Nickel.
Rigid plastics e.g. Epoxy Resin.
Collapsible plastics e.g. PVC.

Expendable formers or mandrels are used where the shape of the product is such that the formers cannot be removed mechanically from the electroform, i.e. re-entrant angles are present. These re-entrant angles mean that it is necessary to use a mandrel which can be removed by either being collapsed into the electroform or destroyed either by melting or by dissolving chemically. Materials which can be employed are:
Aluminium.
Zinc and its alloys.
Fusible alloys.
Plastics.
Wax.

Permanent Mandrels

Stainless steel
This material is probably the best for permanent mandrels. It can be machined to close tolerances and given a highly polished finish. It is hard and resistant to accidental damage. Chemically, it forms a passive film which is inert and prevents adhesion between the mandrel and the electroform thus assisting in the process of separation after plating has finished. These mandrels are also very easy to keep clean as any residual nickel can easily be dissolved by immersion in concentrated nitric acid with 1% by volume sulphuric acid added.

Preparation
After degreasing, the surface should be scrubbed with magnesium oxide on a cotton pad. The mandrel may then be passivated by immersion in a 2% solution of sodium dichromate for 30 to 60 seconds at room temperature, followed by thorough swilling.

Mild Steel
Ordinary mild steel is cheap, easily machined and can be given a high polish. However, because it is a reactive metal, it is necessary to deposit first a thin adherent nickel coating and then apply the dichromate treatment described in the previous paragraph.

Copper and Brass
These non-ferrous materials are generally cheaper than stainless steel and can take a high polish. When intricately engraved or textured surfaces are required, these materials are preferable because of the ease with which they can be worked. Precautions should be taken, however, to protect mandrels from corrosion and physical damage.

Preparation
Where very close dimensional tolerances are necessary, the mandrel is treated in a solution of 8 g/l sodium sulphide which produces a passive copper sulphide film on its surface; it can then be electroformed directly. Care must be taken to get the film neither so thin as to permit adhesion of the electroform nor so thick as to cause premature peeling.

For non-critical work, a thin deposit of nickel or chromium will prevent corrosive attack on the mandrel and possible contamination of the process solutions.
Electroformed Nickel
Electroformed nickel can be used as a master mandrel for the production of further electroforms. This method can be less expensive than others when multiple mandrels are required, for an example of this method in practice.

Preparation
The nickel electroform needs a simple passivation treatment before plating. under à€œStainless Steelà€.

Rigid Plastic
Plastics such as Perspex (poly methylmethacrylate) can be easily machined and polished and can be readily metallised. The material has a tendency to craze in hot acid solutions however, so the life of a Perspex mandrel is very limited.

Epoxi resin is a frequently used permanent mandrel material as it does not suffer from the defect of crazing. The material cannot be produced with such close dimensional tolerances or such a high finish as metal but it is very cheap and is valuable when a à€œnegativeà€™ master cavity is available.

The resin itself must be of a low viscosity type so that fine surface detail is reproduced accurately, it must have minimal shrinkage when cured and must resist both the attack and the temperature of the chemicals in the electroforming solutions.

When the resin is mixed with the hardeners and fillers and poured into the mould, it must first be de-gassed under vacuum for about 30 mins to remove air bubbles. The mandrel can have stiffeners cast into it to act as carriers for any bolts or fittings to be used later for jigging and it may be necessary to treat the master mould with a wax polish to assist removal of the epoxy mandrel.

Collapsible Plastics
For electroformed moulds with re-entrant angles, a deformable but semi-Á–permanent mandrel material is PVC which accurately regains its true shape after removal from the electroform which has been deposited round it. The best types of PVC are the flexible plasticised grades which cure to solid on heating. These should have an as cured hardness of 75 Shore.

Preparation
The à€œMaster-mouldà€™ should be filled with the liquid plastisol, vacuum de-Á–gassed and then heated in an oven at 120° C, (250° F) for 5 to 10 minutes. A skin of hardened plastisol will now be formed progressing from the mould wall. After this initial gelling stage, the mould is removed from the oven and the still liquid centre poured out. The mould is then returned to the oven to complete the cure for about 15 to 30 minutes. On cooling the hollow PVC mandrel can be pulled from the mould and after metallising, can be electroplated.

The PVC is rigid at the temperature of the electroforming solution but becomes flexible and easily removed when immersed in boiling water. After many cycles, the mandrel may become permanently deformed and must be replaced by a new mandrel.

Expendable Mandrels
Aluminium
Aluminium or one of its alloys will machine well and can be finished to a high polish. When a mandrel in this material has been electroformed, the aluminium can be readily dissolved in 10% sodium hydroxide solution at room temperature. The nickel is not attacked under these conditions. For aluminium alloys containing copper the following solution should be used at room temperature.

<table>
<thead>
<tr>
<th></th>
<th>30 g/l</th>
<th>5 oz/gal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Hydroxide</td>
<td>0.5 g/l</td>
<td>0.08 oz/gal</td>
</tr>
<tr>
<td>Sodium Tartrate</td>
<td>0.2 g/l</td>
<td>0.03 oz/gal</td>
</tr>
<tr>
<td>EDTA sodium salt</td>
<td>1 g/l</td>
<td>1.16 oz/gal</td>
</tr>
</tbody>
</table>
Preparation
If the electroform is to be plated under zero stress conditions, the aluminium mandrel is prepared with a conventional degrease and cathodic clean in Minco, followed by 2 minutes in a 50% nitric acid solution at room temperature. The naturally occurring oxide film on the aluminium will prevent adhesion of the electroformed deposit.

If the deposit is to be produced in a stressed state, i.e. greater than 35 N/mm² (5 - 103 lbf/in²) either tensile or compressive, then to prevent the deposit from premature peeling, the Bondal process should be used to give some adhesion. There will however be some slight surface degradation of the aluminium which will reproduce on the electroform, therefore it should not be used where critical dimensional accuracy is necessary.

Zinc alloys
The latest range of alloys are the â€œsuper plasticâ€ alloys which have the ability to be blow moulded into complex shapes at about 250Â°C (482Â°F) in a similar way to plastics. This means that mandrels can be produced with all the advantages of solid metal mandrels but without the expensive machining and with very thin wall sections. Not only does this reduce the time taken to dissolve the metal from the electroform, but also takes less metal to produce the mandrel. This material can be dissolved out with 10% hydrochloric acid without the nickel being attacked.

Preparation
Zinc and its alloys must first be cleaned and then coated with a thin flash of copper deposited from a Cupraxbath or Rochelle solution, before placing in the electroforming bath.

Fusible alloys
Fusible alloys are low melting point metals which can easily be cast into master moulds and after electroforming onto them they can be melted out in hot oil or boiling water. However, many of the common alloys, for example Woods Metal, contain bismuth which can cause grain boundary embitterment of copper and nickel electroforms if not completely removed from the surface of the electroform. To ensure effective removal and separation, it is useful to coat the mandrel surface with colloidal graphite before plating. As an alternative, a patented bismuth free alloy has been disclosed with a melting point of about 250Â°C which is sufficiently low to avoid distortion of the electroform providing it has been deposited with a low to zero stress.

Plastics
Plastics such as ABS or PVC can be used as mandrels and dissolved out with a suitable solvent. PVC can be silver sprayed and ABS can be prepared using conventional plating on plastics techniques.

Wax
Wax is a useful and unique mandrel material since it can be melted out of the electroform at low temperatures and used over and over again. The correct wax must be chosen, however, since many types shrink or crack on cooling or melt at the temperature of the electroforming bath; some cannot be sprayed with silver, their surface is so hydrophobic and so they must be treated with powdered graphite. Beeswax is very successful and certain proprietary wax mixtures are available, one of which is graphite loaded and conducting.

Other Materials
Actual objects such as wood, plaster, leather or cloth can be used as mandrel materials when it is required to reproduce their surface textures. These and other materials are porous and must be sealed with wax or lacquers before they can be made conductive by means of the silver spray or other suitable method. This sealing coat should be as thin as possible to avoid altering the dimensions of the article.
A better alternative is to take a copy of the surface in PVC and then electroform from the PVC copy.

Cadmium Plating
Properties of Cadmium
Cadmium is a silver white metal with excellent corrosion resistance in marine conditions. The metal is harder than tin but may be cut with a knife; it is very ductile and can be easily rolled into a foil or drawn into a wire. The metal is electro-positive to iron and has a very low contact potential with aluminium. The melting point is about 320Â°C (610Â°F) and at this temperature it gives off highly toxic fumes of cadmium metal vapour and cadmium oxide. Ingested cadmium salts are also poisonous.
Cadmium is usually deposited in the matt condition when intended purely for protection but can be electro-plated fully bright where an attractive appearance and corrosion resistance is required. Where the metal is to be passivated after plating, the bright finish is often preferred. The deposit may be polished or scratch-brushed providing that precautions are taken to avoid over-heating the metal.

Applications and Corrosion Resistance
Electro-plated cadmium affords excellent protection to iron and steel as under corrosive conditions, the coating is electrolytically sacrificed to protect the underlying ferrous metal. In many applications however, cadmium is now being replaced by zinc because electro-plated zinc has a much lower basic cost than cadmium. The standards of finish and corrosion resistance of zinc are now equal to, if not better than, those obtainable with cadmium plating.
Zinc has a greater resistance to the acidic atmosphere of industrial and urban conditions than cadmium because it develops a protective film of basic zinc sulphate, whereas cadmium continues to dissolve; where marine or tropical conditions are encountered however, cadmium forms a basic chloride on the surface, which prevents further attack, whereas zinc would continue to corrode away. For this reason cadmium is widely used as a corrosion resistant finish for Service and sea going equipment. The resistance of both cadmium and zinc to corrosive conditions is appreciably increased by the use of post-plating passivation processes.
Cadmium is unaffected by alkalis and can consequently be used in situations where zinc would be attacked, such as in machinery which comes into contact with soaps, lyes, washing powders and industrial and domestic cleaners.
Electro-plated cadmium is used in the electrical and aircraft industries because of its low contact potential difference in relation to aluminium. For example, where it is deposited on steel fittings or fasteners in contact with the aluminium frame or skin of an aircraft, then the possibility of electro-lytic corrosion at the point of contact is greatly reduced.
Cadmium cannot be electro-plated onto articles which come into contact with foodstuffs or drinking water because of its toxic nature. For this reason also, it should not be applied to articles which may be subjected to temperatures in excess of 250Â°C, (482Â°F).

Cadmium Deposits on Non Ferrous Metals
Cadmium is not generally applied to copper or copper alloys, but where this is necessary, an initial deposit of nickel (1.25 to 2.5 micronsâ€“0.000 05 to 0.000 1 in) should be applied before cadmium plating.
For the cadmium plating of aluminium, the Bondal process may be employed or alternatively a special ammoniacal cadmium cyanide solution may be usedâ€“details of this solution are available upon request.

Passivation Processes
In order to prevent surface discolouration and to improve the corrosion resistance, it is usual to passivate cadmium deposits or to treat in chromic acid solution or Kadip bright dip.
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