Energy Conservation in Hard Chromium Plating

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A previous study by the Department of Energy of 20 metal finishing facilities of various sizes found that electrical energy consumption ranged from 3.03 X 10^5 kw-hr/yr to 1.31 X 10^7 kw-hr/yr, with an average of 2.65 X 10^6 kw-hr/yr. Energy consumption for process and space heating ranged from 1. 04 X 10^9 Btu/yr to 4.69 X 10^{11} Btu/yr, with an average of 5.38 X 10^{10} Btu/yr. While the study was done in 1979, it is believed the energy usage patterns for a plating facility have not changed. The study concluded that the major sources of electrical energy consumption in the average metal finishing facility are ventilation systems, rectifiers, energy conduits (bus and cables), process heating, space heating, lighting, motors, boiler systems, and compressors. For hard chromium platers, the order of significance may change, but the categories are similar. Rectifiers that perform the electrodeposition of chromium are a major source of energy usage. In addition, numerous electric motors provide the power to move liquids, heavy loads, or compressed air for use in processing. In each facility, electric heaters or steam from a boiler system may be use to raise the temperature of processing liquids to the operating range and a chilling system is employed to maintain the operating temperature once it is reached. Electric motors drive pumps in cooling towers to allow for cooling of certain processes. Each rectifier has cables or solid copper bus to deliver DC power to rectified tanks. Because each such conductor has a specific resistance, power is consumed by these passive devices as well. The choice of materials for conductors, the types of connections, the cross sectional area of conductors, conductor design, and the cleanliness of connections can translate to energy savings or losses.

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Tank Bus Optimization

Solid copper bus is sold as high-purity, cold rolled copper in a variety of shapes and sizes. Flexible cables may used for connecting rigid bus to current-carrying moving parts, or they may be used instead of solid copper bus to connect rectifiers to small volume plating tanks.

The operating cost of any bus installation is made up of the capital investment and the cost of the energy lost as heat. As the cross section of the conductor is increased, the investment also increases, but the amount of energy lost is decreased. An equation was developed in "Electroplating Engineering Handbook", fourth edition, to allow for a calculation of the minimum annual cost of a copper bus run, taking into account the amortized cost of the copper and the energy losses:

$$\$/Yr = 2.772\ (CB/N)^2\ (IL)$$

Where:

B = bus cost, installed,
I = operating current, amperes
L = total length of bus run (anode & cathode)
C = cost of power, $/KWH
N = number of years to amortize bus cost
$/Yr = Minimum annual cost

The size of bus bars for a required current capacity depends upon the total bus bar length and the permissible voltage drop. The above equation can be used to optimize the length of the bus run.

Energy can also be conserved in hard chromium plating operations by properly sizing the bus. Copper can carry about 1,000 amperes of current for each 1@ (2.54 cm) of cross sectional area. For large currents, 3@ x 1@ (0.6 cm x 2.54 cm) bus is typically used and stacked with air gaps for cooling purposes. Cables can also used, but are normally employed when the total maximum current delivered by the rectifier is under 2,000 amperes as the insulation on the cables does not dissipate heat as well as bare copper.

Bus Joints

For high amperage applications (2,000 + amperes) the best method of producing a bus joint involves placing a sheet of lead (0.008-0.01@ thick) between each of the faces of the bars to be joined. The lead deforms to fill the air cavity created as the bus bars are bolted together, producing a solid, uniform electrical contact. The minimum contact area between bus bars that are to be joined should be the width of a bar, and a frame should be used to apply the joining pressure uniformly. Avoid drilling holes into the bars, as this reduces the amount of conductive metal at the joint and creates ridges that make intimate contact between bars difficult. If drilling must be done, be sure to sand or file each drilled hole flat.

When joining copper, all parts should be coated with joint compound before assembly. It is essential to exclude moisture and electrolyte from the joint. After bolting, excess joint compound should be removed and the surface should be cleaned and primed with a zinc-chromate primer (MIL-P-6879A). Finally the entire area should be painted with 5 mils of epoxy paint.

According to Electroplating Engineering Handbook, bus bar clamps are more practical than bolts when joining a large number of bus bars. Curved back clamps and spring washers are suitable. When the clamp and washers are totally compressed, sufficient clamping pressure has been applied. Welded or brazed connections may also used in permanent installations, and these have the lowest energy losses.

Cables

Flexible cables can eliminate joints, as the cable can be twisted around corners and underneath installed equipment easily. However, since cables come in fixed sizes, some installations must add an excess of cable to provide adequate current carrying capacity. For example, three 500 amp cables would be needed for a 1200 amp installation.

According to Electroplating Engineering Handbook, a 500 MCM copper cable has a resistance of approximately 0.025 ohm/1000 ft. at its operating temperature. When carrying 500 amp the voltage drop is 1.25 volts/100 ft. Therefore, if the distance is greater than 50 ft, it is necessary to parallel two or more cables to limit the voltage drop.

Tank Bus

Tank bus is commonly made of round or square copper bar stock although bars of rectangular cross section are also used. Use of a Abee-hive@ arrangement over a hard chromium plating tank, allows individual rectifier control over each part and minimizes the distance between the anode and cathode, reducing solution heat-up due to resistance effects, increasing plating speed and thereby reducing energy consumption.

Rectifier Efficiency

In general, rectifiers are at their most efficient, when they are used at as close to maximum output voltage as possible. Every rectifier has power losses, such as the power to operate the main contactor and the fan motor in units that are force air cooled. In some rectifiers, power may be consumed even when the rectifier is turned to zero output and no plating is done.

Rectifiers can be cooled by forced air, convection and by water. Cooling is important as the average rectifier loses 0.7-1KW of energy in the diodes due to excessive heat build-up. Rectifier cooling fans typically consume 3% of the total power in-put of a large rectifier. Convection cooled rectifiers save this 3% and last longer, as corrosive air is not moving through the unit at high velocities. At least one plater has selected 12,000 ampere convection-cooled rectifiers because of the anticipated power savings (no fan, more efficient diodes).

Water Cooled Rectifiers may be used as a means of maintaining optimum diode/thyristor efficiency and protecting the unit from corrosive atmospheres. These types of rectifiers transfer the heat generated by the components through heat exchangers, water tubes and water-filled diode heat sinks to water that is piped through the housing of the rectifier.

Water-cooled units include the standard air-cooled type in which air is passed through a water-cooled heat exchanger, similar to a unit heater. The second type is direct liquid cooling, in which diodes or thyristors are mounted directly onto a water cooled heat sink. The liquid (water or anti-freeze) is then cooled through a water-to-liquid heat exchanger. Energy consumption in operating the heat exchanger, and maintenance of the piping (scale and corrosion prevention) must be calculated in any consideration of a water cooled unit over an air cooled unit.

Rectifier Maintenance

One of the major causes of excessive energy consumption in rectifiers is reduced cooling of temperature sensitive components such as diodes and transformers. Also, rectifiers are located near the processing tanks in most cases, subjecting the internals to corrosive fumes (except for water cooled/sealed systems). Fan-cooled rectifiers tend to be operated with clogged intake or output screens, as well as spaces between heat sinks and windings of transformers. This reduces the ability of the equipment to dissipate accumulated heat, reducing rectifier efficiency, and shortening the life of the system. The following monthly maintenance is recommended by Electroplating Engineering Handbook (adjust frequency in high use applications):

1. Clean intake/output screens using a vacuum is highly recommended.

2. Inspect all external and internal connections conducting high current should be inspected and secured, as necessary. Frequent switching of the rectifier has a tendency to loosen internal connections. These loose connections can be a high resistance and, can cause significant voltage drops, which can get hot enough to melt the connection! A loose connection on one diode can cause the other diodes to carry more current than they are rated for, resulting in reduced efficiency and eventual failure.

3. Inspect all moving parts such as the contactor, the fan in fan-cooled units, the tap switch in tap switch units and the brushes in the variable auto-transformer type units; and in automatic control type units, the control potentiometers are performing properly and, if necessary, lubricate them.

4. Inspect the brush on the auto-transformer (if the rectifier has one), for excessive wear.

5. Check the control potentiometer on automatic control units with an ohm-meter to determine if the resistance change from zero to full resistance is smooth.

Rectifier Circuits

Rectifier circuits can contribute to the overall efficiency of the rectifier, by producing a potential as close to pure DC as possible (low ripple). Purchasing a rectifier with the most efficient circuitry will reduce energy consumption. For example, a three phase bridge circuit has a theoretical conversion efficiency of almost 99%, with an actual expected overall efficiency of 82%-92%. The transformer utilization factor is very high and the percent of ripple is only 4.50%. More modern solid state rectifiers can essentially eliminate ripple entirely.

Controlling Current Distribution

Since it takes energy to deposit metal onto a part, energy is wasted when metal is deposited in areas that do not require a deposit, or if more metal than is necessary is deposited on certain areas of a part. Recognition of, and compensation for, current distribution problems leads to energy savings.

When there is more than one part on a plating rack, spacing of the parts becomes important. Sufficient space must be provided between parts to avoid shading of one by another. Belke developed a formula for calculating spacing of parts on a rack for chromium plating as follows:

For parts where the largest dimension facing the anode is less than 2 inches (5cm):

Spacing $= 2(3H/8 + 1/4 + D/4)$

Where H is the largest dimension facing the anode and D is the depth of the part on the rack.

For parts where the largest dimension facing the anode is more than 2 inches (5cm):

$S = 2\ (1\text{inch} + D/4)$

The distribution of deposited metal coating is determined by the local current density at each point along the surface of the part, as well as by the cathode efficiency of the plating solution. The current density at each point along the parts= surface is determined by the primary current distribution and the level of cathode polarization. The primary current distribution is dependent upon the geometry of the plating cell, and is independent of the chemical properties of the solution.

Cathode polarization is a combination of complex effects, including a depletion of metal ions near the surface of the plated part, which results in a "secondary" current distribution that can be significantly different from the primary distribution.

Many subtle variables influence the distribution of electrodeposited metal, primarily:

1. The primary current distribution
2. Variables related to the plating solution composition and operating conditions
3. The shape of the part being plated
4. The throwing power relationship of the plating solution

In most cases, the primary current distribution is the controlling factor in determining the metal distribution. When the primary current distribution is markedly non-uniform, the other three variables may improve or worsen the metal distribution uniformity.

Since hard chromium plating solutions are notoriously poor conductors and offer poor throwing power, a uniform primary current distribution over the part to be plated through expert use of shields, current robbers and masking methods is of paramount importance.

The Role Of The Plating Process In Energy Efficiency
What makes many hard chromium plating processes gross energy consumers includes:

_ Energy lost through the ventilation system
_ Energy lost from open tops
_ Energy lost through tank walls
_ Energy lost through air agitation systems
_ Excess energy required to overcome resistive ingredients/impurities
_ Energy wasted in heating idle tanks
_ Energy wasted in poor or absent temperature controls
_ Energy wasted to overcome coatings on anodes

Ventilation
One of the largest sources of energy losses in northern climates is the ventilation system. The metal finisher spends a significant portion of the budget on heating the inside air of the workplace, and heating process tanks, while the ventilation system removes the heated air from the building and discharges it to the outside. The ventilation system also cools the heated tanks by the movement of air over the tops of the tanks.

The ventilation system is required to produce an acceptable air quality for personnel. However, it has been our experience that most ventilation systems are not optimized or do not employ the best technologies for energy conservation.

The following is an overview of optimizing the ventilation system for energy conservation:

_ Only ventilate those tanks requiring ventilation
_ Verify proper exhaust rates
_ Eliminate ventilation obstructions

_ Employ and adjust dampers
_ Employ outside air for make-up, if possible
_ Cover idle tanks, and reduce/turn off ventilation
_ Employ mist suppressants to eliminate or minimize the ventilation requirements.

Ventilation Design Considerations

Ventilation requirements for electroplating tanks is covered in detail in ANSI (American National Standards Institute) Z9.1. The latest issue is 1991. OSHA 29CFR, 1910.94 was replaced by this ANSI standard as of 1998, and should no longer be used for ventilation guidance. ANSI Z9.1 provides guidance on determining the optimum ventilation rate for any metal finishing process tank, based on the dimensions of the tank and the process inside the tank. These ventilation rates can be reduced based upon dimensions of the tank (narrower tanks need less capture velocity), the use of partial covers, and exhaust hood modifications.

The key to energy conservation in a plating shop is to make certain that only those metal finishing tanks that actually require ventilation are ventilated, and that the rate of ventilation is not excessive. Each ventilated process tank needs to be evaluated per ANSI Z9.1, and be tested for capture velocity to determine if the exhaust rate is what it should be. If the tank is exhausted at a rate higher than this, energy is wasted.

The capture velocity needs to be balanced with the exhaust flow rate, depending on the design of the exhaust hood. Note that for a tank 2‘ wide, 4‘ long, it takes about 250 cfm/ft^2 to achieve a capture velocity of 150 fpm (for chromium plating, with a lateral slot exhaust hood (with baffle), while the same capture velocity can be achieved with about 125 cfm/ft^2 if the exhaust hood has side panels. This reduces the air exhausted by 25/150 = 16.7% with an equivalent energy savings. Lower exhaust rates translates into lower emissions (in some cases) and lower energy bills (in all cases), but be sure you remain within OSHA standards for worker exposure.

Improving Capture For Downdraft Ventilation Systems

If down draft ventilation ducts are employed, note that a vertical baffle installed on the top of the duct tends to maximize capture velocity over a greater distance across the width of the tank and the airspace above the tank (updraft ducts "automatically" employ a vertical baffle). The vertical baffle reduces air draw over the top lip of the hood. The height of this baffle should approach the width of the tank (assuming the baffle won=t interfere with the travel of work over the tank), if ventilation is only from one side.

Cross draft velocities at exhausted tanks should not be greater than 75 ft/min (0.4 m/sec) to avoid excessive fugitive emissions and disruption of mist capture by the exhaust hood. On long tanks, the pull hood/plenum should be divided so that exhaust air is evenly drawn in along the length of the hood. The capture efficiency can be measured using a tracer gas or smoke testing.

Push/Pull Systems

Push/pull exhaust systems are often employed on tanks exceeding 3 ft. in width, although double pull, or four sided pull can also be employed. Push systems effectively reduce the "width" of the tank by about 2-3 feet, so the exhaust rate can be reduced by about 50% vs. a pull duct operating without push, saving a significant amount of energy.

The push air is supplied by a low pressure blower or by a compressor system. Compressor systems have a tendency to spew oil along with the air, so they are not recommended for processes that are sensitive to oil contamination.

Push/pull systems are ineffective on any tanks that are intended for use with a lot of hardware present between the push duct and the pull duct. Hard chromium plating operations often employ auxiliary anodes, cables, clamps, additional copper bus, etc., which act as barriers to both the pull and the push. Since the push air is delivered at high velocity, it tends to cause high speed collisions between the mist and the hardware on top of the tank, resulting in a high amount of fugitive emissions.

By employing four sided pull ventilation capture efficiency is improved and exhaust air requirements may be reduced, even with a lot of hardware on top of the plating tank. Tanks equipped in this manner also yield cleaner copper bus, as the copper is installed above the hood, so mist does not attack the copper bus, which usually results in contamination of the plating solution (which, of course, reduces process efficiency and increases power consumption)

Use of Mist Suppressants/Foam Blankets

The addition of an effective, stable mist suppressant to a hard chromium plating solution can significantly reduce the energy consumption, by reducing the ventilation requirements (and sometimes eliminating the need for ventilation altogether).

Studies have shown that mist suppressants can be used without affecting the quality of the finished product in most cases, but experimentation and verification is a good idea.

Foam blankets are much less expensive, but tend to trap hydrogen gas, creating loud explosions when a spark sets off the hydrogen in the foam.

The Metal Finishers Association of Southern California studied the effect of mist control measures on emission rates and found the following:

Action	Emission Reduction
Elimination of air agitation	5.6%
Floating Poly Balls	87%
Foam Blanket/Mist Suppressants	93-98%
Keeping Solution Clean	20-40%

Make-Up Air

Any facility operating exhaust hoods over process tanks must also provide for the make-up of the exhausted air. This make-up creates either a positive pressure in the building (make-up air is greater than the exhaust air) or a negative pressure (make-up is less than the exhaust). ANSI specifies that the make-up air must be between 90-110% of the exhaust air, but if the facility exhausts toxics, the make up can not exceed 100% of the exhaust, to prevent the possibility of toxics being emitted from any specific process. Therefore most any metal finishing facility should have a slight negative or neutral air pressure in the building. This means that when you open a door outward the air inside the building is pulling on the door to resist your effort. If the opposite is true, an adjustment in ventilation rates may be required. Verification of ventilation rates should be done annually, and any time there is a modification to the system.

Make-up air needs to be heated in the winter and be directed into the work zone in such a manner as to allow for worker comfort. This is a source of a significant amount of energy consumption. In some cases, unheated outside air can be directed over the working tank to make up for exhaust air, resulting in a significant amount of energy savings. For example, an unheated supply duct may be piggy-backed over the pull duct, to provide unheated air for the exhaust system. Rather than exhaust heated air, the pull duct exhausts unheated air (along with some heated air). A fan and damper allows for flow rate adjustment.

Thermal Energy Losses

Metal finishing processes almost always involve a number of tanks operated at elevated temperature. These tanks are typically heated using steam or electric energy, and are subject to heat losses through the open tops of the tanks and through the tank walls.

Steam and electric heating systems are subject to scaling from hard water, with such scale reducing energy transfer resulting in energy waste. Technology is available to reduce the scaling tendency of hard water, and can save energy.

Studies have shown that most of the thermal losses from hot metal finishing processes occur due to heat loss from the open top of hot tanks, but losses through tank walls can be substantial.

Since work must flow into and out of the tanks without interference from tank covers, it is impractical in many cases, to employ a tank cover. In those cases where a tank cover can be employed during idle periods, a simple plastic cover placed over the entire tank top, or even partially over the tank top, can significantly reduce thermal losses and save energy.

"Electroplating Engineering Handbook" provides guidance for estimation of the heat loss, in BTU per hour per square foot from the surface of a hot liquid in a process tank, and from the tank walls (bare and with three thicknesses of insulation)

As an example, assume a hard chromium plating tank is operated at 140°F, and that the tank is un-insulated, ventilated at 150 fpm of moving air, and has the dimensions, 10= x 4= x 8= deep. Also assume the tank is operated 24 hours a day and 30 days per month.

Heat losses from the top of this tank total over 46 M btu per month. At a cost of $1 per therm, this equates to a loss of over $400 per month from the open top alone. The side walls lose about 24 M btu/month and equate to a loss of over $200/month, making the installation of insulation a viable approach.

Insulating Tanks

In the above example, 1" (2.5 cm) of insulation reduces energy losses through the tank walls by 80%, saving $160.00/month. Increasing the insulation thickness to 3" (7.6 cm) reduces energy losses by 93% saving an additional $26/month over the 1" of insulation.

A major consideration in insulating metal finishing tanks is the elimination of moisture between the tank wall and the insulation, as such moisture will corroded the tank wall very quickly and wet insulation loses much of its efficacy. In one concept, a rigid PVC outer shield is mounted with "C" clamps. This protects the insulation from impact and shields against moisture. Each outer wall has an insertion hole for foam injection near the bottom and an exit hole near the top. A wood or plastic spacer is glued to the bottom. This holds the foam and the bottom of the outer shield in place. Additional spacers may be required on larger tanks. Foam insulation is injected into the cavity between the tank wall and the PVC outer shield, using the lower injection holes, until the foam comes out of the upper holes. Once the foam has solidified, the "C" clamps can be removed, along with the wooden spacer at the bottom. A caulk bead between the lip of the tank and the lip of the outer PVC shield prevents moisture and splashes from entering the crevice between the insulation and outer PVC shield. Note, however, that the exterior moisture shield employed in this example is a rigid PVC, which is combustible and can accelerate corrosion of the steel, if it becomes wet.

Polyurethane foam insulation is superior to most all other commonly used insulation materials by a wide margin over the temperatures normally used in metal finishing processes.

Insulation for Piping

The most commonly insulated equipment (aside from hot tanks) in a metal finishing facility is piping used to convey steam. Piping can be insulated with one of a variety of materials, but the most common, is readily available pre-formed fiberglass insulation with a plastic or aluminum outer vapor barrier.

The question of economics must be answered in considering the insulation of any pipe. F. L. Rubin ("Piping Insulation-Economics and Profits, " in *Practical Considerations in Piping Analysis,* ASME Symposium, vol. 69, 1982, pp. 27-46) studied the economics of insulating pipe and his data was used to develop a table that readily allows the reader to determine if insulating a given pipe based upon the cost of energy, the thickness of insulation, the size of the pipe and the temperature of the pipe. Since Rubin=s data was generated in 1982, some assumptions (interest rates at 15%, inflation at 10% per year) may no longer be valid unless adjusted accordingly.

Agitation Systems

By replacing air agitation systems in hard chromium plating, with eductor systems, a significant amount of energy can be conserved, while the efficiency of the process often is improved.

Eductor systems utilize a small pump that delivers a relatively low flow to the eductor. Opening at the back end of the eductor draw additional liquid by a venturi effect and the result is an outflow that can be as high as five times the pumping rate. The eductor system is designed to provide a uniform amount of agitation throughout the tank. The photo in the slide is of a trivalent chromium plating tank that was converted from air agitation to eductors. Note that there is no mist generated as would be with an air agitation system, and note that the tank does not require ventilation.

The Chromium Plating Solution

In hard chromium plating, contaminants tend to build up in the plating solution, reducing the conductivity and increasing hydrogen evolution (and mist generation). By proper maintenance of the solution to remove these contaminants the power required to operate an individual process is reduced.

A conventional chromium plating solution containing 1 oz/gal (7500 ppm) of total metallic impurities can be expected to deliver a plating efficiency of around 9-10%, while the same solution containing 0.5 oz/gal (3500) ppm can deliver 12-14% efficiency. This may not sound like much, but it translates into a 20-40% reduction in energy consumption and a corresponding reduction in mist generation. A new plating tank should be designed to utilize continuous purification (removal) of metallic impurities. Consider ion exchange, membrane purification, or porous pot technologies for purification of chromium plating solutions.

High levels of trivalent chromium increase gas emissions by reducing plating efficiency. If the new plating tank will be used with low anode/cathode ratios (less than 2:1), consider designing continuous electrolysis into the system to oxidize trivalent back to hexavalent.

The cathode efficiency of any chromium plating solution is closely tied to the ratio between the chromic acid and the sulfate content (typically 100:1 for a conventional solution and 200:1 for a mixed catalyst solution). Cathode efficiency is also closely tied to chromic acid concentration. For example, a conventional plating solution is about 20% **less** efficient at 50 (375 g/L) oz/gal than at 33 oz/gal (250 g/L) of chromic acid. Frequent analysis and adjustment of this ratio will optimize plating efficiency. The efficiency of the plating solution can be estimated using a hull cell.

Proprietary solutions that typically operate at 25% cathode current efficiency can dramatically reduce energy consumption and increase productivity, assuming the economics (cost of the process) work out.

Purification by Electrolysis (Porous Pot)

The addition of a porous pot or membrane to the electrolyzing cell can add significantly to the effectiveness of an ion exchange system. By placing the cathode in a porous pot containing plating solution or dilute chromic acid (preferred), it is possible to collect most of the foreign cation contaminants in the catholyte. A substantial amount of the Cr^{3+} concentration will be oxidized to Cr^{6+} if the anode area is large and the solution temperature is maintained at 57 to 63°C (135 to 145°F) in the cell. The catholyte may be removed periodically and waste treated by the same methods used for the cation-exchange regenerant acid. For small plating installations, a porous-pot electrolysis system may provide economical purification because of its relatively low cost and small space requirements. In larger systems, it may be justified by reducing the capital investment required for a complete setup. The energy cost is relatively high, compared to ion exchange, as are the labor costs, but may be justified by the low cost of the equipment.

In one example of porous pot usage, a plater operating 1300 gal (5000 L) of chromium solution keeps his nickel metal concentration in the chromium plating solution down to 4-6 g/L (0.6-0.7 oz/gal) with eight porous-pot cells. He applies 1200 A to the cells, 24 hr/day. At 9 volts, the power consumption is approximately 55,000KWH per year. At $0.1/KWH, the energy cost is $5,500.00 per year. If his solution efficiency is improved by 40%, (assuming operating amperage at 5,000 amperes, 9 volts, 24 hours per day, 210 days per year) his saving is about $4,000.

A typical porous pot can be mounted on a reversible two bus bar plating rack, or on conventional plating tank bus bars. Two outside electrodes (anodes) are placed in close proximity to the walls of ceramic pot having a pore size of 1 micron or less. Inside of the pot is the single cathode, made from lead mesh. When starting the purification, the inside of the pot should be filled with plating solution, or ideally, with 10-15 oz/gal of fresh chromic solution without catalyst. Metallic impurities will gradually collect inside of the pot and re-oxidation of hexavalent chromium will start on the outside anodes. The liquid level inside the pot will have a tendency to rise approximately 2 inches and will become hotter than the rest of the solution. The operating voltage is 6-9 V, depending on the conductivity of the solution.

As the purification and re-oxidation proceeds, there will be a gradual decrease of the current (amperage) as the cathode becomes coated with a layer of insoluble metallic salts and hydroxides. When the amperage becomes low, it is time to remove the cathode, wire brush off the sludge and start again. The process of removing the cathode and re-assembling takes about 5-10 minutes. Heavy contaminated baths will need initial frequent brushing of the cathode until an equilibrium is reached. After that, 1-2 cathode clean-ups per week is typically required for a small operation, to the keep the solution in good workable condition.

The porous pot is usually operated continuously with the production or it is placed in an auxiliary tank. Solution from inside of the pot should be waste treated along with the cathode sludge.

Typical operational conditions are:

1. Anode current density 20 ASF.
2. Cathode C.D. greater than 100 ASF.
3. Temperature as high as practical.

Anode Maintenance

If the trivalent chromium content of a chromium plating solution exceeds about 3.5%, the solution efficiency drops, ventilation rates must be increased, and energy consumption goes up. Proper control and maintenance of the anodes maintains the trivalent chromium concentration below 3.5%.

Anodes should be operated at 100-175 amps/ft^2. Check this periodically with a tong meter. A 1.5" round anode can carry approximately 150 amperes, while a 2" round anode can carry 250 Amperes, depending on hook size and the length of the anode. Visually inspect the anodes frequently. They should have a chocolate brown colored coating. An orange color indicates an anode that is not functioning properly. Remove these, clean them and return them to the tank, making sure they have the correct current density and a good connection between the hook and anode rod.

Periodically check for extra heavy or irregular buildup of lead peroxide (chocolate brown color) or lead chromate (orange color) to prevent problems in current distribution. Heavily worked solutions and those with closely conforming anodes require periodic cleaning of anodes. Acid dipping, alkaline soaking and scratch brushing, plus electrolytic reduction techniques, are useful to remove the lead chromate, which acts as an insulator. Most lead anodes tend to form insoluble chromate or fluoride, when left in chromium plating solutions without applied current. The anodes then must be "energized" with full tank voltage for a period of several minutes to possibly an hour before they are fully reactivated and conductive. Remove anodes from the solution, if they will remain idle for a long time.

Air Compressors:

Compressed air may account for about 5% to 15% of the total energy used in a hard chromium plating facility. Most systems employ multiple compressors. Energy cost may represent as much as 65% of the total expense in producing compressed air. These costs can be reduced by:

1. Repair air leaks. The American Council for an Energy Efficient Economy has published reports which states that typically, 15-25% of the energy used to generate compressed air is lost in leaks.

Leaks can add up to create significant amounts of energy waste. Lower pressure will result in lower leakage from existing holes, as detailed below. The following costs were calculated assuming 8000 operating hours/year, and a cost of $.15/1000 cubic feet of air.

Hole Diameter	Leak Rate Cost 110 psi	Leak Rate Cost 100 psi
1/16"	4.3 cfm $312	3.9 cfm $286
1/8"	17.4 cfm $1,249	15.9 cfm $1,142
1/4"	69.4 cfm $4,997	63.5 cfm $4,569
3/8"	156.2 cfm $11,243	142.8 cfm $10,281
2"	277.6 cfm $19,988	253.9 cfm $18,277

2. Reduce the operating pressure. Most system operate at a pressure much higher than necessary. At 100psi, every 2 psi of pressure increase will increase energy consumption by approximately 1%. Note in the above example, that reducing the pressure from 110 to 100 psi saved about $1700.00 just in leakage alone.

3. Replace undersized air piping to reduce pressure lost.

4. During operation, compressors generate a large amount of heat which can be used for other purposes in the plant. A well designed heat recovery system can recover over 50 percent of the compression heat energy. The waste heat may be used for space heating, and preheating boiler feed water. A 50 horsepower air compressor produces approximately 126,000 Btu/hr of heat energy.

5. Pipe in outside air for the compressors. Colder air increases the efficient of the air compressor.

6. When operating more than one air compressor, a sequencing control system should be added to optimize the operation of the air compressors. Savings of 10 to 20% and over can be obtained by installing the sequencing controls.

7. New air compressors should be equipped with high energy efficiency motors. Variable speed drives can be used to improve efficiency further.

Energy Management Systems

An Energy Management System (EMS) can range in complexity from a programmable thermostat to a computer-based system that controls HVAC, lighting and security for multiple buildings in different cities. They can provide convenience and improved productivity in addition to energy savings. Many systems operate in the Windows PC environment. An EMS can turn equipment off during off hours. It can setback/adjust thermostat control points during off-hours. It can control and adjust the use of outside air for cooling when appropriate. It can turn equipment on/off to limit energy demand. It can also control lighting, optimize chiller performance and track energy usage trends.

Co-Generation

Co-generation is a highly efficient means of generating heat and electric power at the same time from the same energy source. Co-generation can reach efficiencies that are 3-4 times that of conventional power generation.

Although co-generation has been in use for nearly a century, it can only play a role for the plater when natural gas prices are low. However, co-generation equipment can be fired using wood, agricultural waste, peat moss, and a wide variety of other fuels depending on local availability.

There are several types of co-generation systems being marketed and they can range in price from under $50,000 to multi-million dollar systems. System efficiencies range from less than 10% to up to 70% and operating costs, system reliability and complexity can vary over the entire spectrum as well.

Co-generation equipment must be located physically close to its heat user.

A co-gen system utilizes an engine and can produce approximately 500 kW to 2000+ MW when burning natural gas. It can be designed around 60 cycles per second or 50 cycles per second, depending on whether it will service a European or North American company. The fuel consumption for a large co-gen system is approximately 10,000 Btu per kilowatt-hour.

The co-gen system is usually connected with the plant electrical system so that both utility and co-generation systems can either simultaneously or separately feed the plant load.

Co-gen systems may reduce demand charges on the shop, but it may also move the shop into a higher electric rate category. To avoid this, at least one plater has negotiated "interruptible" service, at lower electricity rates than the average shop. In this installation, the power may be interrupted with 30 minutes prior notice.

Energy Efficient Motors

The annual energy cost to run a motor is usually many times its initial purchase price. An energy-efficient motor runs cooler, vibrates less, lasts longer and may have a higher power factor. Energy savings are typically in the range of 2-10%. Energy guidance for motors include the following tips:

1. Failed motors can be rewound, but they're not as efficient as a standard replacement motor. A re-wound motor may lose as much as 2% of it‘s original energy efficiency.

2. If a motor is operating at less than a .50 load factor (average horsepower used divided by its full horsepower rating), downsizing to an energy efficient motor is usually economical.

3. Motors should be sized to operate with a load factor approaching 90 percent.

4. Motors have "slip," yielding an operating RPM slightly lower than their rated synchronous speed. An increase of as little as 5 RPMs can increased flow and reduced efficiency of pumps or fans.

Rewinding may not pay. Efficiency can be reduced by 1 % to 2% or more. Always calculate the operating costs based on nameplate efficiency before you make the decision to replace or rebuild.

The DOE has offered a CD-ROM that allows the user to determine the most energy efficient replacement motor for any application. The Software is called "MotorMaster" 3.0 Visit the website: http:// www.motor.doe.gov.mmplus for more information.

Boilers

Modern boilers offer combustion over 90% and employ direct digital controls/sensors to optimize fuel/air mixtures, control feed water, and control steam pressure. Since most facilities need to improve the efficiency of an existing boiler, we will focus on that opportunity.

The efficiency of an existing boiler increases about 1% for every 5.5^{o}C (10^{o}F) increase in feed water temperature. By pre-heating boiler water, energy consumption dramatically decreases. Other energy reduction tips for existing boilers are:

1. To optimize the fuel/air ratio, install an oxygen trim system which modulates the air intake to the burners according to the amount of oxygen in the flue.

2. Install automatic flue dampers to reduce energy losses by natural convection in the flue if the boiler is shut down.

3. Replace gas pilots with electronic ignition systems.

4. Pr-heat air to the boiler air inlets.

5. Equip the boiler with automatic blow down controls based on boiler water conductivity and pH. A 10% blow down on a 200 psi steam system can produce a 3% energy efficiency loss.

6. Repair all steam leaks.

7. Eliminate the use of excess air as much as possible, as even 50% excess air can decrease efficiency by 5%.

8. Maintain/replace steam traps. Steam losses through poor traps can cost more than the trap and labor required to replace it.

Lighting
Lighting accounts for over 11 percent of electricity consumption in metal finishing facilities. Lighting efficiency improvements can not only reduce energy costs but also provide better lighting, resulting in improved productivity and better quality control.

Increasing the Efficiency of Full-sized Fluorescent Lamps and Fixtures
Many metal finishing facilities are older buildings with full-sized fluorescent systems (lamp diameter of an inch or more). Newer fluorescent lighting systems are more efficient. Ways to increase efficiency include reducing over-lighting, upgrading lamps and ballasts, improving fixture efficiency, and using better lighting control strategies.

Reduce Over-lighting
The Illuminating Engineering Society of North America has established lighting-level recommendations based on the type of activity and characteristics of the task being performed. The suggested levels for metal plating activities are 200-300-500 lux or 20-30-50 foot-candles. In spaces that have too much electric lighting, you can remove lamps, but you need to also retrofit the system with lower output lamp-ballast systems, or saving are significantly reduced, as the ballast continues to draw current for the full number of lamps. Any reduction in light output should take into consideration the resulting light quality, light distribution, surface brightness, and glare, or productivity will be affected. Reducing over lighting generally provides large energy savings within a short payback period and also reduce the cost of lamp and ballast replacement.

Upgrade lamps and ballasts
The most common older fluorescent systems are T-12 lamps with magnetic ballasts. The National Appliance Energy Conservation Act Amendment of 1988 banned the manufacture and import of the standard magnetic ballast used with these older fluorescent systems. Additionally, the Energy Policy Act of 1992 prescribes minimum lumens per watt and color rendering standards for most types of fluorescent lamps. Choices for upgrading the lamps and ballasts of these older systems include:

- Electronic ballasts Electronic ballasts rely on semiconductors to produce the high-frequency alternating current used by the lamp. They operate lamps more efficiently and can drive more lamps per ballast than conventional ballasts. They are also less affected by temperature and voltage variations, have low harmonic distortion, and eliminate visual flicker.

- Hybrid ballasts These ballasts use a combination of magnetic and solid-state technology. They can power either T-8 or T-12 lamps and offer some of the same efficiencies as electronic ballasts at lower cost.

- T-8 lamps and electronic ballasts T-8 lamps have a smaller diameter than the standard T-12s. They fit the same sockets, but require special ballasts. They provide better color rendering and are less costly, on a life-cycle cost basis, than T-12s.

Improve fixture efficiency

Fluorescent lighting fixture components include the housing, a lens or louver system, and possibly a reflector. The fixture distributes the light throughout the space and affects visual comfort. You can make improvements to your fixtures by retrofitting the reflectors and/or changing the diffusers, lenses, and louvers.

- Reflectors are metal sheets designed to widen or narrow the light distribution from conventional fluorescent fixtures. They can decrease the internal losses of the fixture and frequently are used in conjunction with de-lamping (removing lamps).

- Diffusers, lenses, and louvers Diffusers are thin plastic sheets that cover recessed fluorescent fixtures. They are translucent sheets that disperse light equally in all directions and are extremely inefficient because of the amount of light they absorb.
  Lenses are also plastic sheets that cover the fixture but they redirect light rather than diffuse it and are much more efficient.

Louvers are designed to control glare by using curved reflective surfaces that direct light downward while preventing a direct view of the lamp. Parabolic louvers are the most common type and fixtures with well-designed parabolic louvers are optically efficient. Because of this efficiency you may be able to use fewer fixtures and reduce your energy costs. Parabolic louvers however, can create a "dark ceiling" effect that makes the space seem gloomy.

Other Lighting Systems

Metal finishing facilities with ceilings 20 feet or higher may be candidates for high-intensity discharge (HID) lighting systems such as metal halide and high-pressure sodium lamps (not recommended in any area where occupancy rate is high and color definition is important) or the new high-intensity fluorescent systems. Light color characteristics are also an issue with high-pressure metal halide lamps.

HIDs have the following characteristics:

- relatively long life (5000 to 24,000+ hours)
- relatively high lumen output per watt
- relatively small size

However, HIDs require from two to six minutes to warm up to full brilliance. A power interruption or a large enough voltage drop will extinguish the lamp and it then can take from five to 15 minutes to come back on.

Daylight Following And Occupant Sensors

Daylight-following automatically lowers lighting levels as the amount of daylight increases or decreases.

Occupant sensors consists of a motion detector, an electronic control unit, and a controllable switch (relay). The motion detector senses motion and turns on the lights (or turns them off in the absence of motion for a pre-set time).

A variety of occupant sensors, including wall box, ceiling, ultrasonic and passive infra-red (IR) sensors are available for a variety of applications.