
**CASE STUDY: EFFECTIVE WASTE MINIMIZATION
USING ION EXCHANGE TECHNOLOGY**

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INTRODUCTION

Kohler Co. is a world-wide manufacturer of commercial and household plumbing products, small internal combustion engines, generator sets, furniture and other household goods. The manufacturing facility located in Kohler, Wisconsin, produces vitreous china, enameled cast-iron fixtures, brass plumbing fittings and internal combustion engines.

The Brass Division of the Kohler Wisconsin facility manufactures brass plumbing faucets and fittings, which are finished by a wide variety of processes. These metal finishing processes create several wastewater streams which must be effectively managed in order to maintain compliance with established regulatory limits and minimize operating costs within the Brass Division. These wastewater streams are highly variable in terms of composition, volume and flow rate. Management of these wastewaters presents significant challenges with respect to pollution prevention, optimization of treatment methods, and compliance with effluent discharge limits. The Brass Division employs a conventional metal hydroxide precipitation treatment process train for a majority of the wastewater streams generated in the facility. Some streams are shipped off-site for treatment and disposal. A simplified schematic of the Brass Waste Treatment (BWT) facility is presented in Figure 1.

The Brass Division requested the assistance of Kohler's Corporate Environmental Engineering and Safety Department and Chemical and Metallurgical Laboratory to assist them in reducing cost associated with managing their wastewater streams while continuing an outstanding record of regulatory compliance.

The goals of this paper are to present a case study of a waste and cost reduction project which:

- * illustrates the decision process to select an appropriate waste and cost reduction technology
- * describes the selected technology and the interaction with the existing metal finishing and waste treatment operations
- * describes the anticipated and actual benefits achieved

The paper is organized as follows:

- * Background and Previous Work
- * Evaluation of Alternatives
- * System Selection and Description
- * Anticipated and Realized Benefits
- * Summary

BACKGROUND AND PREVIOUS WORK

Analysis of Waste Sources and Costs

A comprehensive operations audit was conducted in order to identify the specific manufacturing operations generating wastewater streams and also to identify the major sources of operating costs incurred by the BWT facility. A summary of the relative percentages of the major wastewater sources is presented in Figure 2. Additionally, a summary of the major contributing sources of disposal costs incurred by the BWT operation is presented in Figure 3, as a percentage of total annual off-site disposal cost for all wastestreams generated in the Brass Division. Conducting the audit of the wastewater generation sources and identifying the primary contributors to waste disposal costs was essential in developing a focused approach to cost and waste reduction. As shown in Figure 3, the most likely target areas for both cost and waste reduction were identified as:

- 1) Miscellaneous Liquids - These consist of seven individual liquid wastes which were untreatable with the technologies available in BWT at the time of this work.

- 2) Cleaners - This waste source represented the largest individual waste stream contributing to total annual disposal costs. The approach taken to address this waste stream was the focus of a previous project.
- 3) Plating Sludges - These are metal hydroxide sludges derived from wastewater streams generated in the nickel and chrome plating operations (rinse water). This waste stream is the focus of this paper.
- 4) Other Sludges - These are metal hydroxide sludges generated from other mixed metal wastewater streams.

Description of Project Approach and Previous Work

A schematic diagram of the project approach is presented in Figure 4. Each of the individual cost components identified in the operations audit provided significant opportunities for both waste reduction and operating cost savings. Initial activities focused on the miscellaneous liquids waste streams and the spent cleaners waste streams. The reduction of both the volume of waste and the cost to treat and dispose of both of these groups of waste streams required no capital investment. The next potential area of waste and cost reduction was the sludge generated by treatment of the plating line, rinse water waste streams, which is the focus of this paper.

Description of Plating Line Sludges Waste Stream

Brass fittings and faucets are finished using several technologies. A majority of the brass parts are finished via nickel and chrome electroplating. A detailed description of the plating line process tanks is presented later in this paper. The plated parts are processed through a series of tanks including rinse tanks. The plating solution which remains on the part is rinsed from the part and accumulates in the rinse tank. While some of this dilute plating solution was recovered under previous process operating methods, a majority of the rinse water was discharged to BWT. These waste streams were co-mingled and treated to discharge standards using conventional metal hydroxide precipitation. As such, the rinse tank contents for both the nickel and chrome plating operations represented potential sources for waste and operating cost reduction.

All methods of waste reduction for rinse water, not requiring significant capital investment, were employed prior to conducting the original operations audit. These included employing dragout drip guards, counter-current rinsing, and maximizing the dwell time over the plating tank. Further reduction in waste and cost reduction for the plating line waste sources required employing a recovery technology and capital investment.

EVALUATION OF ALTERNATIVES

The technologies which were available for evaluation to the project team included: electro dialysis, evaporation, ion exchange and reverse osmosis/ultrafiltration.

Development of Evaluation Criteria

The project team which consisted of members from the Corporate Environmental Engineering group, Chemical and Metallurgical Laboratory and the Brass Division, initially established a detailed set of evaluation criteria, and project objectives to guide decision making. A list of the evaluation criteria follows:

Project Objectives

- 1) maintain high degree of rinse water quality
- 2) achieve recovered metals stream at plating bath quality
- 3) minimize plating line downtime
- 4) maintain or improve quality of plating finishes
- 5) minimize overall impact of new technology on current production operations
- 6) utilize existing equipment to maximum extent
- 7) minimize floor space required by new equipment
- 8) maximize ease of installation
- 9) minimize production personnel time requirements
- 10) provide sufficient training for new equipment
- 11) effluent from system must meet discharge permit requirements
- 12) minimize waste stream volume requiring additional treatment
- 13) minimize sludge production
- 14) maximize useable raw materials recovery
- 15) provide contingency for failure of system or system components
- 16) minimize investment costs; maximize return on investment

Evaluation of Alternative Technologies

The project team evaluated the applicability of each of the potential technologies and reduced the technologies which would be evaluated in detail to ion exchange and reverse osmosis. This preliminary reduction in the number of options evaluated allowed the project team to identify and evaluate, in greater detail, the wide variety of commercially available variations of both ion exchange and reverse osmosis technologies. The project team also invested the time to visit various operating installations of both ion exchange and reverse osmosis systems.

Evaporation was eliminated as a potential recovery technology due to high energy costs, the potential build-up and concentration of contaminants in the plating baths, and concern over air emissions and air emission regulations. Electrodialysis was eliminated as a potential recovery technology due to the uncertainty regarding the membrane life, the need for pretreatment of the feed stock and the need for additional treatment of the recovered metal stream prior to adding back to the plating baths.

The following represents a brief summary of the project team's conclusions regarding advantages and disadvantages of ion exchange and reverse osmosis. It must be noted that these conclusions were made within a framework specific to Kohler Co. operating conditions and the specific list of evaluation criteria.

Ion Exchange Technology

Advantages

- 1) low energy demand of system
- 2) commercially available systems which require little operator attention
- 3) technology appropriate for dilute waste streams, can recover waste streams to match required plating bath quality
- 4) returns the recovered metal as a metal salt
- 5) plating bath additives (brighteners) not recovered
- 6) strong customer service program from some manufacturers

Disadvantages

- 1) potentially high initial cost, particularly if system is automated
- 2) wastewater volume requiring treatment in existing BWT not significantly reduced

- 3) have to purchase, inventory and handle several acids for regeneration
- 4) resins are expensive to replace

Reverse Osmosis

Advantages

- 1) low energy requirements
- 2) small floor space requirements for most commercial applications
- 3) highly automated systems available requiring little operator attention
- 4) batch recycling capability of some units able to concentrate solutions to plating bath concentrations
- 5) strong customer service program available from some manufacturers and remote, on-line monitoring
- 6) able to provide a high quality fresh rinse water stream
- 7) lower initial cost than ion exchange

Disadvantages

- 1) found relatively few applications for nickel plating baths
- 2) concerned about recovering and subsequent build-up of organic additives in the plating bath.
- 3) membranes have not demonstrated a long life in nickel plating applications, costly to replace
- 4) membranes potentially easily fouled by organics and particulates, requires a high degree of upstream protection
- 5) membranes susceptible to pH swings
- 6) not proven for decorative chrome plating operations

Ultimately, the project team selected ion exchange technology as manufactured by ECO-TEC, Inc. of Pickering, Ontario, Canada. The primary reasons for this selection centered around the ECO-TEC, Inc. manufactured equipment being highly automated, capable of producing recovered metal streams which could be added directly to the chrome and nickel plating baths, and non-recovery of organic additive breakdown products. Additionally, ion exchange technology could be effectively employed for both the chrome plating process and the duplex nickel plating process, as opposed to employing different technologies for each process. The manufacturer also had an extensive customer service and training program for their customers, maintained an inventory of replacement parts, and invested significantly in fundamental research and testing in an effort to improve their systems.

SYSTEM SELECTION AND DESCRIPTION

Ion exchange recovery systems were installed on the chrome and nickel plating lines. The chrome systems and the nickel system unit (NRU) will be discussed separately.

Chrome Recovery System and Components

The major components of the chrome recovery system are:

- 1) Conductivity meters that monitor the concentration of chrome in the rinse tanks and on the recovery units.
- 2) Decationizer Unit (DCU) which is comprised of two prefilters and an ion exchange bed.
- 3) Multi Media Filter which functions as a prefilter before the CRU.
- 4) The Chrome Recovery Unit (CRU) which is comprised of a pretreater cation bed, an anion bed and a second cation bed.
- 5) Sulfate adjustment system which removes excess sulfate from recovered chrome product.
- 6) Product storage tank which stores the product until it can be added back to the bath.
- 7) Storage vessels for sulfuric acid and sodium hydroxide.

Figure 5 is a schematic of the ECO-TEC chrome recovery unit, and illustrates how the system is tied into the plating line. Because the chrome recovery system is comprised of two separate units, each unit will be discussed separately.

Decationizer Unit (DCU)

The DCU reclaims hexavalent chrome from the first rinse tank (first reclaim tank) following the chrome plating bath. The chromic acid concentration is monitored in the first reclaim tank using a conductivity meter. As the level of hexavalent chrome in the reclaim tank increases so does the conductivity. When the conductivity reaches a predetermined level, the set point on the meter is exceeded and the DCU begins to cycle. Rinse water from the reclaim tank is pumped to the DCU. The length of a DCU cycle is controlled by a timer. The rinse water passes through two pre-filters before entering a de-cationizer bed. The pre-filters remove particulates that may have built up in the reclaim tank. The filtered solution passes through the de-cationizer bed where cations such as trivalent chrome, iron, copper, nickel, lead and zinc are exchanged with hydrogen ions. The de-cationized solution (re-claimed product) is pumped to the product storage tank where it is stored until it can be reused in the chrome plating bath. The approximate volume generated is 7.5 gallons per DCU cycle.

To remove the cations from the de-cationizer bed, and to regenerate the bed for the next cycle, the de-cationizer bed is washed with a solution of sulfuric acid. The wastewater generated contains NiSO_4 , ZnSO_4 , PbSO_4 , and CuSO_4 (approximately 2 gallons) and is discharged to BWT. Figure 6 is a flow diagram that illustrates the chemistry taking place in the DCU.

Chrome Recovery Unit (CRU)

The CRU reclaims chromic acid from the second rinse tank (second reclaim tank). This is accomplished by using a countercurrent flow system between rinse tanks 4 and 3, and rinse tanks 3 and the second reclaim tank (see Figure 5).

The conductivity in the second reclaim tank is monitored. When a pre-determined set point is exceeded, the CRU begins to cycle. Solution is pumped from the second reclaim tank through a multi-media filter at a rate of 21 gallons per minute.

The multi-media filter removes particulates from the rinse water. After filtration the rinse water is discharged to the CRU. In the CRU, the solution passes through a pretreater cation bed where cationic contaminants are removed (trivalent chrome, nickel, lead, zinc, and copper). The de-cationized solution leaves the pretreater bed and passes through an anion bed where the chromic acid is retained. The remaining liquid (purified return) is returned to the 4th rinse tank and is re-used as rinse water. This cycle continues until a conductivity controller located after the anion bed begins to detect break-through.

When break-through is detected, the purified return water is directed out of the fourth rinse tank and sent to the second reclaim tank. This step is referred to as break-through return. Solution continues to be pumped from the second reclaim tank through the multi-media filter, the cation pretreater bed, and the anion bed. The break-through return step is timed and its purpose is to maximize the concentration of chromic acid in the reclaimed product.

After the break-through return step, the chromic acid deposited on the anion bed is ready to be reclaimed. In addition, the cation pretreater bed must be regenerated. The pretreater bed is regenerated with sulfuric acid. At the same time, the chromate ion is reclaimed off the anion bed by regenerating with sodium hydroxide. Sodium chromate leaves the anion bed and passes through a second cation bed where the sodium ion is exchanged with a hydrogen ion. The hydrogen ion combines with the chromate ion forming the chromic acid reclaimed product. The chromic acid is pumped to a sulfate adjustment system (SAS) where excess sulfate is precipitated using barium carbonate. The solution remaining is the reclaimed chromic acid. The reclaimed chromic acid is stored until it can be added to the plating bath. Figure 6 is a flow diagram of the chrome recovery process and illustrates the various chemistries involved in the process.

Installation and Start-up of DCU and CRU

The DCU and CRU began reclaiming chrome from the rinse tanks following the chrome plating line on January 28, 1991. The reclaimed chromic acid was not added to the chrome plating bath until chemical analyses showed that the product would match the quality of the plating solution. The chromic acid generated in this interim period was stored.

Chemical analyses were routinely performed on the feed solution going to the DCU, the feed solution going to the CRU, the product generated from one cycle per day from both the DCU and CRU, and on the product storage tank. There were two objectives in performing the chemical analysis:

- 1) The manufacturer requested analyses to assist in the start-up of the equipment and to verify that the manufacturer's specifications were being met.
- 2) The Brass Division requested analyses to determine the purity of the recovered product. Typical levels of contaminants found in the plating bath were compared to the contaminant level found in the recovered product.

The frequency of some analyses was dictated by both the manufacturer of the equipment and the project team. As confidence with the equipment increased, the frequency of analysis was decreased. The following is a description of each stream analyzed and the reason for the analysis.

DCU Feed - Each day, when the DCU began to cycle, a sample of the feed to the DCU was collected and analyzed for chromic acid, trivalent chrome, iron, lead, zinc, nickel and copper. The analysis determined the level of chrome was in the first reclaim tank and the concentration of trace contaminants.

DCU Product - One cycle per day was sampled and analyzed. Analyses for chromic acid, trivalent chrome, iron, lead, zinc, nickel, and copper were performed. The analyses determined how capable the DCU was in reclaiming chrome. Also, these analyses were compared to the DCU feed results to determine how effective the DCU was in removing metal cations.

CRU Feed - The solution from the second reclaim tank was analyzed each day. The analysis was requested by the manufacturer to compare to performance specifications. Analyses for hexavalent chrome, iron, lead, zinc, nickel, and copper were performed.

Product Storage Tank - The composite reclaimed product from DCU and the CRU was evaluated daily. The majority of the product came from the DCU which cycles more times per day and generated 7.5 gallons of product per cycle. The CRU cycles about one fifth as often and generates about 3 gallons per cycle. Analyses of the product storage tank contents determined the concentration of reclaimed chromic acid added back to the plating bath and the level of trace contaminants present in the product. The trace contaminants were compared to the actual amount of trace contaminants present in the chrome plating bath. Analyses performed on the product tank included: hexavalent chrome, trivalent chrome, sulfate, iron, copper, lead, zinc, and nickel.

Nickel Recovery System and Components

The NRU is comprised of the following components:

- 1) Conductivity meter in the nickel reclaim tank (first rinse tank after the plating bath).
- 2) Nickel recovery unit which is comprised of two pre-filters and a cation exchange bed.
- 3) Feed tank which accumulates nickel contaminated rinse water until enough is generated to begin a reclaim cycle.
- 4) Product storage tanks which hold reclaimed nickel product until it can be added back to the nickel bath.
- 5) Storage vessels for sulfuric and hydrochloric acid.

Figure 7 is a schematic of the nickel recovery unit, and illustrates how the system is tied into the nickel plating line. The NRU recovers nickel that is "dragged out" from the plating line. This is accomplished by using a countercurrent flow system in the rinse tanks after the nickel plating baths and reclaiming the nickel from the rinsing process. The level of nickel in the first rinse tank (reclaim tank), is monitored by a conductivity meter. When the conductivity meter's set point is exceeded, a transfer pump begins to pump rinse water from the first rinse tank to the feed tank. At the same time, deionized (DI) water is added to the last rinse tank in the countercurrent system to make up for the loss of water from the reclaim tank. The countercurrent flow of the rinse water dilutes the concentration of nickel in the reclaim tank until the conductivity drops below the set point. At this time, the pump stops pumping rinse water from the reclaim tank into the feed tank. In addition to the conductivity meter, a level control in the reclaim tank maintains the water levels in all of the rinse tanks.

The feed tank is eventually filled over time. A level control in the feed tank indicates when the tank contains enough solution to start the NRU reclaim process. The solution is pumped from the feed tank through two pre-filters which remove particulates. The solution is fed through a cation exchange bed where the nickel cations are retained on a selective resin. The remaining solution is then discharged to waste treatment. A conductivity meter monitors for this breakthrough of the resin bed and controls the feed solution being applied to the cation exchange bed. The cation exchange bed is then rinsed with DI water to remove any residual solution left in the bed. The DI water used to rinse the bed is bled back into the feed tank to capture the nickel solution. After the bed is rinsed, sulfuric acid and hydrochloric acid are used to reclaim the nickel from the cation exchange bed. The ratio of hydrochloric acid to sulfuric acid is controlled so that the proper ratio of nickel sulfate/nickel chloride is produced.

The concentrated acids are diluted with DI water before passing through the exchange bed. Hydrogen ions replace the nickel cations on the resin. The nickel chloride, nickel sulfate, and any extra acid solution passes through a deacidification bed that removes the excess acid. The reclaimed product is then discharged to a product storage tank where it is held until it can be returned to the plating bath. The deacidification bed is rinsed with DI water and the retained acid is used during the next cycle. Figure 8 is a process diagram which illustrates the different physical and chemical processes that occur while recovering nickel.

Installation and Start-up of Nickel Recovery Unit

The NRU became operational on January 28, 1991. Chemical analyses were performed on the feed solution and nickel recovery product during start-up to determine if the NRU was meeting the manufacturer's specifications. In addition, the reclaimed product was characterized by performing additional chemical analyses to assure that it would meet the plating bath specifications. The three streams analyzed were the NRU feed, the NRU product, and the product storage tank. The following is a description of each stream analyzed and the analyses performed:

NRU Feed. When the conductivity in the reclaim tank exceeds the set point, solution is pumped from the reclaim tank to the feed tank. When the level in the feed tank reaches a set level, the NRU begins a cycle. Once per day a sample of the feed going into the NRU was collected and analyzed for pH, nickel, iron, copper, lead, zinc and chrome.

NRU Product. The following analyses were performed on the recovered nickel product: nickel, pH, iron, copper, lead, zinc, chrome, nickel chloride, and nickel sulfate.

Product Storage Tank was sampled once per day. This solution represents a composite sample of all the daily NRU cycles. Analyses on the product storage tank would determine the actual concentrations of nickel and trace contaminants in the reclaimed product that would be returned to the plating bath. The following analyses were performed: nickel, nickel chloride, nickel sulfate, iron, copper, lead, zinc and chrome.

ANTICIPATED AND REALIZED RESULTS

Anticipated Results

Prior to approval of the investment in the metals recovery equipment, the anticipated resultant benefits from the project were quantified in an internally generated document termed an Authorized Corporate Transaction (ACT). Installation of the metals recovery equipment for both nickel and chrome recovery was expected to create the following benefits and operating cost reductions:

- 1) anticipated reduced raw material purchases, specifically nickel sulfate, nickel chloride and chrome compounds.
- 2) anticipated reduced sludge disposal costs since the metals recovery equipment would reduce the metals loading to BWT.
- 3) anticipated a reduction in the chemicals purchased for BWT required for metal hydroxide precipitation since the metals recovery equipment would reduce the metals loading and wastewater volume requiring treatment.
- 4) expected improved plating bath quality resulting in lower amount of plating defects; this was expected since the addition of recovered metal product would improve statistical process control for the plating baths.
- 5) expected an improved margin of regulatory compliance since a lower volume and mass of regulated wastewater streams would be discharged to existing treatment and control processes.

- 6) expected a reduction in future liability since reduced volumes of wastes shipped off-site for disposal would result from the metals recovery project.
- 7) expected reduced plating bath maintenance costs since contaminant levels were expected to be reduced in the plating baths.

The anticipated, quantifiable cost savings anticipated at the outset of the metals recovery project are summarized in Figure 9.

Actual Results

The metals recovery project was subjected to a post-project audit by an internal Kohler Company team in January 1992 for the purpose of evaluating projected costs savings and return on investment compared to actual results. A summary of the audit results is included in Figure 10.

Consideration of the initial capital investment for the metals recovery equipment and discounting the actual cost savings as future reduced cash outflows, over a ten (10) year financial planning horizon, results in a calculated internal rate of return of just over 12%.

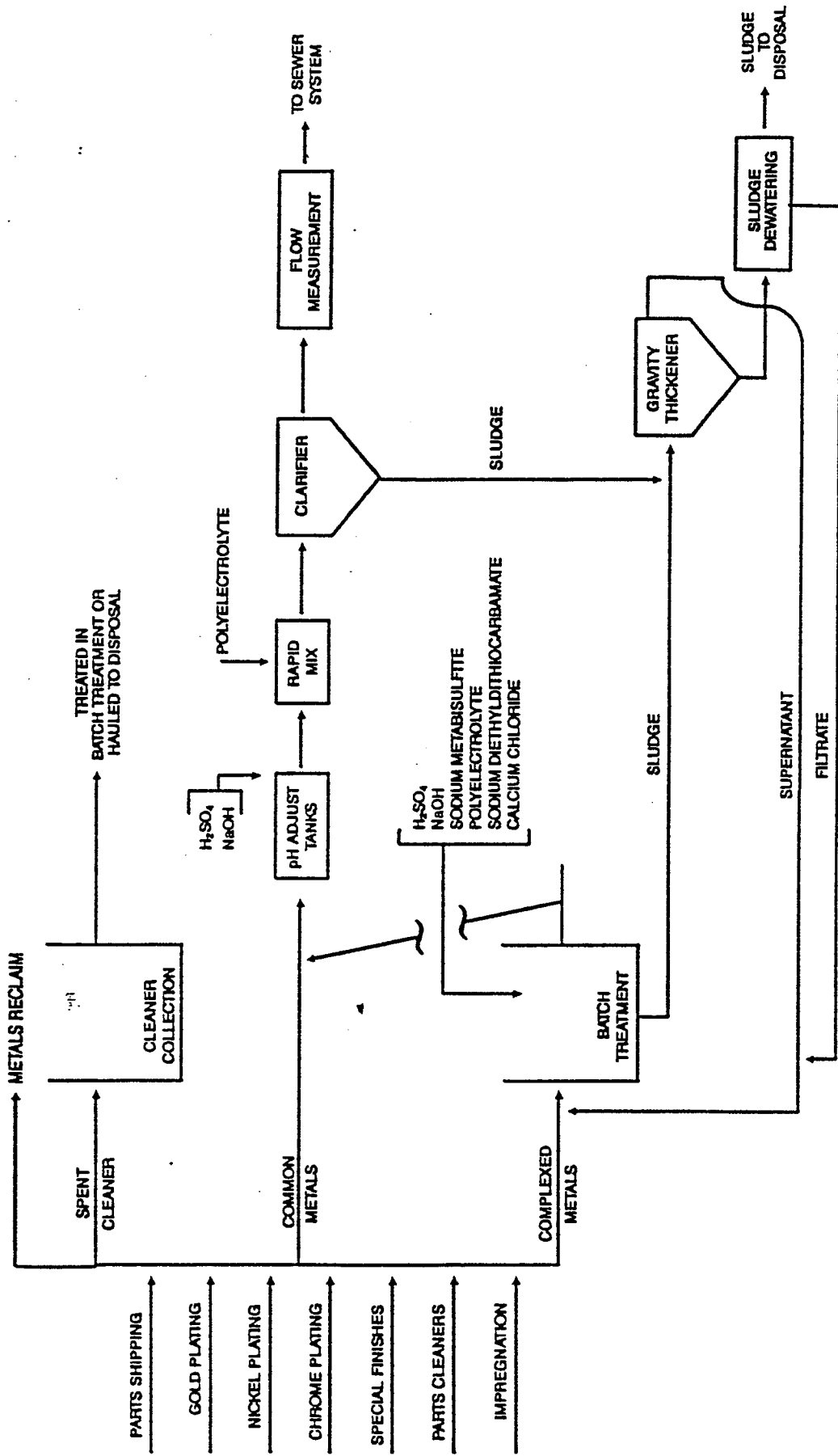
In addition to the quantifiable cost savings delineated in Figure 10, several other qualitative factors were improved with the installation of the metals recovery system. The supervisor of Brass Plating has indicated that the metals recovery system allowed Kohler Co. to change plating chemistry and reduce occurrences of misplating, whitewash and burn on the faucets and fittings. Figure 11 graphically shows that levels of trace contaminant materials have been reduced in the chrome plating bath since start up of the recovery equipment. Other quality improvements have been realized such as brightness, depth and clarity of finishes. All factors have contributed to a better quality end-product for Kohler Co. customers.

SUMMARY

A successful pollution prevention project was implemented for the Brass Division of Kohler Co. This project resulted in several quantifiable cost savings and generated a rate of return of over 12% on the capital investment. Other non-quantifiable benefits were also realized which resulted in improved quality of finished goods and decreased future environmental liabilities. All of these elements helped to stimulate interest and enthusiasm for other pollution prevention projects currently underway at Kohler Co.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the efforts of the Brass Division personnel and the Chemical and Metallurgical Laboratory personnel involved in the planning and implementation of the work described in this paper.



BRASS WASTE TREATMENT SCHEMATIC DIAGRAM

FIGURE 1

KOHLER CO.

BASS WASTE TREATMENT WASTEWATER SOURCES (Percent by Volume)

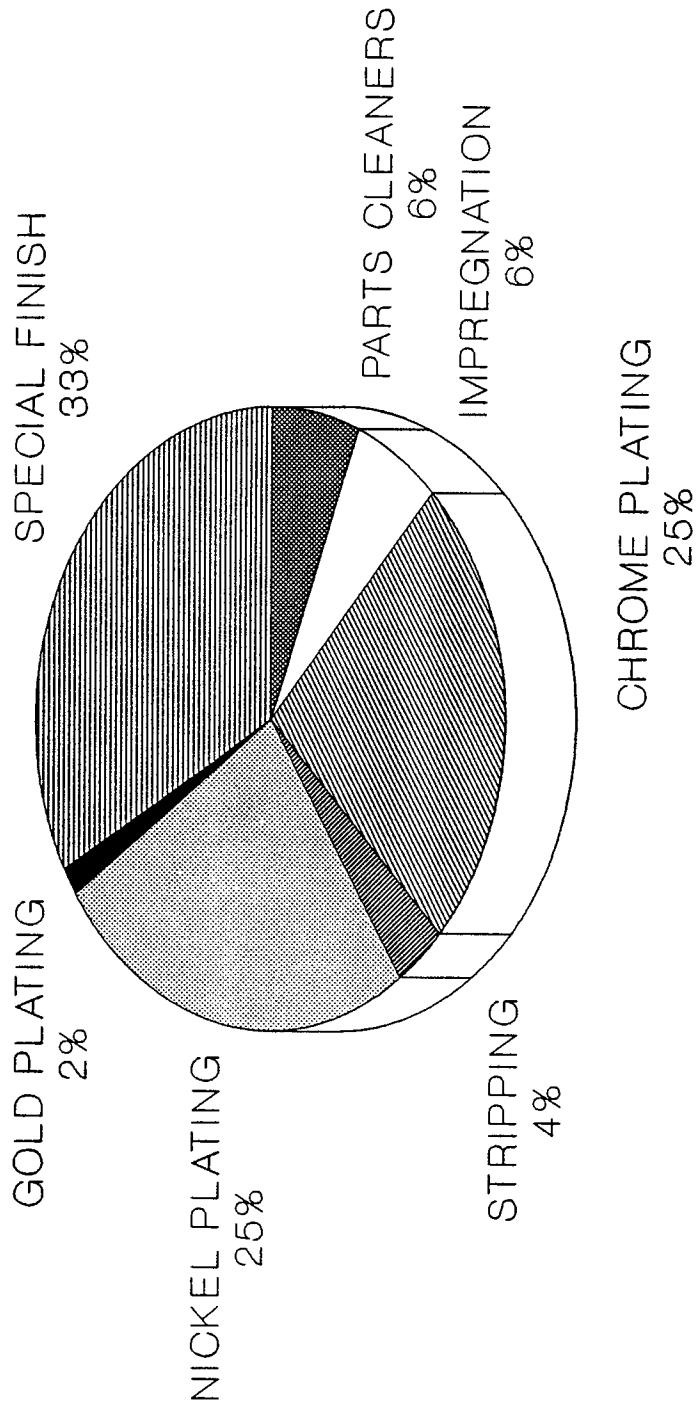


Figure 2

BASS WASTE TREATMENT SOURCES OF DISPOSAL COSTS

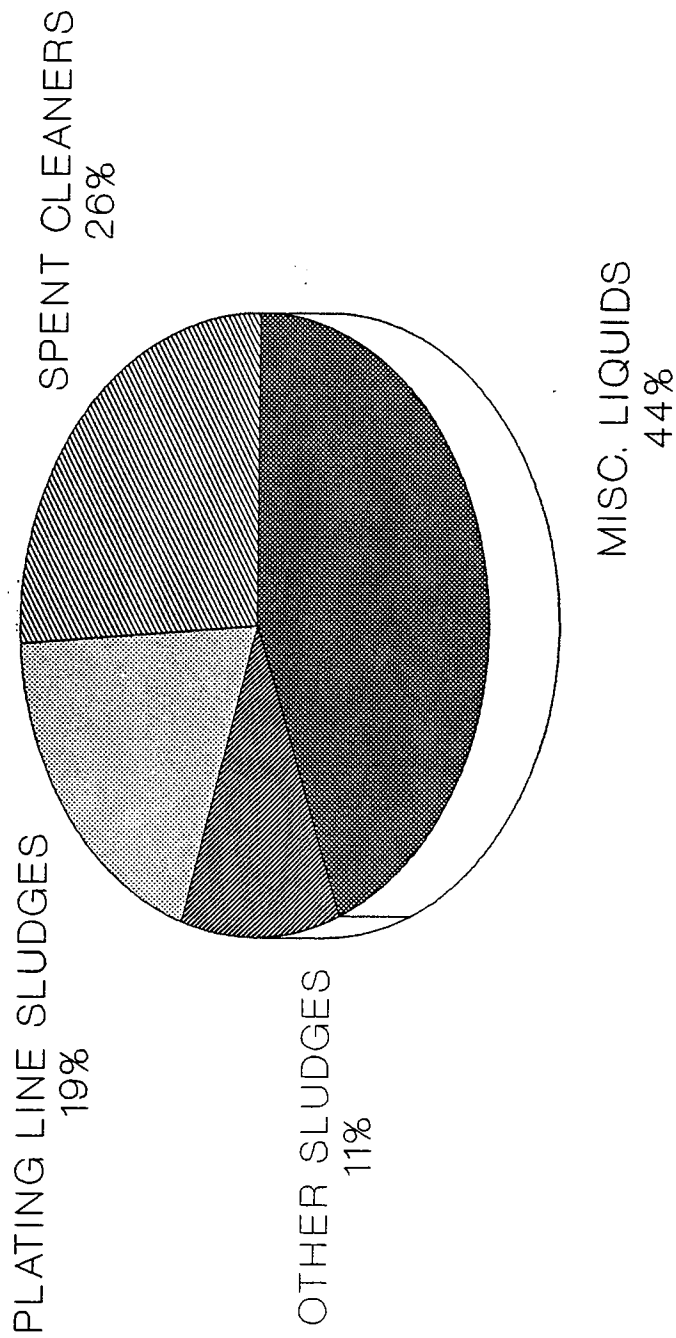


Figure 3

Kohler Co.

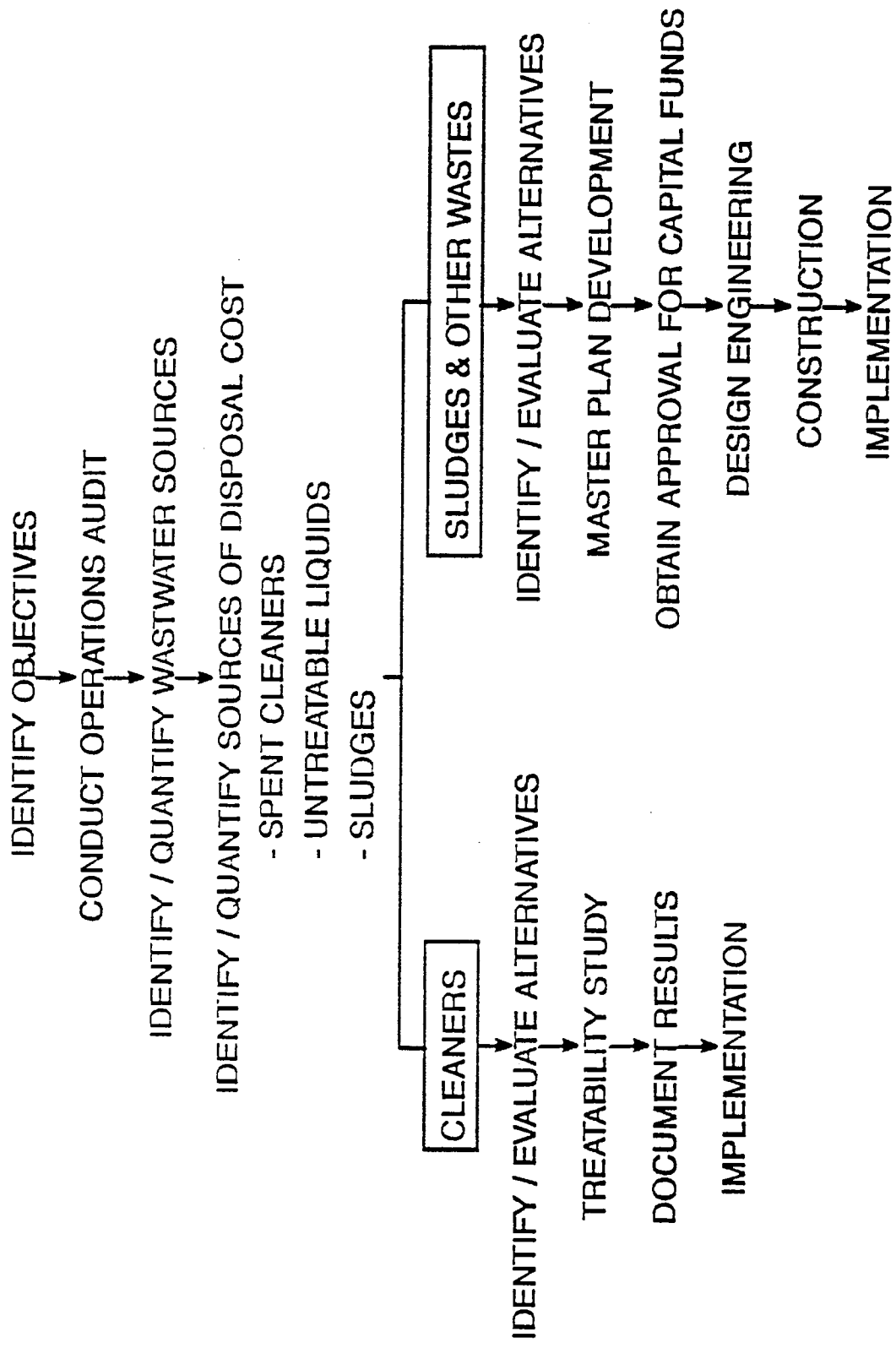


FIGURE 4

BASIC COMPONENTS OF THE CHROME RECOVERY UNIT

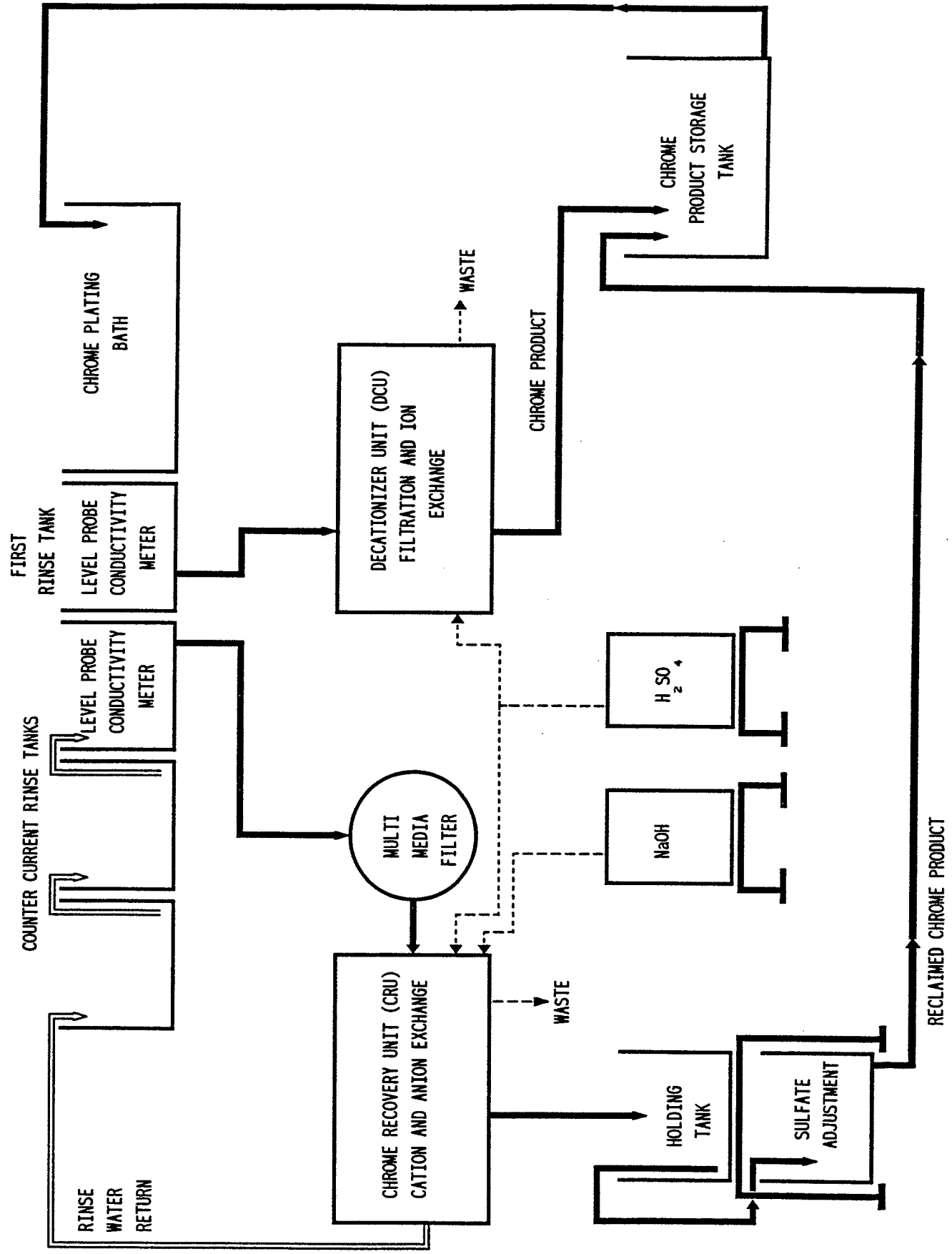


Figure 5

Chrome Recovery Process Flow Train

DCU and CRU Recovery Units

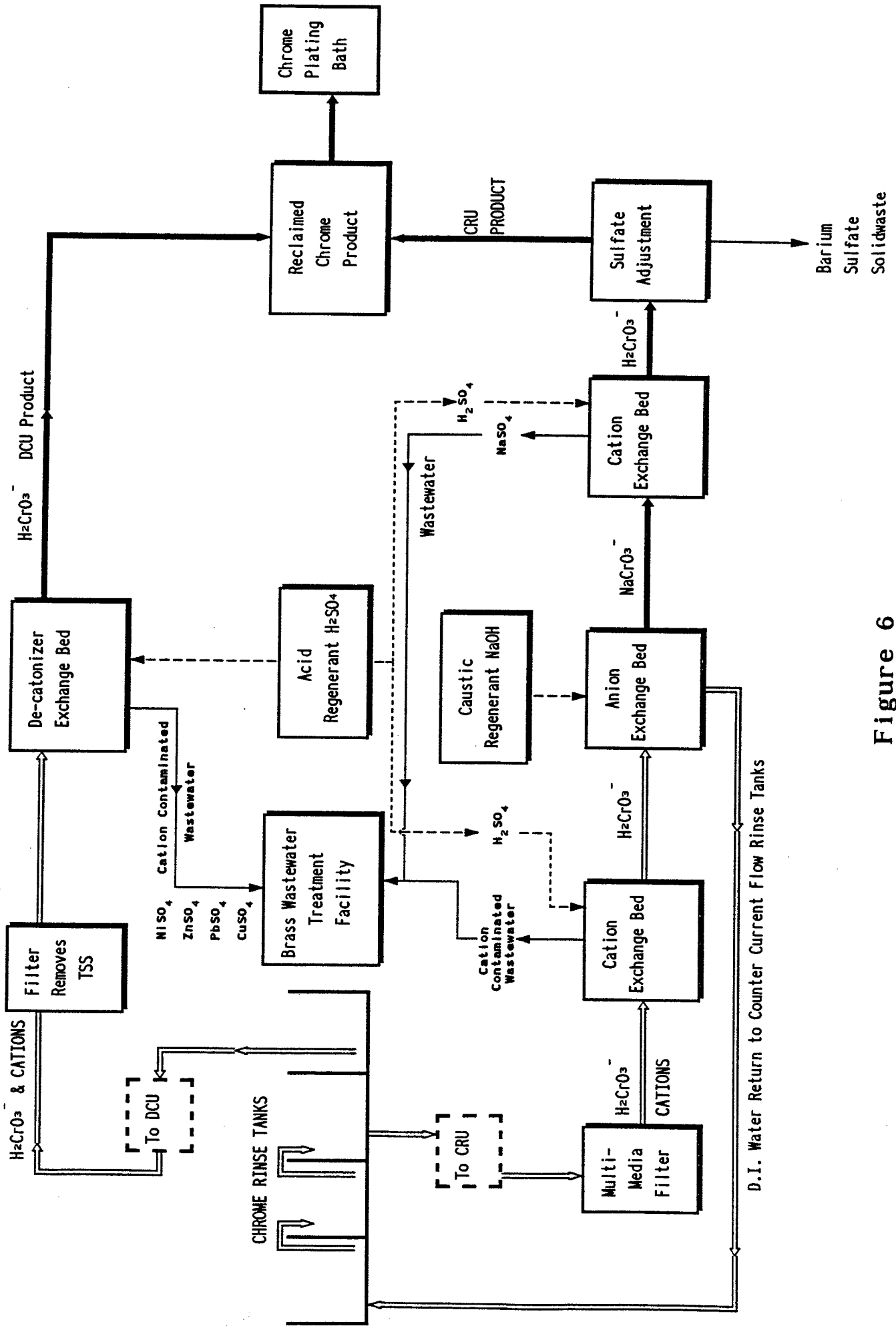


Figure 6

BASIC COMPONENTS OF THE NICKEL RECOVERY UNIT

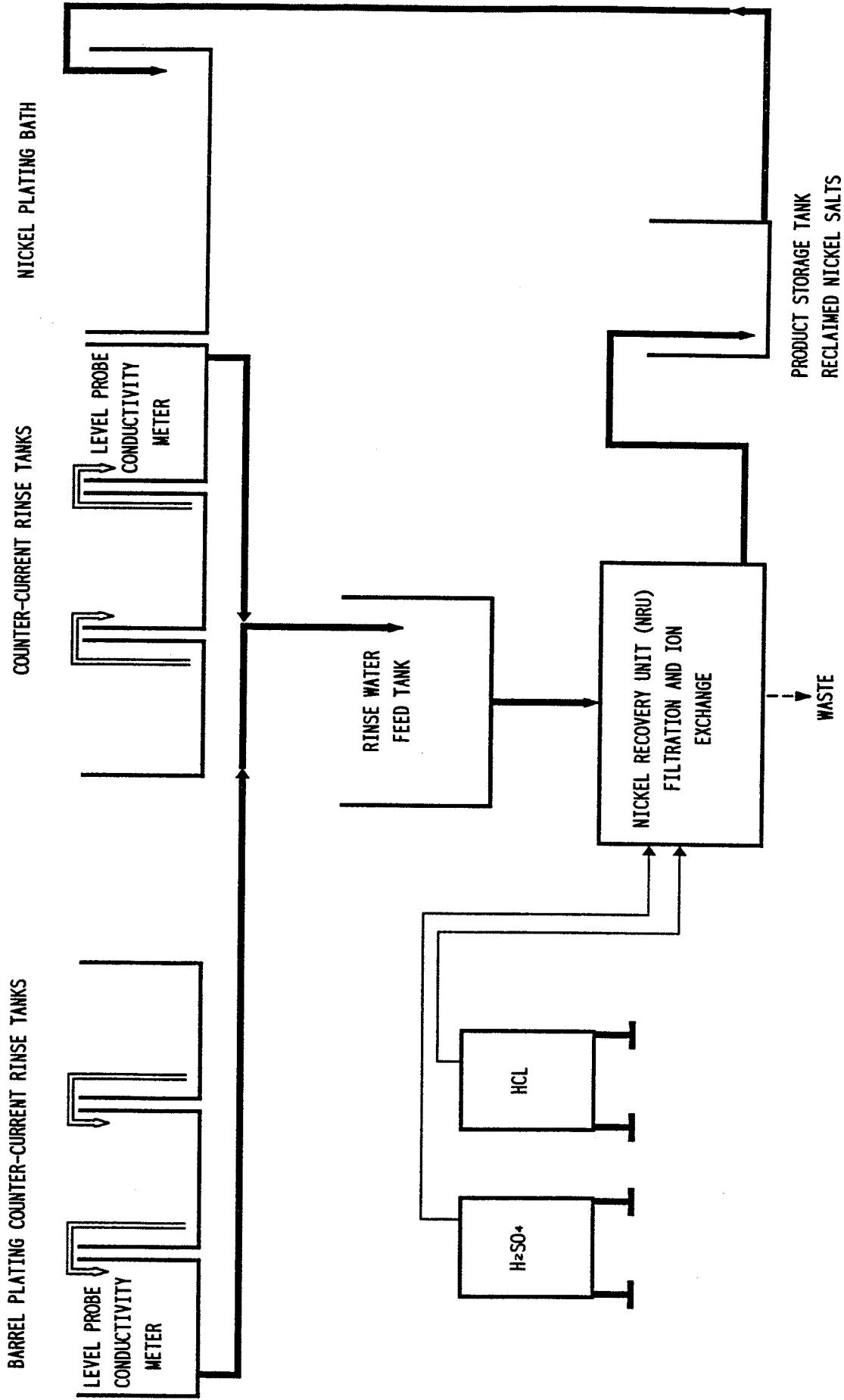


Figure 7

Nickel Recovery Process Flow Train

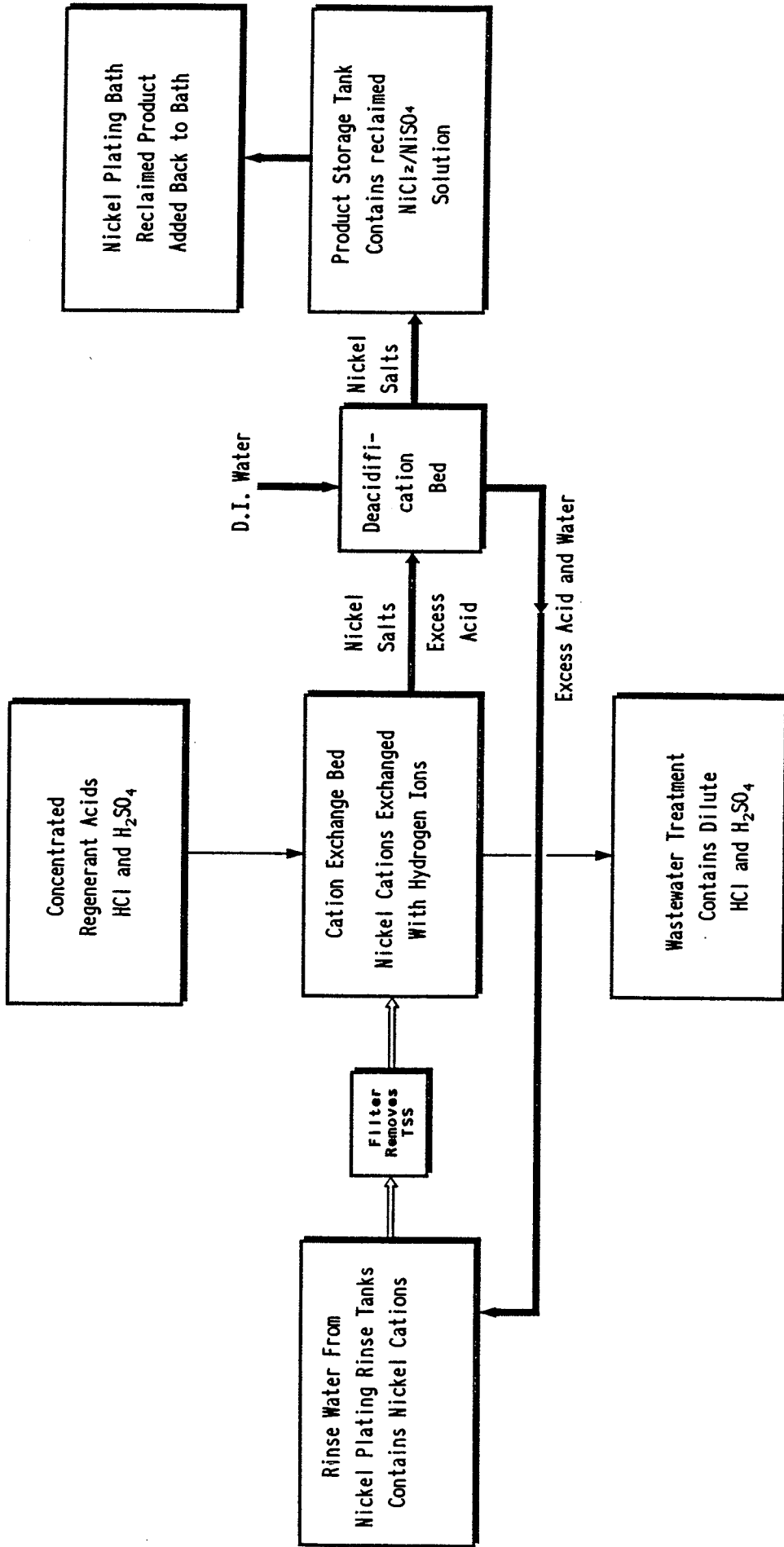


Figure 8

ANTICIPATED ANNUAL COST REDUCTIONS

PLATING RAW MATERIALS PURCHASES (PRIMARILY NICKEL & CHROME)	\$40,000
SLUDGE DISPOSAL	\$12,000
WASTE TREATMENT CHEMICALS	\$11,000

TOTAL	\$63,000

* SAVINGS REPRESENTED A 14.7% INTERNAL RATE OF RETURN (10 YEAR PLANNING HORIZON) BASED ON ANTICIPATED EQUIPMENT AND INSTALLATION COSTS

Figure 9

ACTUAL ANNUAL COST REDUCTIONS

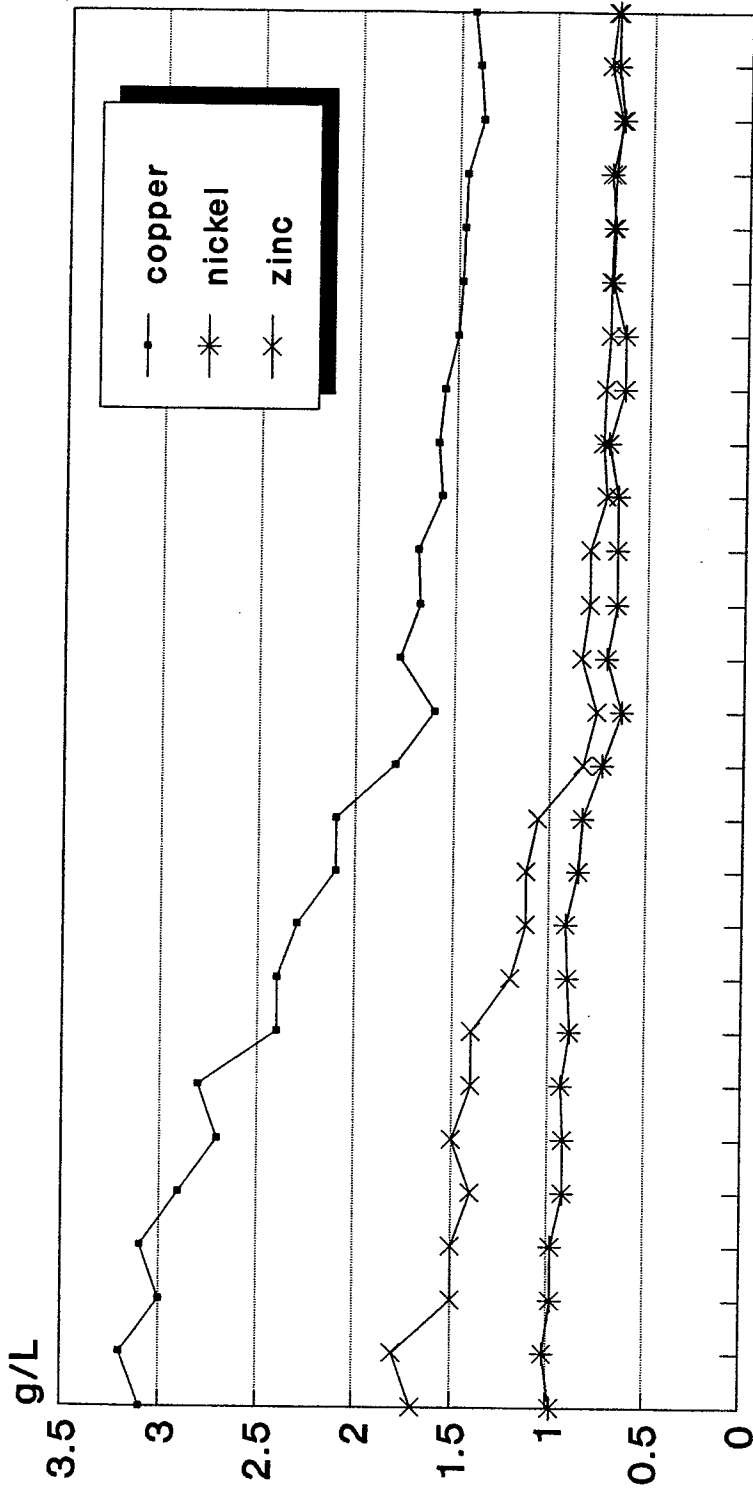
PLATING RAW MATERIALS PURCHASES (PRIMARILY NICKEL & CHROME)	\$32,000
SLUDGE DISPOSAL	\$17,000
WASTE TREATMENT CHEMICALS	\$ 6,000

TOTAL	\$55,000

* SAVINGS REPRESENTED A 12.1% INTERNAL
RATE OF RETURN (10 YEAR PLANNING HORIZON)
BASED ON ACTUAL EQUIPMENT AND INSTALLATION
COSTS

Figure 10

Chrome Plating Bath Metals Concentrations



Analysis Period
Jan. 11, 1991 to March 16, 1992

Figure 11