PHOSPHORIC ACID PLANT DESIGN

FOR THE 21st CENTURY

A VIRTUAL REALITY WITH 3D CAD

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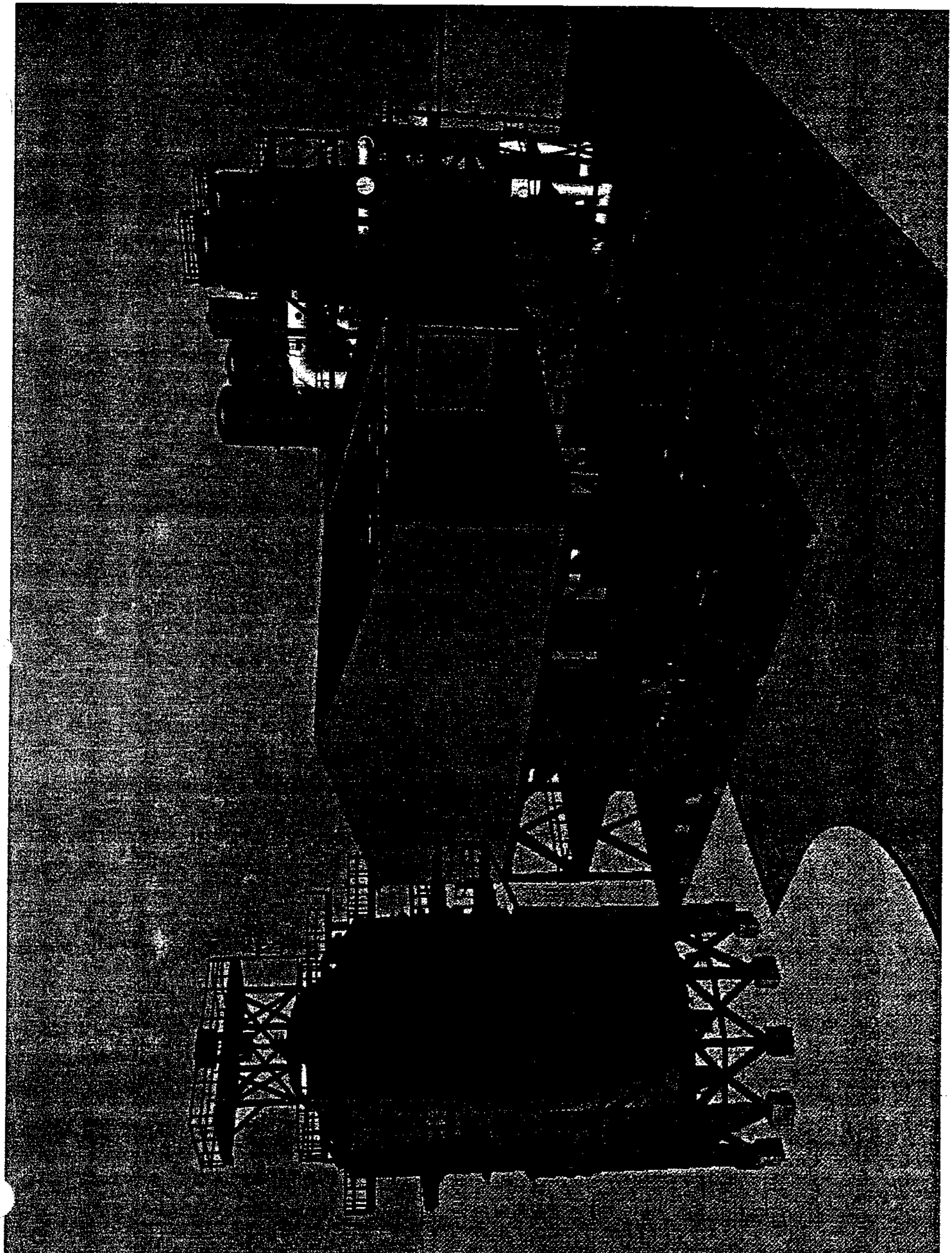

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It has been forecasted that, by the year 2005, an additional 6 million tpy (18,000 tpd) of phosphoric acid (P_2O_5) production capacity will be required to meet world demand for phosphate based fertilizers(1). Recent inquiries received by Raytheon Engineers and Constructions for new phosphate production facilities around the world are based on single train phosphoric acid plants capable of producing 1000 tpd P_2O_5.

In order to meet the anticipated demand for these new facilities, Raytheon Engineers and Constructors (Raytheon) has developed a three dimensional computer model for a nominal 1000 tpd P_2O_5 phosphoric acid plant. The model is based on demonstrated equipment sizes which are utilized in a new phosphoric acid plant which was designed by Raytheon and was recently placed in operation. This plant utilizes Raytheon's proprietary dihydrate Isothermal Reactor Process for the production of phosphoric acid. The new Isothermal Reactor phosphoric acid plant is installed adjacent to an existing 1980's vintage phosphoric acid plant that utilizes square multi-compartment tanks for the reaction of phosphate rock and sulfuric acid. The Isothermal Reactor Process was selected for this world class plant over the competing multi-tank process due to significant advantages associated with the Isothermal Reactor Process including:

- Simplicity of Isothermal Reactor Operation
- Significantly Lower Power Costs
- Lower Maintenance Costs
- Higher P_2O_5 Recovery Efficiency
- Superior Sulfate Control
- Lower Capital Investment

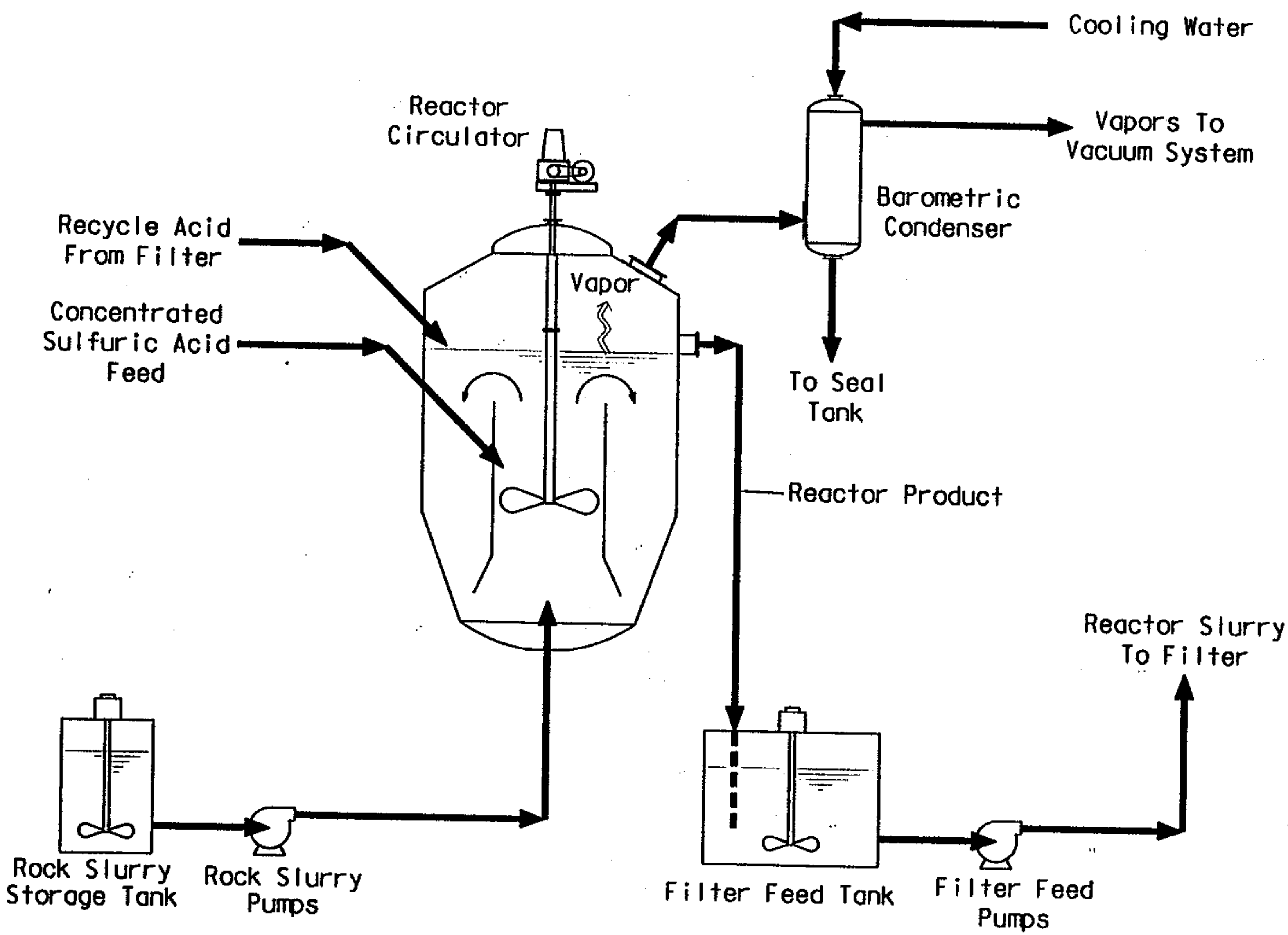
A process flow schematic for the Isothermal Reactor Process is shown in Figure 1. Phosphate rock slurry containing approximately 68 wt% solids is pumped to the bottom inlet of the Isothermal Reactor and into the recirculating mass of reactor slurry. The Reactor Circulator pumps reactor slurry up through the draft tube and around the annular space in the reactor to maintain the necessary velocity for suspension of gypsum solids. Sulfuric acid (93 to 98 wt% H_2SO_4) is injected into the recirculating mass of reactor slurry through feed nozzles located above the Reactor Circulator blades. Phosphate rock slurry and sulfuric acid are fed under flow control to the reactor. The operator has precise control over the free sulfate levels in the reactor. Sulfate corrections are calculated based on the fixed volume of the reactor and physical properties of the reactor slurry. The Isothermal Reactor produces reactor slurry containing 28 to 29 wt% P_2O_5 phosphoric acid (solids free basis) and 35 to 40 wt% gypsum solids.

Reactor slurry level is maintained in the Isothermal Reactor by a fixed point overflow and reactor product line which is sealed below the liquid level in the Filter Feed Tank. A horizontal centrifugal slurry pump, with variable frequency drive, is utilized to transfer reactor slurry to the filter for separation of phosphoric acid product from dihydrate gypsum.

The single train Isothermal Reactor (Figure 2) is 40 feet (12.32 m) in diameter and is equipped with a single 400 hp (300 kw) Reactor Circulator. The Reactor Circulator is designed to circulate 480,000 gpm (109000 m^3/hr) of reactor slurry in order to maintain a reactor slurry differential temperature of less than 1 deg F (0.5 deg C) in the reactor. This high slurry circulation rate turns over the entire volume of the Isothermal Reactor in less than 45 seconds and produces homogeneous and iso-concentration conditions in the reactor slurry. The high circulation rate allows excellent control of free sulfates in the reactor and promotes the formation of large gypsum crystals which results in high reaction and filtration P_2O_5 efficiencies.

Isothermal Reactor Flow Diagram

FIGURE 1



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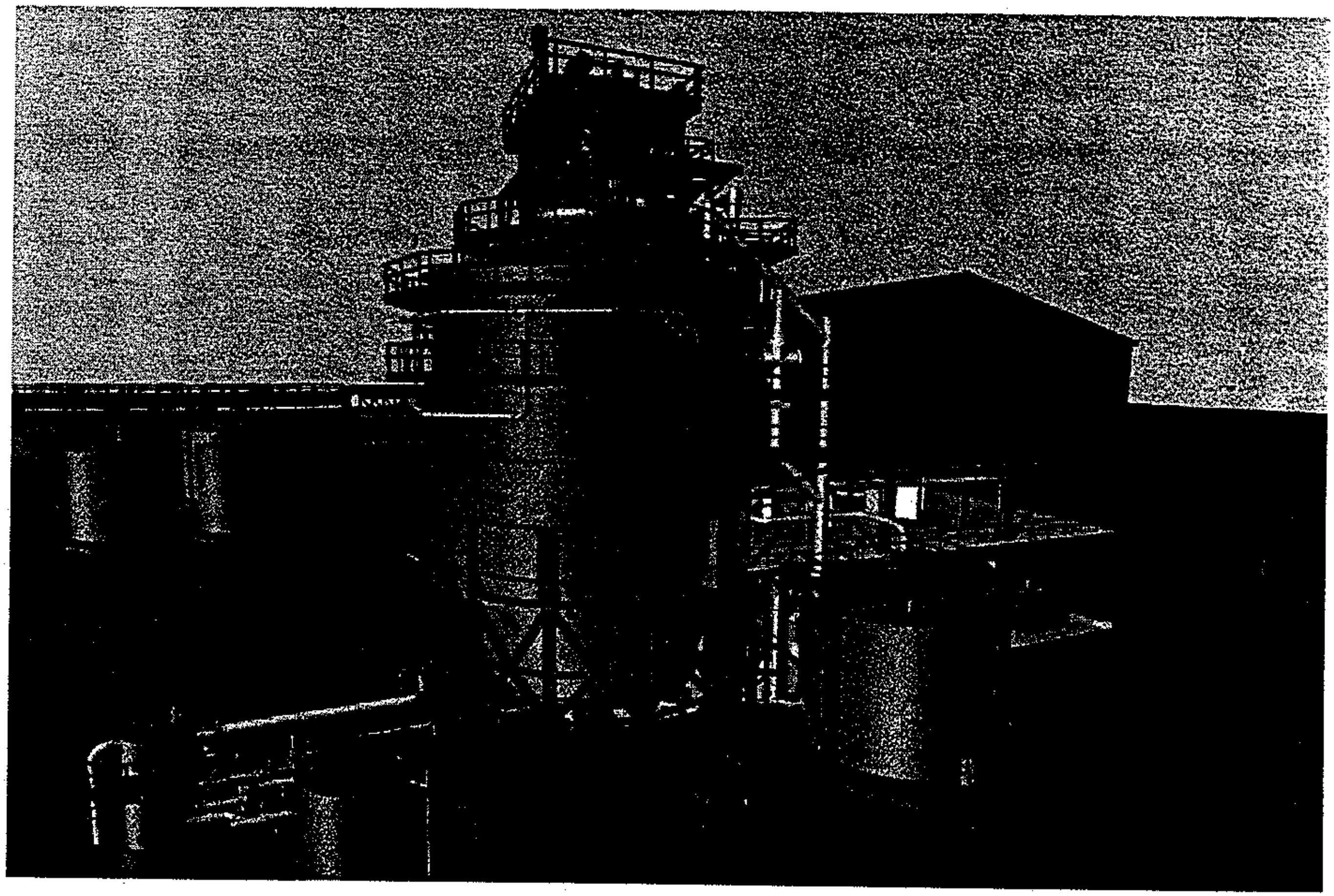

Figure 2 - Isothermal Reactor

The reactor is maintained at constant temperature by controlling the absolute pressure (vacuum) in the reactor. Water vapor, which is flashed from the surface of the reactor slurry, is condensed in a Reactor Barometric Condenser. Non-condensable gases (air and carbon dioxide) produced from the reaction of phosphate rock and sulfuric acid are removed from the reaction system by a liquid ring vacuum pump and are discharged to the atmosphere.

The Isothermal Reaction System for this typical 1000 tpd P_2O_5 phosphoric acid plant is guaranteed to produce 1000 tpd of 28 wt% P_2O_5 phosphoric acid, while achieving 96% P_2O_5 recovery through the primary gypsum filter. The Reaction System, which includes Rock Slurry Feed Pump, Rock Slurry Tank Agitator, Reactor Circulator, Reactor Vacuum Pump and Filter Feed Tank Agitator, is guaranteed to consume less than 20 kwhr of electric power per ton of P_2O_5 produced.

In the Filtration Area, either a single rotating table filter, tilting pan filter or multiple belt filters can be utilized for the separation of phosphoric acid product from gypsum. Due to belt filter size limitations, multiple belt filters of 75 to 100 sq. meters (active area) would be specified for a plant of this size. Belt filters are simpler to install and maintain in locations where labor costs are low and skilled labor is not readily available. Belt filters are a good choice for corrosive services where it is preferred to minimize the amount of high alloy materials in contact with phosphoric acid. Improvements in belt filter design have reduced problems associated with product acid dilution and filter belt support. Belt filters of this size can be supplied by either Filtres Philippe, Eimco or Delkor.

In more developed areas of the world, where labor costs are high and skilled craftsmen are readily available, a single rotating table filter or tilting pan filter with 150 to 200 sq. meters (active area) would be specified to reduce the number of pieces of operating equipment and achieve lower operating and maintenance requirements than can be expected with a multiple belt filter installation. A rotating table type filter of this size can be supplied by either Bird Machinery (USA), Profile (Europe) or UCEGO. Raytheon's 3D plant model utilizes a single #12 UCEGO Filter (Figure 3, 211 sq. meters active area) and Raytheon designed horizontal Filtrate Separator (Figure 4) for the filtration step. The Filtrate Separator disengages air, which is pulled through the filter cake by the filter vacuum system, from phosphoric acid product and filtrate streams. The Filtrate Separator eliminates the need for atmospheric filtrate seal tanks and allows the filter to be installed at a low elevation. Filtrates flow by gravity from the Filtrate Separator to the filtrate pumps (Figure 5). The No. 1 Filtrate Pump transfers phosphoric acid product to the tank farm for storage and clarification. The No. 2 Filtrate Pump transfers recycle acid to the reactor. The No. 3 and No. 4 Filtrate Pumps recycle wash liquors to the filter for counter current washing of the filter cake. Gypsum cake is discharged from the filter and is sluiced for pumping to the gypsum stack.

Filter product acid is transferred from the Storage and Clarification Area to the Evaporators (Figure 6) where the acid is concentrated to 54% P_2O_5 in two single stage forced circulation evaporators operated in parallel. The Evaporators are each 22.5 ft (6.86 m) in diameter and are equipped with Raytheon's patented spiral entrainment separator. Low pressure (25 psig) steam is used to heat the acid in shell and tube heat exchangers constructed either of Hastelloy G-30 or graphite. Water is evaporated from the acid and flows through rubber lined carbon steel ducts to the FSA Tower (Figure 7).

The use of conventional fluosilicic acid (FSA) recovery system design on large diameter evaporation systems would yield low fluorine recovery efficiencies due to high FSA entrainment losses. Conventional FSA system design utilizes a relatively large diameter FSA Tower in order to reduce the velocity of evaporator vapors for scrubbing with a recirculated stream of FSA. The large cross sectional

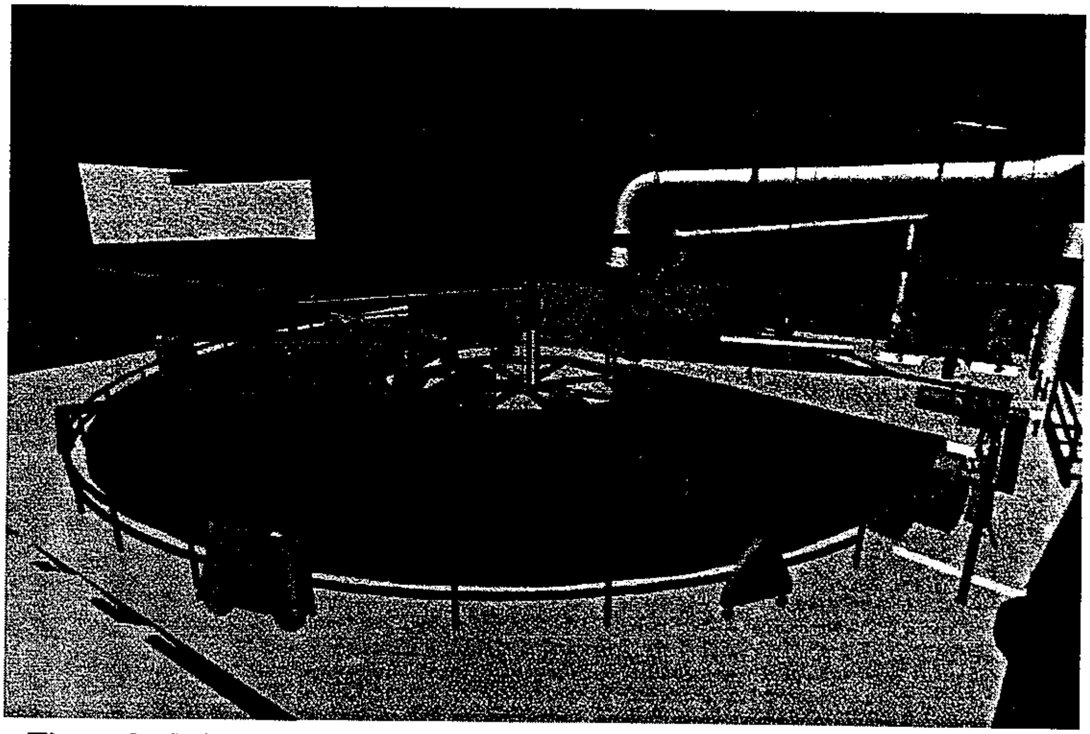

Figure 3 - Primary Filter

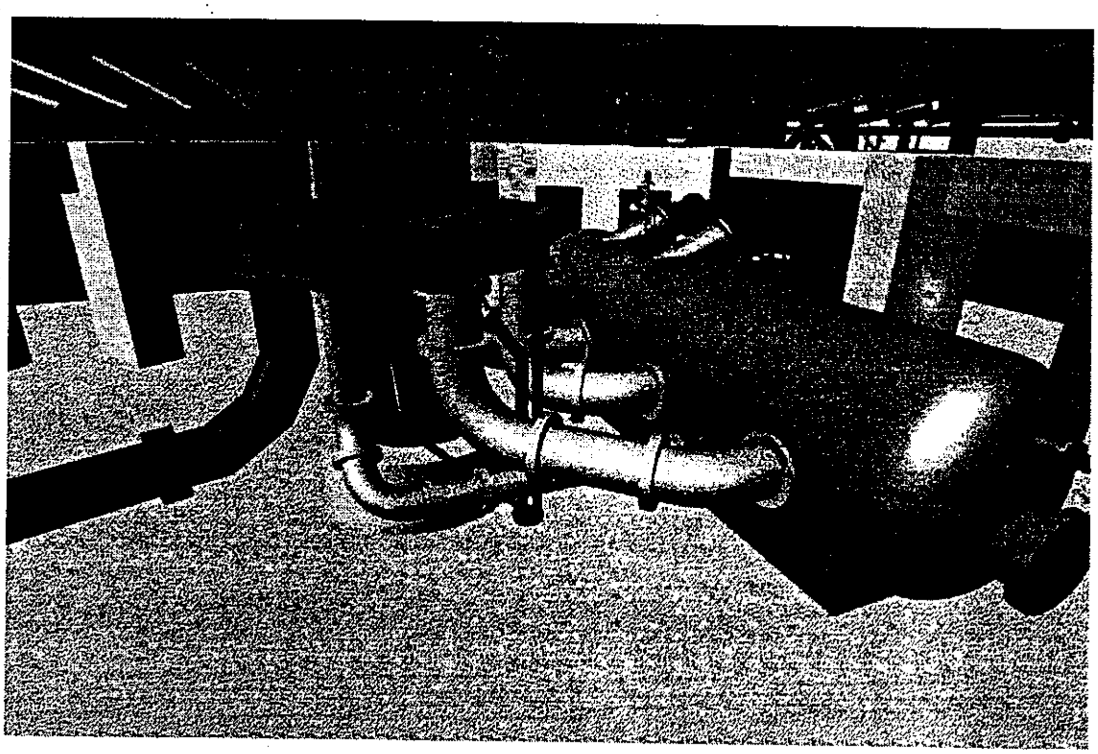

Figure 4 - Filtrate Separator

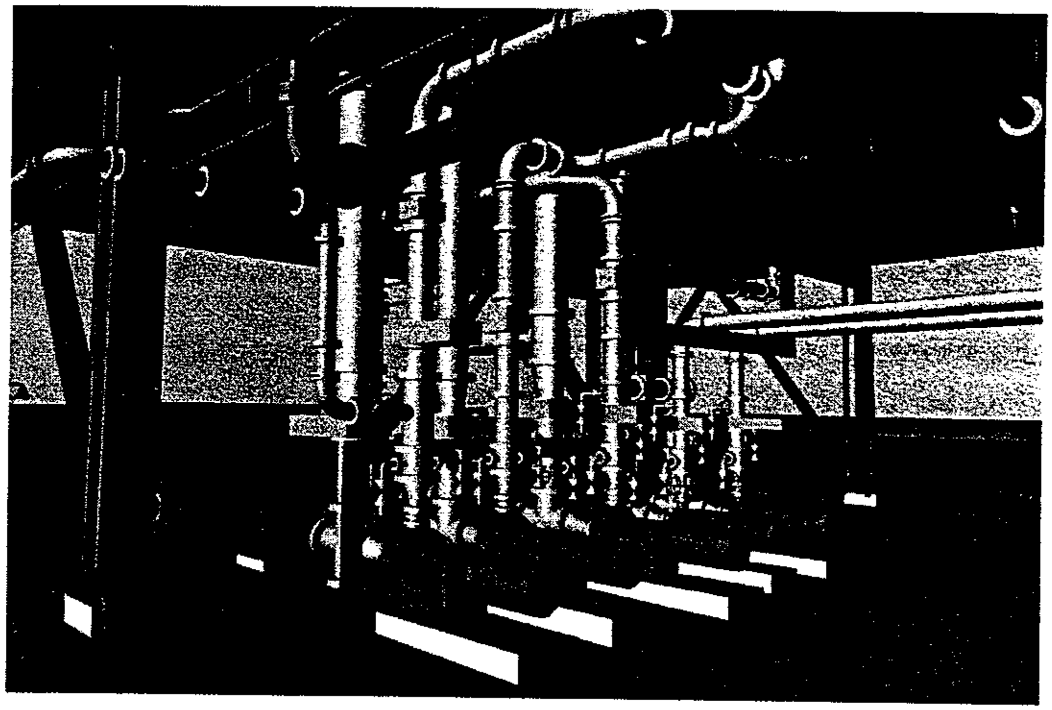

Figure 5 - Filtrate Pumps

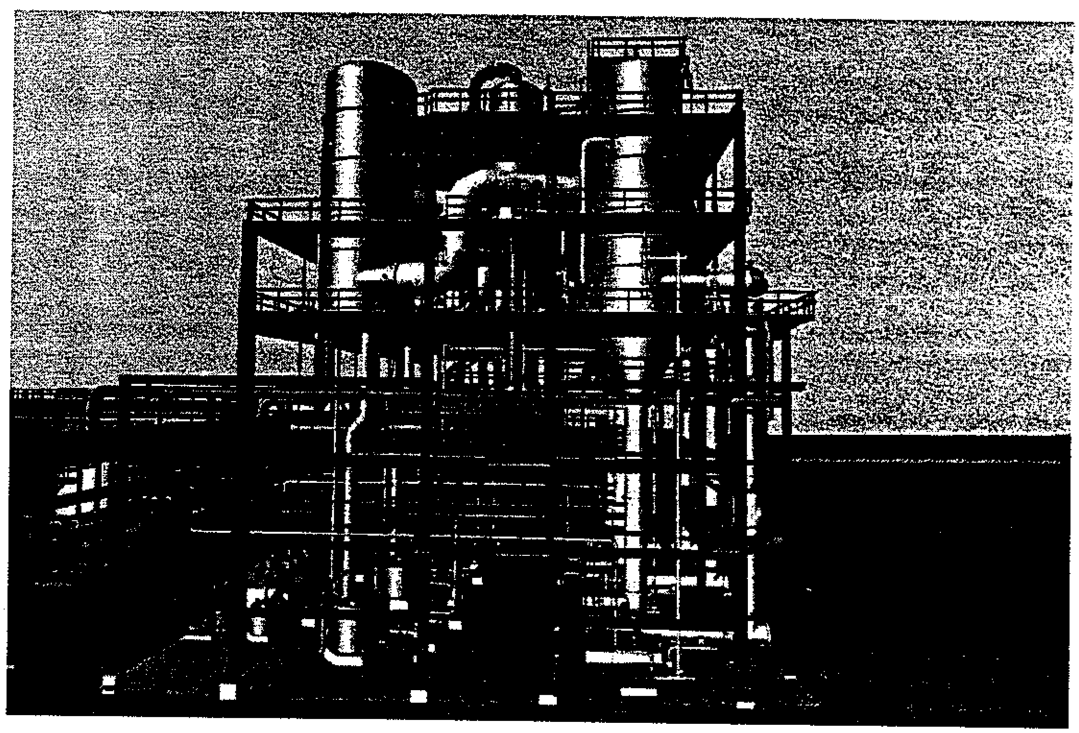

Figure 6 - Evaporator Station

area of a conventional FSA tower requires an extremely high FSA recirculation flow in order to achieve sufficient liquid coverage for FSA recovery. The high flow rate of FSA liquid through the FSA tower spray nozzles would result in high FSA entrainment losses to the Evaporator Barometric Condenser.

Raytheon has developed a new process scheme (patent pending) for the recovery of FSA. This scheme utilizes spray nozzles installed in the evaporator vapor piping (Figure 8). Raytheon's patented spiral entrainment separator is installed in the FSA Tower which is located downstream of the FSA spray nozzles for removal of FSA entrainment. This design reduces the flow rate of recirculated FSA solution and minimizes the quantity of FSA entrainment formed by the FSA spray nozzles. The new design has a higher overall fluorine recovery efficiency than would be achieved with conventional FSA Tower design. A second stage of FSA scrubbing can be installed in the FSA Tower upstream of the spiral entrainment separator to achieve higher fluorine recovery efficiencies.

Vapors exit the FSA Tower and flow to the Evaporator Barometric Condenser where water vapor is condensed by direct contact with cooling tower water. The FSA Recovery System minimizes the amount of fluorine which enters the cooling tower water and associated fluorine emissions from the cooling tower. Non-condensable gases (air) are removed from the Evaporator by a liquid ring vacuum pump or steam ejectors which compress the gases for discharge to the atmosphere.

Virtually all of the new phosphoric acid plants which are in the planning stage are to be equipped with cooling towers (Figure 9) to eliminate or minimize the size of acidic cooling ponds. There are several locations where it is still permissible to discharge gypsum slurry and cooling water to the ocean, however, the general trend throughout the world is to eliminate acidic water discharges to the environment. Most countries now require liners to be constructed under new

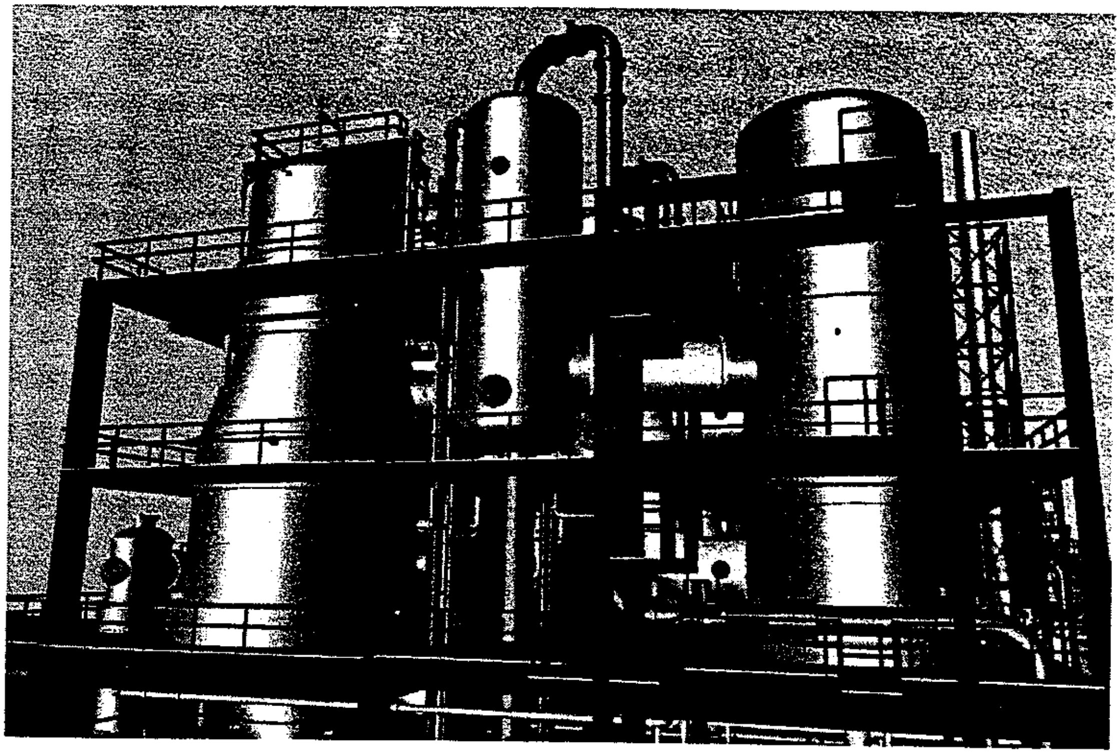

Figure 7 - Evaporator, FSA and Barometric Condenser

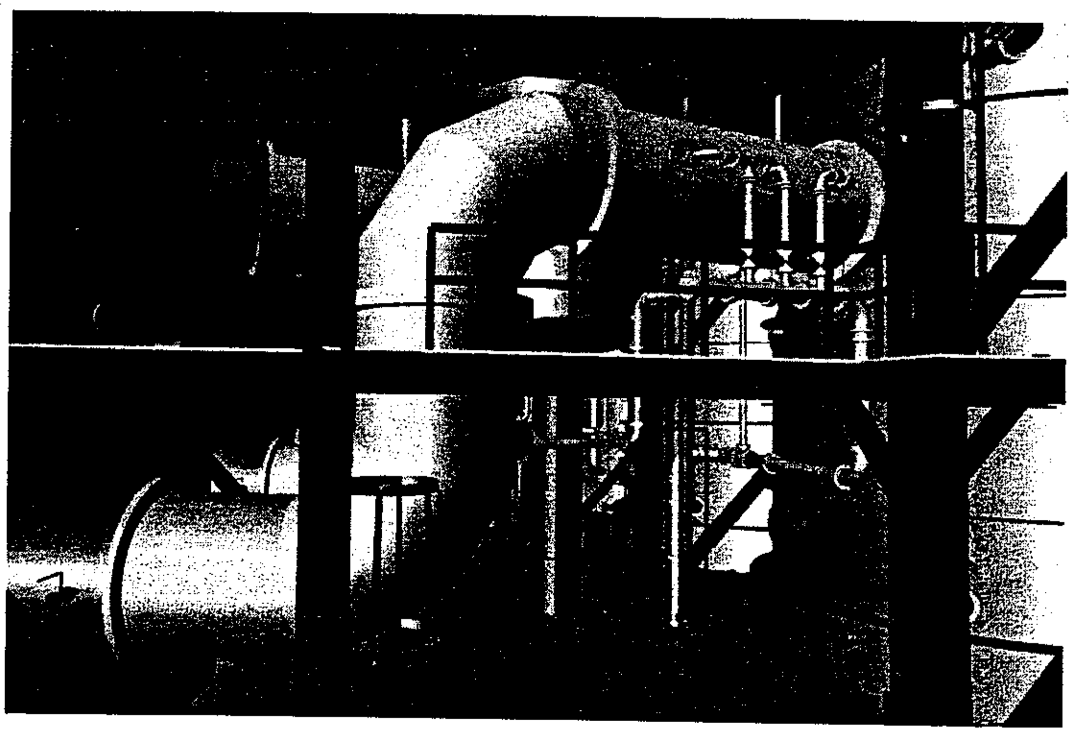

Figure 8- FSA Spray Header

acidic cooling ponds and gypsum stacks. The cost of gypsum stack and acidic cooling pond liners and the associated environmental liability risks has led many clients to include cooling tower installations in their bid documents for new phosphoric acid plants.

The installation of Double Filtration is becoming an accepted method for reducing environmental risks and costs associated with gypsum stacks and cooling ponds[2]. Double Filtration involves the installation of a secondary filter downstream of the primary phosphoric acid plant filter. Belt filters are a good selection for use as secondary filters since they can be operated at high speeds to optimize filtration. Figure 10 shows a 3D rendering of a typical belt filter installation. The gypsum discharged from the primary filter is slurried with sluice water which is recirculated from the de-watering section of the secondary filter. The gypsum slurry is then filtered on the secondary filter and washed to recover additional water soluble P_2O_5. A significant advantage of a secondary filter is that, with a closed plant wash system, all acid spills and wash losses can be recycled to the feed box of the secondary filter for recovery of P_2O_5 value. The installation of a secondary filter, in a new phosphoric acid plant operating with a 2.0% water soluble P_2O_5 loss on the primary filter, can reduce the water soluble P_2O_5 loss from the plant to ~0.5% P_2O_5. Nearly all acid handling and wash P_2O_5 losses can be recovered with the installation of a secondary filter.

Benefits of Utilizing 3D CAD Design

The use of 3D CAD for the design of new chemical plants has many benefits including reduced initial plant cost from optimized designs and improved constructability. Equipment arrangement can be reviewed and optimized by all responsible engineering, operations and maintenance personnel to insure accessibility for equipment installation, operation and maintenance. Interferences between structural steel, piping, electrical and instrumentation are eliminated. Exact material lists are generated automatically for purchase which reduces the

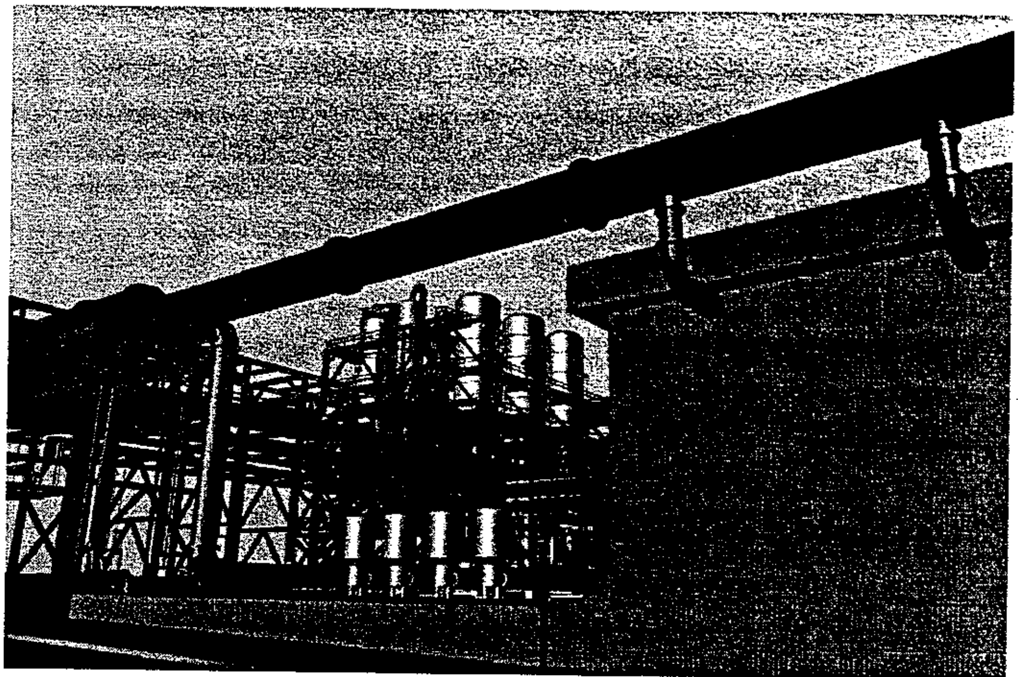

Figure 9 - Cooling Tower

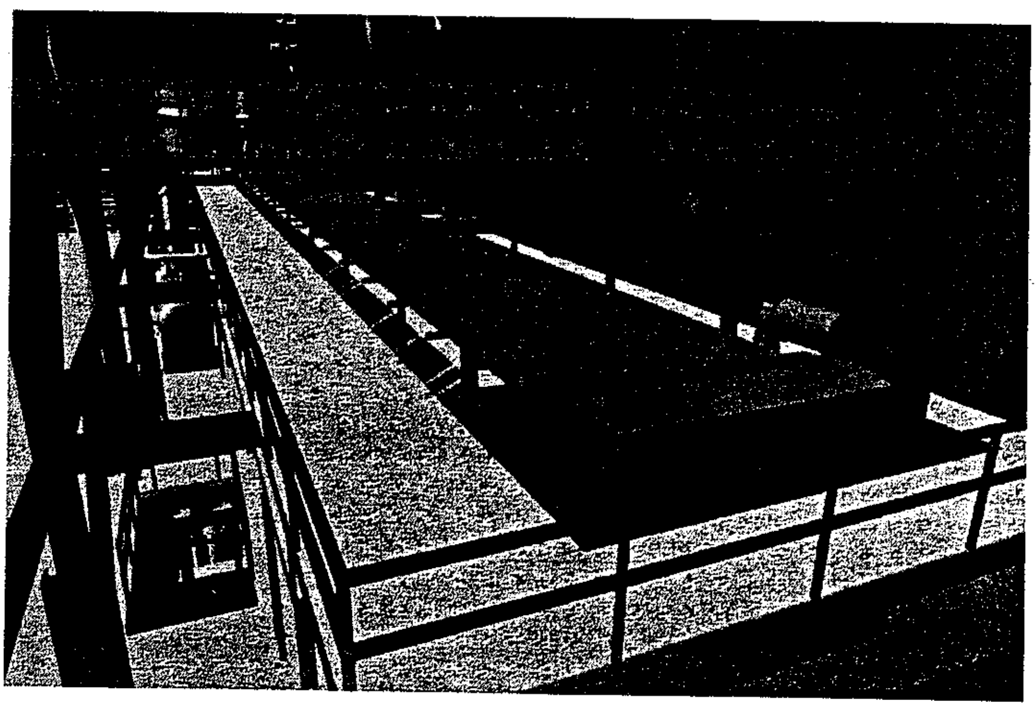

Figure 10 - Belt Filter

amount of surplus material purchased. A 3D model can be used by construction personnel to optimize plant erection schedules which reduces construction time and cost. The model can also be used for operator training, safety and OSHA compliance reviews.

The engineering and design effort for a 1000 tpd P_2O_5 phosphoric acid plant will generate approximately 1400 engineering drawings, 200 specifications and 1100 piping isometric drawings and require approximately 2000 tons of structural steel and 30000 linear feet (9150 m) of pipe to construct. With the use of 3D CAD, a large scale phosphoric acid plant can be engineered and constructed in less than 24 months. Actual construction experience has shown that field construction rework can be reduced to less than 1% with 3D CAD design.

REFERENCES

(1) "Challenges and Opportunities Ahead" - Phosphorus and Potassium, No. 207, January -February 1997, Michael Rahm

(2) "Where does all the process water go?" - Phosphorus and Potassium, No. 207, January-February 1997