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07890

Distr.
LIMITED

ID/WG.270/1
3 February 1978

ENGLISH

United Nations Industrial Development Organization

Arab Federation of Chemical Fertilizer Producers
(AFCFP)/UNIDO Seminar on Raising Productivity of
Fertilizer Plants

Baghdad, Iraq, 24 - 27 March 1978

UTILITIES SUPPLY, OFF-SITE FACILITIES AND TECHNICAL INFRASTRUCTURE FOR EFFICIENT OPERATION OF FERTILIZER PLANTS*

by

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CONTENTS

I. SUMMARY

The causes of plant downtime and equipment breakdowns are reviewed and the role of utility services, offsite facilities, technical infrastructure and their interdependibility in increasing reliability and operational efficiency of a fertilizer complex have been discussed.

It is concluded that in order to operate a fertilizer plant at optimum production capacity the design of utility services and offsite facilities should be achieved in two or more trains. Sufficient safety factors should be allowed in their design so that each train has an over design factor of about 20 percent. In addition, in developing countries, the power generation facilities should be fully integrated with the plant.

Operational control of various utility units are reviewed and their effects on plant performance have been discussed.

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II. INTRODUCTION

During the last two decades dramatic changes have occurred in the design and performance of process plants as a result of relentless commercial pressure for lower unit costs and for better and totally new products. Almost always these changes have been in the direction of improved specific performance and frequently they have involved an increase in plant size to achieve lower capital cost per unit of output. Fertilizer plants are a classic example of these changes where the size of ammonia plants has increased from 100,000 tons per annum about fifteen years ago to about 500,000 tons per annum today.

Essentially the problem facing any Project Manager for a large single stream plant is the overall question of on-stream time which is closely related to process and equipment reliability, instrumentation design and performance, catalyst life cycles, utilities and offsite facilities such as power generation and emergency power availability, cooling water and water treatment facilities, effluent disposal, etc. In addition, there are associated problems of determining the critical spare-parts, equipment inspection schedules such as boiler inspection and periodic inspection of heavy rotary equipment and pressure vessels.

Reliability may be defined as "Freedom from Malfunction or failure and to guarantee satisfactory performance for a specified period of time under certain defined operating conditions". Reliable performance for a specified period applies in particular to those parts which due to severe operating conditions have shorter life than the main machine, for example, roller bearings, gas turbine blades, thrust bearings, pistons and packings, valves etc.

It is a normal practice to specify the required period for which the equipment will run continuously. Petrochemical and fertilizer plants, as an example, are designed with the major rotating equipment suitable for three years continuous operation, while gas and diesel engines are required to operate without break-down for a minimum period of about 10,000 hours. The reciprocating compressors however, have much shorter operating life of about 4000 hours afterwhich they must be stopped for maintenance. These major rotating equipment are further subjected to severe operating conditions during start-up, process up-sets, and emergency shut-downs and the design of these equipment must allow for these un-warranted situations.

Early developments in reliability engineering took place mainly in the military and space-research field where the over-riding objectives were to achieve specified performance and reliability very rigidly irrespective of cost factors. In the commercial world of chemical and fertilizer industries similar situations also exist where for example, reliability is essential for safety, but in general, cost of improving reliability has to be justified on oconomic grounds.

The problem of high reliability of process equipment and of chemical plants has been aggravated by the rapid growth in the capacities of large scale operations. The major advantage of the large single stream plants is that unit cost of the products has been considerably reduced. However, the economic advantages of large scale plants depend upon thoir continuous, uninterrupted operation, high degree of reliability of rotating equipment and individual items of equipment in the battery limits and off-site facilities. In addition, the roquirements for utilities such as steam and power generation, cooling water, water treatment plant, effluent disposal, spare-parts, etc. must be thoroughly examined at the design stage so that these do not affect the continuous oporation of the battery limits plant.

In this paper the requirements of battery-limits plant with respect to utility services, offsite facilities and other technical infrastructure have been examined from the point of view of attaining reliability and design production capacity.

III. COMPREHENSIVE OUTLINE OF ISSUES

For the purpose of this paper, the Fertilizer Complex shall include, but not limited to, the following battery limit processing units, utility, and offsite facilities, and associated technical infrastructure:

A-Battery-Limit Processing Units

The battery-limit processing units include the following plants:

1) Ammonia and Carbon Dioxide Production Plant.
2) Urea Production Plant
3) Ammonia Storage Facility
4) Bulk Urea Storage Facility

B-Process Utilities

The process utilities area in the complex serves as the self-contained support facility for the processing plants. Major support functions include the following:

1) Process Steam

   It is generated for use in the Urea Plant and the offsite facilities.

2) Power and Electricity Generation, Distribution and Standby Emergency Power

   Power requirements are either through generation within the complex or obtained from the national grid. In developing countries, it is desirable that the entire complex is completely independent of any outside source of power during both construction and the following operation phases. Provision should also be made for emergency power supply in case the main power source is cut-off.

3) Water Pre-Treatment and Demineralizer Plant

These facilities are provided for the production of boiler feed water, cooling water for the ammonia, urea and offsites, cooling water systems, service water and potable water for the plant and housing colony. Raw water sources may either be the underground water, irrigation water-ways, lakes or a river.

4) Natural Gas/Fuel-Stock Supply

Feed-stock/natural gas transmission line is provided to the battery limits plant as well as the boilers/steam generation area.

5) Instrument and Plant Air System

Plant and instrument air is provided for the battery limits and offsite facilities.

6) Inert Gas Generation and Supply

Inert gas generation facility is required to protect the ammonia plant catalysts and to provide inert gas cover to the vessels for safety reasons.

7) Fire and Safety System

A fire-water and plant safety protection system is provided in order to serve both process plants as well as the housing colony.

C-Offsite Facilities

The offsite support facilities include the following:

1) Material Handling System

These are provided to convey the bulk urea product to bagging and bagged product storage. Provision for rail-car and truck loading is also included in this system.

2) Storage Facilities

These are provided for

i) Demineralized Water
ii) Filtered Water
iii) Potable Water
iv) Caustic and Acid Storage
v) Oil Storage

3) Maintenance Workshop, Spare-Parts, Warehousing, Control Rooms and Control Laboratory etc.

Maintenance workshop, process and utility control rooms, and laboratory control facilities are provided within the complex.

4) Process and Water Wastes Treatment Facilities

These are provided for the waste streams from the plant. Sanitary sewer wastes also treated before these are discharged from the factory.

5) Administrative Facilities, Medical Centre and General Facilities

In addition to all the major items listed above, minor items and systems required to provide a completely self-sustaining, integrated fertilizer complex are included in the scope of the offsite facilities.

D-Technical Infrastructure

The economics of ammonia and urea production costs have increased sharply. The wave of new construction of nitrogen fertilizer plants has contributed to the sharp increase in costs. Labour and material costs have also increased substantially.

Table-I shows a rough estimate of investment costs for urea and ammonia plants completed in 1973 as compared with similar plants which are scheduled to be completed in 1978. These costs pertain to 1000 tons per day/ammonia and 1700 tons per day urea plants. However, these costs are for plants in U.S.A. Gulf Coast and European locations using natural gas feedstock.

The cost of similar plants in the developing countries are much higher and on present prices are estimated in the region of $220 to 240 million. The major reasons for higher investment costs in the developing countries are freight and shipping costs, investment in integrated power generation facilities, access roads, port facilities, housing, higher licensing, design, engineering and construction costs and other infrastructure necessary at the plant-site.

Basically the major risk in the construction of large fertilizer plants lies in the inability of the plant management, specially in the developing countries, to operate the plant substantially at full capacity within a relatively short period of time after commissioning. The favourable economics of large plants essentially depends upon the attainment of the design production capacity within a reasonable time after the plant is commissioned. This factor is demonstrated in Table II, which records the data on the cost of production and rate of return for 1700 tons per day ammonia/urea complex. Basic data and other material costs used in these calculations are taken from a fertilizer complex operating in a developing country. The production costs have been worked out on the basis of recommendations of the International Financing Institutions that in a developing country, a large scale plant will attain 65 percent production capacity during the first year of operation, 80 percent in the second year, 95 percent in the third year and 100 percent in subsequent years. The profitability of large scale plants in developing countries depends upon many factors such as:

1) Cost of the feedstock
2) Interest rate on the capital investment
3) Availability of technical man-power and their ability to operate the plant at design capacity.
4) Plant down-time

If the capital is available at reasonably low interest rates, as is the case in OPEC countries, the prices of the feed-stocks are kept at low value, and the plant can be operated at near design capacity, it would be possible to produce fertilizer in developing countries at prices competetive with those prevailing in the developed countries where raw material costs, and the cost of capital are relatively high.

It is evident that fertilizer plants are capital intensive, highly sophisticated, and require competent and adequately trained man-power to operate and maintain them at optimum efficiency and design throughput. The technical infrastructure necessary for successful operation of fertilizer plants, in particular in developing countries, should include;

1) facilities for operator training and manpower development;
2. critical spare-parts, catalysts, and chemicals for two years of plant operation and their inventory control;
3) organised preventive and planned maintenance procedures;
4) Efficient management.

E-Causes of Fertilizer Plant Shutdown

The operating difficulties which are encountered with the large ammonia and urea plants fall under several headings. Some of these stem from faults in general design errors in scaling up. Others arise from faults in plant construction and installation which do not become apparent at once although they can be rectified during start up, but at cost. A third group of problems arise from faults in the design and fabrication of plant equipment and these can be extremely serious because most of the equipment for example, reactors, compressors and turbines, are so specialized that replacement is not possible from stocks. Finally there are the technical problems due to faulty supervision and operation and control of the battery-limits process plants, utilities, offsites, and due to the absence of technical infrastructure necessary for the smooth operation of the plant. These problems can arise any time during the life of the plant and these can prove extremely costly in the case of single stream plants.

F-Impact of Performance of Auxiliary Units on Output

Many papers (2,3,4) have appeared in the literature in which a comprehensive survey of ammonia plant shutdowns have been carried out. These surveys cover industry's performance from 1969 through 1976, and focus on the causes of shutdowns. In one of the surveys (3) a total of 30 large tonnage, single train, centrifugal type ammonia plants were investigated, eleven plants rated at 600 ton/day, sixteen at 900 to 1200 ton/day, and three at 1500 ton/day capacity. These plants represent 83 percent of the U.S. and Canadian large tonnage units on-stream before 1975.

An analysis of the statistical data collected in these surveys indicates that the performance of the "average" ammonia plant appears to have "levelledout" at 50 downtime days and 10 to 11 shutdowns per year as shown in Table-III. This is equivalent to an on-stream factor of 86 percent. The operating capacity in the Asian countries is, however, much lower, and according to a survey carried out by UNICO (5) is estimated at 60-62 percent of the design capacity.

It should be noted that downtime is measured from the time that a plant stops exporting ammonia product until it resumes this function. A shutdown occurs whenever the export of ammonia is interrupted.

The range of downtime experienced by individual plants is quite large varying from 10 to 114.7 days per year for the above survey period. Since annual downtime is arithmatically computed, the industry's average is higher than that experienced by most plants. In both the 1973-74 and 1975-76 survey periods, two-thirds of the participating plants experienced downtime equal to or less than the nominal 50 days per year.

The causes of plant shutdown fall into five basic catagories. The frequency of each is given in Table-IV.

This data indicates that one out of every two shutdowns is caused by a major equipment failure. On the other hand the number of shutdowns annually experienced by the "average" ammonia plant has risen from 8½ during the 1971-72 survey period to 11 during the latest survey period. This is equivalent to one shutdown every 33 days.

Instrument failures are quite varied with no specific instrument type or application dominating the number of failures. It is noteworthy, however, that the instrumentation associated with the four major centrifugal compressor units (which are heavily instrumented) did account for one-half of the instrument failures. The survey however, does not specify whether these failures were due to break-down in instrument air supply, power supply, or component failures.

Failures classified as "others" are as equally diverse as instrument failures. However, one significant pattern is discernable, that is, natural gas curtailments were the cause of plant shutdown in many cases.

Since in most of the cases, the maintenance turnarrounds were initiated by a major equipment failure, the number of breakdowns are not affected by this factor. As in the case of shutdown frequency, the overall pattern of downtime has remained the same with major equipment failures and planned maintenance accounting for 85% to 95% of the downtime.

Any mechanical item within the plant (such as piping, relief valves, rotating machaniery, vessels, heat exchangers, etc.) which causes a shutdown is classified as a major equipment failure and the downtime associated with this catagory represents the time required to shutdown the plant, repair the item causing the shutdown, and to restart the plant.

The survey also indicates that primary reformers, major compressors, turbines, and heat exchangers including waste heat boilers, are the leading contributors to plant downtime and breakdowns. These surveys however, do not analyse the reasons for equipment breakdown in the sense whether these failures were initiated by a failure in the supply of utilities and offsites or due to the breakdown in the quality and control of these auxiliary facilities.

Statistical data regarding the role of auxiliary facilities and technical infrastructure on plant downtime and number of breakdowns is not available, but it is a well known fact that major equipment failures are caused due to inadequate control on the quality of various utility streams, lack of program for preventive and planned maintenance on rotating equipments and instruments, absence of inventory program for spare-parts and catalysts, lack of suitably trained operators and technicians and inefficient management of the plant. As an example, inadequate water conditioning program with respect to inhibitor, pH, and bio-control in cooling water recirculating systems can lead to frequent fouling of exchangers or failure of exchanger tubes resulting in equipment breakdown. Insufficient control of silica in the boiler feed water and PH/Phosphate control of boiler mud drum can also result in silica carry over into the steam system, deposition of silica on turbine blades, and premature failure of turbine blades. In the same way improper selection of lubricating oil for rotating equipment and disruption in its flow to various machine parts due to polymerization and consequent high pressure drop through the filtering media can lead to component failures and equipment breakdown.

Power failure, voltage and frequency dips, shortage of imported spares, labour unrest have been identified as the associated contributing factors for prolonged downtime in developing countries. Of these power cuts are the major source of plant breakdown. Moreover, these are external constraints over which the management has no control and yet these vitally affect the performance of the plant. A possible solution to these problems is to set up integrated captive power plants.

Fig.-I shows an inter-relation between main process plants utility services, offsite facilities, and technical infrastructure for a fertilizer complex.

IV. TECHNICAL REQUIREMENTS

A) Power

There is generally, acute shortage of power in the developing countries, and there are many urgent competing demands. The National Governments have allocated priorities and individual industries can do no more than advocating their case for preferential treatment. If despite that a power cut is imposed, the consequences have to be faced by the industry.

The problems associated with the supply of power are of two types. The first is the availability of power and the second is connected with frequency and voltage fluctuations. The magnitude of the first can be substantially reduced through priority allocation of power to fertilizer industry. A long term solution to both problems however, is the setting up of captive power generation facilities within the fertilizer plants. Fortunately, this problem is well understood in the developing countries and new ammonia/urea fertilizer plant designs are based on integrated energy supply concept where power units are a part of the utility plants.

B) Cooling Water Re-Circulating System

The most critical area of concern in the safe, efficient operation of ammonia/urea fertilizer complex is the cooling water system. Continuous availability of good quality cooling water is essential for any fertilizer plant facility. Poor quality cooling water can quickly, render a plant unsafe, inefficient and ultimately inoperable.

1. Once-through System

In this system, the water is passed through the heat exchanger equipment and the cooling water is then discharged to waste. This system is used where water is at suitably low temperature, is readily available in large volumes and at low costs, as an example, from lakes, rivers and sea.

The formation of scale on heat exchangers can result due to inadequate cooling water treatment program. For example, the precipitation of calcium carbonate will form scale. In addition products of corrosion also result in deposits of iron oxide on heat exchanger surfaces.

Calcium carbonate, because of its low solubility is usually the chief cause of scale formation in once-through cooling water systems. The other factors which affect scale formation are temperature, rate of heat transfer, mass flow rate, pH of the water, and dissolved impurities.

The most common method used to inhibit Calcium Carbonate scale formation is the use of anti-nucleating agents. These have the property of preventing crystal growth and thereby scale formation. The materials most commonly used include poly-phosphates, tannins, lignins, poly-acrylates, and combinations of these products.

At pH values below 4.3, the chief controlling factor in promoting corrosion is pH. However, in the range of most natural waters, between pH 6.0 to 8.0, the pH of the water is not the controlling corrosive factor, in the presence of oxygen.

The presence of free carbon dioxide lowers the pH value of the water. In such a case the rate of corrosion increases. Therefore, carbon dioxide is an important factor in increasing the rate of corrosion, since it influences pH.

Galvanic action between dissimilar metals is another important variable which influences the rate of corrosion. This tendency is minimized by the use of sacrificial anodes.

2. Cooling Water Re-Circulating System

With divindling supplies of fresh cold water available for industry's cooling requirements, increased use is made of re-circulating systems in which cooling water is used over and over again. In such a case the make up water required to take care of the evaporation losses and the "blow-down" constitutes about 2 to 3 percent of the total rate of cooling water circulation. In view of this, circulation of dissolved salts in the re-circulating water increase which aggravates its scale formation and corrosion tendencies.

i) Fertilizer Plants Cooling Water Control

The ammonia/urea fertilizer complex is the largest water user with a circulating load of about 20,000 m^3/hr for a 1000 ton/day ammonia and 1700 tons/day urea complex. It has also associated with it many problems arising from cooling water quality. Moreover, a fertilizer plant has a number of high pressure heat exchangers which have cooling water flowing on the shell side, and such exchangers are notorious for frequent fouling resulting in poor water side performance.

Osman, R.M. and Brandsman M., (6) has described the effect of insufficient control of cooling water re-circulating system which led to severe fouling of the heat exchangers and heavy localized corrosion. As a result, both the synthesis gas intercoolers had their bundles replaced due to severe water side corrosion. At the same time the authors reported 29 leaking tubes in "hot" bundle of the first stage air compressor intercooler. In addition, in what the authors described as "time bomb" potential for the future, the ammonia converter effluent water cooler started leaking ammonia containing gases into the cooling water. Various other exchanger failures were also reported during subsequent plant turn-arounds which ultimately made the plant management to believe that the cooling water system, if not improved, could cause a significant plant service factor reduction. Accordingly, the management awarded first priority status to the task of reducing cooling water fouling and corrosion in order to achieve the overall goal of fertilizer plant service factor.

The authors attacked cooling tower related heat exchanger problems on two different fronts; improving the quality of the cooling water, and improving heat exchanger design and operation. Despite a considerable degree of interaction, the task of cooling water quality improvement may be divided into the following three areas:

a) Reducing the scaling and fouling tendency of water
b) Reducing the corrosivity of water
c) Achieving bacteriological control.

a) Reducing the Scaling and Fouling Tendency of Water

The concentration of scale forming solids in water re-circulating systems introduces the scale forming tendencies of water specially due to its over-saturation with respect to calcium carbonate. In order to avoid such an over-saturation and also to control formation of calcium sulphate, calcium silicate, and magnesium silicate it is necessary to limit cycles of concentration.

While blowdown is an effective method for limiting cycles of concentration and hence the scaling potential of the circulating water, it is not always possible to use excessive rates of blowdown to accomplish this objective. In many localities, the supply of fresh water is either limited or costly. It is therefore, desirable to resort to treatment measures which will permit higher cycles of concentration in the circulating water, with consequent lower rates of blowdown.

In such cases where low rates of blowdown are desirable, either for technical or economic reasons, the scale forming tendencies of water can be reduced either by softening of the make-up water or by using acid treatment of the circulating water.

External softening of the make-up water can be accomplished through the use of cold lime process, lime-soda, or lime-gypsum process or by zeolite softening. However, these external softening processes are expensive and generally can not be justified on economic grounds in comparison with acid treatment.

Sulphuric acid is generally used for acid treatment because of its low cost. The objective of such a treatment is to reduce the scaling tendency, but not to develop an acid condition in the circulating water. In this process calcium bicarbonate is converted into more soluble calcium sulphate.

The pH of cooling water is generally controlled at 6.5 to 7.5 depending upon the process conditions. The control must be as automatic as possible in order to avoid fluctuations and frequent adjustment of pH by operating personnel.

Fouling deposits are formed due to the presence of impurities in the water. Fouling reduces heat transfer, increases resistence to water flow, and also increases localised corrosion.

The use of suitable anti-foulants has reduced the fouling tendency of circulating water. Various anti-foulant materials are available which may be classified as:

i) Flocculants
ii) Dispersants
iii) Chelants

Flocculants are cationically charged substances which enter into a surface reaction with the fouling materials to form a floc. Since mud, silt, and biological matter has a negative charge, a cationic poly-electrolyte has the property of neutralizing this charge and changing it into a floc.

Dispersants interfere with the agglomeration of colloidal particles and their attraction to metal surfaces. Various organic and synthetic dispersants are available which the property of forming a layer on the colloidal particles thus hindering their growth.

Chelants are also natural and synthetic organic compounds which react with undesirable metal ions to form heat-stable, soluble complex ions such as Fe, Mg, Al and Mn can be chalated to prevent their precepitation.

Generally, a mixture of a flocculant and a dispersant is used in the cooling water recirculating system as anti-foulant. The doses of anti-foulants depend upon the impurities and the rate of blow-down from the cooling water system.

The mass flow rate of water through the heat exchangers with flow through the shell side have much lower mass flow rate and therefore, they are more susceptible to fouling. Thus, the range of velocities in the heat exchanger equipment has an important bearing on the anti-fouling treatment of the recirculating cooling water and this factor must be considered in the design of heat exchangers.

b) Reducing the Corrosivity of Water

The intimate contact of the cooling water with air in passing over the tower renders the circulating water continuously saturated with dissolved oxygen. The presence of oxygen is thus the major cause of corrosion. In addition, corrosive fumes in industrial areas such as hydrogen sulphide and sulphur dioxide also contaminate water and these are other sources of metallic corrosion. Other causes which enhance the corrosion rate are:

i) dissolved solids such as chlorides and sulphates
ii) galvanic action of dissimilar metals which are part of heat exchanging equipment.
iii) outside contaminating effects such as the presence of dust, sand, wood fibres, sludge and slime etc.

Each iron atom that corrodes at the pitted surface (anodic location) is accompanied by the production of two hydroxyl ions (OH) at the non-corroding metal surface (cathode). It follows that the inhibitor formulation must effectively use these hydroxyl ions to develop a protective film.

The standard corrosion inhibitor used in recirculating water systems generally contains two of the following components:

i) Zinc
ii) Chromate
iii) Phosphate

Zinc developes a zinc hydroxide film on the cathodic surfaces and chromate helps to form a tight, adherent bond of iron oxide-chromic oxide on anodic surfaces.

Corrosion inhibition is normally excellent if these films are well formed on clean, metallic surfaces. However, the protective film will be liable to be damaged if proper conditions of pH and chromate levels are not maintained in the circulating water. For effective corrosion control, it is necessary that;

i) the metallic surfaces are properly cleaned before inhibitor treatment is started specially after plant turnaround;

ii) the pre-treatment is carried out with a double dose of chromate-zinc inhibitor for at least two weeks before reducing chromate levels to normal maintenance values. This helps in the formation of adherent protective film;

iii) the chromate levels in the cooling water system should be maintained at 20 to 25 ppm. If the chromate level in the system drops below 12 ppm or the pH of water is reduced to a value below 6.0, this should be followed by a double dosage of chromate inhibitor for a period of about one week, in order to normalize the system conditions. The effect of chromate inhibition on the rate of corrosion is shown in Fig. 2.

c) Microbiological Control

Since ammonia, urea, nitrates and other fertilizers are prime nutrients for microbiological metabolism, fertilizer plant cooling waters are continuously succeptible to sudden and excessive microbiological outbreaks. Ammonia contamination of cooling water may be due to process leaks or ammonia gas being dissolved in the water as it is aerated over the tower.

The control of this potential microbiological problem is a prime consideration in the maintenance of safe, efficient, and smooth running of cooling water systems. Ammonia and urea fertilizer plants, due to design parameters, critical heat exchangers and sensitivity of poor cooling water practices demand an effective cooling water bio-control program.

Historically, chlorine and non-oxidizing biocides have been used to control biological outbreaks in industrial cooling water systems. However, despite the established use of chlorine as a biocide in many facilities, chlorine dioxide is proving both more effective and more economical in a rapidly growing number of ammonia plants while greatly reducing or eliminating the need to handle potentially hazardous gaseous chlorine.

Although chlorine is an effective biocide in many cooling water systems, it suffers from the following disadvantages:

i) The reaction of chlorine with ammonia nitrogen compounds to form chloramine which is much less effective as a bio-cide.

ii) Chlorine, in the presence of water, forms hypochlorous acid which is more effective biocidal form of chlorine. Under alkaline conditions, however, hypochlorite ion is formed which is again not as effective as a bio-cide as hypochlorous acid.

Thus chlorine as a bio-cide would be most effective under non-alkaline conditions and in the absence of ammonia-nitrogen compounds. If these conditions exist, high dosage of chlorine would be desirable which might be prohibitive on economic consideration.

Recently, use of chlorine dioxide has proved very successful and effective in cooling water system which contain ammonia-nitrogen contamination, alkaline pH, and persistent slime problems, because chlorine Dioxide does not react with ammonia compounds nor its biocidal effectiveness is impaired by alkaline pH conditions. Chlorine dioxide remains an extremely effective biocide over a wide range of pH (6.0 to 10.0).

Ward, W.J. (7) has described a number of case histories where chlorine had failed to combat microbiological growth, and chlorine dioxide resulted in effective microbiological control in cooling water systems.

C) Steam Generation and Distribution

Most modern ammonia plants are based on generation of steam at elevated pressures in the interest of reducing fuel costs. High pressure superheated steam is used in an efficient energy cycle linked closely with the process and turbines drive systems. The pressure usually selected for the process is dependent on the fuel cost structure. For a high fuel cost area, steam generation pressures in the order of 100 Kgm/cm^2 are used. Fig. III shows layout of a typical high pressure steam system for a conventional ammonia plant. High pressure superheated steam is delivered to the steam turbine coupled to the synthesis gas compressor, after which steam is extracted at an intermediate pressure and delivered to the reformer catalyst tubes, vacuum condensing turbine drives, and to other process services.

The pressure selected for the intermediate steam heater is governed by the inlet pressure of the reformer, As an example, if hydrocarbon is reformed at 30 Kgm/cm^2, the inlet pressure would be 38 Kgm/cm^2.

In an ammonia/urea complex, the utility steam pressure is governed by the intermediate steam header pressure in the ammonia plant. This is because during ammonia plant start-up, steam is imported from the utility boilers for the I.D./F.D. fans, the boiler feed water pumps and the process steam for the reformer. In addition, if the ammonia plant auxiliary boiler is to be operated at low loads or is shutdown for some reasons, the utility steam can be used as balance steam for the ammonia plant.

Akitsum, K., Takahashi, H., and Jojima T., (8) have described an integrated steam system used in ammonia/urea fertilizer complex in which all the steam for urea plant is supplied by the extracted steam from syn. gas compressor turbine of ammonia plant. This means that after the syn. gas compressor turbine, the steam header of 40 Kgm/cm^2 steam is common in urea and ammonia plants. In urea plant, carbon dioxide booster compressor is driven by the turbine combined with extracttion and condensing, and the centrifugal carbamate pump is driven by the back pressure turbine. All the process steam at 12 Kgm/cm^2 is supplied as extracted steam from these turbines. The typical integrated steam system for ammonia/urea complex is shown in Fig. 4.

These authors have carried out an economic comparison between the steam integration system and the conventional motor driven system and the results are recorded in Table-5. Although the steam consumption is increased by 0.24 T/T urea for the power turbine (based on the 40 Kgm/cm^2 and 378°C), the electric power for carbon Dioxide compressor and carbamate solution recycle pump is decreased by 50 KW/T urea.

The total conservation of electric power in the case of 1600 T/Day urea plant has been shown to be upto 3400 KWH/hr.

A limitation of this system is that the relation between the generated steam from ammonia plant and the required steam for the urea plant does not correspond to the simple proportion at each stage of plant loads. Ammonia plant has to be kept at 75% load before start-up of urea plant, because 60 T/H steam must be supplied to urea plant as the minimum steam supply and at start-up, not only steam balances but also a balance between ammonia produced, carbon dioxide, and demineralized water have to be considered for the stable state operation.

D) Boiler Feed Water, Make-up Water, High Purity Process Water Supply System (Demineralization, Silica Removal, Water Quality Etc.

1. Raw Water

The quality of make-up water for the boiler depends upon the raw water supply, and the efficiency of the water treatment plant. If the raw water is obtained from sub-level sources, this may contain free carbon dioxide which might corrode the tubewell pipeline and associated equipment. In order to limit corrosion rate, corrosion inhibitor is introduced into the tubewells. The recommended dosage of corrosion inhibitors (zinc polyphosphates) is 1 to 2 ppm, depending upon carbon dioxide concentration in well water.

If the sources of raw water is an irrigation canal, lake or river, water might contain suspended colloidal particles and organic matter. These are removed by the addition of flocculants. Whatever the source of raw water, it is passed through pressure filter in order to remove the suspended matter.

ii. Boiler Feed Water

In general, as boiler pressures increase, improved feed water quality is required. Low pressure boilers are often able to use raw water make-up with internal treatment only. High pressure boilers at the other end of the scale would require almost complete removal of all dissolved solids from the make-up water. And there are all degrees of feed water treatments for boiler pressures that fall between these two extremes.

Low pressure boilers generally cover boiler pressures upto 10 Kgm/cm^2. Medium pressure boilers will be limited to pressures upto 50 Kgm/cm^2 and high pressure class will cover all those boilers operating above this value.

For low pressure boilers where the make-up water is less than 20%, the water seldom needs external treatment except the provision of a de-aerator in feed water cycle to remove dissolved oxygen and carbon dioxide. However, enough internal treatment with phosphate and adjustment of pH with an alkali would be necessary to reduce boiler water hardness to zero and to bring the pH to a desirable level.

Medium pressure boiler make-up water need extensive pre-treatment. Degree and type of treatment system will vary with percent make-up, water analysis and overall economics.

Demineralization produces good make-up water compared with other methods of external water treatment such as hot soda-lime process or sodium zeolite process. Main drawback is high operating and equipment costs. However, there are tangible advantages such as reduced boiler blow-down, and the production of high quality steam.

High pressure boilers require the most exacting feed water treatment. Main impurity which must be completely removed from the make-up water is silica. At high pressures silica in boiler water volatilizes and passes over with steam to the turbine. As steam expands through the turbine this silica deposits on the blades. This affects the turbine efficiency and eventually the turbine must be shutdown for thorough cleaning to remove these deposits.

Thus for high pressure boilers, silica level in the make-up water must be kept at a very low level in the region of 5 to 10 PPM. External treatment under these conditions is limited to either evaporation or demineralization.

Demineralized water quality depends upon the type of system used. The conductivity of the treated water may be in the range of 0.5 to 1.0 micromhos with silica less than 0.02 ppm.

There are two general sources of impurities that enter the boiler and cause trouble with deposits. The first is mineral impurities in the condensate, usually coming through the condenser from the cooling water. Second is metal oxides from pre-boiler corrosion. In order to ensure complete removal of these impurities in the recycle condensate, it is a good practice to treat the condensate stream by passing it through a condensate polisher which generally consists of mixed bed demineralizer unit. In this process the total dissolved solids are reduced below 0.04 ppm and silica is reduced to below 0.01 ppm.

The choice between a demineralizing unit and an evaporator should be based on an economic analysis which should include installed equipment cost, heat-lost or energy degradation in the evaporator, chemical and operating costs, labour and maintenance charges.

Boiler Water Treatment

The formation of scale and sludge deposits on boiler heating surfaces is the most serious problem encountered in steam generation. The objective of the majority of external treatment processes is to remove from the boiler feed-water those objectionable substances which will contribute to scale or deposit formations in the boiler.

The internal treatment of boiler water varies according to the operating pressure of the boiler. Typical control limits for boilers operating upto 50 Kgm/cm^2 are shown below:

	ppm
Sodium Hydroxide	150-300
Phosphate as PO_4	20-30
Silica as SiO_2	40-50
total solids	2000-2500
pH (Maximum)	11.0

At low temperatures, that is below 200°C, the first product of reaction between water and steel is the formation of ferrous hydroxide. This reaction can be suppressed by making the boiler water alkaline, and the presence of hydroxyl alkalinity keeps the sludge in mobile form.

For high pressure boilers the need for more precise methods of controlling boiler water becomes greater. Different methods of control are available and those are described below:

a) Precision Control

In this mode of control, the following limits for different parameters are maintained:

	ppm
Sodium Hydroxide	15-50
Phosphate as PO_4	2-4
pH at 25°C	10.6 to 11.1
Dissolved Solids	20-200

This control is based on the assumption that alkaline boiler minimizes steel corrosion and the presence of hydroxyl alkalinity keeps the sludge particles from adhering to the heat transfer surfaces. However, practical considerations tend to indicate that these conditions can result in localised high concentration of caustic in critical areas resulting in the dissolution of protective layor and ultimately leading to caustic embrittlement of the metal.

b) Co-Ordinated Phosphate pH Control

As the boiler pressure increases beyond 100 Kgm/cm^2 the inadequacies of precision control become apparent. In this control the problem of caustic embrittlement is avoided by the regulation of free hydroxyl ions.

The design limits of co-ordinating phosphate-pH control are set as follows:

	ppm
Hydroxyl Alkalinity	Nil
Phosphate as PO_4	3 to 5
pH at 25°C	9.5 to 10.6
Dissolved Solids	5 to 100

In order to avoid the formation of free hydroxyl alkalinity in boiler water, pH and phosphate limits are controlled at or below curve 1 in Fig. 5. Tri-sodium phosphate is added to keep the ratio between sodium and phosphate at 3.0.

However, even with this type of control, failure of boiler tubes has been experienced. The mechanism of corrosion is not very clear, but it is considered that sodium phosphate destroys the protective layor of iron oxide. Some investigaters have proposed that the protective film is destroyed when phosphate migrates into the magnetite lattice (Protective layor).

The contention that the presence of phosphate can lead to tube failures has led to the belief that maintenance of alkaline conditions in high pressure boilers is detrimental to proper boiler control and should be avoided as far as possible. Based on this hypothesis, "pure water" operation has been suggested.

c) The Pure Water Approach

The limits for this type of control are:

	ppm
Free Hydroxyl Alkalinity	Nil
Phosphate as PO_4	Nil
pH at 25°C	8 to 9.5
Dissolved Solids	0 to 5

Pure water operation is successful only in a contaminant free system. In actual practice, some contamination of boiler water is inevitable due to the leakage of sodium from the demineralizer plant, carry over from an evaporator, or through a leakage in the condenser. In the absence of phosphate, there are no means for providing buffering action against sodium or calcium leakages.

d) Congruent Control

A technique of congruent control has been developed in order to overcome the deficiencies of other types of controls mentioned. This control provides some buffering action and protection against calcium scale while avoiding the development of free caustic under hideout conditions. The design limits for congruent control are as follows:

	ppm
Hydroxyl Alkalinity	Nil
Phosphate as PO_4	2-4
pH at 25°C	8.5 to 9.3
Dissolved Solids	4 to 15

A relationship between phosphate content and pH of boiler water is plotted in Fig. 5 which shows that the ratio between sodium and phosphate should be kept at about 2.6.

E) Instrument Air Preparation And Distribution

The instrument air should be oil-free, clean, and dry. The normal supply should be from an instrument air compressor which is a non-lubricated machine, but there should be a standby piping arrangement from the ammonia process air compressor which automatically assumes the load in case the instrument air compressor fails. The back-up instrument air arrangement must be sized to handle the total instrument air requirements of the plant and should be designed to pick up the load quickly enough to prevent any upsets on pneumatic instruments.

All instrument air from any source should be dehumidified by passing through an air-drier which usually is of dessicant pattern (silica gel or molecular sieve), with automatic switch-over for steam regeneration, designed to reduce the dew point of instrument air to -40°C. All instrument air from any source must further pass through a prefilter before entering the distribution network. All cleaning and drying equipment must be of dual design so that they can be maintained while the system is in operation.

Instruments air should be stored in an instrument air receiver, sized for a minimum of 30 minutes retention time at full consumption for the whole complex. Normal instrument air distribution pressure should be 7.0 Kg/cm^2.

F) Storage Facilities for Intermediates and Products

Prilled urea is susceptible to caking followed by the formation of hard lumps if stored in bags over long periods. The lumps are difficult to break which interfer with uniform application of the product. The storage of urea must be in the bulk form because under these conditions the caking tendency is reduced specially if temperature and humidity conditions are maintained.

The size of the bulk storage is determined by the marketing conditions. If the plant caters for internal markets within the country, bulk storage facilities equivalent to one month's production should be sufficient. If the product is to be exported, the capacity of the bulk storage should be designed to store at least two months production capacity of the plant.

The storage building should be provided with a shuttle type feed conveyer along the apex of the building as a means of distributing the urea into the specified pile configuration. The distribution mechanism should preferably be motor driven for position change and be capable of operation from a ground floor control position. Provision should be made for bypassing the pile and conveying directly from prilling to reclaim and bagging.

The bagged urea storage building should have a capacity equivalent to fifteen days production. It will/be preferable if this building is integral with the bulk storage building. It should incorporate any required reclaim screening equipment, house the bagging systems, and provide the empty bag storage and assembly space.

The bagged warehouse building should be essentially enclosed with adequate ventilation, overhead doors, and platform access to accomplish the required bagged goods loading requirements.

Bagged urea storage on pallets is preferred. The bags should normally be stored a maximum of 20 deep with a minimum of 3 pallets for each stack. The loaded pallets can be handled by fork-lift trucks. In addition, flexible bag conveyors for effecting a continuous flow to the stacking area should also be provided. Similarly, the use of sufficient bag conveyors to both multiple truck and rail loading points should also be provided.

V. EXTERNAL SUPPLIES AND DEPENDENCIES

A. Electric Power Supply

It has already been mentioned that the power supply from a grid suffers from two disadvantages. The first is concerned with the continual availability of power due to system breakdown and the second is due to variations in frequency and voltage fluctuations. The effect of these two drawbacks can result in unscheduled emergency breakdowns of the plant with consequent severe strains on the rotating machinery, high maintenance costs, and prolonged plant downtime.

For this reason, it is now recognised that the fertilizer projects in developing countries must provide power generating facilities within the complex in order to take load of required power for the total process units, utilities, offsites, and other supporting facilities.

The system should include two generators each consisting of 70 percent of the total electric load, and designed in such a way that in the event of the failure of one generator, the major load is taken up by the second generator and that it does not cause the shutdown of ammonia plant and necessary facilities.

The system should also include the provision for an emergency generator for the instruments, emergency lighting, critical electric driven pumps, etc. This generator should be driven by an electric motor with an automatic start diesel motor attached via a flywheel and automatic arrangement. In the event of power failure the flywheel inertia together with automatic diesel start and clutch arrangement should effect an uninterrupted changeover. Suitable manual and automatic circuit switching and isolation and adequate visual and audible alarms should also be provided.

B. Maintenance Facilities

One of the major factors in sustaining productivity is organised maintenance of plant and equipment. No doubt, this is an area in which there is scope for tremendous improvement and innovative efforts. The maintenance programme can be covered under two heads:

i) Preventive Maintenance

A preventive maintenance system is a useful philosophy by which equipments are taken down for maintenance prior to their failure. Preventive maintenance combines on-stream inspection, records, and diagnostic work. On the basis of this continuous on-line progress it is possible to predict when equipment will fail and advise the operating department to schedule downtime. It is therefore, a data collecting system for improving the reliability of equipment on an operating plant.

The inspection procedures used for implementing a preventive maintenance programme may be classified as:

a) On-line inspection of equipment
b) On-line maintenance of instruments
c) Corrosion control

One of the problems facing the designers and plant operators is that, as equipment becomes more and more reliable it becomes increasingly difficult to predict or anticipate incipient failure before serious damage or failure of equipment occurs. Various on-line techniques have been developed such as, vibration analysers, which can give advance warning about the condition of equipment and alert the plant management to take corrective action before damage is done to the equipment.

ii) Planned Maintenance

The introduction of preventive maintenance techniques has increased reliability of plant equipment, reduced plant downtime, and increased intervals between consecutive turnarounds.

In spite of very high reliability of rotary equipment the auxiliary equipment associated with it are not sufficiently reliable. Therefore, the maintenance philosophy followed by plant operators is to keep the plant in operation as long as possible and plan plant turnarounds for inspection and overhauls according to the schedules recommended by the equipment manufacturers.

In addition to inspection requirements for rotary equipment, certain catalysts used in reactors to accelerate the rate of production of an end product de-activates with time and have to be replaced periodically depending upon their life cycles. The modern tendency is to predict the actual life of these catalysts by using computer optimizing techniques, and schedule plant turnarounds for catalyst change to coincide with major equipment overhauls. In this way it is possible to carry out all major jobs during the planned down-time which is usually scheduled once in 18 or 24 months.

C. Critical Spare-Parts

The prime objective of the spare-parts maintenance program is to ensure that the consequences of failure of any plant component is minimized by having the replacement part on hand. The non-availability of any critical spare-parts for a plant intended for a developing country in the event of its failure can keep the plant shutdown for long periods resulting in considerable production losses. Spare-parts cannot always be purchased off the shelf and where long distances are involved, the procurement of critical spare-parts can take long time. Therefore, special attention should be given in determining the critical spare-parts list for plants intended for developing countries.

The critical spare-parts program must take into account;

i) normal loss or damage of components/spare parts during construction of plants;
ii) loss of spare parts/components due to operational faults during commissioning;
iii) loss of spare parts due to normal wear during operation.

The basic requirement of spareparts program in developing countries should be that the investment in replacement parts be as small as possible but should also fulfill the stated objectives. Other factors which must be taken into consideration in determining the provision for spare parts are;

i) the plant must operate for two years without access to any imported replacement parts;
ii) it is assumed that there is a market for 100

percent of the end-product; consequently, the plant has to run at maximum operating efficiency throughout the year;

iii) equipment will be purchased from all over the world and the lead time for getting these spares at the plant is very long.

In order to minimize investment in spare parts program, the procurement of equipment should be made from reputable suppliers and for this purpose, the following guidelines should be followd:

i) Each vendor/equipment manufacturer must demonstrate that the equipment is already in operation on similar plants elsewhere and also has satisfactory record of performance for a minimum period of two years.

ii) A workshop capable of fulfilling the projected plant needs should be provided. This workshop must have the capability to manufacture most of the required spare parts.

iii) A maintenance warehouse should be provided. It must have provision for raw materials necessary to support manufacture of replacement parts at the plant site.

iv) The operating equipment should be grouped together and purchased in such a way that the number of vendors can be reduced and also that the variety of equipment is cut down, by following normal standardization procedures.

Another important part of the replacement program requires the plant to have tools, material and equipment to manufacture the spare parts required. To fulfill this function, the machine shop should have, in addition to a coverage of lathes, drill presses, milling machine, shapers, etc. the equipment to harden surfaces, grind, super finish, heat treatment and dynamically balance parts wherever necessary.

An integral and important part of the spare parts program is the development of required procedures, organisation, and physical facilities to receive, catalogue, store and control spare parts. Standard techniques cannot be successfully applied when lead times cannot be determined. A unified program of inventory control must be used to maintain the spare parts at the required level.

During project development, the selection and the quantity of parts to be maintained should be determined on the basis of recommendations from plant suppliers, engineering contractor and the operating company.

D. Procedures for Determining Spare Parts Requirements

a) All manufacturers and suppliers should be requested to recommend spare parts for two years of service on their equipment.
b) The engineering contractor should review their recommendations and, modify this list on the basis of their own experience.
c) The consultant and the project team of the owners should further evaluate the recommendations, and make any changes based on their operational experience.

As an example, reciprocating compressor manufacturers recommend the purchase of replacement valve plates and springs for rebuilding compressor valves. However, in order to rebuild a single valve, which includes removal, disassembly, cleaning, machining, lapping, reassembly and finally, reinstallation would take about 6 to 8 hours. Further, this need to rebuild valves arises when pressure on maintenance is maximum. Thus valuable production time can be lost if complete assembly is not readily available. Therefore, from an operating view point, the most economical recommendation would be to purchase a complete valve replacement in order to allow the rebuilding of valves while the plant is in operation, and keep those ready in case of valve failures.

Another example where economies in spare parts inventories can be effected is to use identical turbines or pumps or compressors where conditions permit such a selection.

VI. EMERGENCY SITUATIONS

It is expected that emergencies will arise from time to time and these situations can be handled if the operating personnel is adequately trained in the operation of the plant. The knowledge of the plant and a complete understanding of the processes involved are the best guarantees that the operators concerned can safely and efficiently cope with any unusual conditions that may develop. The action taken by the operators should satisfy the following requirements:

i) The action taken must be one that can be performed without undue hazard to plant personnel. The operator should not jeoperdize his own safety and that of others.

ii) The action taken should ensure that the unit equipment is in safe condition. Design temperatures, pressures and flows should not be exceeded.

iii) The action taken should permit resumption of operations as quickly as possible after the emergency has been corrected.

Some examples of emergency shutdowns and the corrective actions necesaary are given below:

i) Loss of Process Steam in Ammonia Plant

The operation of boiler feed water pumps is necessary for the continued operation of the ammonia plant. There are two boiler feed water pumps and both are turbines driven. In order to ensure that the spare pump will come into operation quickly in case of a pump breakdown, it is necessary that the spare pump is on slow roll at all times.

In some design for ammonia plants, the boiler drum has very low capacity and the residence time for boiler water in the drum is three minutes only. If the spare boiler feed water fails to pick up the load in case of the failure of boiler feed water pump in operation, an emergency situation will arise.

If it is impossible to re-establish the feed water flow to the drum, the action taken must be positive and immediate and should be as follows:

a) Shutdown the fuel gas flow to the auxiliary and reformer furnaces.
b) Discontinue the air flow to secondary reformer.
c) Discontinue the process gas flow to the primary reformer.
d) Blow the outlet from the shift convertor and open the inlet vent to atmosphere.
e) Shutdown all the compressors (air,refrigeration, synthesis), stop the catacarb, ammonia product, and quench pumps.
f) Switch the motor drives in critical services.
g) Isolate L.T.S., methanator, and the synthesis loop.

The loss of feed water can also be caused by the loss of demineralized water. There should be no question as to theneed to shutdown the ammonia plant if the quality of demineralized water drops.

ii) Instrument Air Failures

Instrument air to process plants is supplied from the utility area. Although there is little likelihood of the failure of the main instrument air supply, air failure at individual instruments is more probable, and it is important to know what will happen in case of such a failure.

In case of total air failure, the plant will be shutdown completely. The positions of the various control valves for fail safe operations are usually indicated. The philosophy with regard to valve action when the air fails is that the valve will move in the direction of the greatest safety. Thus, for example, air failure will shut the process gas feed to the primary reformer, but the process steam valve will fail open, beaause it is advantageous to keep a flow of steam moving over the reforming catalyst.

iii) Electric Power Failure

It should be recognised that most power failures are usually of very short duration and provision of two power generators, each capable of taking 70 percent of plant load, should prevent a complete shutdown.

In case of total power failure, an emergency source of power is provided within the complex, which becomes automatically available when the normal power supply fails. This emergency power will supply power to the instrument panel, lights, and some control valves and pumps. Efforts will be made to bring the plant back into operation if the power failure is of short duration.

If the power failure is prolonged, it will not be possible to continue operation, a decisian should be made for an orderly shutdown of the plant so that the rotating equipment is protected from the effects of a crash shutdown.

iv) Safety Considerations

The fertilizer plants deal with flammable and potentially toxic materials at high temperatures and pressures. As the plants have become more complex and sophisticated, the potential risks associated with the processes have also increased. There is therefore, greater need to adopt more rigorous methods of ensuring safety. It is necessary that new projects are examined more critically in order to provide protection against any feasible risks before the plant comes into operation.

Process safety in chemical and process plants depends upon (a) how a plant is designed and (b) how it is operated.

a) Safety in Plant Design

Just as it is virtually impossible to build facilities which are foolproof in the hands of inadequately trained operators, it is also impossible to safely operate equipment that is basically faulty in design. Most hazardous operating situations can be avoided at the design stage with little or no extra costs.

The planning and design stage is the first opportunity to weed out hazardous situations. There is a wide range of engineering codes which must be rigorously followed during the design of a plant. A unique and helpful process oriented design check has been evolved, by Imperial Chemical Industries Ltd (ICI). This is called "Hazard and Operability Study", and is mandatory in all new capital projects and major plant extensions and can also be used to improve safety and operating standards on existing plants. The technique involves critical examination of process design, systematically looking for every process deviation from normal. This is done by applying a carefully chosen check list of guide words to each integeral part of the system. The checklist promotes unrestricted free ranging thought to detect all conceivable process abnormalities which helps in identifying potential hazards.

b) Safety in Plant Operation

Rigorous attention to process and plant design will minimize the risk of explosion, fire, loss of material, but will not eliminate the risk completely. The residual risk due to equipment or human failure must also be recognized and taken care of.

Despite the high degree of automation in modern chemical plants, the role of operators is still very important and it should be recognised that they are infallible. Half of all industrial incidents are attributed to human errors and arise from thoughtlessness, negligence, inadequacy of training, lack or absence of motivation, poor communications, poor inspection and supervision, and weak management.

There is an affective plan for reducing operator errors and oversights in a system which has led to reduction in injury frequency and severity rates of industrial accidents. This system is known as "Job Safety" analysis, and the secret of its success lies in systematic identification of the hazards that may be associated with each step of a job, and the subsequent development of the means to control or eliminate the hazards that are identified. This system is described by Nakano, T. (9) in an article "Safety Design of Chemical Plants".

VII. ENVIRONMENTAL CONSIDERATIONS

Environmental pollution is a problem which is of growing importance since the minimum quality of environment which the society is prepared to accept has improved considerably over the past few years. Because of this awareness about the quality of environment, industry must endeavour to reduce the sources of pollution although this can only be done at cost and the price of pollution control will ultimately be borne by the society.

For many problems of stress on environment, knowledge of the limiting biological values are still lacking. In other areas, criteria for assessment of the permissible degree of the environmental influences is avoidable, but the present state of technology does not make it possible to maintain this degree with certainty.

There have been many worthwhile changes in recent years in the engineering design of various devices used to control emission, but it is to the chemical engineer that we must turn for new processes with minimal emissions and for innovative principles of control.

In the U.K. the Alkali Act lays down that a process may not be operated unless it is registered, and that the Alkali Inspector will not register it unless he is satisfied that the "best practicable means are being used to prevent the discharge of noxious offensive gases, or to render such discharge harmless and inoffensive.

The Clean Air Act 1956 in U.K. further states that "Practicable means reasonably practicable, having regard amongst other things, to local conditions and circumstances, to the financial implications, and to the current state of technical knowledge" should be employed for pollution control.

In a fertilizer complex a number of effluent streams are involved and each of these is suitably treated before it is discharged either to the atmosphere or into the natural water-ways.

The main effluents are:

i) Demineralizer Plant Effluents

These consist of acids and alkalies used for the regeneration of water treatment resins. The acid and alkali streams are mixed together and passed through a bed of limestone to adjust the pH of the effluent stream before it is discharged outside the factory area.

ii) Coolant Water Blowdown

The coolant water blowdown contains 20 to 25 ppm of chromate. This chromate level must be reduced to permissible limit, before it is discharged to the natural streams. The specifications for chromate limit in the effluent stream varies in the U.S. from state to state. For discharge in to the Missisipi River in Texas, the upper limit is as high as 5 ppm.

Chromate is used as corrosion inhibitor in the recirculating cooling water system. The chromate level can be reduced by different methods as follows:

a) Reduction of Chromate

Chromate is reduced with Sodium Sulphide at a pH of 4.0. In this process chromate is precipitated and decanted or filtered out.

b) By ion Exchange with Resins

These resins retain chromate. The regeneration of resin is done with a solution of sodium chloride and hydroxide.

c) Grannular Activated Carbon

This is used to adsorb chromate ions. The removal of chromate is then effected by leaching with a solution of sodium chloride and hydroxide. Activated carbon is further regenerated with an acid solution.

d) Electro-chemical Method

Chromate is removed by electro-chemical method in which a special electrode is used to ionize chromate which is then deposited as mud and removed.

iii) Process Condensate

Process condensate from an ammonia unit contains substantial amount of ammonia, carbon dioxide, methenol, and light organic compounds. The concentration of each of the substance depends upon the operating conditions and the activity of the catalysts. The average organic content ranges between 1000 to 2000 ppm while ammonia levels may be as high as 1000 ppm.

In order to reduce the value of chemical oxygen demand, different treatments of waste water have been developed, but steam stripping is the most accepted process used in the fertilizer industry.

In this process the undesirable impurities are steam stripped in a packed column. The stripped condensate is passed through a condensate polisher and used as make-up water for low pressure steam system. Alternatively, where the purity of the recovered condensate is not sufficiently high to be used in boiler feed water, it is used as shaft sealing liquid for many kinds of pumps instead of steam condensate or demineralized water.

iv) Prill Tower Dust Chamber Vent Gas

The dispersion of urea dust in the effluent gas from the prill tower in a urea plant is a big source of pollution. During the last decade new methods of dust removal have been developed which substantially lower the dust concentration in the off-gases from dust chambers.

The principles of dust removal is a combination of scrubbing dust with water spray and filteration by a special plastic filter pad. A sketch showing the process developed in Japan (8) is shown in Fig. 6.

The life of the filter is more than six months and the pressure drop through the filter is very small. This system is claimed to work at dust collection efficiency of 95 to 99 percent.

Statistical data regarding the effects of inadequate treatment of effluents on the performance of a fertilizer plant are not available. However, isolated examples have appeared in in literature.

It is well knownpractice to discharge the cooling tower blowdown into large evaporation ponds within the factory area where the water is either evaporated or it percolates through the sub soil. This is the cheapest form of effluent water disposal containing undesirable chromates of zinc. This method was also used at Zoari in India, but unfortunately the effluent water contaminated the sub soil water in the area. In the absence of alternate methods for effluent disposal, the plant had to be shutdown for many months.

The emissions from the prill tower dust chamber are well known source of pollution. This not only produces undesirable environment inside the factory, but also gets deposited on the plant equipment, increases the corrosion rate and results in high maintenance costs.

VIII. ECONOMIC CONSIDERATIONS

In order to achieve maximum operational flexibility and efficiency, it is necessary that the utility plants, offsite facilities, and the basic technical infrastructure is designed with maximum reliability as the main criteria and must be based on sound and proven processes and equipment. Attention should be given to effecting economies in the overall operation of the complex by selection of the most appropriate utility systems. This selection must relate to ammonia pressure and temperature levels of utilities and to the actual positioning of generation capacity and users. Considerations should be given for example, to the selection of relative capacities of on-plant ammonia and boiler plant steam generation, and grouping of main compressors with steam drives. Integration should be based on maximizing reliability and operational flexibility.

Particular attention should be given to integrate units for easy start-up, reduced capacity operation, shutdown and emergency conditions. Additionally, design of utility generation systems should consider annual plant turnarounds, where for example, urea bagging and shipping must continue to be operational.

The design of utility services and offsite facilities should be such that the total production of any utility (steam, power, instrument air, etc.) is achieved in at least two trains instead of a single train plant. This will ensure that the process plant can still operate at reduced loads if one of the trains is temporarily down in case of some operational problems. In addition, sufficient safety factor should be allowed in the design so that each train has an overdesign factor of about 20 percent. The basic requirements for the design of various utility system, to achieve maximum reliability, are given below:

i) Water Treatment Plant

The demineralizer system has to be regenerated periodically. In order to ensure continuity in the supply of treated water, it would be necessary to have a minimum of three trains so that if one of the trains is down due to operational problems, the other two can still provide sufficient treated water to operate the plant at 80 percent of design capacity.

In addition, it would be necessary that the utility water and boiler feed water pumps are 100 percent spared, with one pump steam driven except in the case of dozing pumps which can both be electric driven.

ii) Cooling Water Tower and Coolant Pumps

The number of cells in the cooling system should be so chosen that a failure of one cell shall not affect the overall performance of the plant. In addition, considerations should be given to three 50 percent capacity coolant water circulation pumps; two operating and one stand-by. To meet the requirements that the ammonia unit can keep running during power failure, the operating pumps should be steam driven. The stand-by pump may be electrically driven.

iii) Power Generation

In order to allow maximum reliability in power supply, the power generating system should operate at 70 to 75 percent design capacity. Therefore, two generators each of 70 percent of the total electric load should be provided. The system should be designed in such a way that if one of the alternators fail, this failure will not cause shutdown of ammonia plant and necessary facilities, but urea plant might be completely shutdown.

An emergency generator should also be provided for instruments, emergency lighting, critical electric pumps in case of the failure of both main generators.

iv) Steam Generation

The steam system must be arranged to provide for maximum overall heat recovery from waste heat, maximum flexibility in start-up of process units, and economic consumption by the various turbines and process duties consistent with good overall operability.

The auxilliary steam generating system should consists of two identical boilers and so arranged and integrated that individual or simultaneous operation requires absolute minimum isolation or operation activities.

v) Instrument Air

Normal supply of instrument air should be from an air compressor, but with a standby piping arrangement from the ammonia process air compressor which should automatically assume the load if the instrument air compressor fails. In addition, provision should be made for two utilities air compressors, one of those being electrically driven.

If sufficient safety factors are allowed in the design of utility systems and the systems are also made flexibile by providing more than one trains, partial break-down of any of these systems will still allow the operation of process plants at reduced loads.

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TABLE - I

	Completion Date $ Millions)	
	1973	1978
Ammonia Plant	19.0	56.0
Urea Plant	10.5	27.8
Auxiliary & Support Facilities	14.8	27.8
SUB TOTAL:	44.3	125.7
Storage Facilities Ammonia & Urea	4.0	7.3
TOTAL:	48.3	133.0

TABLE - II

EFFECT OF CAPITAL INVESTMENT AND SHORTFALL IN PRODUCTION CAPACITY ON THE COST OF PRODUCTION AND THE RATE OF RETURN IN A DEVELOPING COUNTRY

Assumption:

1.	Plant capacity	Ammonia/	1000 Tons/day
		Urea	1700 Tons/day
2.	Total Capital Investment:		$240 Million
3.	Loan/Equity ration		70:30
4.	Operating days/year		330

% Design Capacity	100	95	80	65
Production (Tons/Annum)	561,000	532,950	448,800	364,650
Sales Revenue (Million $) (at $140/ton)	78.540	74.614	62.832	51.051
Operating Costs $/Ton				
1. Gas	23.40	23.40	23.40	23.40
2. Catalyst and Chemical	0.60	0.60	0.60	0.60
3. Maintenance Materials	2.25	2.37	2.86	3.46
4. Labour (including contract labour)	0.425	0.472	0.531	0.654
5. Salaries & Benefits	5.50	5.74	6.88	8.46
6. Marketing	0.20	0.232	0.25	0.31
7. Head Office Expenses	2.00	2.32	2.50	3.10
8. Packing Materials & Packaging	10.00	10.00	10.00	10.00
9. Taxes	0.40	0.40	0.40	0.40
10. Insurance	0.65	0.65	0.65	0.65
11. Depreciation at 7½%	32.00	33.80	40.00	49.23
TOTAL COST:	77.625	80.034	88.011	100.26

(Contd.....P-2)

	100%	95%	80%	65%
Total Operating Cost/ annum ($ million)	43.548	42.654	39.499	36.560
Margin ($ million)	34.992	31.960	23.333	14.491
Interest on External Finances @ 10% ($ million)	16.800	15.160	6.533	2.309
Corporation Taxes @ 55% ($ million)	10.006	8.338	3.592	
Net Profit ($ Million)	8.186	6.24	2.941	
Return on Equity	11.360	4.470	4.080	

TABLE - III

AVERAGE ANNUAL DOWNTIME AND NUMBER OF SHUTDOWNS

	1969-70 (22 Plants)	1971-72 (27 Plants)	1973-74 (30 Plants)	1975-76 (30 Plants)
Days of Downtime	50	45½	49	50
No. of Shutdowns	9½	8½	10½	11

	Steam Integration Process	Conventional Process
Specific consumption of steam	1.13 T/T urea	0.89 T/T urea
Specific Consumption of Electric Power	29.1 KW/T urea	78.1 KT/T urea
CO_2 Compressor Carbamate Pump	29.1 KW/T urea	78.1 KW/T urea

Table;5 Comparison of energy consumption between steam integration process and conventional process.

TABLE - IV

NUMBER OF SHUTDOWNS OF LARGE TONNAGE AMMONIA PLANTS

Classification	1969-70 (22 Plants)		1971-72 (27 Plants)		1973-74 (30 Plants)		1975-76 (30 Plants)	
	Nos/Year	Day/Year	Nos/Year	Days/Year	Nos/Year	Days/Year	Nos/Year	Days/Year
1. Instrument Failures	1	1	2	1	1½	1	1½	1½
2. Electrical Failures	1	1	½	½	1	1½	1	1½
3. Major Equipment Failures	5½	29	5	19½	6	25	6	22
4. Thurn Arounds and Planned Maintenance	1	16	½	23½	½	18	½	20
5. Others	1	3	½	1	1½	3½	2	5
TOTAL:	9½	50	8½	45½	10½	49	11	50

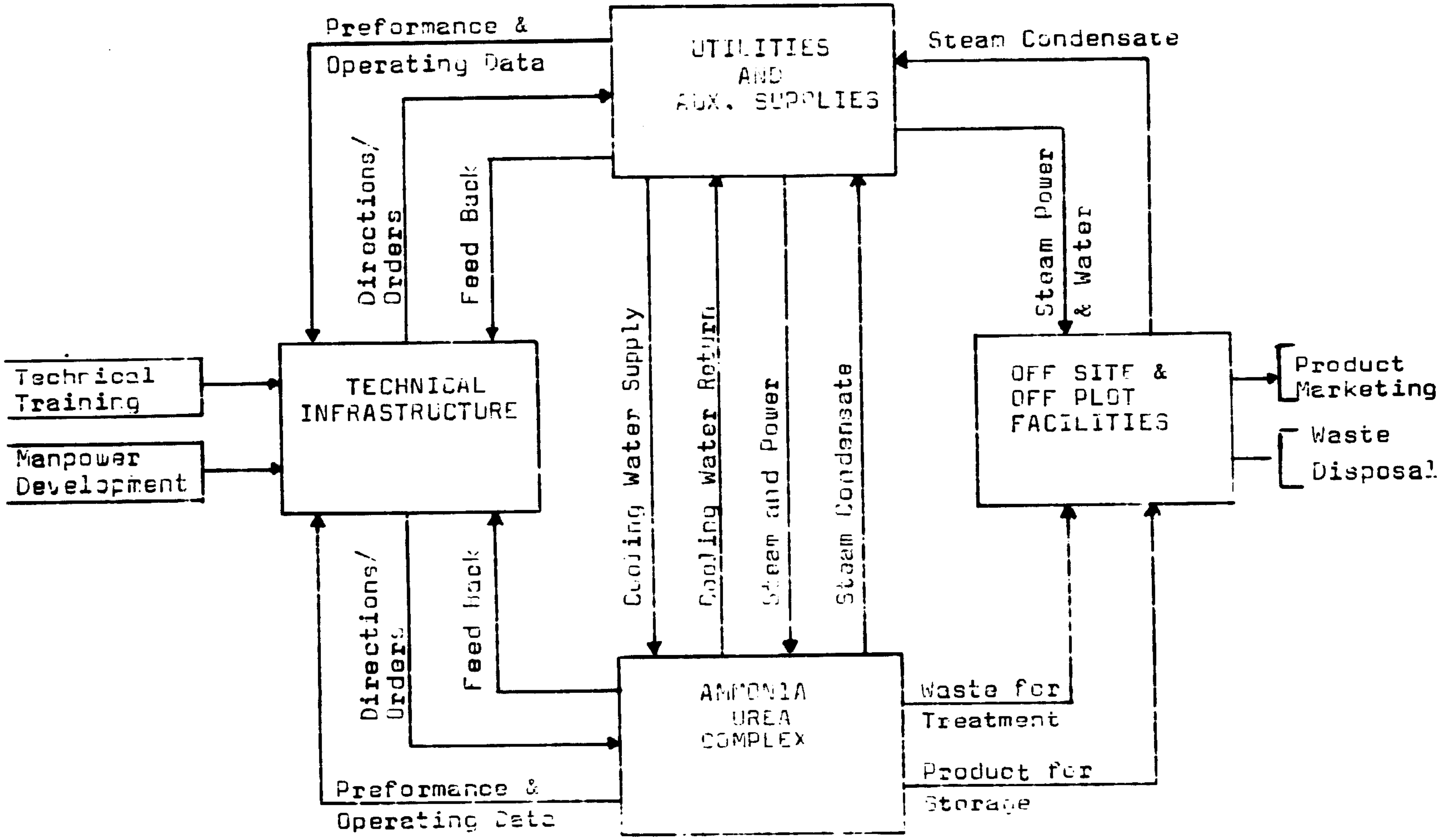

Preformance &
Operating Data
Directions/
Orders
Feed Back
UTILITIES
AND
AUX. SUPPLIES
Steam Condensate
Steam Power
& Water
Technical
Training
Manpower
Development
TECHNICAL
INFRASTRUCTURE
Cooling Water Supply
Cooling Water Return
Steam and Power
Steam Condensate
OFF SITE &
OFF PLOT
FACILITIES
Product
Marketing
Waste
Disposal
Directions/
Orders
Feed Back
AMMONIA
UREA
COMPLEX
Waste for
Treatment
Product for
Storage
Preformance &
Operating Data

FIG. I

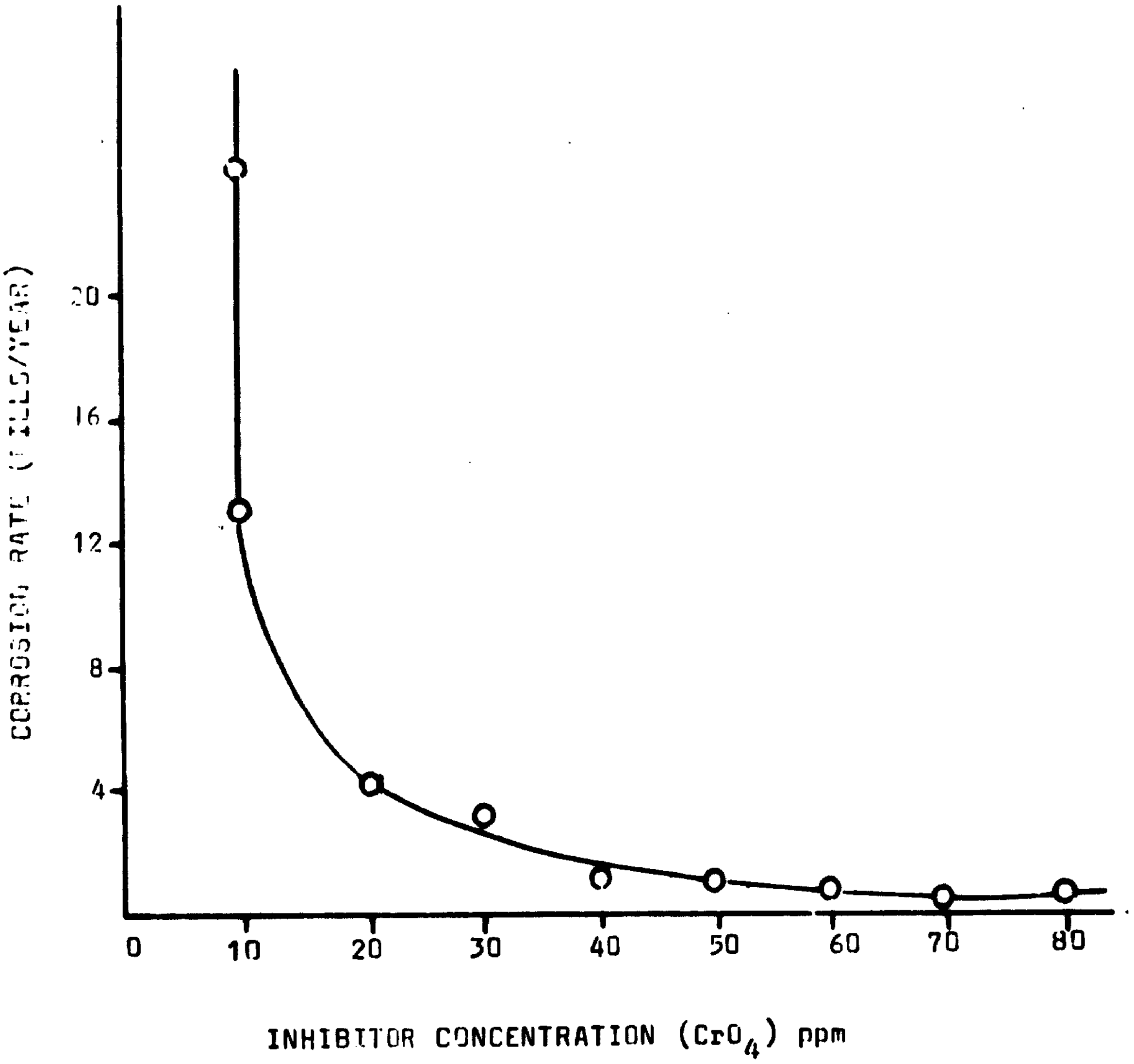
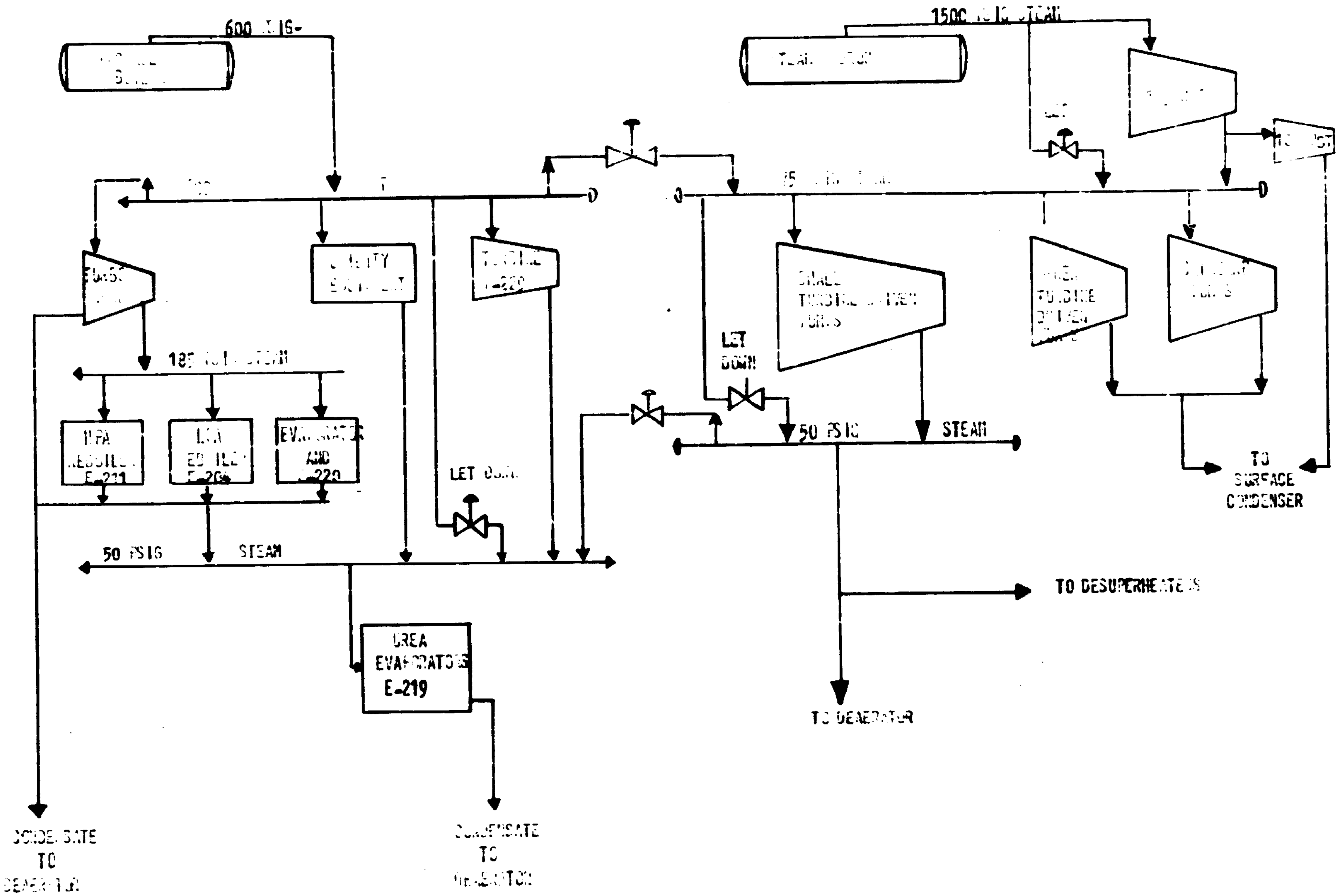

CORROSION RATE (MILLS/YEAR)
20
16
12
8
4
0
10
20
30
40
50
60
70
80
INHIBITOR CONCENTRATION (CrO_4) ppm

FIG. 2



INTEGRATED STEAM SYSTEM FOR AMMONIA/UREA PLANT

FIG. 3

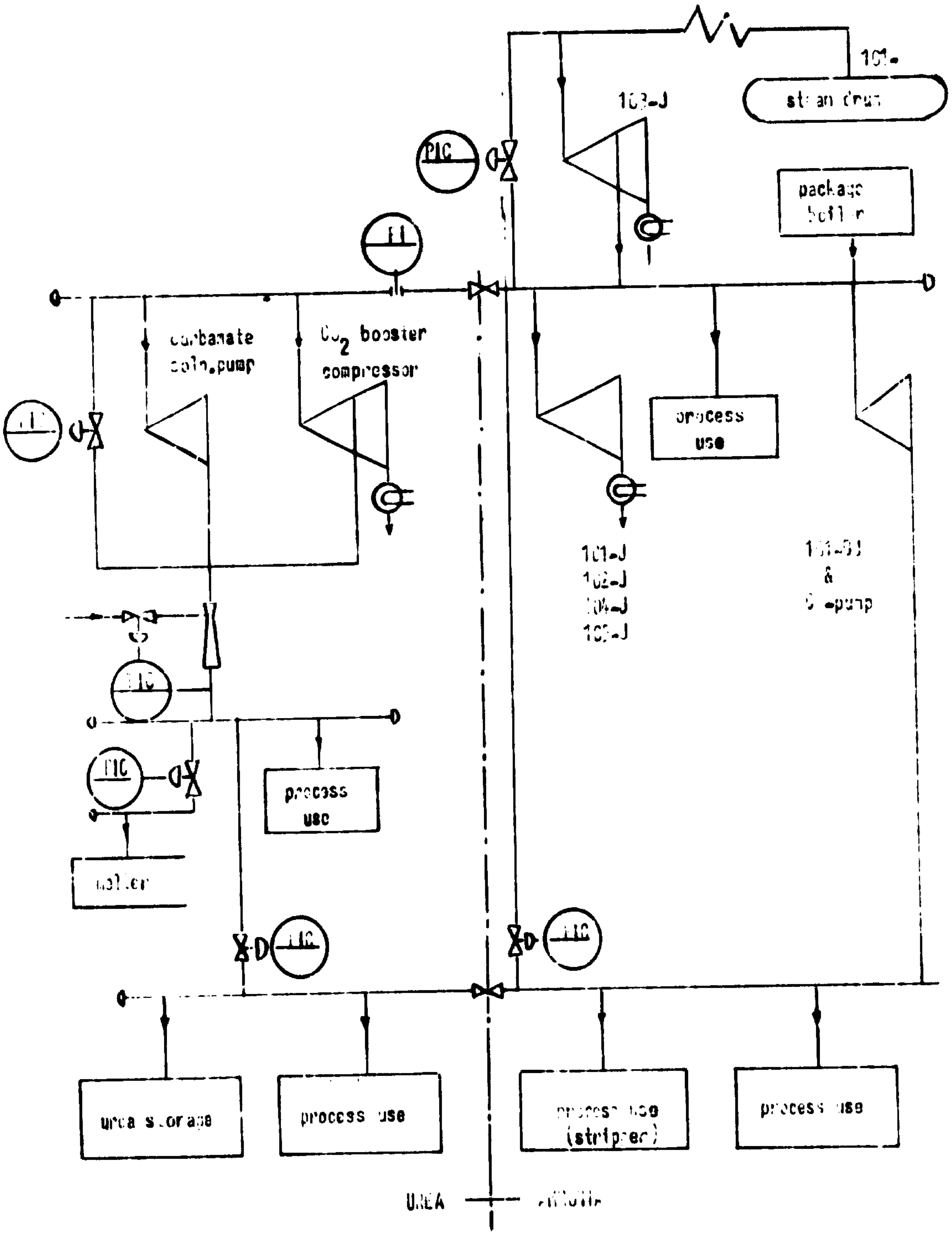


FIG. 4 SCHEME OF STEAM SYSTEM FOR AMMONIA AND UREA PROCESS

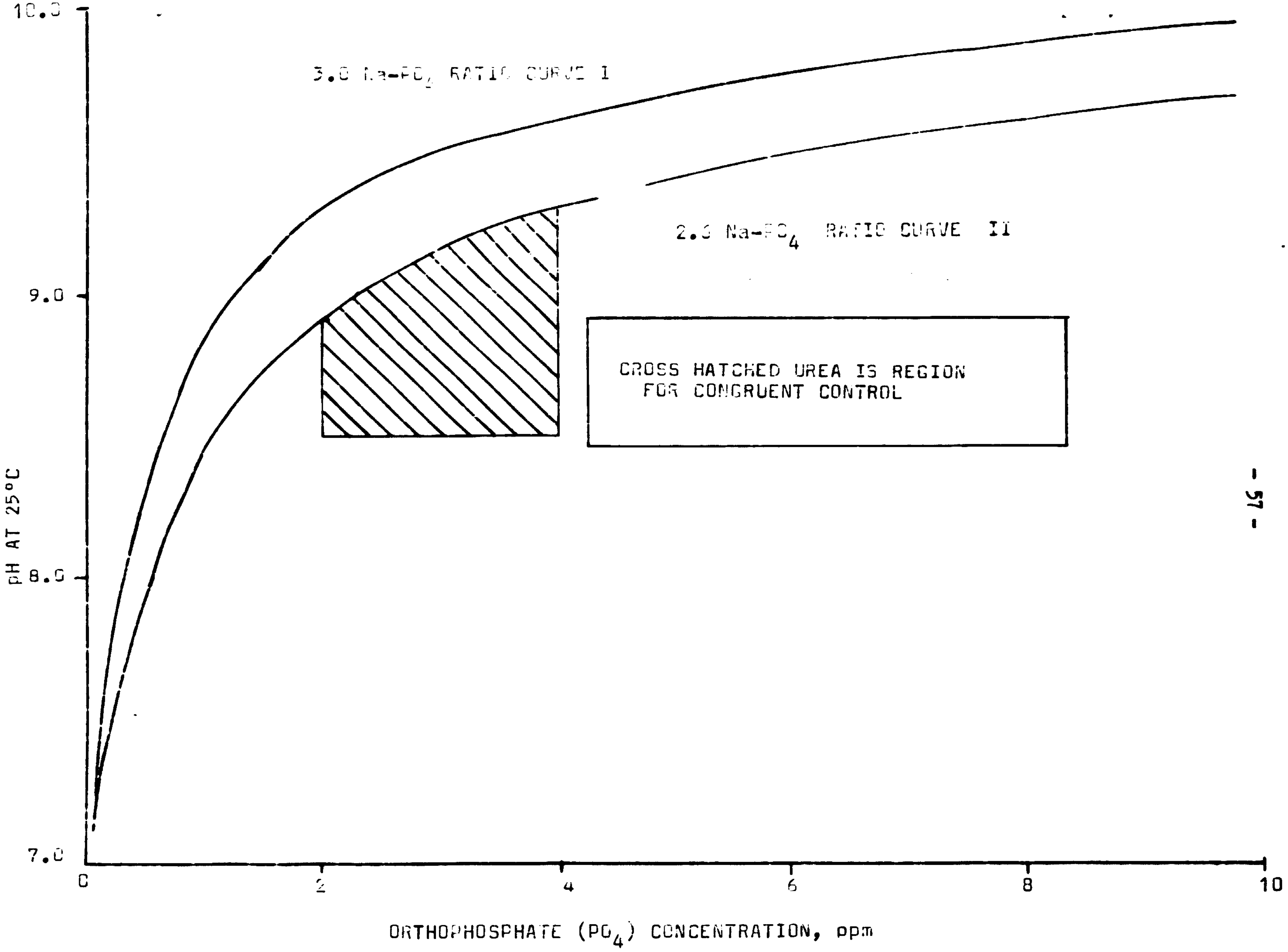
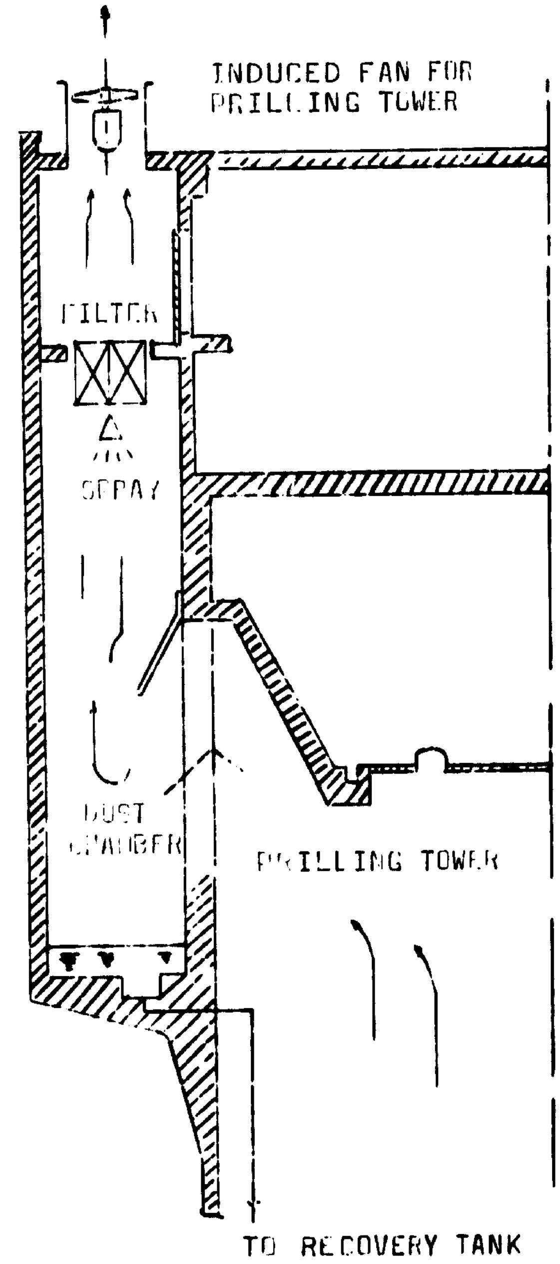
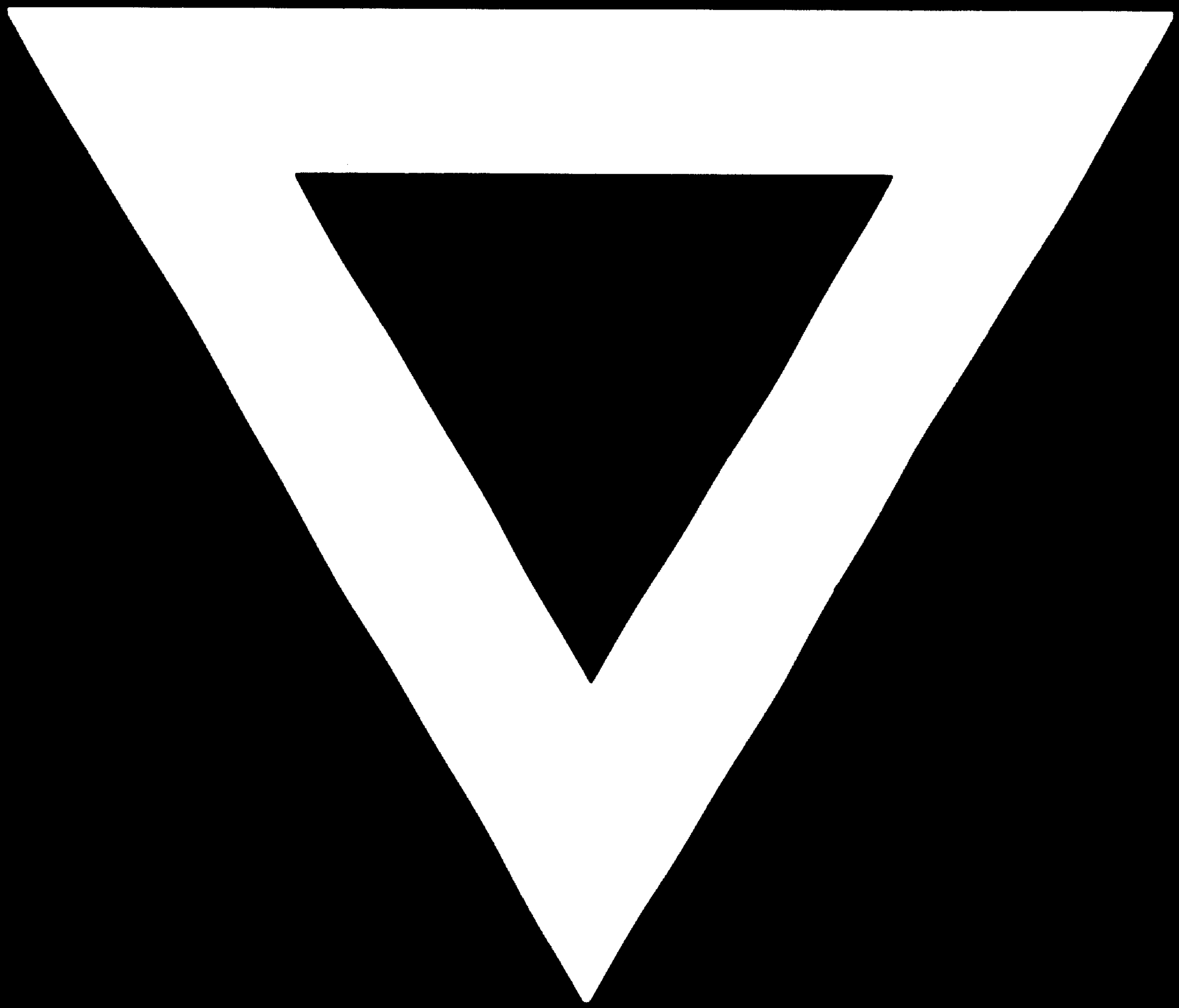

10.0
9.0
8.0
7.0
pH AT 25°C
0
2
4
6
8
10
ORTHOPHOSPHATE (PO_4) CONCENTRATION, ppm
3.0 Na-PO_4 RATIO CURVE I
2.3 Na-PO_4 RATIO CURVE II
CROSS HATCHED UREA IS REGION
FOR CONGRUENT CONTROL

FIG.5



IG. 6 Scheme of dust recovery chamber installed at the top of prilling tower

C-667



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