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Integrated Maintenance and Energy Management in the Chemical Industries

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Dedicated to those maintenance and operating technicians who work hard in a spirit of cooperation for the safe, pollution free, and efficient running of the chemical industries.

Preface

Chemical industries provide many essential products for meeting the daily requirements of the citizens and also for the economic growth of a country.

Managements run the chemical industries successfully by meeting the product quality and delivery schedules specified by the clients while operating safely and efficiently without causing environmental pollution.

It is well known that the cost of production depends on the yield of raw materials, smooth working of the plant, energy consumption, and recovery. However, it is very difficult to control the cost of raw material which depends on the availability as per specifications and certain external factors like weather conditions, transport bottlenecks, power tariff, etc.

Hence, it is very important to have an efficient integrated maintenance and energy management for ensuring smooth, efficient running of the chemical plant which can reduce the cost of production. *It is also very important to keep in mind that the selling price of products will depend on the competition in market*.

A large number of chemical industries need considerable energy (mainly electrical and thermal) for carrying out various operations like handling and pre-treatment of raw materials, operation of the reactors, further processing (purification) of crude products, and safe disposal of any hazardous waste generated. Senior engineers should look into all these activities carefully for reducing the need for energy.

The operating cost of the process units and machinery can thus be reduced by integrated maintenance and energy management (minimising losses, conservation of energy, and maximising recovery from process streams).

Conflicting Priorities

Important departments of the industry such as purchase and sales, production plants, maintenance section for process units and machinery, stores (inventory control), and utility arrangements (water, power, and fuels) face different situations and have their own priorities in their working areas. Human resources, research and development, logistics, and finance also have their own priorities.

However, priorities of these departments/sections may not be concurrent.

Managements shall prepare guidelines and instructions for these various departments so that all of them understand each other's difficulties and work in close cooperation to meet the common goal of successful running of the organization while ensuring safety in all activities.

Revenue Allocation

The revenue obtained by sale of products shall be judiciously allocated to procure (i) necessary raw materials and other inputs; (ii) spares for maintenance of process units, plant machinery, energy recovery units and facilities for effluents treatment; (iii) wages to employees; (iv) provision for depreciation of equipments; (v) expenses on research and development; (vi) taxes to statutory authorities; and (vii) payment to investors.

Managements of running plants also have to consider and take decisions for:

- Acquiring idle plants (which may be available at low cost) and reviving them
- Expansion of production capacity to meet increased demand
- Diversification to new products for increasing the presence in market
- Modernisation of existing process plants for improving efficiency
- Making certain changes in the plant for safer working and/or better pollution control

Suggestions can be generated in-house after consultation with various departments for all of the above to get improved design or better construction of processing units.

This book gives guidelines for:

Integrated Maintenance: Planning and Implementation
(Very important for a safe, efficient plant which does not cause environmental pollution):

(i) Assistance for preparing purchase orders for process units and machinery (see below), (ii) ensuring safety of human beings and plant assets, (iii) assistance to increase equipment life, (iv) guidance for operating the plant within safe limits as recommended by OEM, (v) regular condition monitoring of equipments and preventive maintenance, (vi) analysis of breakdowns, (vii) arranging timely repairs, (viii) replacement of components by procuring correct spares, (ix) planning for major maintenance jobs and safe procedures for all activities

Procurement activities: classification of process units, materials and machinery

- Capital equipments such as *process units and machinery*

- Process inputs such as *raw materials*, *catalysts*, *stabilisers*, *tower internals*, and *filter aids*
- Equipments related to energy and utilities such as *waste heat recovery boilers*, *steam turbine/gas turbine driven generators*, *electrical motors*, and *refrigeration plants*

Maintenance engineers have the responsibility to maintain the chemical plant so that it can work in a safe, smooth, pollution free, and efficient manner.

Their jobs involve not only looking after machineries like pumps, compressors, conveyors, and electrical equipments but also working in close cooperation with process operation engineers and plant operators for the cleaning of process units like reactors, converters, evaporators, and absorption towers, thorough inspection of their internals, and repair/replace the faulty units.

This may require entering inside such processing units and remain there for several hours for cleaning, inspection, and repairs till the units are ready for restart.

Assistance to Plant Management

The senior management must involve chemical process engineers along with maintenance engineers when selecting the process technology and machinery when a new plant is set up, an idle plant is revived, or an existing plant is diversified.

These engineers have to apply their knowledge and experience to check whether the process units and machinery will be able to deliver the required performance in terms of rated capacity per day and total production per annum (which depends on total running time per year), while handling the various chemicals in severe operating conditions. The design and construction of the equipments should be carefully checked during the procurement of machinery itself so that deterioration of performance shall not occur (less output, not able to meet quality, development of unsafe conditions) during operation of the plant and heavy costs are not incurred due to frequent breakdowns.

The required performance, necessary features, material of constructions, operating conditions etc shall be frozen and clearly mentioned in the inquiry document for process units and machinery.

Drafting the purchase orders: terms and conditions to be included
For a new plant: safe, efficient process units and machinery with proper conditions for performance guarantees for output and environmental pollution control

Expansion/diversification of existing plant: possibility for improving the plant layout, better process control by the use of appropriate *well-maintained* instrumentation, maximising energy efficiency

(Terms and conditions for performance guarantee for the machinery must be specified in the purchase order and agreed upon by the supplier. Include terms and conditions for annual maintenance contract also if required.)

Maintenance of Plant:

- Process units along with their internals (absorption tower internals, filter cloth, etc.)
- Machinery essential for the safe and smooth operation
- Effluent treatment facilities for controlling environmental pollution
- Important electrical equipments such as transformers, motors, rectifiers
- Instrumentation and civil works

Inventory Control

Keeping adequate stock of essential inputs required for process units, Effluent treatment Plant

Maintaining sufficient spares for machinery in the plant

Energy Management: Maximizing Energy Efficiency

- Reduction of consumption by improving the plant layout, for easier handling of procurement of the right materials
- Minimisation of losses of energy by better refractory lining and insulation
- Evaluation of potential for energy recovery
- Selection, operation, and maintenance of efficient heat recovery equipments
- Cogeneration (power and heat)

Useful tips are also given for (i) increasing life of plant units, (ii) good lubrication of machinery, (iii) reducing vibrations in running units for better performance, and (iv) repairs to protective lining of process units.

These tips are useful as they can minimise the breakdowns and hence can reduce energy losses (which occur during frequent stop and restart of the plant).

The main aim of the book is to acknowledge the responsible hard work put in by the maintenance teams of various disciplines and to create an understanding among production, marketing, finance, and human resources departments to work in cooperation.

The book also aims to highlight the management of (i) maintenance of process units and their internal equipment *and* (ii) maintenance of the machinery used in the plant *for* (iii) safe and smooth operation thereby maximising energy efficiency of the production unit without causing environmental pollution.

The book thus aims to highlight the **Integrated Maintenance and Energy Management** for the successful running of a chemical plant.

This book has therefore been written in a simplified manner for a better appreciation of the practical situations by the readers (who could be plant managers, fresh engineers, and students of chemical, mechanical electrical, and industrial engineering).

Suggestions are welcome from the readers for including more information and improving the book further.

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2. *Production Management of the Chemical Industries*

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I have referred to standard textbooks on chemical process industries, *Chemical Engineers' Handbook*, my own classroom notes, and the practical experience gained while working in various capacities for design, modernising, diversification, erection, commissioning, operation, and maintenance of chemical industries in India (GRASIM Industries, Gopalanand Rasayan, Kesoram Rayon, Tanfac Industries, Parksons Dyestuff, IDI Chemicals Ltd, National Rayon Corporation Ltd, SMS Infrastructure, Vidula Chemicals and Manufacturing Industries, V K Engineers, Evergreen Technologies, SKG Refractories, Calderys India, NEAT Consultancy Ltd, etc.), in Kenya (East Africa Heavy Chemicals), Thailand (Thai Rayon Co.), and Indonesia (PT Indo-Bharat Rayon) for writing on various process units, their construction, plant machinery, and their operation and maintenance in various chapters of the book.

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Chapter 1
Introduction to Some Important Chemical Industries

1.1 Introduction to Some Important Chemical Industries

Process units, machineries and equipments in many chemical industries are operated at high temperatures, high pressures and/or are subjected to corrosive and erosive conditions.

Typical equipments used in chemical plants are:

- Crusher, pulveriser, grinders, calciners, melters, filters for pre-treatment of raw materials
- Conveyors of various types
- Process units operating at high temperatures
- Reactors, condensers, waste heat recovery units
- Water treatment, effluent treatment, air pollution control
- Steam heated (jacketed/traced) process units, pipes, pumps and storages
- Cooling systems
- Electrical equipments

1.2 Importance of Process Units and Machinery

Production engineers and maintenance engineers should carefully understand properties of all materials being handled. Material Safety Data Sheets (**MSDS**) as well as the operating conditions of the process units and machinery in the plants must be carefully looked in to.

Some typical units used for carrying out reactions are process reactors (specially operating at high pressures) while units like filters, melters, calciners are used for pre-treatment of raw materials. Heat exchangers are necessary for heating and cooling of process streams for efficient running of the plant. Condensers are required for condensation of reaction products and recovery of volatile materials; while

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absorption towers are necessary for completing the reactions, for absorbing valuable volatile materials and for pollution control.

It is necessary to operate and maintain all of them always in proper working condition for **safe, pollution free and smooth working of the process plant**.

Careful monitoring of process operations and condition of equipments is required to prevent any mishap since many of these materials being handled are corrosive, inflammable/dangerous and high temperature/high pressure units are involved.

Statutory rules must be complied with to produce, store, handle, operate and maintain the production facilities at site.

Certain mechanical equipments in these process plants need considerable energy for their operation and careful attention during operation. They operate almost continuously and are subject to erosion and corrosion. Some typical equipments and machinery required in these plants are highlighted in the section following description of the processes.

The actual process design, machinery required, installation, operation and maintenance efforts required will depend on product mix, scale of operations, local climatic conditions, quality of raw materials available.

1.3 Brief Description of Some Important Chemical Industries

1.3.1 Manufacture of Sulphuric Acid

Raw sulphur is molten by steam coils and filtered by Pressure leaf filters. It is fed to the furnace at a controlled rate to produce SO_2. Temperature of the exit gases is reduced by the WHRB before passing through the multistage converter for oxidising the SO_2 to SO_3. It is then absorbed in Inter Pass and Final absorption towers in stream of circulating sulphuric acid. Product acid is transferred to storage tanks. The drying tower serves to dry the air for the plant.

Main Equipments

- Steam coils in sulphur melter ………subjected to corrosion (free acidity in sulphur)
- Filtration system for liquid sulphur… subjected to corrosion (free acidity in sulphur)
- Sulphur feeding pumps……………subjected to corrosion (free acidity in sulphur) and erosion due to some particulate matter (ash)
- Sulphur burning Furnace…………operation at high temperature; corrosive gases are present.
- Air Blower …………….required to supply air to run the plant, very important machine
- Water treatment plant…… required. to supply DM water to the WHRB and process units plant

- Waste heat recovery boilers WHRB…… required to cool the furnace exit gases and recover heat as steam. Subjected to corrosive gases at high temperature; covered by statutory regulations.
- Economiser(s) … required to cool the converter exit gases and recover heat as hot water; subjected to corrosive gases at high temperature; covered by statutory regulations due to high pressure working.
- Boiler feed water pump(s) and piping … required. to supply DM water to the WHRB, covered by statutory regulations due to high pressure working.
- Converter system and heat exchangers……. required to convert SO_2 to SO_3; subjected to corrosive gases at high temperature
- Acid Circulation Tank, Acid Towers, Pumps, acid coolers ….required to operate the SO_3 absorption system and supply dry air to furnace; subjected to corrosive concentrated acid
- Water Pumps…for producing DM water for boilers, for producing acid, for cooling acid
- Instrumentation subjected to corrosive gases at high temperature, and to concentrated acid

1.3.2 Manufacture of 25%, 65% Oleum, Liquid SO_3 Plants

- These plants are add-on units to a sulphuric acid plant. Gases from exit of converter third pass are passed through cold heat exchanger CHE and economiser (optional). The gases are now passed through 25% oleum tower to absorb SO_3 and thereafter through Inter pass absorption tower for further absorption of SO_3 if sulphuric acid is also to be produced. Exit gases from IPAT are reheated by CHE and hot heat exchanger HHE to conversion temperature again; and passed through fourth and fifth passes of converter. Exit gases from converter are passed through economiser and oleum boiler (if SO_3 vapours are to be produced). The equipments required are:
- 25% oleum circulation tower with internals.
- 25% oleum circulation pumps and cooling system.
- Oleum boiler for generating SO_3 vapours. (it can be heated by process gases or steam).
- Heat exchangers for hot oleum exiting from boiler/incoming oleum to boiler
- 65% oleum tower with internals.
- 65% oleum circulation pumps and cooling system.
- SO_3 condenser of special design
- Cooling tower
- Storage tanks
- Dispatch pumps for 25% and 65% oleum tower.
- Steam tracing of piping for 25%, 65% oleum lines and liquid SO_3 tank.

1.3.3 Manufacture of Papermaker's Alum

Alumina hydrate is a pure raw material. It is reacted with sulphuric acid in a reactor with acid resistant lead and brick lining and equipped with steam coils to initiate the reaction. The reacted material is heated in evaporator to remove excess water and is then taken out for pouring in to moulds. Sulphuric acid to be used for this product should not contain more than 50 ppm iron. Only demineralised water should be used. The steam coils shall be of stainless steel 316 L or of hardened lead (if permitted by client).

- Hoist …required to take up alumina hydrate bags to reactor
- Main reactor with lead and brick lining (MS-LL-BL)… subjected to corrosion due to free acidity
- Boiler with accessories…essential to supply steam to reactor and evaporator
- Fuel tank, Fuel oil pump, Air Blower ….to operate the boiler
- Water treatment plant…to feed the boiler and reactor
- Steam coils…to run the reactor and evaporator; subjected to acidic corrosion
- Acid transfer pump, and acid day tank… to feed the reactor; subjected to corrosive concentrated acid

1.3.4 Manufacture of Alum

Bauxite lumps are crushed and ground to 150 mesh (about 85%) and then fed to reactor lined with acid resistant bricks. 98% sulphuric acid and filtrate (with recovered alum) from filter press is added to the reactor. Live steam or specially lined steam pipe is used for stirring and reaction. The reaction mass is sent to clarifier to settle the unreacted impurities. Clarified solution is evaporated by using steam coils made from stainless steel 316 L or hardened lead. The concentrated solution is poured in moulds, crushed and bagged.

- Bauxite feeder …to feed bauxite lumps to crusher; subject to erosion
- Crushing and Grinding Machines…to produce bauxite powder; subject to erosion
- Bag filter for dust control…for pollution control
- Acid Resistant Brick lined Reactor…for main reaction, subjected to erosion as well as acidic corrosion
- Sulphuric acid main storage tank, transfer pump and day tank…for the reactor; subjected to corrosive concentrated acid
- Boiler with accessories, Fuel storage, Oil firing system, air blower…… essential to supply steam to reactor and evaporator.
- (*Steam is available from exit of back pressure type steam turbine in some plants*).
- Thickener (settler and clarifier tanks) with acid resistant lining … subjected to acidic corrosion

- Filter press with accessories (air compressor)…to recover alum solution from waste water; subjected to pressurised liquor and acidic corrosion
- Evaporators with SS 316 L or lead steam coils … subjected to acidic corrosion;
- Dispatch section……Weighing and Packing of alum slabs/crushed pieces…

1.3.5 Manufacture of Single Super Phosphate

Rock phosphate is ground to about 100 mesh and mixed with 65–70% sulphuric acid in a mixer with Ni-hard blades. Gases are evolved with fluorine compounds, acid mist, CO_2 and water vapour due to reaction with sulphuric acid (a small quantity of CaF_2 is generally present in rock phosphate).

Some un-reacted particles of rock phosphate also get entrained. The gases are scrubbed in wet cyclone, venturi scrubber, spray tower and polishing alkali scrubber (optional). Generally rubber lined induced draft fan is used to suck the gases from mixers-reactors. The outgoing scrubbing liquor contains silica and H2SiF6 solution. The silica is taken out from bottom as precipitated material and the acidic solution is recycled to the mixer-reactor. Reaction material is dropped to a vessel below and reaction is allowed to continue for a few hours. It is then cured for a few days in the shed before bagging.

Important units and machines are:

- Storage shed for rock phosphate lumps…large shed subject to dust, movement of material handling machinery
- Pulveriser/grinder…subjected to big lumps; and can cause dust pollution during operation (which is controlled by providing cyclone separator, bag filter and suction fan)
- Bucket elevator, screw feeder
- AR brick lined mixer (reactor) with paddles of special alloy…for main reaction; subjected to acidic corrosion, erosion due to particles and higher temperature,
- Den Cutter for reacted mass…for continued reaction; subjected to acidic corrosion, erosion due to un particles of rock phosphate
- Acidic liquor (H2SiF6) recycle system from scrubbers… subjected to acidic corrosion and erosion due to particles of silica
- Dilution of sulphuric acid and sending to feed tank for mixer (reactor)… subjected to acidic corrosion
- Air pollution control units (scrubbing liquor circulation pumps for ventury scrubber, spray tower, polishing tower, induced draft fan)… subjected to acidic corrosion and erosion due to particles of silica and unreacted particles of rock phosphate
- ID fan…(rubber lined)..subject to erosive particles of silica and acidic gass
- Precipitated Silica removal from APC units…essential to control erosion due to particles of silica

- Effluent Treatment Plant…to treat acidic liquor which cannot be reused
- Covered Storage shed is provided with hoists, electrical overhead travelling crane (with operator console). The shed is for curing reacted material and storing finished product.

1.3.6 Manufacture of Caustic Soda and Chlorine by Electrolysis

Common Salt is dissolved in depleted brine (with fresh water if required) and treated to remove impurities. It is filtered and fed at controlled rate to the electrolysis cell with nafion membranes (which allow migration of sodium ions to cathode). Dil. NaOH solution with DM water is fed to cathode chamber. Reaction with $OH(-)$ ions produce NaOH while hydrogen gas is evolved. Chlorine gas (it is generally with water vapour) evolved from anode chamber. DC power for electrolysis is supplied by rectifiers.

NaOH solution exits from cathode chamber with higher concentration.

The wet chlorine gas is dried, compressed, cooled and liquefied. It is then filled in cylinders.

Likewise, hydrogen is also compressed and filled up in cylinders.

Hydrogen and Chlorine are reacted in a graphite furnace to produce HCl gas which is absorbed in DM water to produce HCl acid.

- Salt feeder and dissolver …for maintaining concentration of feed brine to electrolytic cells Brine Purifying units and filters…… subject to corrosive conditions
- Brine Feeding system, Flow meters… subject to corrosive conditions
- Electrolytic cells with accessories (Anodes, and Cathodes assemblies) … subject to corrosive conditions
- Membranes and fixing arrangements … subject to corrosive conditions
- Rectifiers…for supply of DC power to electrolysis cells
- Bus-bars…carry heavy currents; even minor resistance/any loose contact can waste lot of power
- Gas evacuation from Electrolytic cell… subject to corrosive conditions due to wet chlorine; any leak can be dangerous
- Chlorine compressor (very important machine) Dryers, Liquefaction system… Any leak of pressurised chlorine gas is dangerous
- Chlorine Cylinders filling arrangement… … Any leak of pressurised chlorine gas is dangerous
- Hydrogen gas compressor (very important machine) dryers and filling in cylinders… Any leak of pressurised hydrogen gas is dangerous