

# Advanced Energy and Environment Management of Urea Complex in Indian Fertilizer Industry

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**Abstract**—The Indian Fertilizer Industry (IFI) is much effected by the amplified qualitative and quantitative demands of food grain supplies with technologically improved, cost effective and eco friendly methods of production. The article shall present the concept of advanced and intensified energy recovery for reduced effluents and increased effective yield.

**Keywords**—Indian fertilizer industry, Urea manufacturing, Energy recovery, Effluents, Environmental impact

## I. Introduction

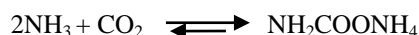
India has always been an agriculture oriented country thereby making it as an important pillar for the supporting economy of the nation. The earliest IFI was established at Ranipet (Tamil Nadu) in 1906 to encourage domestic fertilizer production keeping in view the agricultural needs of country. But as the population increased, the qualitative and quantitative food grains demands also increased tremendously and therefore it became important to identify a low cost and efficient fertilizer for the food crops. It was found that Urea enjoys high popularity among all the Nitrogen-Phosphorous-Potassium (NPK) fertilizers mainly because of its high Nitrogen content (~46%), low cost and water solubility.

## II. Urea Processing and Energy Recovery

Urea is a nitrogenous fertilizer that is commercially manufactured using liquid ammonia (NH<sub>3</sub>) and CO<sub>2</sub> gas. The use of CO<sub>2</sub> as a raw material for urea synthesis is extensively practiced in India because of lesser raw material pretreatment cost and easy availability of coal. CO<sub>2</sub> is generally processed from the coke oven plants while liquid NH<sub>3</sub> is gathered from the ammonia synthesis plant making it as an integral part of the urea manufacturing complex.

### A. Synthesis of Urea

The reaction between NH<sub>3</sub> and CO<sub>2</sub> yields suitable results at temperature as high as 190°C and pressure up to 200 bar producing Ammonium Bicarbamate which is successively dehydrated to form urea and water as represented in the following set of reactions;



In the above set of reactions urea thus formed is present in molten state due to the high thermal treatments while ammonium bicarbamate is an undesired product along with dehydrated water necessary to be recovered for intensified operation of the plant. The dehydration of ammonium bicarbamate to form urea is relatively slow and endothermic in nature with maximum 50-80% of CO<sub>2</sub> conversion which increases with increasing temperature and NH<sub>3</sub>/CO<sub>2</sub> ratio while is adversely effected by increasing H<sub>2</sub>O/CO<sub>2</sub> ratio thereby making it an inevitable parameter for energy calculation and environmental impact assessment. A detailed plan of the process flow in a urea manufacturing plant is shown schematically in Fig 1, which also can be referred for the energy recovery options within the process.

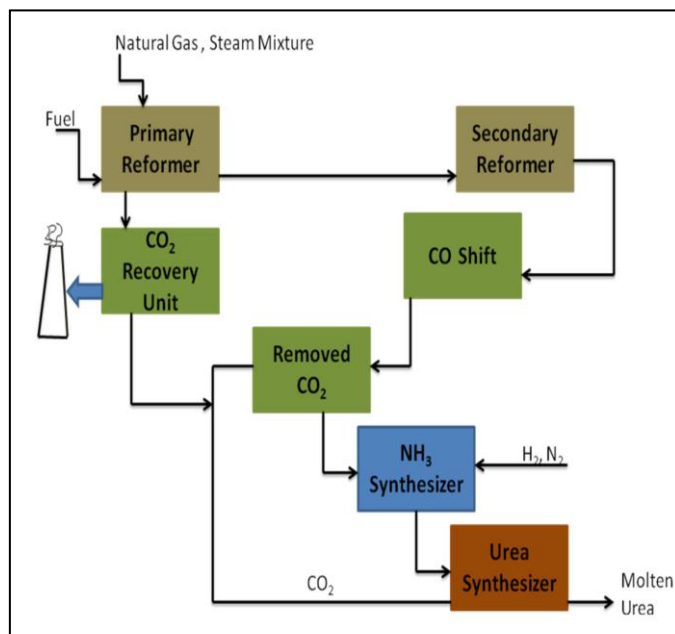


Figure 1 Process flow of urea manufacturing plant

### B. Energy Recovery Methods

The production and processing cost of urea from ammonia is highly anticipated by the amount of energy consumption and therefore to improve before proposing process intensification it is necessary to understand the scope of energy conservation in a urea synthesis and processing plant. Since most of the energy recovery and process intensification revolves around alternate methods for heat recovery, NH<sub>3</sub>/CO<sub>2</sub> molar ratio regulation and water recycling during the

synthesis of urea therefore on the pretext of current practices in energy conservation and emission control it is important to first understand the processing of molten urea to finished urea granules.

Under a combined effect of temperature and pressure ( $180^{\circ}\text{C}$  , 150-240 bar) the molten urea as obtained from Figure 1 is send to a reaction vessel along with a stream of recovered  $\text{CO}_2$  as feed material. Under reduced pressure the product from the synthesis unit is decomposed to get separate streams of unused  $\text{NH}_3$  and water. Possibility of trace amount of  $\text{CO}_2$  cannot be neglected and therefore this stream outlet is concentrated to evaporate the excess amount of water and  $\text{CO}_2$  to achieve rich urea with as much as 99% concentration. The urea rich stream from concentration or evaporation unit is then feed to a granulator or a prilling tower that works on the principle of spray tower to produce small prills of urea. This process of obtaining urea prills have been shown schematically in figure 2.

Most commercial units carries out either one of the three processes of energy recovery from urea processing plant, i.e. Once through Process (OTP), Partial Recycle Process (PRP) or Total Recycle Process (TRP). Since the conversion of ammonia is based on a  $\text{NH}_3/\text{CO}_2$  molar ratio, so clearly the increase in the molar ratio shall directly increase the urea yield thereby involving a series of loops to decompose carbamate at progressively low pressures. This initiative was known as the Total Recycle Process (TRP). OTP is the least expensive and least flexible method of urea processing thereby making it least favorable among all the available options. Among the

remaining process TRP is widely appreciated and accepted process among Indian fertilizer industries as it is solely based on the concept of 99% recycle of unused or remaining  $\text{NH}_3$  and  $\text{CO}_2$ , thereby making it most flexible due to its restricted dependency. Although the investment of installation of TRP units in old plants make seem a costly affair yet with some modifications this energy recovery method, if installed can increase the productivity by significant amount. Apart from the conventional techniques, combined assessment of the Best Available Technique (BAT) with TRP has gained immense popularity in Indian scenario and the growth and development in terms of IFI w.r.t improved energy consumption rates has been recorded briefly over the span of three decades;

- **Phase I**

$\text{CO}_2$  emission and  $\text{NH}_3$  consumption during the process of urea synthesis is quite inevitable and therefore the specific energy consumption can be done only when a provision of carbon dioxide is focused mainly on reducing the number of utilities thereby recovering maximum heat followed by ammonia stripping to provide energy saving solutions. The most widely acceptable energy recovery techniques used during 1980-90 included Purge Gas Recovery Unit (PGRU) besides improving the reformer designs by using better metallurgy for making reformer tubes,  $\text{CO}_2$  removal using solvent etc for better heat recovery near the convection zone. These technologies mainly focused on reducing the cost of production by regulating the amount of effluent discharge.

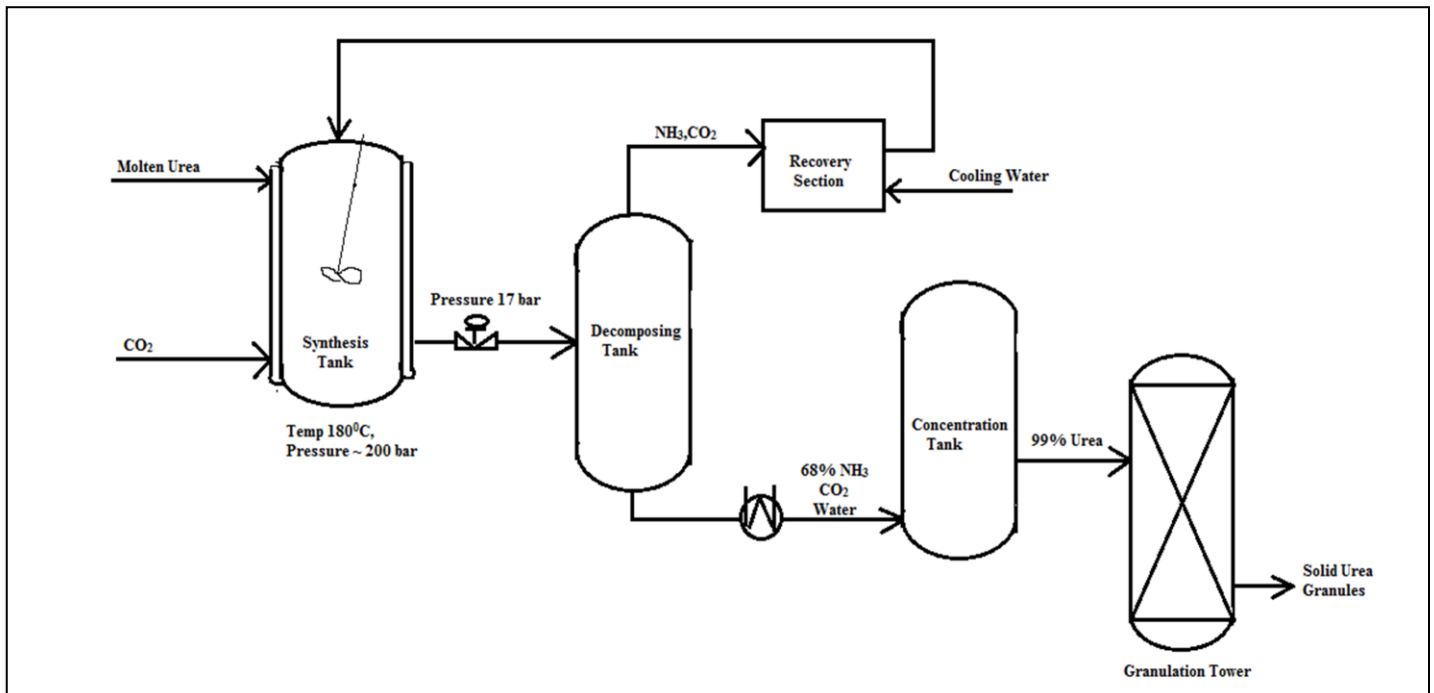


Figure 2 Processing of molten urea to form solid urea granules.

- **Phase II**

Before the beginning of 2000, many technological changes have brought along with them wide main frame of reforming or upgrading the existing process equipment design yet even after the improvement in the material of reformer unit the emphasis was still on the waste heat recovery from the off gas of the reforming furnace. Additional heat recovery from the reforming sections using air pre heaters was one of the earliest attempts towards energy saving in this field. The synthesis convertors of the old plants were changed from axial to radial-axial or radial flow to allow restrained pressure drop throughout the reactor which in turn resulted in the increase in conversion per pass thereby reducing the energy consumption of synthesis gas.

The installation of Distributed control System (DCS) and Programmable Logic Controllers (PLC) ensured added security provisions and leak detection of the process flow so that unwanted discharges of the effluents in the flow streams can be avoided. [5]

- **Phase III**

Since the economic inflation was at its highest throughout the past decade, therefore rather than investing on new technologies, upgrading the existing ones was more feasible. This technological up gradation was done using relatively cheaper methods of energy recovery from the existing CO<sub>2</sub> removal method and upgrading them to single or two stage regeneration units with more efficient packing and hydraulic turbines. Although by this time most of the process plants were automated with advanced process controls still a very conventional and reliable method of energy recovery was by calculating specific energy requirements of individual process and their respective plants. This method did not only helped in analyzing and arresting the unnecessary energy consumption from the utilizes but also introduced the concepts of pinch technologies within the heat exchanging networks for better energy efficiency at relative lower cost and almost negligible environmental damage.

Apart from these other widely accepted industrial alternative include a Low Temperature Shift (LTS) guard with an additional heat recovery to preheat the boiler feed water was employed. The improved heat integration and better CO<sub>2</sub> removal was a result of the multi stage regenerator that allowed an energy recovery of around 0.02 gigacalorie (Gcal) per megatonne (Mt). [2], [6]

Compared to the global averages, the Indian fertilizer complex shows a relatively better performance in aspect of both energy consumption and green house gas emissions. In this regard, the recent developments that are introduced around the later end of 2000's in fertilizer complexes are namely Advanced Process for Cost and Energy Saving (ACES) and Isobaric Double Recycle Process (IDR) which is another modified stripping

process that was developed by Montedison, to recycle most of the unused ammonia and ammonium bicarbamate in to two separate decomposers. The whole process is divided in to two complex streams and probably because of this issue only; IDR is not that common in the industrial scenario. [1], [4]

### III. Effluent discharges & their Environmental Impact

Despite adopting the Best Available Techniques (BAT) for advanced energy recovery from the fertilizer complexes, there still exists a major escape route for hazardous pollutant emission in form of the effluent discharges from these processing units. The Indian Government and pollution regulatory boards of all states are therefore jointly working in this direction to provide a healthy working environment for not only the workers inside the factory but also preventing the toxic emissions by effective effluent treatment methods associated with BAT.

Nagarjuna fertilizers carried out a survey that estimated 29 out of all 32 active urea production plants in the country with maximum capacity of 22 Mt per year urea production using CO<sub>2</sub> gas and liquid ammonia as feedstock with an approximate energy consumption of 6.31 Gcal/t of Urea. [1] Unfortunately 80% of the total allocated energy to the industry is used in the ammonia synthesis step itself, thereby declaring such practices costly, inefficient and most importantly environment effecting.

Therefore, this section shall discuss the sources of effluent discharge and current practices of pollution control as employed in the urea complexes.

#### A. *Gaseous and Liquid Effluent*

The processed urea during its manufacturing and synthesis stage is molten as shown in Figure 1 and therefore to convert it in a more useful form this molten urea is cooled in to large prilling towers with massive amounts of cool air so that small granules and prills could be obtained. Most certainly the air coming out of the prilling tower contains excess amounts of urea laden dust at a rate of 100-150 mg urea/m<sup>3</sup> of NH<sub>3</sub> air while the internationally accepted limit for this is not more than 50 mg urea/m<sup>3</sup> of NH<sub>3</sub> air. Apart from this, purging done at the urea plant to dispose the once fed inert with raw materials like NH<sub>3</sub> and CO<sub>2</sub> is another source of effluent emission.

Liquid effluent from the urea plant is generated during the synthesis itself. The water recovered from the dehydration of ammonium bicarbonate is used as absorbent to recover unused urea from the recovery section, while urea solution is concentrated by evaporating CO<sub>2</sub> and water to give solid urea as end product along with unwanted urea mist. This mist is therefore essentially treated to prevent secondary air pollution.

## B. Impact of Emission & Pollution Control

Almost 30% of the overall waste water from any urea plant consist very high amounts Ammonia (NH<sub>3</sub>) and Urea itself which are potential pollutants for both human as well as animals. Despite the low NH<sub>3</sub> content that is naturally existing in the water bodies, special aquatic plants and marine creatures like algae and cold water trout are very vulnerable to NH<sub>3</sub> contamination if present in higher concentration. Some highly sensitive marine plants like *Zostera marina* may tend to become necrotic or at times even die due to NH<sub>3</sub> imbalance. Urea may not have such harmful impacts on human life until a chronic exposure but it particularly activate a specific type of ocean algae to produce toxins called *Domoic Acid* (C<sub>15</sub>H<sub>21</sub>NO<sub>6</sub>) that can be quite harmful for the aquatic life.

Remaining effluents emitting from Indian Urea complexes mainly have CO<sub>2</sub>, urea mist, spent catalyst and waste water. While on one hand most plants emits spent catalyst as the solid waste from the processing units beneficiate before their disposal as scrap in to the yards considering them ineffective now, the ill effects of CO<sub>2</sub> are emphasized mainly and have already been well known and studied on many occasions. While the increased levels of CO<sub>2</sub> in atmosphere can cause drowsiness, headache, and suffocation or at acute levels can even lead to hypercapnia or asphyxiation for humans, continuously increasing CO<sub>2</sub> emissions in aquatic bodies can cause sudden temperature rise leading to death of the marine habitat. [6], [7]

The pollution control from these fertilizer complexes are therefore associated by improving and intensifying the current practices to assure lower levels of effluent emission during processing. As per the directives received by the pollution regulatory boards, most of the Indian fertilizer industries are intensifying the process of urea granulation to save as much as 30% of the energy and improving the production by 50%. The process of urea granulation itself causes maximum environmental damages followed by concentrator/ evaporators and conveying of urea solution from high to low pressure vessels. Therefore, the BAT that are adopted while process intensification for Indian fertilizer industries includes mainly the installation of dust scrubbing towers with the prilling towers accompanied by advanced process control systems to manipulate the NH<sub>3</sub>/CO<sub>2</sub> and H<sub>2</sub>O/CO<sub>2</sub> molar ratios at the recovery section and better leak

detection instruments to subdue the quantitative effluent discharge during synthesis and conveying from the main process stream. [3]

## IV. Conclusion

The overall discussion is to attract the reader's attention on the currently growing need for advanced energy management with eco friendly alternatives to the Indian urea fertilizer complexes.

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