The Vadodara complex is situated at Fertilizernagar, India, and includes one ammonia plant, one synthesis gas plant, two urea plants, an ammonium sulfate plant and a diammonium phosphate (DAP)/ammonium sulfate phosphate plant. It also has two sulfuric acid plants and a phosphoric acid plant.

The complex is owned and operated by Gujarat State Fertilizers & Chemical Ltd. (GSFC), a manufacturer of nitrogenous and phosphatic fertilizers, as well as petrochemicals and other industrial products. The company decided to expand its business by constructing a new 40 000 tpy melamine production unit with an associated urea (off-gas treatment [OGT]) unit, feeding on fresh liquid ammonia and gaseous carbon dioxide (CO₂) and recycled melamine off-gas.

G. Di Carlo, Casale, Switzerland, reviews the design of an integrated melamine and urea unit in the Indian state of Gujarat.
After evaluation of the melamine market in India, which took into account domestic melamine production, melamine imports and future melamine demand in India, GSFC selected Casale as its partner for the realisation of the project in 2015. The first step entailed the basic engineering package, supply of proprietary items, and a detailed engineering design review.

The low energy melamine (LEM™) unit proposed to GSFC was based on the design of the Borealis plant currently running in Piesteritz, Germany, which has a capacity of 80 000 tpy, with two high pressure (HP) synthesis sections of 40 000 tpy each operating in parallel and a single common low pressure (LP) section of 80 000 tpy.

The HP synthesis section of the new GSFC plant design is identical in both design and size to one of the two HP synthesis sections operating in parallel in Piesteritz. The LP section is identical in design to the LP section operating in Piesteritz, but has smaller equipment as it has half the capacity.

All the improvements that have been made to the German plant since its start-up in 2004 were incorporated into the GSFC project.

Advantages of LEM technology include:

- Low energy consumption (steam, gas, electricity), so low OPEX.
- High urea-to-melamine conversion in the HP section, leading to low CAPEX and OPEX.
- Low CAPEX and OPEX for the urea unit, as the off-gas is at high pressure and free of water, so no additional water is recycled to the urea unit.
- The entire plant and each of its individual equipment items are already in industrial operation for a capacity equal to or larger than 40 000 tpy. The proposed plant does not contain any single piece of equipment that has been scaled up and is not already in operation for a capacity of 40 000 tpy. The proposed design has already been used for 30 000 tpy, 40 000 tpy and 80 000 tpy melamine plants.
- Flexibility of operation: the proposed plant, with all its single parts, has been proven in the reference plants of being capable of operating at 15% above its design capacity.
- Link between technology provider and melamine plant operator: during the technology transfer phase and start-up of GSFC’s plant, Casale has received full technical and operational support from Borealis, which has experience in the design and operation of melamine plants. This support also included access for Casale and its clients to the operational plants for site visits and training.
- High environmental performance and safety record.
- High product quality and consistency.

**Urea unit**

The urea (OGT) unit is an important part of the plant and is designed to produce the required amount of urea to be transformed into melamine in both the new melamine unit and the existing LP melamine units. The urea is produced by reprocessing the ammonia (NH₃) and CO₂ contained in the off-gas generated from the melamine production, together with fresh NH₃ and CO₂ feed from the existing ammonia plant.

A typical problem faced by combined urea-melamine plants (where most of the urea synthesised is used to produce melamine) is the insufficient heat availability to the reactor due to the reduced amount of fresh CO₂. This is a particular problem in urea plants based on the self-stripping process.

In fact, gaseous CO₂ can be regarded as the heat source for the reactor, because the reaction of CO₂ with NH₃ (forming ammonium carbamate) is highly exothermic and generates the heat...
required for the endothermic dehydration of ammonium carbamate to urea. Since, in a combined urea-melamine plant, part of the CO₂ entering the urea reactor comes from the off-gas of the melamine process (which has already been condensed) less gaseous CO₂ condenses in the reactor itself, so less heat is produced. Therefore, maintaining the desired rate of urea production entails extremely high energy consumption and capital investment because of the larger equipment sizes required.

A solution to this problem of CO₂ availability is to apply Split Flow Loop™ urea technology, where the gas emerging from the stripper is split into two streams (Figure 1). The first stream is mixed with the melamine off-gas and with a recovered carbamate solution and is condensed in the HP carbamate condenser (HPCC) of the urea synthesis loop, generating steam; the condensed carbamate is driven into the urea reactor by the HP carbamate pump. The remaining (second) gas stream from the stripper is sent directly to the urea reactor.

Splitting the gas phase from the stripper has numerous advantages. In the first place, splitting can be adjusted in order to send to the reactor only the quantity of vapours necessary to control its heat balance, with the remainder being mixed with the melamine off-gas and recovered carbamate solution upstream of the HPCC.

The pressure in the synthesis loop does not depend on either the amount of material condensed in the HPCC or the pressure of the steam generated in the condenser itself.

The inert gases contained in the process gas stream are also split between the reactor and the condenser, which reduces the amount of inert gas in the reactor, enhancing the urea conversion rate.

The heat content of the HP melamine off-gas can be efficiently recovered during the condensation process by producing steam.

Mixing the recovered liquid carbamate solution with the melamine off-gas enhances condensation of the gaseous NH₃ and CO₂ and reduces the crystallisation temperature of the resulting carbamate solution, which in turn reduces the risk of carbamate deposits forming in the plant. Another advantage is that the condensation produces a carbamate solution at high pressure and high temperature which is substantially free of water. This carbamate solution can be recirculated to the urea reaction stage without expensive pumping and without increasing the water content in the reactor.

In the GSFC project the majority (approximately 53%) of the NH₃ and CO₂ is fed to the urea (OGT) unit as a liquid stream derived from melamine off-gas, and the remainder is fresh liquid NH₃ and gaseous CO₂. The conditions in the plant can be quite different from those in a standard urea plant fed with 100% fresh NH₃ and gaseous CO₂, particularly if the liquid stream produced from the off-gas contains a significant amount of water. That will be the case if the liquid stream originates from an off-gas treatment section processing off-gas released at low pressure.

However, the situation changes if the liquid stream contains only NH₃ and CO₂, as in that case it is equivalent to fresh NH₃ and CO₂.

Virtually all existing melamine plants are associated with a large urea plant, so the amount of NH₃ and CO₂ fed to the urea plant that comes from melamine off-gas is small in comparison with the amount of fresh liquid NH₃ and CO₂. However, if the urea unit to which the off-gas treatment unit has to be integrated is not big enough and if the liquid off-gas stream contains a significant amount of water, it is necessary to make major changes to the urea plant design.

An exception to this is LEM technology, as the liquid stream obtained from its off-gas essentially contains no water.

The combination of melamine technology and the Split Flow Loop urea technology allows the urea (OGT) unit for the GSFC melamine unit to be designed in the same way as a standard urea production unit that feeds 100% fresh NH₃ and gaseous CO₂.

The benefits of Split Flow Loop technology can be summarised as:

- Low energy consumption, leading to low OPEX.
- High NH₃ and CO₂ to urea conversion, due to the company’s high-efficiency urea reactor design and to the fact that the off-gas from the melamine plant is recycled without water, leading to low CAPEX and low OPEX.
- The proposed design for the urea unit is the same as that of plants designed by the company elsewhere. This is possible because the off-gas from the melamine plant is a pure mixture of NH₃ and CO₂ and thus no additional water is recycled to the urea unit. As discussed, there are no modern melamine plants operating with a stand-alone urea unit as in the case of GSFC, as all existing melamine plants are associated with large urea

Figure 3. GSFC melamine plant.
production plants. Thus, no recent proven design of stand-alone urea units is available. On the other hand, if the off-gas stream fed to the urea unit contains water, the urea plant design will have to be different to that of any existing urea production unit.

- The proposed design has a built-in margin to cope with normal operation flexibility requirements.

**Process description**

The melamine and urea (OGT) units are fully integrated from the point of view of utilities, raw materials and intermediate streams.

The NH₃ feed to the melamine unit is taken directly from the discharge of the urea plant HP ammonia pump. No additional pump is required. Similarly, the CO₂ is fed to the melamine unit directly from the discharge side of the urea plant centrifugal compressor. No additional compressor is required.

Molten urea is fed to the HP scrubber of the melamine unit by a HP pump that is fed directly from the urea plant melt pump.

Off-gas from the melamine unit is fed directly to the HP synthesis of the urea unit, where it is condensed at high pressure, generating steam.

Carbonate solution from the melamine unit is recycled to the LP section of the urea unit directly from the discharge side of the wastewater desorber reflux pump. No additional pump is required.

Steam and condensate networks are fully integrated, allowing surplus steam generated in the urea unit to be exported to the steam network of the melamine unit.

The block flow diagram of the integrated process is shown in Figure 2.

**Melamine unit process description**

In full-scale production, melamine is produced as a powdery white solid, which is used mainly as a raw material for the production of melamine-formaldehyde resins. The main field of application of these resins is the production of laminates for the furniture industry. Other applications are in coatings, bonding agents, adhesives and flame retardants.

Melamine is industrially produced almost exclusively from urea. Urea is converted at temperatures of over 350˚C into melamine and off-gas in either a non-catalytic HP process or a LP catalytic process.

The production process to be used in the planned melamine unit is the non-catalytic HP process, in which urea melt is converted into liquid melamine, NH₃ and CO₂ in two reactors, in sequence, at 375˚C under an ammonia pressure in the range of 100 – 140 kg/cm² g. The reaction heat for the endothermic urea conversion is provided by a molten salt heating system.

The molten melamine obtained in this way is then subjected to aqueous processing.

The melamine unit is divided into the following sections:

- HP (synthesis and scrubbing).
- LP (quenching, decomposing, ammonia removal and filtration).
- Crystallisation section.
- Melamine filtration and drying.
- Pneumatic transport, storage and handling.
- Molten salt and thermal oil.
- NH₃ evaporation and super-heating.
- Sodium hydroxide (NaOH) storage and pumping.
- Process vent.
Wastewater treatment.
Steam and condensate.

An overview of the GSFC melamine unit is shown in Figure 3.

Urea (OGT) unit process description
The urea (OGT) unit is designed to recover the off-gas and carbonate solution coming from the melamine unit and to produce all the 99.7 wt% urea melt needed in the new melamine unit, as well as an extra 50,000 tpy (as 100% urea and biuret) that is sent outside battery limits to the existing LP melamine plants.

The urea unit is comprised of the following sections:
- NH₃ pumping and CO₂ compression.
- Urea synthesis and off-gas condensation.
- Decomposition and recovery.
- Urea concentration and vacuum condensation, HP molten urea feeding.
- MP and LP absorption.
- Wastewater treatment.
- Steam and condensate.

An overview of the GSFC urea reactor and OGT unit is shown in Figures 4 and 5 respectively.

Raw material and energy consumption
The following average results have been obtained in a 96 hour test run at the plant (raw material consumption is practically steechiometric):
- NH₃: 1522 kg/t.
- CO₂: 2017 kg/t.

The overall energy consumption, which includes the consumption of all utilities (steam, natural gas, electricity) necessary for melamine production, is 7.64 Gcal/t, below the guaranteed figures.

A single approach
Casale was the single licensor in charge of the project. The two units were designed as a single plant, the battery limits of which were fresh NH₃ and CO₂ (inputs) and the melamine product (output).

The project has been carried out by a single team of melamine and urea process engineers, thus making communication and information-sharing between the teams as well as GSFC easier and more time-efficient.

Conclusion
This project demonstrates the possibility of setting up a melamine production unit that utilises NH₃ and CO₂ from an ammonia plant as feedstock without having urea product to be commercialised. Combining the two units also allows clients to have an integrated melamine-urea plant with a low energy consumption and capital investment cost. Furthermore, the whole project can be executed and managed by a single point of responsibility, thus ensuring an efficient and timely execution.