

Development of the ACES 21 Process

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INTRODUCTION

Toyo Engineering Corporation (TEC), a worldwide engineering contractor and one of three major urea process licensors, has firstly announced the development of an advanced version of the ACES urea process named ACES 21 at an international conference Nitrogen 99 held in Caracas, Venezuela in March 1999. Since its establishment 40 years ago, TEC has engineered and constructed, as of the end of 1999, 93 urea plants in 24 countries based on TEC own urea technologies, giving a quarter of the world's total production capacity by the three major urea processes licensors. P. T. Pupuk Sriwidjaja (PUSRI) of Indonesia, one of the largest ammonia-urea producers in the world, joined from the beginning of the R & D for the ACES 21. The final process evaluation and the engineering study for ACES 21 have completed in 1999 and the ACES 21 Process is now ready for commercial application.

DEVELOPMENT HISTORY OF TEC UREA PROCESS

TEC has made continual efforts to improve the urea process as the process licensor and the E-P-C contractor, and has contributed to the fertilizer industry by supplying reliable, efficient and economical urea plants. Realizing the future technical demands for the urea process technologies during the 21st Century, TEC has improved the existing ACES Process to realize further reducing investment costs while maintaining all features of the ACES Process. The improved process has been named the ACES 21 Process.

Traditionally, TEC has concentrated its process development activities on energy saving, preventing pollution and improving product quality. As a result of these efforts, the ACES Process and Spout-Fluid Bed Granulation Process have been developed and came into operation in the early 1980's. In the middle of 1990's, TEC commenced R & D work on a new urea process, aiming to reduce plant investment cost and save energy consumption further. The new process, ACES 21, has become ready for industrial application in late 1999 (See Fig. 1).

THE ACES PROCESS

The main concept of the original ACES Process was to minimize energy input to the urea plant by combining the features of solution recycle process and stripping process i.e. a high CO₂ conversion and the highly efficient separation of unreacted materials. The ACES Process drastically reduced steam consumption compared to Total Recycle Process (See Table 1).

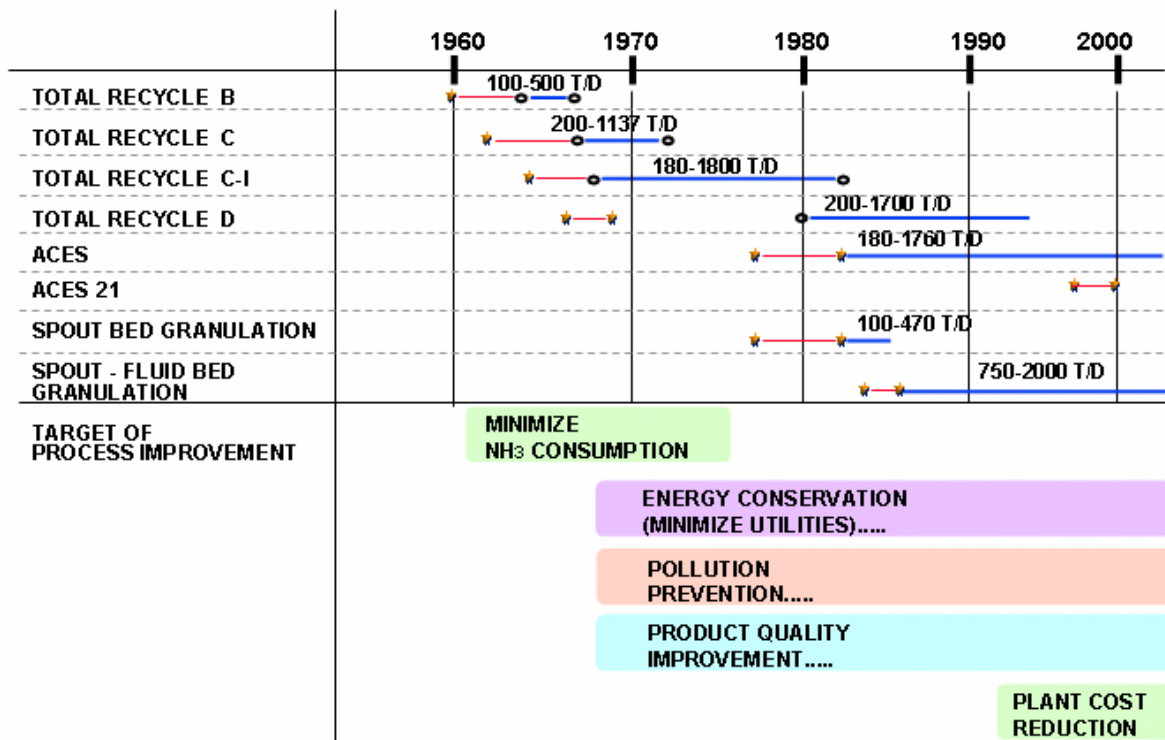


Fig. 1: Development History of TEC Urea Process

Table I TEC Urea Process Performance

	TR-B	TR-C	TR-CI	TR-D	ACES
SYNTHESIS CONDITION					
PRESS. (KG/CM ² G)	250	250	250	250	175
TEMP. (° C)	185	200	200	200	190
NH ₃ / CO ₂ (MOL)	3.7	3.8	4	4	4
CONVERSION (%)	60	69	69	69	68
UTILITY CONSUMPTION					
STEAM (TONS/TON)					
IMPORT 22 KG/CM ² G	-	-	-	-	0.57
13 KG/CM ² G	1.78	1.15	0.93	0.78	-
ELEC. POWER (KWH/TON)	190	155	140	137	121
COOLING WATER (TONS/TON) (ΔT=10° C)	120	100	84	64	51

The ACES Process, by ensuring NH_3 to CO_2 molar ratio (N/C ratio) of 4.0 and an operating temperature of $190\text{ }^\circ\text{C}$ in the reactor give CO_2 conversion of 68%, the highest among modern urea processes. The high CO_2 conversion reduces the energy required for decomposition of unconverted materials. The proprietarily designed tray-falling film Stripper efficiently decomposes and separates ammonium carbamate and excess ammonia in urea synthesis solution from the reactor. Fig. 2 shows the simplified flow diagram of the ACES Process synthesis section.

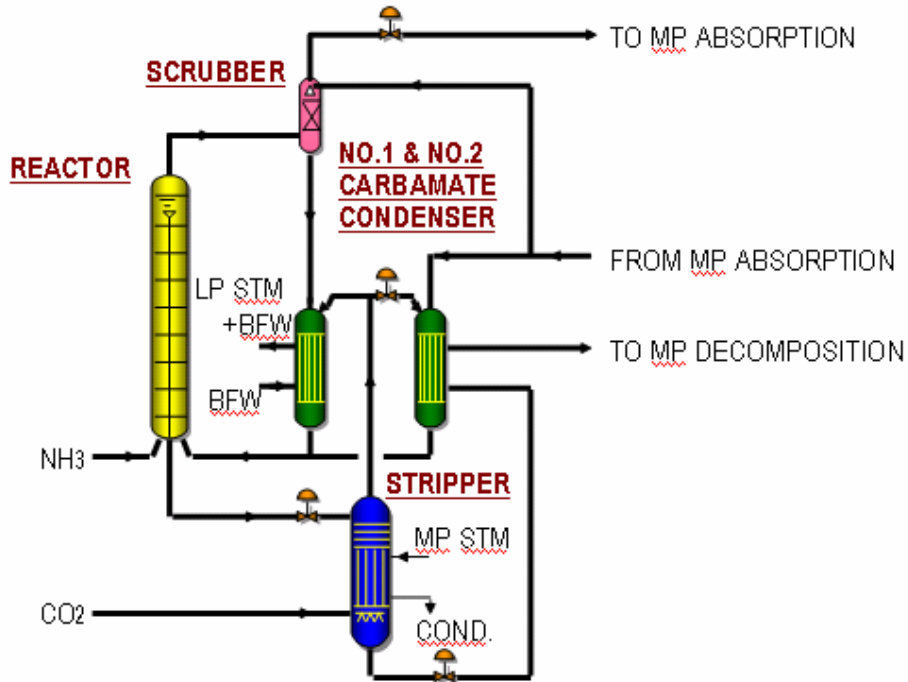


FIG. 2: ACES PROCESS SYNTHESIS SECTION

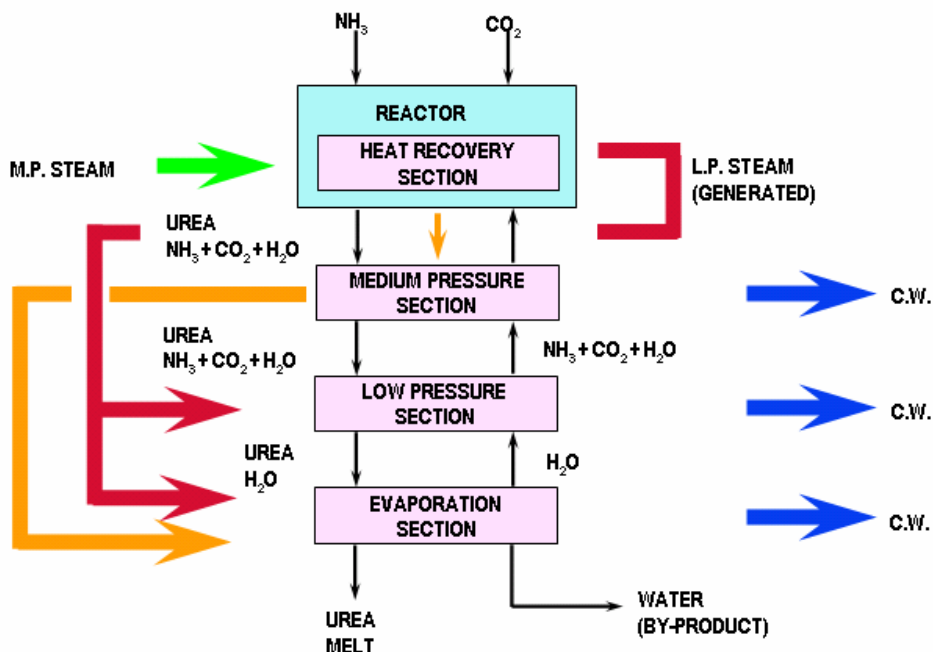


FIG. 3: CONCEPT OF HEAT FLOW

The unique heat integration between the synthesis section and downstream sections further reduces energy requirement (See Fig. 3). MP steam is supplied to synthesis section to decompose and separate excess NH₃ and carbamate in the stripper. The stripped NH₃ and CO₂ gas mixture is sent to the carbamate condenser and the condensation heat is recovered by the two parallel carbamate condensers. One is utilized for decomposition in the medium pressure section and the other is for low pressure steam generation to be utilized in the low pressure and evaporation sections. Condensation heat in medium pressure section is also utilized in evaporation section. This multiple heat integration concept, originally invented and developed by TEC, gives the most energy efficient urea process.

The ACES Process has been employed in 12 urea plants since its first application in 1983 (see Table 2). Over last 10 years, 10 urea plants in 5 countries have employed this process.

Table II
List of TEC ACES Urea Plant

CLIENT	COUNTRY	PLANT CAPACITY (MTD)	ON-STREAM
1. KOREA FERTILIZER AND CHEMICALS CO.	KOREA	600	MAY 1983
2. FERTIBERIA S.L.	SPAIN	750	OCT. 1988
3. UREA FERTILIZER FACTORY LTD.	BANGLADESH	1,422	FEB. 1993
4. P.T. PUPUK SRIWIDJAJA	INDONESIA	1,725	MAR. 1994
5. P.T. PETROKIMIA GRESIK	INDONESIA	1,400	MAY 1994
6. P.T. PUPUK SRIWIDJAJA	INDONESIA	1,725	FEB. 1994
7. WEIHE CHEMICAL FERTILIZER	CHINA	1,760	MAY 1996
8. WEIXIAN CHEMICAL FERTILIZER	CHINA	180	JAN. 1997
9. PAK - AMERICAN FERTILIZER	PAKISTAN	1,050	SEP. 1998
10. ENGRO CHEMICAL PAKISTAN LTD.	PAKISTAN	1,755	OCT. 1998
11. CHAMBAL FERTILIZERS AND CHEMICALS LTD.	INDIA	2,350	OCT. 1999
12. P.T. PUPUK ISKANDAR MUDA	INDONESIA	1,725	(2001)

SPOUT-FLUID BED GRANULATION PROCESS

TEC has its own technology for urea granulation developed in early 1980's, called Spout-Fluid Bed Granulation. Fig. 4 shows a typical flow sheet of TEC urea granulation process. Basically characteristic and performance of granulation process strongly depends upon the granulator design.

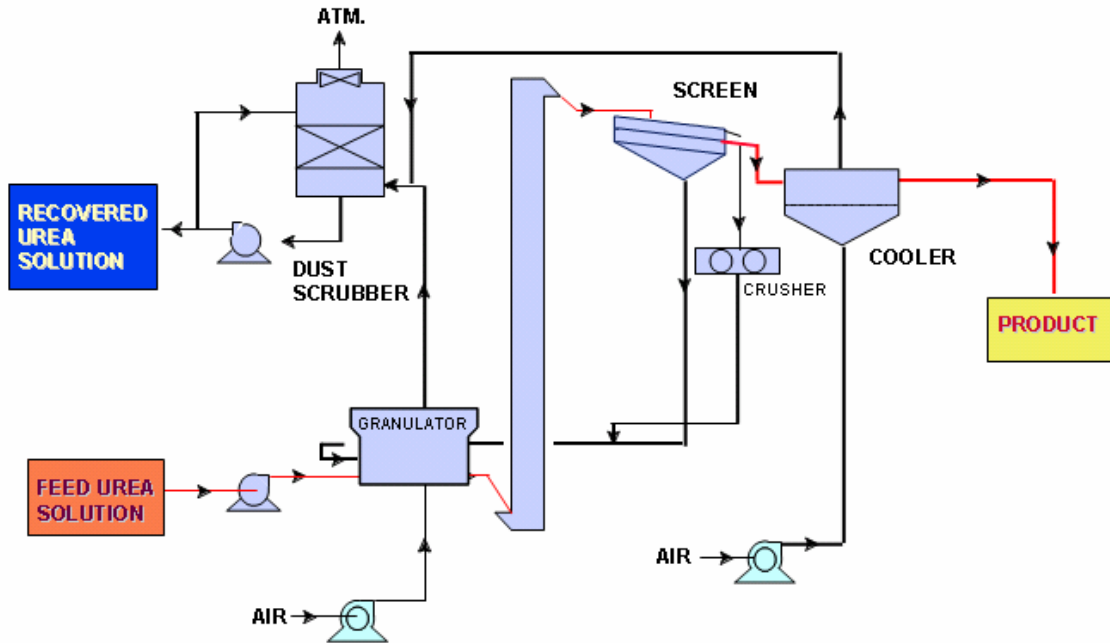


FIG. 4: PROCESS FLOW DIAGRAM OF TEC GRANULATION PROCESS

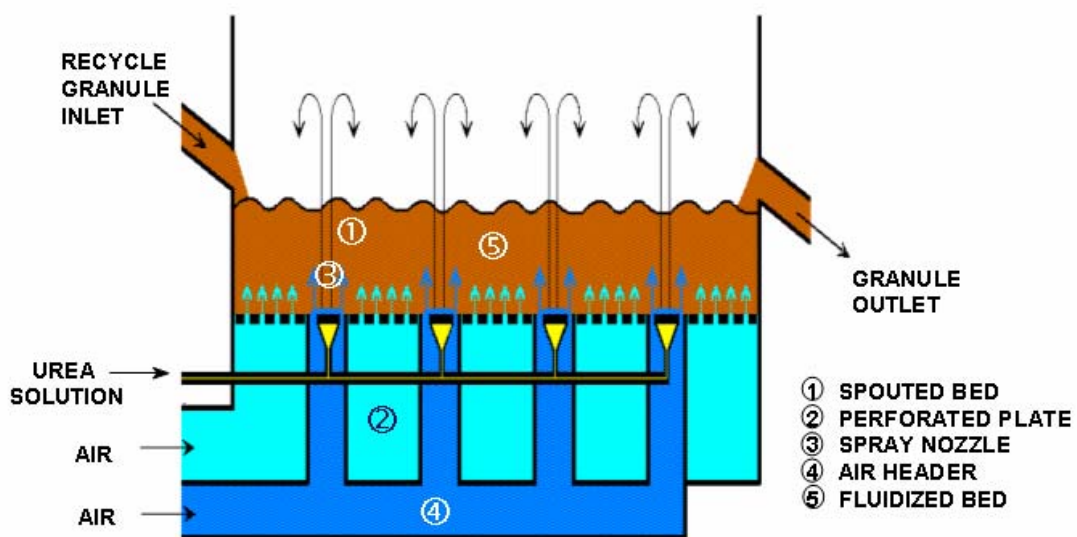


FIG. 5: SPOUT FLUID BED GRANULATOR

Fig. 5 shows a schematic diagram of TEC Spout-Fluid Bed Granulator. The granulator consists of spouted bed, fluidized bed on perforated plate, spray nozzles and air duct manifolds. Spouted bed is surrounded by fluidized bed without partitions. One spouted bed has one spray nozzle. As indicated in Fig. 5, the granulator has multi-spouted bed arrangement. Recycle urea granules (seeds) are enlarged while passing through the spouted bed and the fluidized bed. Urea solution at higher urea concentration than 95 wt.% is sprayed into a spouted bed with a pressure spray nozzle without compressed atomizing air. Air for spouted bed and fluidized bed is separately introduced into the lower section of the granulator.

Table 4 summarizes a typical performance of TEC granulation process. TEC urea granulation process has been used in 9 urea plants (see Table 3). In the last five years, four plants, including a 1,750 mtpd granulation plant in China, have been commissioned. Two large scale plants over 1,700 mtpd capacity are at the stage of engineering and construction in China and Indonesia to be commissioned in 2000 and 2001. Fig. 6 shows a 1,200 MTPD granulation plant for SKW Piesteritz, Germany operated successfully since 1995.

Table III
List of TEC Urea Granulation Plant

	Client	Country	Plant Capacity (MT/D)	On-Stream	Remarks (Synthesis)
1	Mitsui Toatsu Chemicals Inc.	Chiba, Japan	50	1979	(200 MT/D)
2	Petrochem Ltd.	Kapuni, New Zealand	470	1983	(470 MT/D)
3	Mitsui Toatsu Chemicals Inc.	Osaka, Japan	100	1983	(1,800 MT/D)
4	SKW Piesteritz GmbH	Piesteritz, Germany	1,200	1995	(2,100 MT/D)
5	Petrochem Ltd.	Kapuni, New Zealand	750	1996	(750 MT/D)
6	SKW Piesteritz GmbH	Piestritz, Germany	500	1998	(1,050 MT/D)
7	Ning Xia Chemical Works (SINOPEC)	Ning Xia, China	1,740	1999	(1,740 MT/D)
8	P.T.Pupuk Iskandar Muda (PIM-II)	Aceh, Indonesia	1,725	2001	(1,725 MT/D)
9	Lutianhua Group Incorporated (CNTIC)	Sichuan, China	2,000	2000	(2,000 MT/D)

Table IV
Typical Performance TEC Urea Granulation Process

Granulation Method	Urea solution spray to spouted bed in fluidized bed
Electric Power	23 kWh/T
<u>HCHO</u>	4.5 kg/T
Recycle Ratio	Nor. 0.5



FIG. 6: 1,200 MTPD GRANULATION PLANT FOR SKW PIESTERITZ, GERMANY

THE ACES 21 PROCESS

R & D for ACES 21 Process

In CO₂ stripping technology, the reactor, the largest and the heaviest vessel in urea plant, is normally installed at 20-22 meter level so as to feed urea synthesis solution to the stripper by gravity. If the reactor is installed on the ground level, civil and erection cost can be greatly reduced. R & D work aimed at installing the reactor on ground level in CO₂ stripping technology has started from its process concept study and pilot plant planning in 1996. Since the beginning of the R & D, P. T. Pupuk Sriwidjaja (PUSRI) of Indonesia, one of the largest ammonia and urea producers in the world with four large scale urea plants based on TEC urea technologies, joined the project as a partner. The pilot plant has been operated at PUSRI's plant site in Palembang, Indonesia and the operating data have been analyzed concurrently using a PC-based DCS and process analysis software at the plant site since June 1998. Fig. 7 shows the pilot plant constructed beside the ACES Process urea plant of PUSRI-1B (see Fig. 8). In the pilot plant, main equipment of the synthesis section of the ACES 21 Process, the carbamate condenser, reactor, stripper and ejector have been tested and verified in the process performances and the corrosion environment. Electro-chemical tests and immersion test of possible construction materials have also been carried out in the pilot plant to select most suitable materials. Process evaluation has been carried out based on the pilot plant test and very positive performance results have been obtained.



FIG. 7: ACES 21 PILOT PLANT



FIG. 8: 1,725 MTPD ACES UREA PLANT FOR P. T. PUPUK SRIWIDJAJA, INDONESIA (PUSRI-1B)

ACES 21 Synthesis Section

Fig. 9 shows the ACES 21 Process synthesis section. The reactor, stripper, carbamate condenser and ejector comprise the synthesis section as major equipment. Liquid ammonia is fed into the reactor via the ejector. Most of the CO₂ is fed to the stripper as stripping media and the rest is fed to the reactor as a source of passivation air and a raw material for urea synthesis in the reactor. Carbamate solution from the carbamate condenser is fed to the reactor after being pumped by the ejector motive fluid high pressure liquid ammonia. Urea synthesis solution leaving the reactor is fed to the stripper. Stripped urea solution is sent to MP decomposition stage. The stripped off gas is fed to vertical submerged-type carbamate condenser. NH₃ and CO₂ gas condenses to form ammonium carbamate and urea in the shell side of the carbamate condenser. The condensation heat is recovered to generate low pressure steam in the tube side. Packed bed is provided at the top to absorb uncondensed NH₃ and CO₂ into recycle carbamate solution from MP absorption stage. Inert gas from top of the

packed bed is sent to MP absorption stage. The driving force for liquid and gas circulation in the synthesis loop is mainly provided by the ejector, while appropriate elevation of the carbamate condenser supplies additional driving force by gravity.

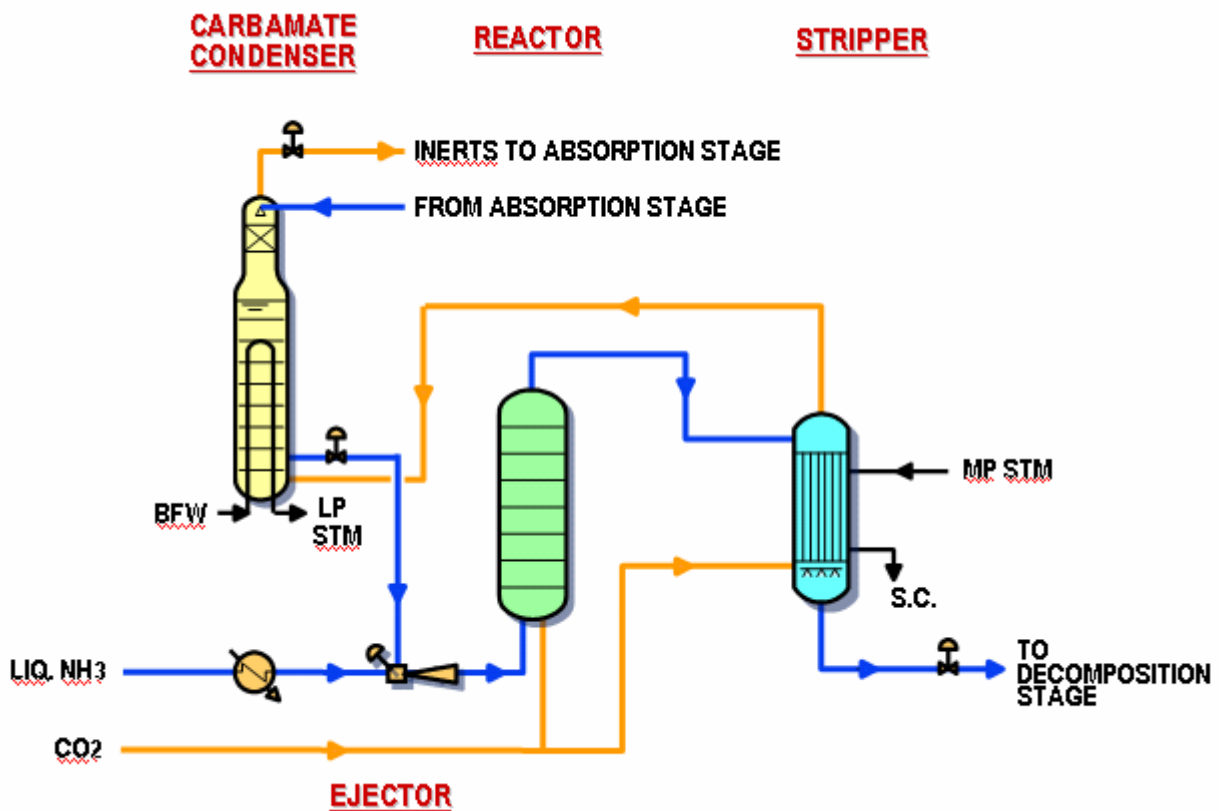


FIG. 9: ACES 21 SYNTHESIS SECTION

Vertical Submerged Carbamate Condenser

Vertical submerged design is employed for the carbamate condenser. From process view point, this provides the following advantages.

- (1) High gas velocity, appropriate gas hold up and sufficient liquid depth in the bubble column promote mass and heat transfer;
- (2) The appropriate number of baffle plates distribute gas bubbles in the column effectively without pressure loss;
- (3) A vertical design inevitably requires smaller plot area

Optimized N/C Ratio

In the ACES 21 Process, the N/C ratio in the carbamate condenser differs from that in the reactor. A lower N/C in the carbamate condenser reduces vapor pressure, reducing vapor loss from the carbamate condenser. A higher N/C ratio in the reactor increases CO₂ conversion, reducing the heat required for decomposition of carbamate in the stripper. Equilibrium vapor pressure becomes its lowest level at around an N/C ratio of 2.5 – 3.0 at which the carbamate condenser is operated. The reactor N/C ratio

should be as high as possible to maximize CO₂ conversion as far as its operating pressure has appropriate excess pressure to that of equilibrium (See Fig. 10).

Since different levels of N/C ratio are employed for the carbamate condenser and the reactor, urea synthesis reaction takes place in two steps as indicated in Fig. 11.

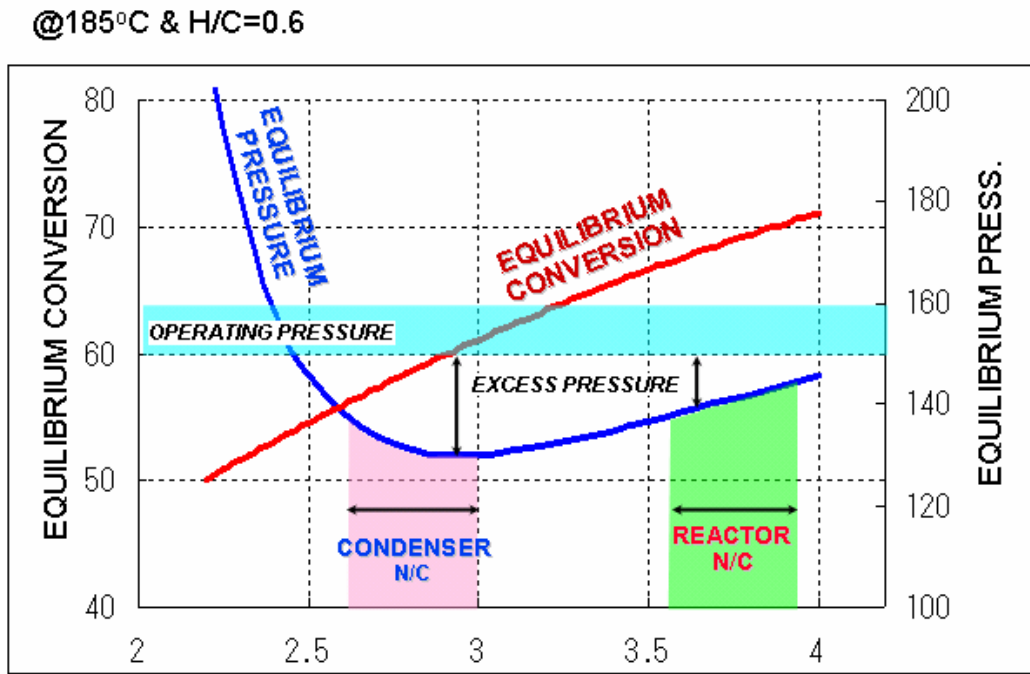


FIG. 10: SELECTION OF OPTIMUM N/C IN CONDENSER AND REACTOR

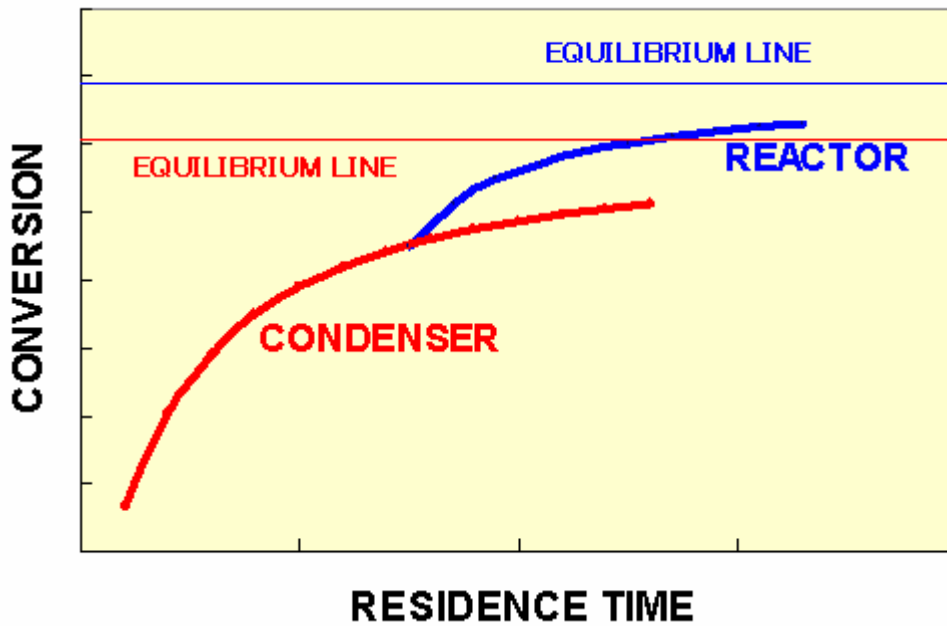


FIG. 11: CONVERSION VS. RESIDENCE TIME IN CONDENSER AND REACTOR

Advantages

Features and advantages of the ACES 21 Process are summarized below:

1. The horizontal layout of HP vessels has the following advantages compared to the vertical layout:
 - (a) less HP piping and construction materials are used;
 - (b) easier erection using commonly available construction equipment and techniques;
 - (c) easier operation and maintenance
2. Combining the functions for carbamate formation, heat recovery, urea synthesis, and inert gas scrubbing into one vertical submerged carbamate condenser has the following advantages in comparison with conventional separate reactor and falling film carbamate condenser:
 - (a) fewer and smaller sized HP vessels;
 - (b) a smaller heat transfer area for heat recovery;
 - (c) less HP piping and construction material are required
3. Simplified synthesis loop offers the followings advantages over conventional stripping technologies:
 - (a) less HP piping and construction materials are required;
 - (b) easier operation and maintenance
4. Improved design for the reactor and the stripper give the following advantages in comparison to conventional ones:
 - (a) less volume and weight for both the reactor and the stripper;
 - (b) easier reactor and stripper fabrication
5. Optimizing N/C ratios at different levels for the carbamate condenser and the reactor at lower synthesis pressure results in the following advantages over the ACES Process:
 - (a) lower mechanical design pressure of HP vessels and rotating equipment;
 - (b) less energy consumption

TEC and PUSRI confirmed the combined effect of the above improvements, by one-year operation of the pilot plant and the following engineering study for an industrial scale plant, greatly reduces plant cost, energy consumption and operating cost.

ACES 21 ENGINEERING STUDY FOR INDUSTRIAL SCALE PLANT

Engineering study for a typical industrial scale plant has been carried out concurrently with the pilot plant test to estimate and evaluate process performance

and plant investment cost of ACES 21. The engineering study includes:

- process simulation based on the pilot plant operation to compute the material and heat balance of the overall urea plant and to optimize process conditions
- process basic design for a typical ACES 21 grass roots plant
- preparation of the standard process engineering package
- estimation of the overall energy consumption of the typical plant including the performances for CO₂ compressor and HP pumps based on manufacturers' information
- detailed study on mechanical design and engineering of critical HP vessels and exchangers including investigation on fabrication technology in cooperation with fabricators
- equipment layout and piping planning study including bill of quantity of piping materials
- civil design based on the equipment layout and the loading data including bill of quantity of concrete structure, steel structure and piling
- study on construction and erection to be evaluated in comparison to that for the existing ACES process
- preparation for instructions for operation and maintenance
- cost estimation of a typical plant investment to be evaluated in comparison to that of the existing ACES process.

As the result of the engineering study, the ACES 21 process has been confirmed to be sufficiently advantageous for industrial scale plant application in both the process performance and the plant investment cost in comparison to the existing technologies.

Process Performance

About 10% reduction of energy consumption from the existing ACES process has been confirmed based on the pilot plant test results, the engineering study for an industrial scale plant, computed process material and heat balance and performance data of CO₂ compressor, HP pumps and steam turbines provided by the major manufactures.

Mechanical Design and Fabrication of HP Equipment

Mechanical design and fabrication of critical HP vessels and exchangers have been verified to be sufficiently feasible by applying the proven and available present technologies, in cooperation with some major vessel fabricators. Total erection weight of HP vessels and exchangers comprising the synthesis section decreases by about 10 % in comparison to the existing ACES process. During the course of the study, design and fabrication of HP vessels and exchangers for 3,500 mtpd ACES 21 single train urea plant, which is equivalent to 2,000 mtpd ammonia plant capacity, has been confirmed to be feasible based on present available technologies.

Equipment Layout and Planning Study

Fig. 12 shows a bird's-eye view of a urea plant based on the ACES 21 Process. Owing to the horizontally laid out synthesis equipment, the synthesis section is very compact and the top height is only 30 m.

HP stainless steel piping for the synthesis section also greatly reduced because of the low elevations for HP equipment and the compact layout, resulting in 20% reduction of the total weight of piping for a whole urea plant based on a piping planning study for an industrial scale plant.

Civil and Erection

Concrete and steel structure, and piling for a typical plant excluding the prilling tower and the granulation plant are estimated to be reduced by 50 % and 40 % respectively from the original ACES Process. More commonly available construction equipment and technique can be applied for erecting HP vessels in the synthesis section than the case for a urea plant based on conventional urea process technologies. For example, construction equipment and technique applied for erecting HP vessels such as the reactor, the carbamate condensers, the stripper and the scrubber for a 1,750 mtpd ACES urea plant can be applied for erecting HP vessels for up to a 3,000 – 3,500 mtpd ACES 21 urea plant owing to the smaller-sized, less weight and lower elevation of equipment. The required period for the erection work can also be reduced significantly.

Plant Investment Cost

Plant investment cost has been estimated 10% less than the existing ACES process, based on TEC in-house cost database and the price estimated by major equipment vendors and subcontractors of construction and erection works.



FIG. 12: A BIRD'S-EYE VIEW OF ACES 21 UREA PLANT (3D GRAPHIC)

STUDY FOR REVAMPING A CONVENTIONAL SOLUTION RECYCLE PLANT

The ACES 21 Process is also fit for revamping conventional solution recycle process plant in an efficient way. For example, TEC's Total Recycle C-Improved Process plant can be revamped to have 130 – 150 % capacity of original nameplate together with 30 – 40 % saving of specific energy consumption per metric ton of the product, simply by adding a carbamate condenser, a stripper and an ejector to the synthesis section and utilizing full volume of the existing reactor installed on the ground level. A brief study for revamping a 1,725 mtpd TEC Total Recycle C-Improved urea plant by ACES 21 Technology has been carried out. The following is the concept for the revamp project.

Revamped Capacity:	2,350 mtpd (136% of original nameplate capacity)
Targeted Energy Saving:	30% or more saving per metric ton of urea product

Revamp Scheme:

- Existing reactor is fully re-utilized as ACES 21 reactor without relocation.
- HP carbamate ejector, stripper and condenser are added in the synthesis section.
- Purification and recovery section is utilized without major modifications.
- Crystallization section is utilized without modification.
- New evaporators equivalent to the additional capacity (625 mtpd) are added.
- Granulation plant equivalent to the additional capacity is newly installed.
- CO₂ compression section equivalent to the additional capacity is added or replaced by a whole new centrifugal machines.
- NH₃ feed pump and the carbamate pump do not require any modification.

Process scheme for the revamped synthesis section and block flow diagram for the overall revamped urea plant are shown in Figs. 13 and 14 respectively. A preliminary evaluation study of the revamp project has shown positive feasibility in view of profitability, environmental protection and energy saving.

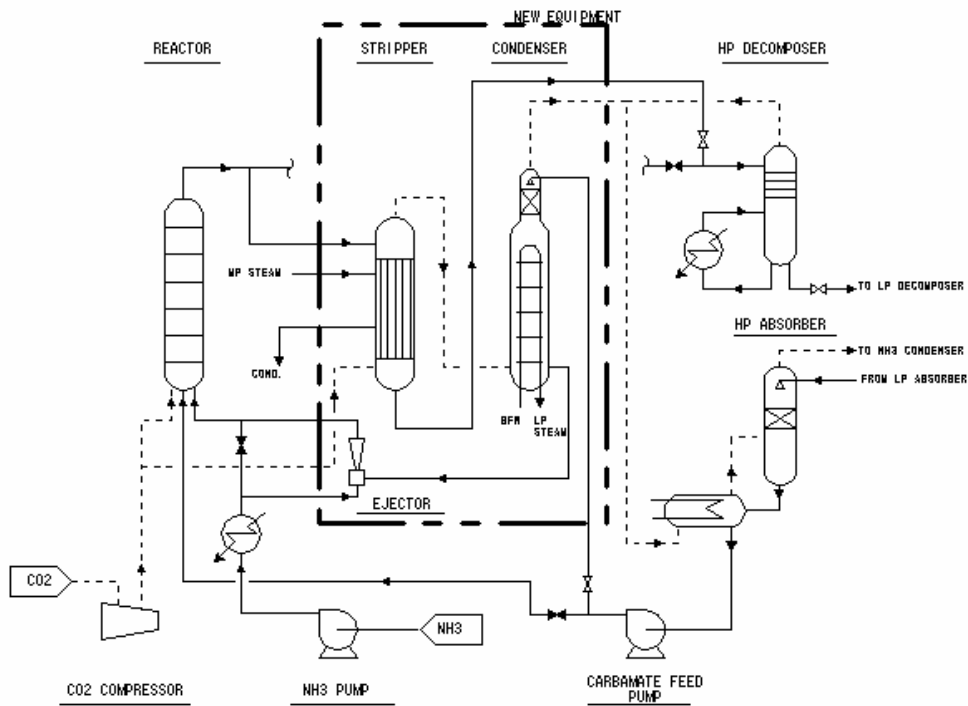


FIG. 13: REVAMP SCHEME FOR TR-CI UREA PLANT BY ACRES 21

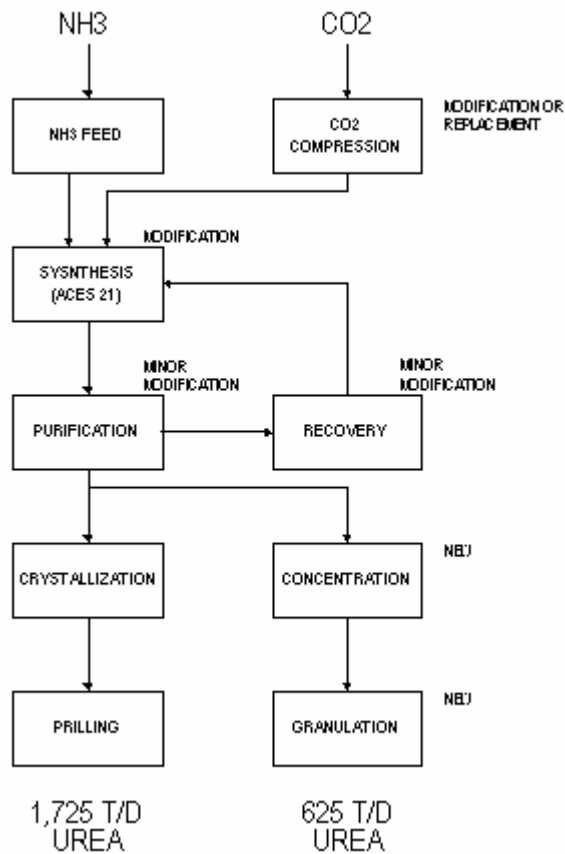


FIG. 14: BLOCK DIAGRAM FOR REVAMPING A 1,725 MTPD TR-CI UREA PLANT

CONCLUSION

TEC, the only urea process licensor that covers by itself all the proven essential technologies, i.e. urea synthesis, prilling, granulation and pollution abatement, has jointly developed a new process ACES 21 cooperating with PUSRI. TEC and PUSRI has carried out detailed engineering study and final evaluation of the ACES 21 Process with the result of 10% reduction in both plant investment cost and energy consumption. Now the ACES 21 Process is in the full commercial status and TEC and PUSRI are jointly starting intensive study to realize the ACES 21 Process for a large scale plant from the beginning of the year 2000.