Mega-capacity Urea Plants – TEC's Approach

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In accordance with increased production capacity of the recent ammonia plants, the production capacity of urea plant also becomes large. To meet such demands, TEC has established the design of 3,500 metric tons per day (mtpd) urea plants based on the ACES Urea Process by confirming all considerable aspects of process, equipment fabrication, construction and so forth.

This paper reports how TEC evaluates the investigation results and concluded that the Mega-capacity Urea Plant design and construction in comparison with currently operated 1,750 mtpd ACES Process urea plants can be realized.

INTRODUCTION

Urea plant capacity has continually increased since the establishment of industrial production processes in the late 1940s. In 1969, Toyo Engineering Corporation (TEC) scaled up its urea process and successfully commissioned a 1,800 MT/D urea plant, which was the largest single train plant in those days. And until 1990s, 1,700 – 2,200 MT/D grass roots urea plants were the largest in single train although several revamped urea plants over 2,000 MT/D were in operation. However, nowadays most of grass roots fertilizer projects are aiming at larger urea capacities, i.e. 2,600 – 3,250 MT/D, which is equivalent to 1,500 – 1,800 MT/D ammonia plant capacity. Considering the recent trend and feasibility of larger ammonia units than 2,000 MT/D, urea plant capacities should be over 3,500 MT/D sooner or later.

Based on the recent capacity trend of ammonia-urea complex, TEC has completed technical survey, study and engineering design of 3,500 MT/D urea unit comprising TEC ACES/ACES21 urea process and TEC spout-fluid bed granulation as an urea technology licenser and an engineering contractor aiming at more economical and reliable urea production for the near future. This paper reviews the feasibility of single train urea plant of 3,500 MT/D or larger from the following aspects:

- Process Scale-up Approach
- HP Vessels and Rotating Machinery
- HP Piping and Control Valves
- Transportation and Erection
- Process Performance and Economics
- Single Train or Double Train – Advantages and Disadvantages

Finally, TEC concluded that the Mega-capacity urea plants of 3,500 mtpd or larger could be materialized without specific difficulty.

H. P. STATIC EQUIPMENT

Fig. 1 shows a schematic process flow of ACES Process synthesis section. Process and mechanical design aspects of H. P. static equipment in the synthesis loop are discussed in the following paragraphs.

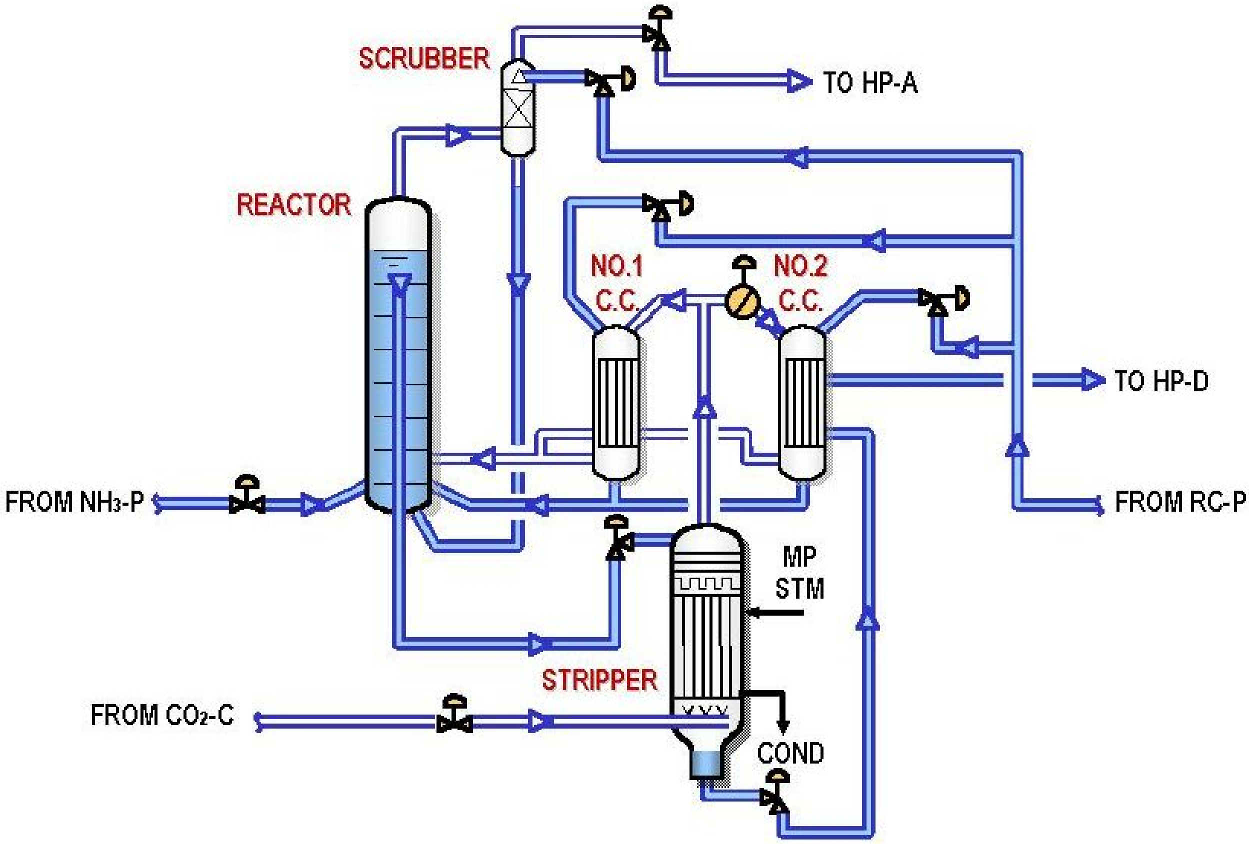

Fig.1: Schematic Process Flow of ACES Process Synthesis Section

Reactor

The reactor is the largest and heaviest key equipment in the urea plant. As the performance of the reactor influences overall performance of the whole urea plant in production capacity and utilities consumption.

Key factors of the reactor design are as follows:

(1) Process Design

Retention Time (Reaction Volume)
Length / Diameter (L/D) Ratio
Number and Type of Baffle Plate

(2) Mechanical Design & Fabrication

Size and Weight
Forge or Multi-layered Shell

To maintain high CO_2 conversion rate, the reactor requires certain volume (retention time) for the reaction. Therefore, in general, the reactor is scaled-up by increasing its volume in proportion to the production capacity. If the reactor volume is increased by maintaining constant L/D ratio, the fluid dynamics in the reactor is also maintained, and CO_2 conversion can be expected same as before the scale-up. In this case, for example, two-times scaling-up the reactor volume maintaining similar configuration (L/D = 10.4) increases the height of the reactor (tangent to tangent length) by 26%, i.e. about 7 m (See **Fig. 2**).

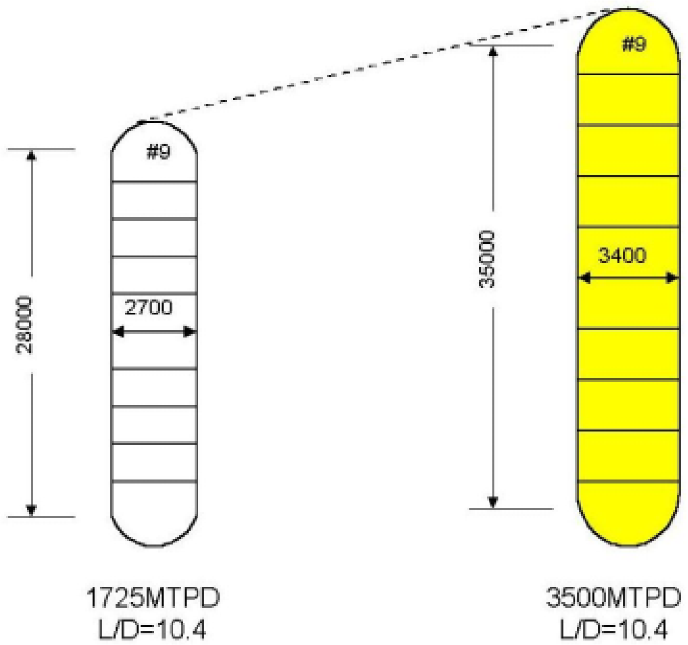

Fig.2: Reactor Scaling-up / Similar Configuration

On the other hand, there may be some limitation of the total height of synthesis structure in view of erection, operation and maintenance. Therefore, reactor scaling-up by maintaining the reactor height (tangent – tangent length) could be an alternative (**Fig. 3**). Experimental and theoretical approach based on the common practice of chemical reaction engineering for bubble column reactor such as urea synthesis reactor shows that undesirable axial back-mixing in bubble column reactor by reducing L/D ratio can be compensated by increasing the number of the baffle plates.

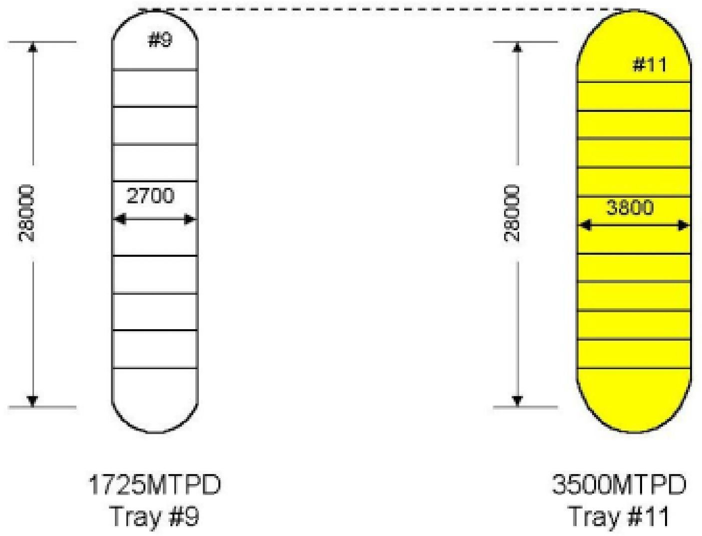

Fig.3: Reactor Scaling-up / Maintaining Height

These effects on the reactor performance by changing L/D ratio and number of baffle plates can be easily computer-simulated based on multi-stage CSTR (Continuous Stirred Tank Reactor) model (**Figs. 4 & 5**). **Fig. 5** shows the effect of the number of baffles plates, represented based on simulated number of CSTR vs. L/D ratio. As shown in **Fig. 5**, for the two-times scale-up of the reactor without increasing its height, two additional baffle plates (9 baffle plates to 11 baffle plates) are sufficient to achieve at least same (or higher) CO2 conversion as before scale-up.

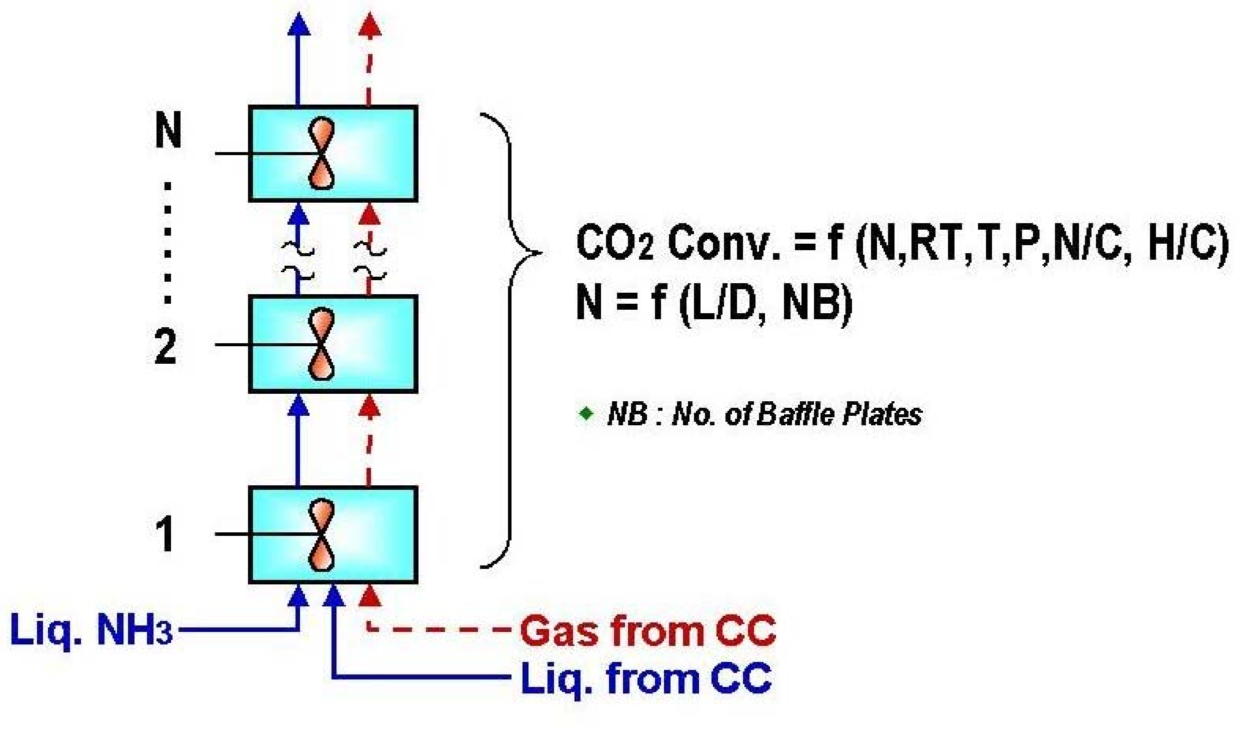

Fig.4: Multi-stage CSTR Model

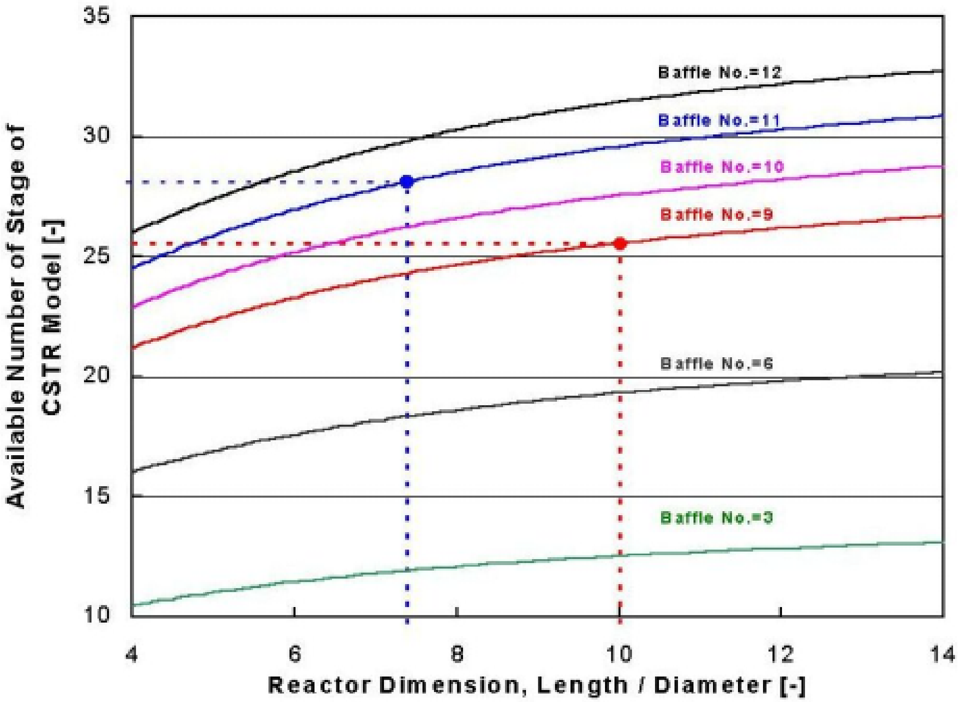

Fig.5: Effect of Baffle Plate Number

In case that the reactor has relatively smaller L/D ratio and more baffle plates, baffle plate design improvement is also to be considered. Cross flow type baffle plate, originally invented by Mitsui Toatsu Chemicals Inc. in 1960s [1] gives better gas-liquid contact and effective path-way between the upper and the lower baffle plates. **Fig. 6** and **Fig. 7** show the computer-simulated gas-liquid flow pattern for conventional and cross flow type baffle plate respectively.

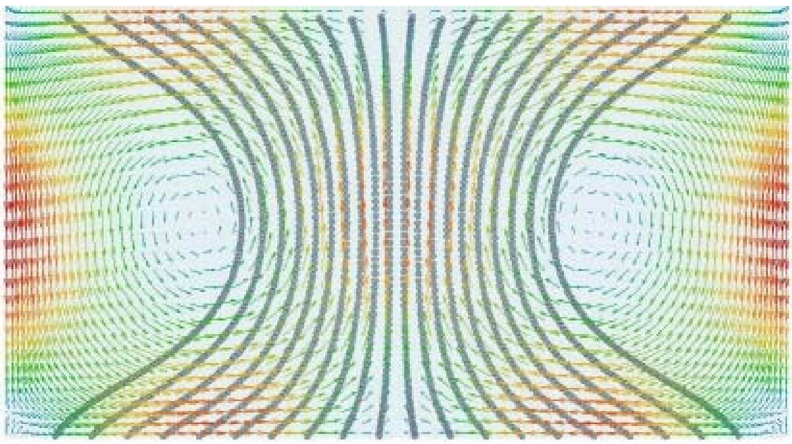

Fig.6: Gas-liquid Flow Pattern / Conventional Baffle Plate

Fig. 6 indicates that conventional baffle plate give sufficiently good mixing without any short-pass in liquid phase due to rising gas bubbles between the two baffle plates, however, gas bubble stream tends to gather in the central part, resulting in locally liquid-rich region in the circumference. In case of cross flow baffle plate, as shown in **Fig. 7,** all liquid flow crosses the gas bubble stream, from the left-bottom entrance to the right-top exit, while axial liquid circulation forced by the rising gas stream is maintained, resulting in better gas-liquid contact and less back mixing between the two baffle plates. TEC's in-house simulation study and pilot test results have indicated that the cross flow baffle plate gives significantly higher CO_2 conversion compared to the conventional one, which has been also confirmed by some actually operating industrial scale urea reactors.

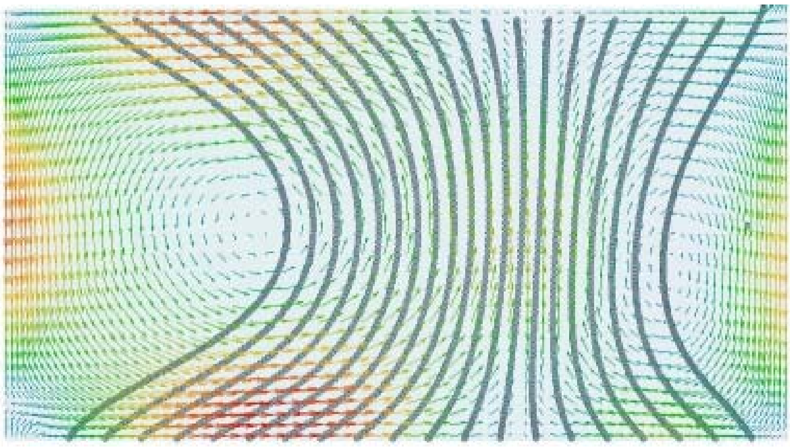

Fig.7: Gas-liquid Flow Pattern / Cross Flow Type Baffle Plate

Based on the above studies, TEC has completed the 3,500 mtpd reactor design as shown in **Table I** and contacted qualified worldwide experienced fabricators. Two Japanese fabricators have confirmed the reactor can be fabricated based on the dimensions and weight shown in **Table I**. It has been also confirmed that major European vessel fabricators are capable in fabricating the reactor for 3,500 mtpd urea plant.

Table I
Reactor Design

	1,750mtpd	3,500mtpd
Design Code	AD Merkblatter	←
Shell ID	2,700mm	3,800mm
TL-TL	28,000mm	28,000mm
Weight	270 ton	510 ton
Availability	Experienced	Available

Stripper

The stripper is also a crucial equipment in view of fabrication, operation and maintenance. Key factors of the stripper design are:

(1) Process Design

Tray Design
Tube Load, Tube Length
Liquid / Gas Distribution
Construction Material

(2) Mechanical Design & Fabrication

Tube Sheet Size
Verticality of Tube Bundle
Weight

To maintain high stripping efficiency in the stripper, the excess ammonia in the urea synthesis solution is first separated through three stage sieve trays and then ammonium carbamate is decomposed and separated by steam heating and CO2 stripping in the falling film heater. In case of 3,500 mtpd plant, four-pass trays are employed instead of two-pass trays of 1,750 mtpd plant, due to increased liquid flow rate (See **Fig. 8**). The four-pass tray configuration gives uniform liquid distribution on the distributor plate even in large diameter channel (3.55 m) and then divides the liquid equally to each swirl tube to form thin and uniform liquid film on the internal surface of heating tubes. In addition, verticality of all tubes and flatness of tubesheet has to be carefully controlled during fabrication and operation to ensure its performance, especially for large diameter stripper.

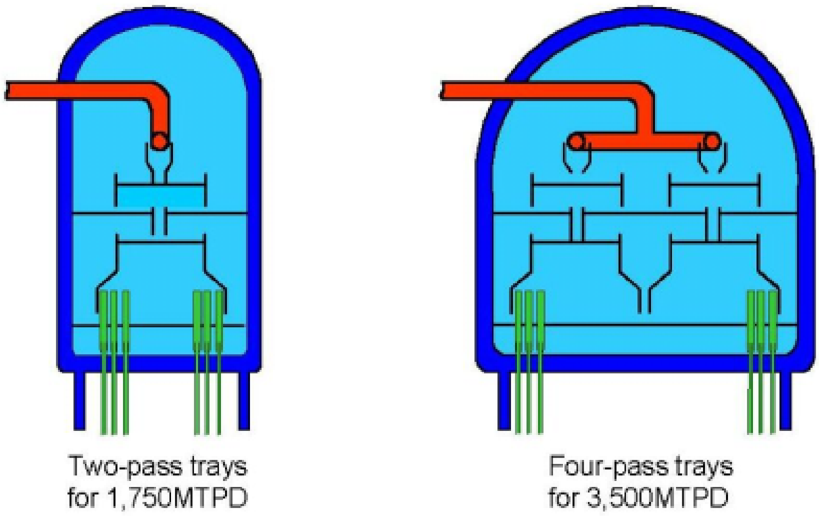

Fig.8: Sieve Tray Design for the Stripper

Table II
Stripper Design

	1,750mtpd	3,500mtpd
Design Code	ASME SEC.VIII DIV.2	←
Shell ID	2,450mm	3,450mm
Channel ID	2,550mm	3,550mm
Tube No.	2,800	5,600
Tube Sheet THK	420mm	610mm
Weight	170 ton	330 ton
Availability	Experienced	Available

As the results of the study, the stripper brief specifications for 3,500 mtpd urea plants will be as shown in **Table II**. The required tubesheet thickness will be 610 mm. The critical issue for tubesheet fabrication is drilling tube holes for thick tubesheet, which is still within the fabrication range of 800 mm maximum. TEC has confirmed that major equipment fabricators in Japan and Europe can handle the stripper for 3,500 mtpd plant in their workshop without any problems.

Carbamate Condensers

The ACES process has two parallel carbamate condensers.. One is for low pressure steam generation and the other is for heating urea solution for MP decomposition stage. Therefore, each carbamate condenser size is relatively small compared to the reactor and the stripper. Both are vertical falling film type condensers. The key factors of the carbamate condenser design are:

(1) Process Design

Heat Transfer Design
Liquid Distribution to Tubes

(2) Mechanical Design & Fabrication

Tube Sheet Size
Verticality of Tube Bundle
Weight

The heat transfer design is carried out with proven thermal rating software (HTRI) supported by carbamate condenser performance of actually operating plants. The selected design parameters of the carbamate condensers are shown in **Tables III** and **IV**.

Table III
No.1 Carbamate Condenser Design

	1,750mtpd	3,500mtpd
Design Code	ASME SEC.VIII DIV.1	←
Shell ID	1,350mm	2,000mm
Channel ID	1,450mm	2,100mm
Tube Sheet THK	280mm	430mm
Weight	63 ton	130 ton
Availability	Experienced	Available

Table IV
No.2 Carbamate Condenser Design

	1,750mtpd	3,500mtpd
Design Code	ASME SEC.VIII DIV.1	←
Shell ID	1,100mm	1,600mm
Channel ID	1,200mm	1,700mm
Tube Sheet THK	260mm	380mm
Weight	48 ton	90 ton
Availability	Experienced	Available

Since dimensions and weight of the both carbamate condensers are much smaller than those of the stripper, no difficulties are expected in case that the equipment vendors qualified for the stripper fabrication fabricate the carbamate condensers.

H. P. ROTATING MACHINE

Table V shows required capacity, maximum experienced capacity and present availability of CO2 compressor, H. P. ammonia pump and carbamate pump. TEC's survey results and related technical aspects are discussed in the following paragraphs.

Table V
H.P. Rotating Machine Design

	3,500mtpd	Max. Experience	Availability
CO_2 Compressor	56,000Nm^3/h	51,400Nm^3/h	Available
NH_3 Pump	152m^3/h*1)	178m^3/h	Experienced
Carbamate Pump	138m^3/h*2)	138m^3/h	Experienced

*1) 10% margin included
*2) 20% margin included

CO2 Compressor

TEC has surveyed the availability of CO2 compressor for 3,500 mtpd capacity and studied the technical feasibility in cooperation with a compressor manufacturer in Japan who has abundant experiences in CO2 compressor for urea plants. The study result confirms that the existing largest model of LP casing can be applied to 3,500 mtpd design though it depends on the CO2 supply pressure from ammonia plant. In addition, appropriate increment of LP case compression ratio makes the existing HP case model applicable to 3,500 mtpd design. Based on those facts, it can be concluded that 3,500 mtpd urea plant does not require any new design of HP and LP case and any R & D factors for CO2 compressor. It is also suggested by the manufacturer that the existing LP and HP case model can be applied up to 4,500 mtpd design by adding the number of impellers.

H. P. Ammonia Pump and Carbamate Pump

TEC has surveyed all the experiences of H. P. ammonia pump and carbamate pump by EBARA Corp., who has been the collaborator of TEC for the R & D of centrifugal H. P. ammonia pump and carbamate pump for urea plant since 1960s. As the ammonia pump and carbamate pump were developed so as to be applied to conventional total recycle process, the maximum experienced capacity and head of the two kinds of pumps cover those for 3,500 mtpd ACES Process (See **Figs. 9** and **10**). Therefore, TEC confirms that centrifugal H. P. ammonia pump and carbamate pump for 3,500 mtpd ACES Process plant are available based on proven design and experiences.

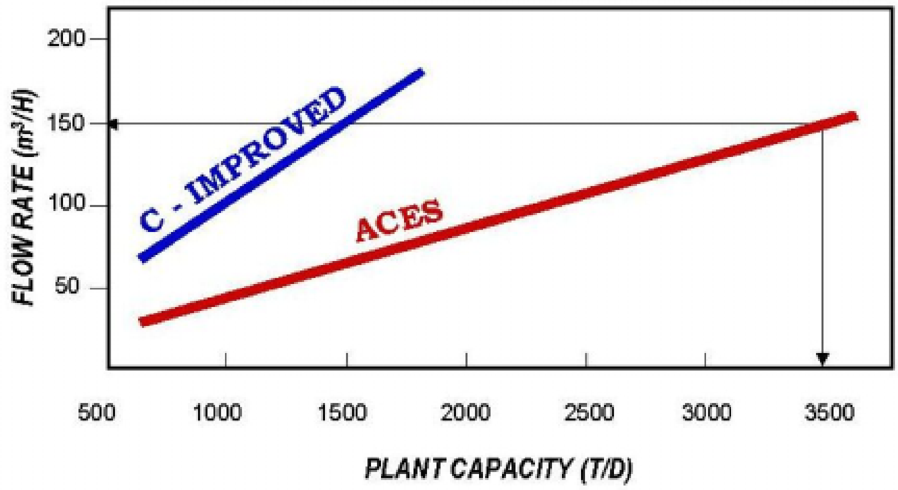

Fig.9: Ammonia Pump Capacity

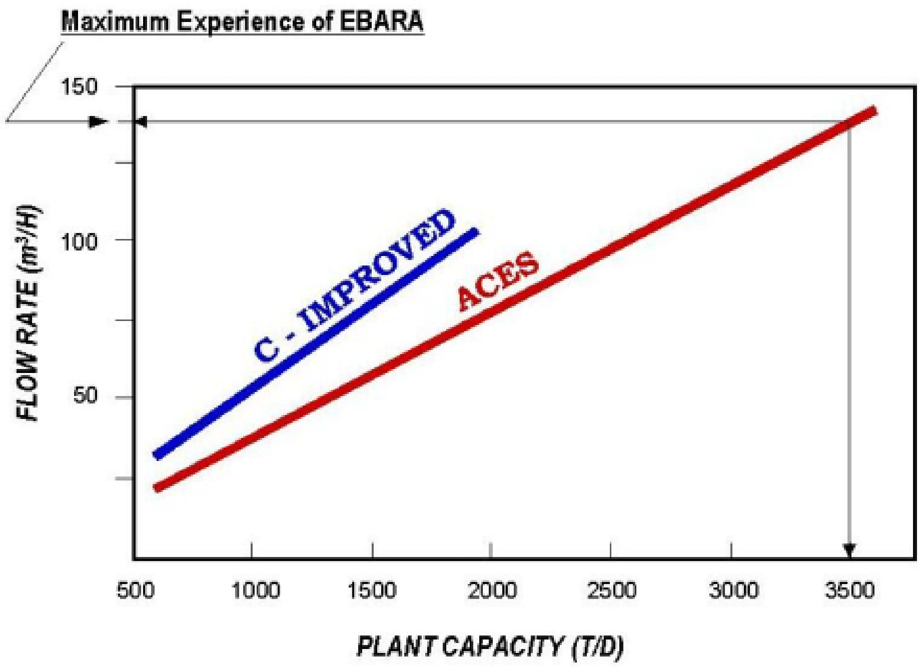

Fig.10: Carbamate Pump Capacity

H. P. PIPING

AISI 316L stainless steel is applied for H. P. piping in synthesis loop. The largest nominal diameter of H. P. piping in synthesis section of 3,500 mtpd plant is 16 inches with 40.5 mm thickness. TEC has confirmed that such thick and large diameter 316L seamless pipe is available in both Europe and Japan. The pipe can be produced by hot pierced, hot drawn process or forging. Though TEC does not expect any technical difficulties to apply 16 inch 316L H. P. piping including fittings in synthesis loop, some economic study would be necessary to select 16 inch single pipe line or 12 inch double line considering procurement cost of pipe and fitting, erection cost and associated washing connections, etc.

H. P. CONTROL VALVE

The most critical control valve with respect to the cost and the availability is the solution feed control valve from the reactor to the stripper. TEC has contacted a major Japanese manufacturer of H. P. control valve for urea service and carried out the design, engineering and cost evaluation of the control valve in close cooperation with the manufacturer. **Table VI** shows a major specification of the control valve of 3,500 mtpd plant in comparison with that of 1,750 mtpd plant. As the result of the study, TEC and the manufacturer have concluded that the design and production of control valve for 3,500 mtpd urea plant is technically feasible with sufficient reliability and quality because the required port size and selected CV are within actual design and operation experience of the manufacturer. However, the cost is estimated higher than two control valves of half capacity. Therefore, the number of the control valve (single or double) should be carefully determined considering not only control valve cost but the cost of associated flanges, nozzles, fittings, pipe, washing connections, operability and maintainability.

Table VI
Control Valve Design (Reactor to Stripper)

	1,750mtpd	3,500mtpd
CV	815	1,550
Size	10 inch	14 inch
Material Trim	R-4 or EQ.	←
Material Body	316LSS	←
Availability	Experienced	Available

GRANULATION UNIT

TEC has presented the technical feasibility of single train 3,500 mtpd urea granulation plant based on TEC Spout-Fluid Bed technology at Nitrogen 2001, Tampa, Florida, USA [2]. The granulator, dust scrubber and product cooler can be single line even for 3,500 mtpd plant while solid handling equipment such as screens, crushers are in multiple trains in accordance with the available capacity of single unit. TEC has already completed the design of 3,500 mtpd granulation plant also.

TRANSPORTATION AND ERECTION

Transportation and erection are also an important factor to be studied. Though they strongly depends on the construction site location and condition, it can be concluded that transportation, erection and construction of mega-capacity urea plant are technically feasible based on TEC's experiences of other chemical plants. For example, in case 1,000,000 T/Y ethylene plant designed, engineered and constructed by TEC, propylene fractionator has 8 m diameter, 70 m height and 1,300 tons weight. These experiences in handling huge and heavy key equipment of ethylene plant prove that transportation and erection for 3,500 mtpd urea plant of which the largest equipment is the reactor having 3.8 m diameter, 30 m height and 510 tons weight are technically and economically feasible. However, of course, depending on the site conditions and restriction in inland transportation, local assembling of over-dimensioned equipment might be considered.

PROCESS PERFORMANCE AND ECONOMICS

Table VII shows typically expected consumption of raw materials and utilities of 3,500 mtpd ACES urea plant combined with TEC spout-fluid bed granulation of equivalent capacity. Owing to the better efficiency of rotating machines, steam consumption would be 3% less than that of 1,750 mtpd plant. Since the specific fixed cost (US$/mt-urea) of 3,500 mtpd urea plant including depreciation, maintenance, personnel, etc. is less than that of the 1,750 mtpd plant, the urea production cost (US$/mt-urea) would be also less.

Table VII
Expected Consumption of TEC ACES Urea Plant Combined with TEC Spout-Fluid Bed Granulation

	1,750MTPD	3,500MTPD
NH_3	0.563 ton	0.563 ton
CO_2	0.731 ton	0.731 ton
Steam (42 Kg/cm2G x 380 ºC)	0.98 ton	0.95 ton
Power	35 kWh	35 kWh

Notes:

1) unit: per metric ton of final granular urea product
2) Steam consumption includes the steam for steam turbines for CO2 compressor, ammonia pump and carbamate pump
3) Final granular urea product includes 0.25 wt% moisture and 0.45 wt% formaldehyde.

SINGLE TRAIN OR DOUBLE TRAIN?

In general, based on the above discussions, it can be concluded that 3,500 mtpd single train urea plant is technically feasible and economically advantageous over 1,750 mtpd double train urea plants with respect to production cost. However further discussion would be needed to select single train or double train even if the site condition and location do not deteriorate the feasibility of single train plant, for example, regarding the following aspects:

Technical Provenness

No single train urea plants of 3,500 mtpd or over are under engineering, construction and in operation in the world so far. Same capacity plant consisting of double train 1,750 mtpd plant can be designed, engineered, constructed and operated within proven experiences, in other word, no technical risks relating to lack of experiences in big capacity plants would be expected.

Operation Flexibility

Two train configuration has some operating flexibility in view of following:

- Urea can be produced with one train even shut-down of the other train due to maintenance or unexpected shut-downs. Thus, double train plant can minimize the risk of total shut-down of the plant.
- The production rate can be adjusted at 50% or less without sacrificing the plant efficiency by operating one train.

Environmental Impact

When the urea plant is operated at normal condition, there will be no difference between two train configuration and single train configuration in emission and effluent levels. However, in emergency conditions such that pressure relief device works due to overpressure or equipment failure, the magnitude of environmental impact due to ammonia and carbamate emissions will be significantly large in 3,500 mtpd plant in comparison to two train configuration. The probability of such serious troubles and its impact should be carefully examined so that the preventive measures can be appropriately designed and incorporated into the pollution abatement system.

CONCLUSIVE REMARKS

In the previous paragraphs, TEC has discussed and confirmed that a single train 3,500 mtpd urea plant based on TEC ACES urea process is technically feasible and economically advantageous. The improved version of the ACES Process, the ACES 21 Process (see **Figs. 11** and **12**) is designed more compactly and simple than the ACES Process in equipment itself and plant layout. Therefore, TEC is, with confident, ready to supply the mega capacity urea plants based on the ACES 21 Process as well.

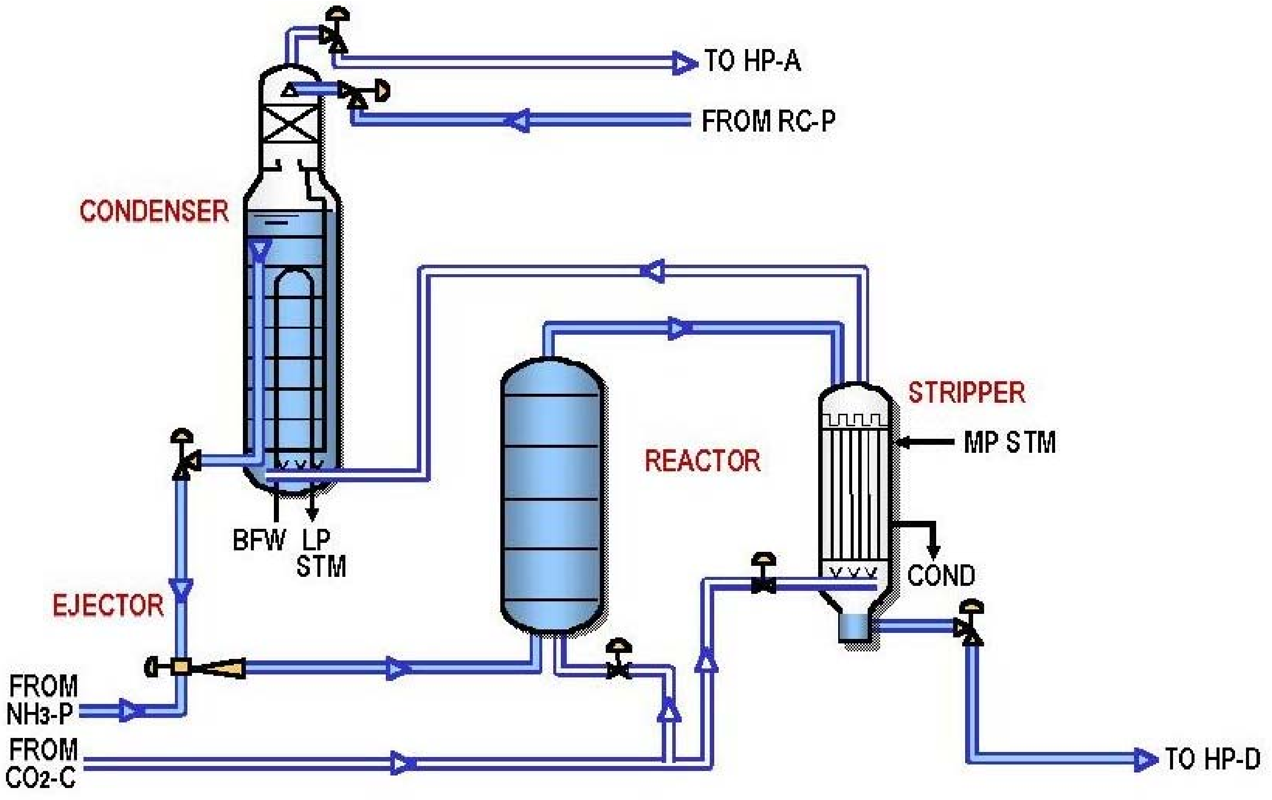

Fig.11: Schematic Process Flow of ACES 21 Process Synthesis Section

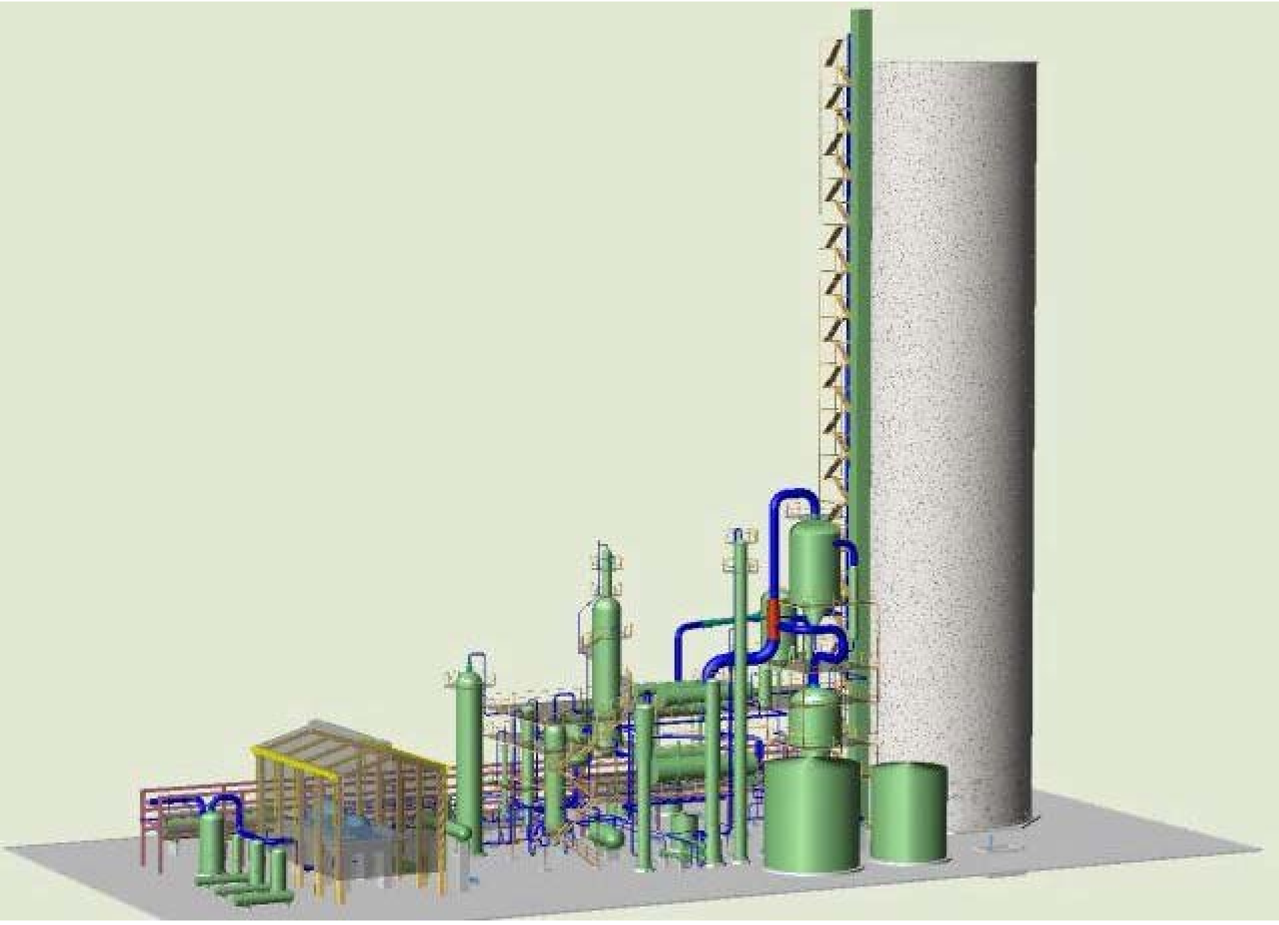

Fig.12: 3-D graphic representation of ACES 21

REFERENCES

[1] Japanese Patent No. 835812

[2] G. Nishikawa et al, “Large Scale Urea Granulation Plants based on TEC Technology”, Nitrogen 2001