

# Urea Plant Energy Improved by Installing Vortex Mixture

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**Abstract** - The paper intended to enhancement of energy and product quality by installing Vortex mixture in urea Reactor. This is the new approaches to convert reactant to useful product. In urea plant Carbon dioxide & ammonia are the reactants, in which the ammonia in liquid form and carbon dioxide is in gas form. The Carbon Dioxide is the limiting reactant. The percentage conversion calculated how much carbon dioxide converted to urea. The ammonia is excess reactant. For enhancement of conversion different process technique are used e.g. high efficiency trays etc. The Vortex mixture also the same function like CSTR. Efficiency enhancement of the synthesis section not only improves process parameters, but also increases final product output. The contact surface is increased by 1.5 - 2.0 times compared to conventional mixing arrangements. Efficient operation of synthesis section greatly depends on the amount of ammonia and Carbon Dioxide recycle. The worldwide Russian company M/S. NIIK is supplied the Vortex mixture at reasonable cost. The energy saving reported 0.03 to 0.08 G.cal. /ton of Urea as depends upon plant capacity and process.

**Keywords**- Vortex mixture, conversion, efficiency, Urea, Reaction.

## INTRODUCTION

The National Fertilizers Ltd. Vijaipur is located in Madhya Pradesh (India). The Plant have two ammonia plant M/S. Haldor Topsoe Technology, Denmark capacity 1750 & 1864 TPD for line-I & line-II respectively and four urea plant of M/S. Saipem ammonia stripping process, Italy . The line-I plant installed in 1988 and that of line -II in

1997. The capacity of Urea-I urea -II is 3030 & 3231 TPD respectively. The raw material used includes natural gas, water and power. Three Numbers Captive power plant of capacity 17 X 3 MW are used in this complex. The national Fertilizers contribute 16 % to India's total urea production. The technology used to produced ammonia and urea has been revamped over the years and won the managements numerous productivity excellence awards and accolades. For capacity enhancement and energy saving we had installed five numbers additional trays in four reactor, the conversion rate increased by 1.5-1.8 % in terms of Carbon Dioxide. Now our future plan to installing Vortex Mixture in our four reactors. In India Nagarjuna chemical & Fertilizers Ltd, Kakinada is the first in India then RCF Trombay is the installing in previous year and energy saving reported 0.07 G.cal/ton of urea. This figure depends upon plant process and plant capacity. This device is very useful for energy saving scheme and plant problem for bottleneck.

## Description of urea process

As figure No. 1 the vortex mixture installed in bottom parts of urea reactor as carbon Dioxide is gas formed and trying to escape top of the reactor part without reaction with ammonia the Carbamate is having very high vapour pressure. The Vortex mixture is the best device to convert and mixing the both ammonia & carbon Dioxide. The reaction rate is directly proportion to contact surface area, turbulence etc.

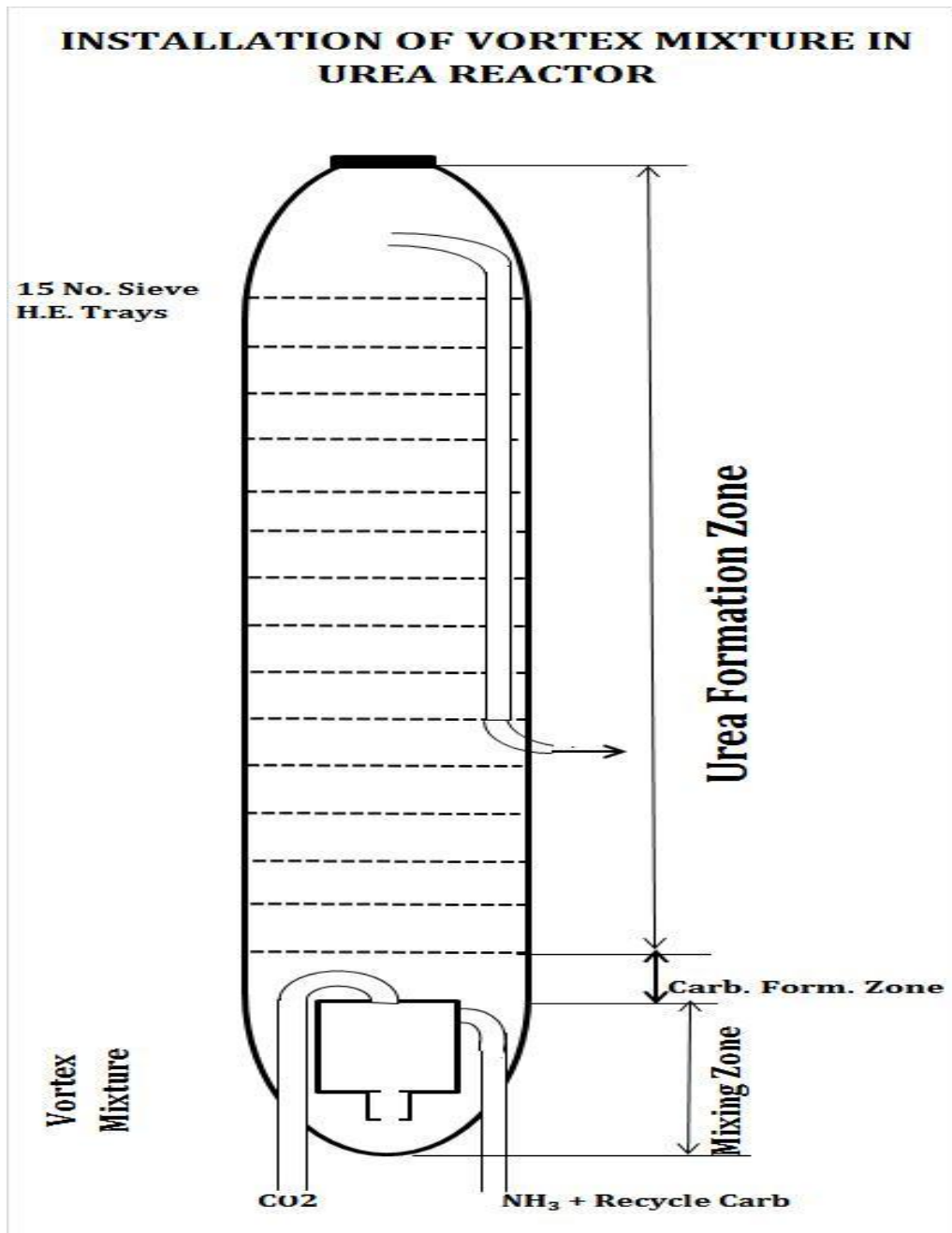
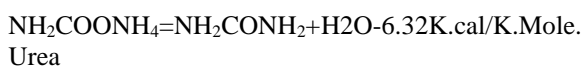
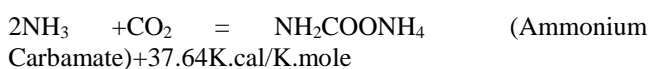


Fig -1

Urea is produced by synthesis from liquid ammonia and gaseous carbon dioxide. In the reactor the ammonia and carbon dioxide react to form Ammonium Carbamate, a portion of which dehydrate to form urea and water. The reactions are as follows.



In synthesis conditions (T-189°C & P-159 bar) the first reaction occurs rapidly and completed, the second reaction occurs. The molar ratio of Ammonia to Carbon Dioxide is around 3.6 to 1. The molar ratio of water to carbon Dioxide is around 0.67 to 1. The Reaction No. 1 given above is instantaneous and complete very fast. It is exothermic reaction in nature and 37.64 K.cal/K.mole heats are produced in the formation of ammonium Carbamate. By installation of Vortex mixture this reaction is very fast and produced heat and this heat is utilizing in reaction No. 2. The reaction No. 2, however it is very slow and control the urea formation. From the 2<sup>nd</sup> reaction which represent the decomposition of ammonium Carbamate it is evident that

- (i) The forward reaction involves volume increase and hence lower pressure favour it

- (ii) The reaction is accompanied by absorption of heat; therefore the Vortex mixture is very important because the reaction heat is involved.
- (iii) The reaction is directly proportional to mixing of the fluid i.e. Contact surface area.
- (iv) However the overall reaction is plug flow but internal mixing act as a bank of CSTR(continuous stirred tank Reactor)

- 6. Urea Concentration in two steps, 1<sup>st</sup> operated at 0.33 ata and final operated at 0.03 ata.
- 7. Urea Prilling section
- 8. Waste water treatment section.

Mainly urea plant process divided into following steps.

1. The urea reactor with HET & Vortex mixture
2. Urea synthesis and high pressure recovery at 159 ata
3. Urea purification and medium pressure recovery at 18 ata
4. Urea purification at low pressure 4.5 ata,
5. Urea pre concentration section at 0.345 ata

The ammonia is feed in reactor through Ejector at the pressure of 232 ata as a motive fluid and recycle Carbamate feed through ejector and resultant discharge pressure is 159 ata .Carbon Dioxide is feed at pressure 160 ata and temperature 115°C.

The dust emission contents in the Prilling tower exhaust air is not exceed more than 40 mg/Nm<sup>3</sup> and the total particulate matter emission is about 1.0 to 1.1 MT in a day. The air flow in the Prilling tower is about 1200-1250 Nm<sup>3</sup>/tone of urea.

The emission from M.P section i.e. 40-45 % fuels in terms of Methane; Hydrogen has been recovered in HRU fuel. The ammonia contents are very low i.e. 0.1 to 0.2 % mole %) the detail process flow diagram shown in the fig No. 2.

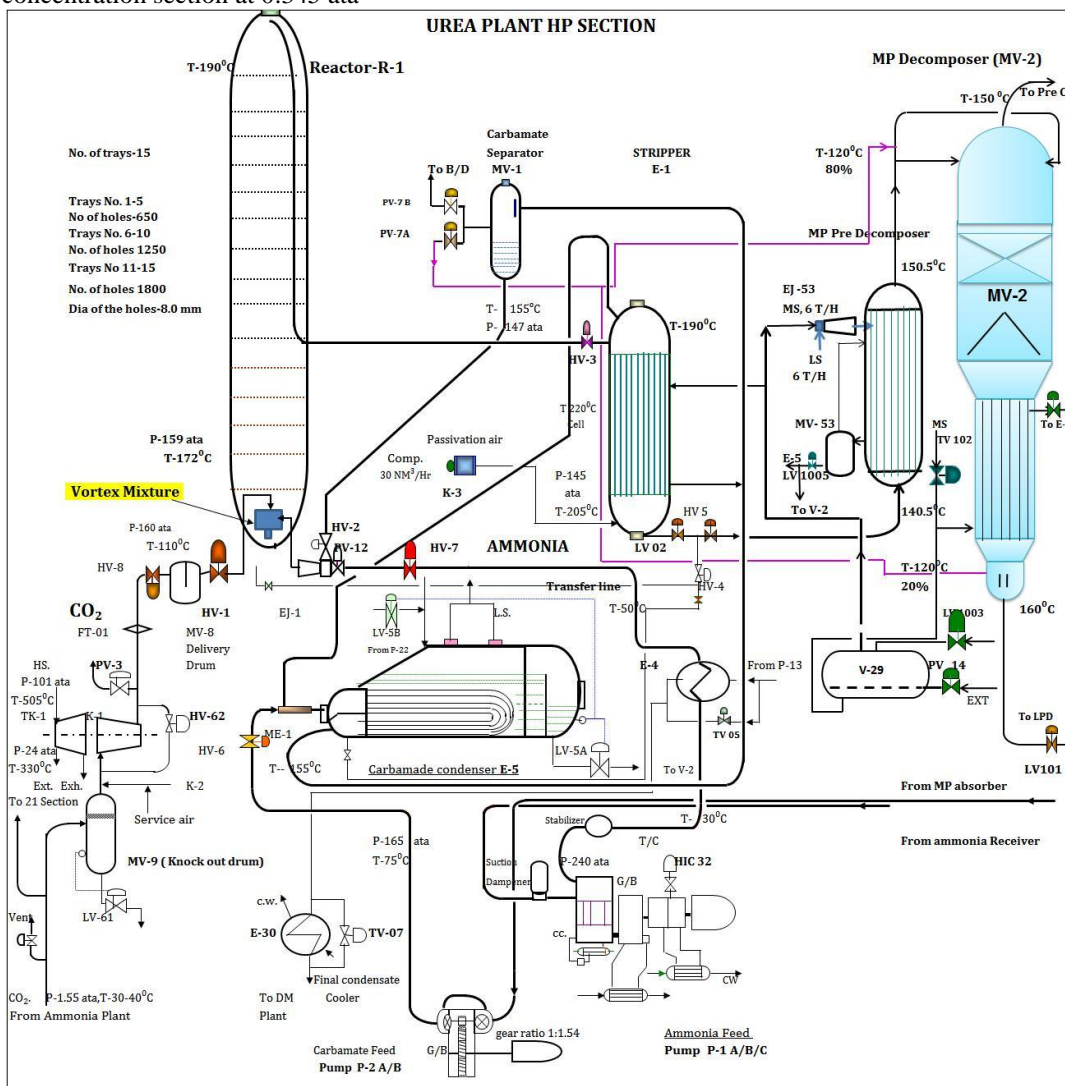


Fig.2

### *Description of Vortex Mixture*

The design of a gas-liquid reactor with a rising unidirectional phase movement and can be used, in particular, for the industrial production of urea. Pipes for introducing reactants into the vertical entrained-flow carbon dioxide and-ammonia reactor are connected to inlet pipes of a mixer which is located in the lower part of the body and the axial outlet pipe of which is directed either towards the bottom of the reactor or upwards, and which is equipped with a diffuser. The mixer consists either of a coaxial tube and of one or more consecutively connected coaxial vortex chambers with tangential inlet pipes, or only of two or more vortex chambers. The Ammonia in by force of fast velocity tangentially. The tangential pipes ensure an identical direction of rotation of the flows in all of the chambers. At least one of the tangential pipes is inclined in the opposite direction of the outlet opening in the axial pipe. The mixer, with the outlet pipe directed upwards, is located within a cylindrical shell which is concentric to the body of the reactor. The technical result is an increase in the intensity of dispersion of the interacting phases and in the uniformity of dispersion of the reactants in the two-phase flow formed.

A hollow conic surface installed below the pipe for reaction Ammonium Carbamate outlet facing the reactor bottom with its open basis, a cyclonic ejector installed under the conic surface, having a tangential pipe connected to one of the inlet pipes for liquid ammonia a nozzle directed towards the bottom of the reactor, and a coaxial pipe located inside an ejector, the top end of the pipe being connected to the space of the hollow conic surface, its lower end being located at the level of the nozzle outlet over the distribution device for supply of a carbon dioxide. The present design of a reactor is characterized by non-uniform distribution of carbon dioxide in the volume of liquid because of separate inlet of Ammonia & Carbon dioxide and specific design of the gas distribution device.

How to improve urea reaction rate with installing Vortex mixture in bottom part Urea reactors and for turbulence maximum contact area. Effective carrying out of processes in Carbon Dioxide & ammonia column reactors with rising unidirectional phase movement is possible only in the

conditions of uniform distribution of speeds, sizes of bubbles and carbon Dioxide content in the cross-section of rising Carbamate flow. Efficient operation of synthesis section greatly depends on the amount of ammonia and Carbon dioxide recycle. Any change of this amount results in changes in energy consumption. In a synthesis reactor it is very important to achieve the maximum conversion of original feedstock into the final product under the required process Conditions. The distribution depends on design features of a reactor. Feedstock Ammonia & carbon Dioxide are introduced into the reactor by separate jet-axial flows through three pipes. Having passed the mixing device, the flows enter the reaction space in the form of a mixture.

A mixer should have the following features:

1. It must fill up the volume of the reactor with a gas-liquid mixture as much as possible;
2. It must ensure the largest possible specific surface of media contact of components supplied to the reactor.

The axial outlet pipe of the mixer fitted with a diffuser. The mixer may contain at least one additional vortex chamber as per plant capacity and load condition reactor height etc. Coaxial to the first one and consecutively connected with it, having the tangential inlet pipe and an axial outlet pipe, and the axial outlet pipe of each foregoing chamber being introduced into cylindrical body of next chamber. The tangential inlet pipe at least of one additional chamber may be inclined towards the mixer body in the opposite direction of outlet opening of the axial outlet pipe, in the same way as in the main chamber.

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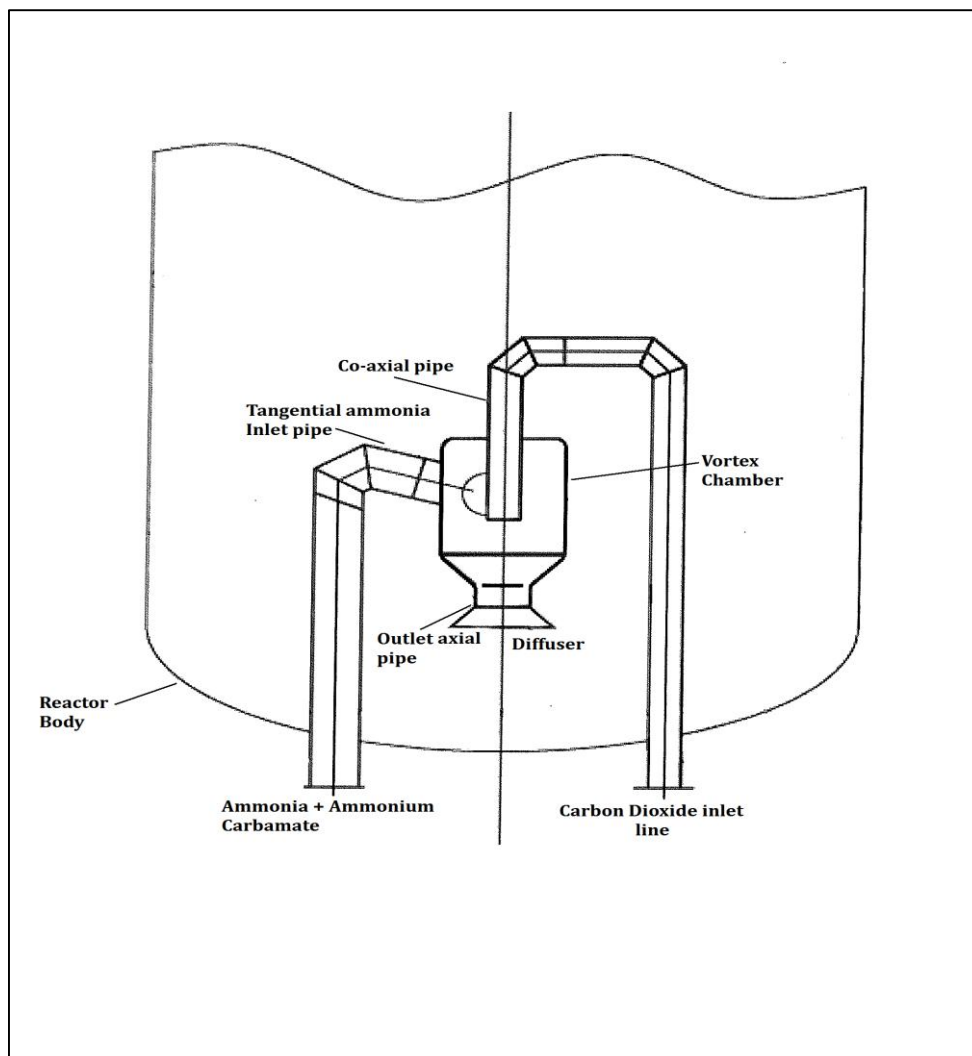


Fig -3

The Principle of Vortex mixture:-

1. Mass transfer factor by distribution phase movement.
2. Contact pattern of surface and diffuser.
3. Fluid dynamics factors.
4. Interfacial surface area.
5. Geometry of Vortex vessel.
6. Chemical kinetics factors.
7. Temperature & pressure of the reactants.



Fig. 4, Vortex Mixture

Reactor outlet sample Analysis before Vortex mixture installation

Table -1

ANALYSIS	Reactor Outlet		Stripper outlet	MPD outlet	LPD outlet
	weight %	Moles	weight, %	weight, %	weight, %
As per lab report:-					
Ammonia	33.60	1.976	23.65	7.42	2.72
Carbon Dioxide	14.00	0.318	7.74	2.86	2.02
Urea	34.10	0.568	43.95	63.12	71.14
Water	18.30	1.017	24.66	26.6	24.12
Total	100.00	3.880	100	100	100
Ammonia to CO <sub>2</sub> molar ratio					3.51
Water to CO <sub>2</sub> ratio					0.51

Table -2. Calculation

Sr. No.	Description	unit	value
1	(i) CO <sub>2</sub> required for 0.568 moles urea	moles	0.568
	(ii) Reactor outlet CO <sub>2</sub>	moles	0.318
	(iii) Therefore reactor Inlet CO <sub>2</sub> would be	moles	0.887
2	(i) Ammonia required 0.568 moles of urea	moles	1.137
	(ii) Reactor outlet Ammonia is	moles	1.976
	(iii) Therefore reactor inlet Ammonia would be	moles	3.113
3	(i) Water at Reactor Inlet	moles	0.448
	(ii) Hence Stripped CO <sub>2</sub> from stripper	moles	0.182

Table -3, Result

Sr. No.	Description	Result
1	Percentage Conversion of CO <sub>2</sub> in Reactor	64.10 %
2	Efficiency of stripper	57.15
3	Efficiency of M.P. decomposer	74.30 %
4	Efficiency of L.P. decomposer	37.30 %

Reactor outlet sample Analysis after Vortex mixture installation

Table -4

ANALYSIS	Reactor Outlet		Stripper outlet	MPD outlet	LPD outlet
	weight %	Moles	weight, %	weight, %	weight, %
As per lab report:-					
Ammonia	32.99	1.941	22.59	7.40	2.45
Carbon Dioxide	13.50	0.307	7.45	2.50	21.00
Urea	34.61	0.577	44.98	63.80	71.85
Water	18.90	1.050	24.98	26.30	24.00
Total	100.00	3.874	100	100	100
Ammonia to CO <sub>2</sub> molar ratio					3.50
Water to CO <sub>2</sub> ratio					0.54

Table -5. Calculation

Sr. No.	Description	unit	value
1	(iv) CO <sub>2</sub> required for 0.577 moles urea	moles	0.577
	(v) Reactor outlet CO <sub>2</sub>	moles	0.307
	(vi) Therefore reactor Inlet CO <sub>2</sub> would be	moles	0.884
2	(iv) Ammonia required 0.577 moles of urea	moles	1.154
	(v) Reactor outlet Ammonia is	moles	1.941
	(vi) Therefore reactor inlet Ammonia would be	moles	3.094
3	(iii) Water at Reactor Inlet	moles	0.473
	(iv) Hence Stripped CO <sub>2</sub> from stripper	moles	0.177

Table -6, Result

Sr. No.	Description	Result
1	Percentage Conversion of CO <sub>2</sub> in Reactor	65.30 %
2	Efficiency of stripper	57.54 %
3	Efficiency of M.P. decomposer	76.30 %
4	Efficiency of L.P. decomposer	39.60 %

Observed the above result the conversion of reactor in terms of CO<sub>2</sub> improved by 1.2 %. And steam saving in reactor downstream Heat exchanger in stripper, MP decomposer & LP decomposer by 50 to 70 kg per ton of urea. The efficiency of the decomposers are also increased because the less recycling of unconverted ammonia & carbon Dioxide.

### CONCLUSION

Those plants which have problem of bottleneck and high energy the Vortex mixture may be installed in urea reactor, after that the energy will be come down about 0.04-0.07 G.cal /tone of urea as per process and plant load. For Vortex mixture may contact to NIIK, Russia, Oleg Kostin (Mr) General Director Tel: +7 (8313) 26-40-88. NIIK, R&D Institute of Urea, 31 Griboedov street, Dzerzhinsk, Nizhny Novgorod region 606 008, Russia. NIIK is a leading Russian Engineering and Technological company. NIIK provides comprehensive services for nitrogen productions comprising qualification procedures, feasibility studies, proposal, basic and detailed design, equipment procurement and post-project services (inspections, maintenance and repairs). NIIK can implement projects on the turn-key basis. The Vortex mixture will be designed as per plant load i.e. the number of Vortex mixture. NIIK can offer a number of activities aimed at increasing urea unit capacity and improving energy efficiency. One of the key activities in the NIIK revamping concept is the

modernisation of the synthesis section. Efficiency enhancement of the synthesis section not only improves process parameters, but also increases final product output.

Urea plants have been modified to improve the conversion efficiency of reactor by installing improved designed trays. As shown in the figure No. 2. In a recent revamp, one of the urea plants installed a Vortex mixer in the reactor to increase the conversion efficiency and reduce steam consumption. The increase in carbon Dioxide pressure from compressor before the reactor compared to the base case test was 0.5-0.7 bar. This is a result of slightly increased load of the urea unit (the difference at similar loads is around 0.1- 0.2 bar). In any case this increased value is negligible and within the measurement accuracy of the meter. This will not affect further increase of the unit load 1800 TPD to 4000 TPD plant. Now a days the higher capacity urea plants are coming 4000-5000TPD mega plants.

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Legends,  
CSTR-continuous stirred Tank Reactor  
G.Cal- Giga calorie  
TPD- Ton per day  
MW- Mega watt  
Ata- Absolute Pressure  
HET- High efficiency trays  
H.P section- high pressure section.