Chapter III :

PROCESS TECHNOLOGY FOR FERTILISER MANUFACTURE

The period between 1925-1950 was the golden era in the history of fertiliser industry. Various processes for the production of different types of fertilisers from a variety of raw-materials were invented and modified.

Development in process technology

Since 1950, the process technology has developed remarkably as a result of which the consumption of utilities (i.e. power and water) per unit of fertiliser production has come down substantially. There has also been more economical use of raw materials and capital per unit of fertiliser production. Table 3.1 shows the decrease in consumption of intermediates as well as utilities with the modification of urea process. Although the consumption of intermediates NH_3 and CO_2 have not shown significant decrease, there is substantial saving in the consumption of utilities like steam, power and cooling water. Table 3.2 shows the saving in Horse Power with the modification of granulation process for NP/NPK fertilisers. The 'melt process' used for granulating NPK complex fertilisers will use 202.5 H.P. less than the conventional process in a plant having 30 tonnes per

Table 3.1 : Consumption of intermediates and utilities for one tonne of urea production.

Process developed in year	Ammonia (NH_3) (Tonnes)	Carbon dioxide gas(CO_2) (Tonnes)	Steam (Tonnes)	Power (kwh)	Cooling water (Tonnes)
Process-A(1958)	0.585	0.780	2.0	200	135.00
Process-B(1960)	0.580	0.770	1.8	185	120.00
Process-C(1966)	0.575	0.760	1.2	165	100.00
Process-D(1971)	0.570	0.760	0.5	114	63.86
Process-E(1973)	0.575	0.750	0.5	135	41.91

Source: 1. Shonosuki Kimura, Cost reduction in urea production, Fertiliser Association of India Seminar,1966,p.130.
2. Fertiliser News, Sept.1971, Fertiliser Association of India, New Delhi, p.33.
3. Fertiliser News, Feb.1973, FAI, New Delhi, p.36.

hour granulating capacity and the same process used for granulating ammonium phosphate will use 375 H.P. less than the conventional process in a plant having 50 tonnes per hour granulating capacity. These data, of course, are produced by the manufacturers supplying the process technology.[1] However, in actual operation, the coefficients may vary depending upon the capacity utilisation or other factors affecting overall efficiency.

1 (a) Shonosuki Kimura: Technical Manager, Toyo Koatsu Industries Inc., Toyo, Japan.
(b) Young R.D. and Lee, R.G., Tennessee Valley Authority (TVA), Alabama, U.S.A.

Table 3.2 : Savings in horsepower for melt process over conventional process for granulation of NP/NPK fertilisers.

	Capacity 30tph* NPK	Capacity 50tph* ammonium phosphate
(A) Horse poer eliminated		
(a) Dryer combution oil blower	7.5	10.0
(b) Dryer drive motor	160.0	300.0
(c) Fan drive motor	125.0	200.0
(d) Elevator drive	10.0	15.0
Total saving	302.5	525.0
(B) Increased Horse power for layer cooler, scrubber and fan.	100.0	150.0
Net saving in H.P.	202.5	375.0

* tph = tonnes per hour

Source: Young R.D. and Lee R.G. Advantages in energy, fuel and investment by melt type granulation processes, Fertiliser Association of India, Seminar 1975, p.II/372.

Raw material and intermediate based processes :

The consumption of inputs (raw-materials, utilities etc.) per unit of product are known as 'input-coefficients'. Tables 3.3 and 3.4 are input coefficient matrices for the fertiliser industry. Table 3.3 is the input coefficient matrix for fertiliser intermediates ammonia (NH_3) and sulphuric acid (H_2SO_4). Ammonia can be produced from various hydrogen generating raw materials.

Table 3.3 : Input structure for the manufacture of fertiliser intermediates ammonia and sulphuric acid. (Figures in tonnes per tonne of product)

Name of the raw material	Ammonia (NH_3)				Sulphuric acid (H_2SO_4)	
	Process I	Process II	Process III	Process IV	Process I	Process II
	1	2	3	4	5	6
Natural Gas*	860					
Naphtha		0.90-1.02				
Fuel oil			0.91			
Coal				3.62		
Sulphur					0.35	
Pyrites						0.90

Note: * Natural gas is measured in terms of NM^3.

Source: Fertiliser Statistics, 1979-80, Fertiliser Association of India, New Delhi, p.I-241.

Presently for fertiliser manufacture natural gas, naphtha, fuel oil and coal are commonly used. Similarly sulphuric acid can be produced from sulphur or pyrites containing sulphur ingredients. Since all these raw materials are alternate raw material, they can be substituted for one another. Thus each column of table 3.3 represents a separate process which can be distinguished from the other processes on the basis of raw material consumption. Since there are four alternate raw-materials for ammonia production and two alternate raw-materials for sulphuric acid production in Table 3.3, there

Table 3.4 : Input structure for the manufacture of fertiliser intermediates and products.

Raw-material/ intermediate	Fertiliser Intermediate: Phosphoric acid (H_3PO_4)	Fertiliser Intermediate: Nitric acid (HNO_3)	Fertiliser Products: Ammonium Sulphate (20.6%N) From sulphuric acid	Ammonium Sulphate (20.6%N) From Gypsum route	Calcium ammonium nitrate (CAN) (20%N)	Urea (46%N)	Single super phosphate (SSP) (16% P_2O_5)	Triple super phosphate (TSP) (46% P_2O_5)	Urea ammonium phosphate (UAP) (28-28-0)**	Di-ammonium phosphate (DAP) (18-46-0)	NPK complex (14-35-14)***	NPK complex (17-17-17)***	NPK complex (19-19-19)	NPK complex (12-32-16)***	Nitro phosphate
1. Phosphoric Acid (H_3PO_4)	-	-	-	-	-	-	-	0.36	0.29	0.48	0.38	0.18	0.20	0.34	0.16
2. Nitric Acid (HNO_3)	-	-	-	-	0.59	-	-	-	-	-	-	-	-	-	0.36
3. Ammonia(NH_3)	-	0.29	0.27	0.27	0.16	0.60	-	-	0.37	0.24	0.18	0.22	0.24	0.15	0.10
4. Sulphuric Acid(H_2SO_4)	2.85	-	0.78	-	-	-	0.36	-	-	-	-	-	-	-	-
5. Carbon dioxide Gas(CO_2)	-	-	-	0.38	-	0.77	-	-	-	-	-	-	-	-	-
6. Phosphate rock (73-75% BPL)*	3.30	-	-	-	-	-	0.60	0.46	-	-	-	-	-	-	-
7. Potash (KCl) (60% K_2O)	-	-	-	-	-	-	-	-	-	-	0.25	0.30	0.33	0.28	0.26
8. Gypsum	-	-	-	1.30	-	-	-	-	-	-	-	-	-	-	-

* % BPL = 2.18 x % P_2O_5 and % P_2O_5 = 0.46 x % BPL

** Total ammonia including the quantity required for producing urea which is incorporated in the end product.

*** Small quantities of urea are also added to make these formulations.

Source: Fertiliser Statistics, 1979-80, Fertiliser Association of India, New Delhi, pp.I-24 to-242.

are four ammonia processes (columns 1 to 4) and two sulphuric acid processes (columns 5 and 6).

Table 3.4 is the input coefficient matrix for fertiliser intermediates phosphoric acid (H_3PO_4) and Nitric Acid (HNO_3) and various fertiliser products. Coefficients presented in a particular column of Table 3.4 represent the raw-materials/intermediates required for the manufacture of that product. All products except nitric acid of Table 3.4 require more than one input and their input coefficients are given in the respective cells. Thus each column in the table is a process of producing a fertiliser. These processes are distinguished on the basis of intermediates and raw materials used within each one of these processes. There might be further sub-processes based on the design of the plant. These sub-processes make a difference in the use of utilities particularly. That is why in these tables we are not presenting the coefficients for utilities like water and power. This we will deal separately.

The input-coefficients given in Tables 3.3 and 3.4 may be regarded as first approximation to deal with much complex problem of process technology for fertiliser manufacture. The coefficients of these tables are computed on the basis of consumption norms for various processes developed by a number of engineering firms.

Process differentiation based on design of the plant :

Before we go in for analysing the problem empirically it is important to mention that fertiliser industry is a multiproduct industry and for each type of product various processes are available. Furthermore, the output of one process is used as an input in another process. Also the output of each process depends on the designing of the process and input used. For example, if hydrocarbon raw-material is used for the production of intermediate ammonia, by-product carbon-dioxide gas is generated which is used for the production of urea fertiliser. However, in the electrolysis of water process which generates hydrogen from water, carbon-dioxide gas can not be produced. Therefore, if urea fertiliser is to be manufactured in such a plant, a separate carbon-dioxide producing plant will have to be installed.

A brief description about the comparative study of two ammonia processes will throw some light on the complex nature of fertiliser technology. The processes for the manufacture of ammonia from a variety of hydrocarbon raw-materials may be classified in two categories (i) Partial oxidation Process and (ii) Steam reforming process. These two processes are used by a fertiliser manufacturing firm in three different ammonia plants.[2]

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2 Sharma, P.C. "Cost study of synthetic gas production at FACT" Fertiliser Association of India Seminar, 1969, New Delhi, pp.167-170

"Partial oxidation process consumes less quantity of naphtha than steam reforming process. The gas generated from partial oxidation plant contains 42% carbon monoxide (CO), 3.5% carbon dioxide (CO_2) and 52% hydrogen (H_2) whereas steam reformed gas contains only 13-14% of CO, 11% CO_2 and 52% H_2. The carbon monoxide gas is further heated with steam to generate hydrogen and carbon dioxide. Thus, the total generation of hydrogen gas is higher in partial oxidation process. On the other hand, the amount of steam required for shift conversion is available in steam reformed gas while it is picked up by the hot gas in the water scrubbers in the case of partial oxidation. Thus the gas has to be heated again before it enters the shift conversion. On the other hand in the steam reforming process, the hot gas has to be cooled to a certain degree to suit the converter inlet temperature, as a result of which some quantity of steam is also generated there. In the partial oxidation, the use of catalyst is more and the reactor equipment is comparatively costlier. In steam reforming process the pressure of CH_4 and argon in synthesis gas necessitates a continuous purge from NH_3 synthesis loop to keep the levels low. This results in a higher consumption of gas per tonne of NH_3 leading to higher consumption of raw material. Since the partial oxidation plant requires an air separation unit, the initial capital cost is higher and it also accounts for a higher requirement of electric power per ton of

NH_3. The power requirement for producing one tonne of NH_3 at FACT Alwaye Phase III plant which is based on partial oxidation process is 1.440 Mwh of which nearly one Mwh power are required for the production of synthesis gas alone. On the other hand Phase-IV plant at Alwaye and Cochin plant are based on steam reforming process. The power requirements for Phase-IV plant at Alwaye are only 0.810 Mwh and for Cochin plant which makes use of centrifugal compressors for compressing the synthesis gas the power consumption is only 0.210 Mwh." Since the generation of steam in the partial oxidation plant is lower, it necessitates the use of more fuel (coal, fuel oil etc.). It should be noted here that 13.63 KL fuel oil and 1050 Kgs of water are required for the generation of one tonne of steam. Apparently there is tendency for input coefficients to differ in different processes. Tables 3.5 to 3.8 show the input coefficients for the production of various types of fertilisers in different fertiliser plants. Although the ingredients of a particular fertiliser remains the same, whether it is manufactured by one process or another, the input coefficients vary significantly from one process to another.

Ammonia contains 82.3% nutrient nitrogen. All the seven but one processes in Table 3.5 are based on raw-material naphtha. Of the seven processes first five processes use the general process 'steam reforming' and later two processes are based on the general process 'partial oxidation'. The input coefficients for

Table 3.5 : Input Structure for Ammonia Production by various processes (in India)

(Inputs required per tonne of product)

Name of the Input	Unit	Steam reforming process					Partial Oxidation Process	
		Plant-A ICI/ kellog process	Plant-B ICI/ process	Plant-C Chemico process	Plant-D ICI/PGC process	Plant-E Seles process	Plant-F Shell/ chemico process	Plant-G Shell/ chemico process
Naphtha	Te	0.788	0.850	1.159	0.839	-	0.801	0.841
Natural Gas	Nm^3	-	-	-	-	951.184	-	-
Fuel oil	KL	-	-	0.156	0.549	-	0.013	-
Power	Mwh	0.790	0.886	0.135	0.069	0.950	1.710	1.889
Steam	Te	1.400	0.846	NA	NA	0.119	1.471	1.592
Water*	Te	9.579	9.579	9.579	9.579	9.579	9.579	9.579

NA = Not Available.
* water includes water for steam generation and cooling water.

Source: Ministry of Fertilisers and Chemicals, Government of India.

the ammonia production by these processes differ substantially. The water consumption in these processes is taken as similar since the data pertaining to this input is not available and normally the water consumption per tonne of ammonia production is about 9.58 tonnes.

Table 3.6 shows input structure for urea production. This table also gives similar information. Although the urea process was supplied by the same engineering firm to two fertilisers plants, their input coefficients differ. The variation in input coefficients for different processes or for the same process in different fertiliser plants confuse the analysis. We can compare the efficiency of a particular process on the basis of its input

Table 3.6 : Input structure for urea production in different fertiliser units (in India)

(Inputs required per tonne of product)

	Unit	Plant-A chemico process	Plant-B chemico process	Plant-C Montedison
Ammonia	Te	0.617	0.622	0.635
Carbon Dioxide Gas(CO_2)	Te	0.617	0.622	0.635
Fuel oil	KL	-	0.152	-
Power	Kwh	230	131	247
Steam	Te	2.180	NA	2.254
Water	Te	2.180	2.763	6.180

NA = Not Available.

Source: Ministry of Fertilisers & Chemicals, Government of India.

structure, but when these coefficients for the same process are unequal for different plants, the problem becomes too complex. In Table 3.6 the values of only two inputs vary proportionately. They are coefficients for input ammonia and carbon dioxide gas. Carbon dioxide gas and ammonia are reacted in equal quantities for producing urea. It should be noted here that these coefficients are not equal in value in Tables 3.1 and 3.4. Thus we may conclude that the real value of input coefficients may be different from their theoretical value.

Effect of capacity utilisation :

Tables 3.7 and 3.8 show the effect of capacity utilisation on the stability of input coefficients. These tables show the variation in designed and actual input structure for a few fertiliser plants in India. Although the data is available only for two years of plant's operation, these tables give very important information. Firstly, the input structure for a particular process depends on the designing of the process. Secondly, the value of input coefficients are affected by the capacity utilisation of the plant.

The average purge and emission of product gases directly affect the input coefficients. At full capacity utilisation, the emission and purge of product gases will be normal and at over capacity utilisation, the average loss will decrease in

Table 3.7 : Input coefficients for urea production indifferent fertiliser units (In India)

(Inputs required per tonne of product)

Name of the input	Unit	Plant-A Montedison Process (Capacity:330,000 tonnes)			Plant-B Montedison Process (Capacity:330,000 tonnes)			Plant-C Mitsui Toatsu Process (capacity: 284,000 tonnes)		
		Designed norms	Actual Norms Capacity utilisation		Designed norms	Actual Norms Capacity utilisation		Designed norms	Actual Norms Capacity utilisation	
			25.15% 1977-78	35.06% 1978-79		33.52% 1977-78	24.91% 1978-79		67.74% 1977-78	67.46% 1978-79
Naphtha	Te	.832	.975	.916	.522	.875	1.165	.495	.509	.551
Fuel Oil	KL	.075	.115	.114	NA	.030	.067	-	-	-
Coal	Te	.450	.938	.983	NA	.435	.716	.550	.576	.618
Power	mwh	.048	.085	.081	NA	.077	.097	NA	NA	.169

Name of the input	Unit	Plant-D Mitsui Toatsu Process (Capacity:450,000tonnes)			Plant-E Stami-Carbon Process (Capacity:210,000 tonnes)		
		Designed norms	Actual Norms Capacity utilization		Designed norms	Actual Norms Capacity utilization	
			94.89% 1977-78	89.53% 1978-79		46.03% 1977-78	77.44% 1978-79
Naphtha	Te	NA	.454	.490	.466	.554	.550
Fuel Oil	KL	NA	.006	.007	.078	.098	.082
Coal	Te	NA	.132	.144	-	-	-
Power	mwh	NA	.069	.075	.068	.086	.081

NA = Not available. Source: Mimistry of Fertilisers & Chemicals, Govt. of India, New Delhi.

Table 3.8 : Input coefficients for NPK fertiliser production.
(Inputs required per tonne of production)

Name of the Input	Unit	NPK Fertiliser Grade 10-26-26(A) Dorr Oliver Process: Designed norms	Actual 1977-78	Norms 1978-79	NPK Fertiliser Grade 12-32-16(B) Dorr Oliver Process: Designed norms	Actual 1977-78	Norms 1978-79
Phosphoric acid	Te	0.277	0.249	0.271	0.340	0.304	0.332
Ammonia	Te	0.112	0.113	0.127	0.134	0.155	0.151
Urea	Te	0.035	0.018	0.017	0.042	0.021	0.023
Muriat of Potash	Te	0.469	0.421	0.451	0.289	0.257	0.278
Fuel oil	KL	0.017	0.013	0.010	0.017	0.013	0.010
Power	Mwh	0.070	0.050	0.035	0.070	0.050	0.035

Source: Ministry of Fertilisers & Chemicals, Government of India, New Delhi.

the initial stages as a result of which the value of input coefficients will further decrease. But, when the capacity utilisation exceeds certain limits, the average purge and emission of product gases will start increasing due to overload of product in the process. Hence the law of decreasing returns will become applicable beyond that level of capacity utilisation. Apparently, the capacity utilisation affects the input structure very significantly and, hence, the cost of production too.

Table 3.7 shows the variation in the input-coefficients for urea fertiliser. The capacity utilisations in plants A, B, C, D and E are respectively 25.15%, 33.52%, 67.74%, 94.89%, and 46.03% during 1977-78 and 35.06%, 24.91%, 67.46%, 89.53% and 77.44% during 1978-79. As the capacity utilisation increases, the value of input-coefficients decreases and vice-versa.

Table 3.8 cites the case of a complex fertiliser plant. This plant has over capacity utilisation. Since the designing of a complex fertiliser process is done for multiproduct manufacture, it is difficult to specify exactly the effect of over capacity utilisation for one particular fertiliser product because the production of one product can be increased at the cost of another. The plant which we analyse here has the annual installed capacity to produce 92.8 thousand tonnes of NPK grade 10-26-26, 92.8 thousand tonnes of NPK grade 12-32-16 and 189.9 thousand tonnes of NPK grade 14-36-12. It should be noted here that the annual installed capacity is fixed on the basis of 330 working days. Thus the case of over capacity utilisation will occur only if the plant is operated at full load throughout the year. The production of fertiliser 10-26-26 in this plant during 1977-78 and 1978-79 was 108, 900 tonnes and 78,600 tonnes respectively. The production of fertiliser 12-32-16 during 1977-78 and 1978-79 in the plant was 392,200 tonnes and 484,400 tonnes respectively. This plant did not manufacture fertiliser 14-32-12 during both the years. Total installed capacity of NPK fertilisers in this plant is 375,500 tonnes and total production of these fertilisers during 1977-78 and 1978-79 was 501,100 tonnes and 563,000 tonnes respectively. Hence the total capacity utilisation of this plant during 1977-78 and 1978-79 was 133.45% and 149.93% respectively. Table 3.8 shows that the value of actual input coefficients of the plant was lower than that of designed norms during 1977-78 and 1978-79. But during 1978-79, the value of input coefficients was slightly higher than that of 1977-78.

Although the data is not sufficient to derive forceful conclusions, we may say on the basis of available evidence that the value of input coefficients decrease with the increase in capacity utilisation, it reaches approximately the designed level at full capacity utilisation and further decreases at over capacity utilisation. However, this decrease is not continuous and beyond certain level the value of input coefficients start rising.

Complex fertiliser process, variation in grades and input coefficients :

The production of NP/NPK nitrophosphate fertilisers and NP/NPK complex fertilisers has brought a major break through in the fertiliser technology. The terms 'nitrophosphate' and 'complex' deserve clarification because their inherent qualities often confuse a layman. Complex fertiliser may be defined as the fertiliser which contains two or more plant nutrients and is produced by a process which involves a major degree of chemical reaction. Chemical fertilisers mainly provide three primary nutrients. They are nitrogen (N), phosphate (P_2O_5) and Potash (K_2O). The grade of a fertiliser is the composition of these primary nutrients and is expressed in terms of percent content of these nutrients in the order of N-P_2O_5-K_2O in a particular product. If a nutrient is absent in the product grade it is denoted by zero. Thus ammonium sulphate may be represented as 20.6-0-0 as it does not contain nutrients P_2O_5 and K_2O. Diammonium phosphate is represented by 18-46-0 as it contains 18% N and 46% P_2O_5 and zero K_2O. Other grades of fertilizers are represented in the similar manner.

Formerly the name nitrophosphate was used for NPK fertilisers having low percentage of water soluble P_2O_5 say about 30 per cent. Presently the term is used for representing the fertiliser produced by acidulating phosphate rock with nitric acid instead of phosphoric acid. Nitrophosphate fertilisers are also included in the general class of complex fertilisers.

It is obvious that both nitrophosphate and complex fertilisers contain two or more plant nutrients. The only point which can distinguish 'nitrophosphate' and 'complex' term is the use of acid for the manufacture of fertiliser. If nitric acid is used the product is called nitrophosphate and on the other hand if phosphoric acid is used the product is called complex fertiliser.

Since sulphuric acid is the basic raw material for the manufacture of phosphoric acid, the development of nitrophosphate technology has proved beneficial for the sulphur importing countries. Nitrophosphate plants also create less nuisance in the atmosphere. Phosphuric acid using plants emit comparatively large quantities of pollutants as a result of which the overall recovery of product is just 91-92% whereas in nitric acid using plant the product recovery is 97-98%.[3]

The designing of the reactor as well as granulator also affects the purge and emission of gases. Processes are being developed and modified for the control/recovery of product through purge and emission. The replacement of 'Pipe Cross' reactor for 'Pipe Tee' reactor in the modified TVA (Tennessee Valley Authority, USA) granulation process for NP/NPK fertilisers has significantly controlled the emission of product gases. Other advantages of this process are that it can be

3 Grundt, T. and I.S. Mangat: "Modern Nitrophosphate Process Technology, Economics and Application to Fertiliser, Production in India", FAI Seminar 1975, p.ii/4-5.

used for comparatively large size NP/NPK fertiliser plants and for the production of large number of fertiliser grades. The cost of drying the product in this process is also low.[4]

Table 3.9 shows the input structure for the manufacture of different grades of NP/NPK fertilisers in a few fertiliser factories. This table gives very interesting results. Although a process is designed for the manufacture of various grades of fertilisers and the raw materials/intermediates used in a particular process in a fertiliser plant remains the same but their consumption do not vary proportionately along with the variation in product grade. This variation alters the input structure for each grade significantly. Hence in a multiproduct process, the relatiomship between input coefficients and product grades will be non-linear.

<u>Choice of process technology</u> :

It is possible now to design some of the processes in such a way so that with minor alterations they may be operated with different raw-materials. Fertiliser industry is very sensitive to raw material prices. During the 1960's naphtha was given more importance for the fertiliser manufacture but in the later 1960's it was realised that naphtha can be used more profitably in the petrochemical plants. Hence it was

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4 Parker, B.R., M.M.Norton and D.G.Salladay, "Development in Production of NP and NPK Fertiliser Using Pipe and Pipe Cross Reactor", FAI Seminar 1977, p.Tech.II/4-6.

Table 3.9 : Input structure for NP/NPK fertiliser manufacture in different fertiliser plants in India.

(Inputs required per tonne of production)

Name of the Inputs	Unit	Fertiliser Grade NP (20-20-0) PEC process modified by FCI	Fertiliser Grade NPK (15-15-15) PEC process modified by FCI	Fertiliser Grade NPK (14-28-14) Dorr oliver process	Fertiliser Grade NPK (17-17-17) Dorr oliver process	Fertiliser Grade DAP (18-46-0) Dorr oliver process	Fertiliser Grade DAP (18-46-0) Mitsui process	Fertiliser Grade UAP (28-28-0) TVA process	Fertiliser Grade UAP (28-28-0) TVA process	Fertiliser Grade UAP (24-24-0) Dorr oliver process	Fertiliser Grade NPK (14-35-14) TVA process
Fertiliser Plant :		A	B	C	D	E	F	G	H	I	J
Phosphoric acid	Te	0.059	0.039	0.285	0.180	0.484	0.489	0.301	0.334	0.255	0.395
Sulphuric acid	Te	0.087	0.027	-	-	0.016	0.009	-	-	-	-
Ammonia	Te	0.129	0.086	0.124	0.085	0.242	0.250	0.130	0.139	0.107	0.197
Nitric Acid	Te	0.401	0.326	-	-	-	-	-	-	-	-
Fuel oil	KL	NA	0.016	0.025	0.019	0.039	0.020	0.007	0.016	0.019	0.010
Power	Mwh	0.073	0.045	0.011	0.009	0.018	0.080	0.050	0.080	0.009	0.040
Urea	Te	-	-	0.102	0.265	-	-	0.449	0.576	0.389	-
DAP	Te	0.162	0.110	-	-	-	-	-	-	-	-
Mariate of Potash(MOP)	Te	-	0.262	0.241	0.292	-	-	-	-	-	0.260
Phosphate rock	Te	0.229	0.192	-	-	-	-	-	-	-	-
Gypsum	Te	-	-	-	-	0.25	-	-	-	-	-
Water	Te	1.616	1.350	0.241	0.185	0.371	0.820	0.120	0.830	0.181	0.100
Watercool	Te	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Steam	Te	0.063	0.041	NA	NA	NA	0.294	1.30	0.378	NA	1.400

NA= Not available

Source: Ministry of Fertilisers and Chemicals, Government of India, New Delhi.

decided to base the new fertiliser projects on fuel oil but with the escalation of oil prices the use of fuel oil in the fertiliser plants has become uneconomical. At present natural gas and coal are considered to be the only alternate raw materials for future fertiliser projects in India. Thus the relative prices of the inputs also affects the input structure of an industry.

The selection of process technology for a fertiliser plant is determined by various factors. The most important factor is the raw material to be used. Table 3.10 shows the alternate processes which may be used for the production of synthetic gas for intermediate ammonia based on different raw materials. Second factor which determines the process selection is the availability of foreign collaborator.

Table 3.10 : Raw materials for synthesis Gas production.

Raw material	Process
1. Water	1. Electrolysis
2. Hydrogen rich refinery gas	2. Steam reforming or partial oxidation
3. Natural gas	3. Steam reforming.
4. Naphtha	4. Steam reforming or partial oxidation.
5. Crude or residual oil	5. Partial oxidation
6. Coal and carbonaceous material	6. Water gas reaction and/or partial/oxidation.
7. Coke oven gas	7. Reforming or partial oxidation or low temperature separation.

Source: Handbook on Fertiliser Technology, 1977, Fertiliser Association of India, New Delhi, 1977, p.15.

The location of fertiliser projects also influences the designing of process technology. The consumption of inputs especially utilities varies from process to process and so also their availability from place to place. At present all the engineering collaborators emphasise more on the reduction of utility consumption as these constitute a substantial part of cost of production. The modification of technology has brought substantial savings in utility consumption. This has been shown in Tables 3.1 and 3.2 and also discussed earlier in this chapter.

Technological advancement and capital input.

Fertiliser plants require substantial investment of which, about 30 to 50 per cent in India has, in the past, been borrowed from foreign sources such as IBRD, IDA, loans from foreign Governments, etc. With the advancement in process technology, the scale of production in the fertiliser industry also tends to increase. Large-size fertiliser plants require higher capital outlay on fixed assets, especially on machinery and equipment which constitutes about 80 to 85 per cent of total investment in the plant. However, the questions to be answered are :
(a) whether with the increasing scale, the capital investment per unit of output has changed, and if so, in what direction;
(b) between scale and technological advancement (in case they are not necessarily concomitant) which has a dominating influence on capital intensity of output.

To answer these questions, we have selected a number of plants for which the data on investment as well as the date of commissioning and the capacity installed were available and also in a way that these plants cover a fairly long time span. The advancement in process technology has been taking place over time and, hence, in a general way one could say that later the date of commissioning the more advanced technology a plant represents. These data are presented in Table 3.11. The plants are arranged in chronological order of the date of their commissioning. Column 4 of the table shows the investment in the plant at the time of commissioning and column 5 shows the capacity created in terms of nutrients for the corresponding investment. Investments in this table are at current prices. There is a few year's time lag between the start of construction of the plant and the date of its commissioning (say 3 to 4 years). Over this period investments are made continuously. However, for the sake of a practical way of converting these investments into constant prices, we assume that the whole of investment on the plant was made on the date of commissioning of the plant. Some of the plants have subsequently expanded their capacity. For our purpose such capacity expansion and the investment associated with it has been treated as erection of a new plant. That is how in the table we have, for example, GSFC-I in 1967-68, GSFC-II in 1969-70 and GSFC-III in 1974-75.

Table 3.11 : Capital investment in fertiliser industry in India.

Plant No.	Name of the Plant	Year of comission	Total capital investment (in current prices) (Rs.million)	Total installed capacity in terms of nutrients ($N+P_2O_5+K_2O$) ('000 tonnes)	Real Capital Investment: Total investment at constant prices of 1960-61 (based on Index I)* (Rs.million)	Real Capital Investment: Investment per tonne of nutrient capacity (at constant prices) (Rs.'000)	Real capital investment: Total investment at constant prices of 1960-61 (based on index 2)* (Rs.million)	Real capital investment: Investment per tonne of nutrient capacity (at constant prices) (Rs.'000)	Fertiliser product to be manufactured
1	2	3	4	5	6	7	8	9	10
1.	FCI, Nangal	1961-6[illegible]	312	80.00	309	3.86	304	3.80	CAN
2.	EID Parry-I	1962-63	42	10.61	40	3.77	40	3.77	AS
3.	FCF, Trombay	1965-66	456	117.54	369	3.14	374	3.18	Urea, 20-20-0 (Nitrophosphate)
4.	NLC	1966-67	344	70.84	250	3.53	242	3.42	Urea
5.	GSFC-I	1967-68	630	146.44	445	3.04	4[illegible]0	2.94	Urea, DAP, AS
6.	CFL	1967-[illegible]	509	221.50	359	1.62	348	1.57	Urea, 28-28-0
7.	FCI, Namrup-I	1968-69	243	45.90	166	3.62	164	3.57	Urea, AS
8.	FCI, Gorakhpur	1968-69	349	80.40	239	2.97	236	2.94	Urea
9.	EID, Parry-II	1968-69	42	7.95	29	3.65	28	3.52	AS
10.	SCI, Kota	1968-69	270	110.40	185	1.68	183	1.66	Urea
11.	GSFC-II	1969-70	337	51.49	216	4.19	228	4.43	Urea, AS
12.	IEL	1969-70	610	207.00	391	1.89	412	1.99	Urea
13.	FACT-IV	1971-72	56	68.60	31	0.45	34	0.50	20-20-9
14.	MFL, Madras	1971-72	641	289.38	356	1.23	386	1.33	Urea, 17-17-17, 14-28-14, 28-28-0 18-36-0, 24-12-12, 11-22-22
15.	Zuari Goa	1973-74	566	241.70	253	1.05	290	1.20	Urea, 28-28-0, 19-19-19, 14-35-14
16.	FACT, Cochin-I	1973-74	630	151.80	283	1.86	322	2.12	Urea
17.	GSFC-III	1974-75	350	112.53	123	1.09	139	1.24	AS, 18-46-0
18.	FCI, Durgapur	1974-75	599	151.80	211	1.39	238	1.57	Urea
19.	IFFCO, Kandla, Kalol	1974-75	920	411.29	324	0.79	365	0.89	Urea, 10-26-26, 12-32-16, 14-36-12
20.	MCFL	1976-77	676	156.40	224	1.43	238	1.52	Urea
21.	FCI, Namrup-II	1976-77	920	151.80	305	2.01	324	2.13	Urea
22.	FCI, Barauni	1976-77	668	151.80	228	1.50	242	1.59	Urea
23.	SPIC	1976-77	897	347.20	297	0.86	316	0.91	Urea, 10-26-26, 18-46-0, 15-15-15
24.	FACT, Cochin-II	1976-77	540	271.40	179	0.66	190	0.70	17-17-17, 28-28-0, 18-46-0
25.	RCF, Trombay-IV	1977-78	760	150.00	245	1.63	255	1.70	20-20-0 (Nitrophosphate)

* See Table 3.12.

Source: 1. Fertiliser Statistics, Fertiliser Association of India, New Delhi.
2. Fertiliser Production in India, Fertiliser Association of India, New Delhi.

We are taking the investment as a lump-sum figure because the break-up figures on land, buildings, machinery and equipment, etc., are not available, but all these investments are on fixed assets. Since the investments in these plants were made in different years and the prices are subject to variation, for comparability we have to reduce them to constant prices. This necessitates the use of a suitable price deflator.

Two wholesale price indices for domestic capital formation in manufacturing industry by types of assets are available from National Accounts Statistics. One index pertains to all assets, while the other pertains only to machinery and equipment. These indices are shown in Table 3.12. The indices reported in Table 3.12 are implicit price deflators as they are obtained by dividing the gross domestic capital formation at current prices by the gross domestic capital formation at constant prices.

Column Nos.6 and 8 of Table 3.11 are computed on the basis of Index-I and Index-2 of Table 3.12 respectively. These columns show real capital investment (on the plants) at 1960-61 constant prices. Column No.5 of Table 3.11 shows the total installed capacity of fertiliser nutrients in the respective fertiliser plants. On the basis of column Nos.5, 6 and 8 we have computed capital investment per tonne of nutrient capacity at constant prices. Capital investment per tonne of nutrient capacity,

Table 3.12 : Whole-sale price indices for domestic capital formation in types of assets in manufacturing industry (1960-61=100)

Year	All assets (Index 1)	Machinery & Equipment (Index 2)
1960-61	100.00	100.00
1961-62	100.94	102.48
1962-63	104.34	105.18
1963-64	110.54	113.60
1964-65	116.11	114.94
1965-66	123.71	122.04
1966-67	137.43	142.20
1967-68	141.69	146.37
1968-69	146.03	147.93
1969-70	155.85	148.07
1970-71	169.03	160.03
1971-72	180.15	165.87
1972-73	193.27	179.59
1973-74	222.63	195.40
1974-75	283.92	252.08
1975-76	297.07	284.09
1976-77	301.53	283.75
1977-78	310.44	297.74
1978-79	327.21	309.15

Computed from :
1. National Accounts Statistics, February 1976 (for figures prior to 1970-71)
2. National Accounts Statistics, January 1979(for figures for the year 1971-72.
3. National Accounts Statistics, January 1981 (for figures for the year 1970-71 and 1972-73 onward).

Source: National Accounts Statistics, Central Statistical Organisation, Department of Statistics, Ministry of Planning, Government of India.

computed on the basis of Index-1 is given in column 7 and capital investment per tonne of nutrient capacity computed on the basis of Index-2 is given in Column 9.

An important point which emerges from column Nos.7 and 9 of Table 3.11 is that the advancement in process technology, as represented by time factor, has resulted in substantial capital savings in fertiliser industry. The real investment per tonne of nutrient capacity has decreased substantially over the period. Plant Nos.6,13,14,15,17,19,23 and 24 produce NP/NPK complex fertilisers in large quantities, Plant No.3 produces urea and nitrophosphate and plant No.25 produces only nitrophosphate fertilisers. Other plants produce only straight fertilisers of various types. This is shown in Column 10. It is apparent from the table that straight fertiliser plants require higher capital investment and NP/NPK complex fertiliser plants require lower capital investment per tonne of nutrient production. The investment per tonne of nutrient production on nitrophosphate plants is higher than that of complex fertiliser plants. Column Nos.7 and 9, although, computed from two different indices give almost similar results.

As can be seen from Column 5, although, there is tendency for scale to rise over time, there is no direct correlation between scale and time. Technology can fairly be assumed to be improving directly over time. It appears from column 7 and column 9 that investment per unit of capacity declines more or less steadily with time. Therefore, it appears that technology improvement has more impact on decrease in capital investment per unit of production than just the scale of production. To examine this further we have attempted a simple functional relationship between investment per unit, time and scale of production (in terms of installed capacity in nutrients). The functional relationship is given as

$$y = a + b_1 t + b_2 x$$

where y = investment per unit of capacity,

t = time (in years),

x = installed capacity

a = is constant and b_1 and b_2 are parameters.

To examine this relation we have run two regression models : (i) linear multiple regression (ii) double log multiple regression. The results obtained are given in Table 3.13 and Table 3.14. Table 3.13 shows the linear multiple regression results based on Index-1 (column 7) and Index-2 (column 9) and Table 3.14 shows the double log multiple regression results based on Index-1 (column 7) and Index-2 (column 9). The former gives absolute variation in dependent variable (y) with the change in the value of independent variables (t and x) whereas the latter

Table 3.13 : Regression results based on index-1 and index-2 (Linear multiple regression)

	a	b_1	b_2	R	R^2	$\bar{R}^2$	F Statistics
Index 1	4.2675	-0.1319** (-3.7247)	-0.004946** (-3.0599)	0.8318**	0.6918**	0.6638**	24.6921 (2,22)
Index 2	4.1835	-0.1191** (-3.3248)	-0.004953** (-3.0306)	0.8141**	0.6628**	0.6321**	21.6182 (2,22)

Note: 1. **Significant at 1% level.
2. Values in parenthesis below b_1 and b_2 show their t value.
3. Values in parenthesis below F statistics show the degree of freedom.

Table 3.14 : Regression results based on Index 1 and Index 2 (double log multiple regression)

	a	b_1	b_2	R	R^2	$\bar{R}^2$	F Statistics
Index 1	1.1616	-0.3860** (-2.4051)	-0.2621** (-2.2996)	0.7119**	0.5069**	0.4620**	11.3063 (2,22)
Index 2	1.1120	-0.3461** (-2.2526)	-0.2474** (-2.2669)	0.6977**	0.4867**	0.4401**	10.4318 (2,22)

Note: 1. ** Significant at 1% level.
2. Values in parenthesis below b_1 and b_2 show their t value.
3. Values in parenthesis below F statistics show the degree of freedom.

gives the percentage variation in dependent variable (y) with percentage change in the values of independent variables (t and x).

Table 3.13 gives us better results since it explains 69% variation in y (based on Index 1) and 66% variation in y (based on Index 2).

Table 3.14 explains about 51% variation in dependent variable y (based on Index 1) and 49% variation in y (based on Index 2). In this table the value of b_1 for both the indices is higher than the value b_2. We may interpret it as meaning that the influence of time on investment per unit of capacity is higher than that of scale of production.

Since the values of b_1 and b_2 are negative, there is a negative relationship between the independent variables and the dependent variable. The higher values of F statistics further strengthens our conclusions that the improvement in technology over the time as well as increase in the scale of production reduce the investment per unit of capacity.

Conclusion

Process technology of fertiliser manufacture has advanced remarkably since 1950's. A variety of processes for the manufacture of a number of fertilisers, from different raw materials, have been invented and further modified.

Processes can be distinguished on the basis of raw materials used. Since a number of engineering firms in the world have got the patent to supply their own designed processes, there are sub-processes of each process depending upon the designing of the process. Each process developed by a particular engineering firm has different input structure than that of others, and each process has certain advantages over the others. For example if process-A consumes less of one input, it may consume more of other input than another process-B. The competition among process designers in the international market accelerates the research activities for further modification in process technology.

NP/NPK complex fertiliser processes are multiproduct processes. The input coefficients for different grades of NP/NPK fertilisers produced by the same process in a particular fertiliser plant do not vary in proportion to nutrient contents in that grade. Hence, there is no linear relation between input-coefficients and product grades.

We have seen that technological advancement and scale economies have significant impact on both the capital investment as well as consumption of inputs. However, the coefficients of material inputs are more sensitive to the level of capacity utilisation, given the design of the plant.

The fertiliser industry is a multiproduct industry in which one fertiliser intermediate/product is used for the production of another fertiliser intermediate/product. A flow chart given in Figure 3.I may summarise the linkages of process technology in this industry. It is seen from the flow chart that ammonia and phosphoric acid are the most important intermediates in the fertiliser manufacture. The designing of the plant for the reaction of one intermediate with another intermediate or raw material in different proportions for the production of different types of fertilisers will change the input structure and hence, make fertiliser technology more complex.

FIG.1: 3.I FLOW CHART OF FERTILISER MANUFACTURE