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RELIABILITY - A MUST IN AMMONIA PRODUCTION

Ib Dybkjaer
Haldor Topsoe A/S, Denmark

INTRODUCTION

The purpose of the present presentation is to illustrate the important effect of reliable plant operation, i.e. high capacity utilization, on the production cost of ammonia. Furthermore, the most frequent causes for loss of on-stream time will be discussed, and some new developments ensuring improved reliability will be described. Finally, operating results obtained in two plants designed by Topsoe will be presented, illustrating what can be obtained in modern, well-operated plants.

THE IMPORTANCE OF RELIABILITY

In a discussion of the importance of reliable plant operation it is very difficult not to end up in one of two pitfalls. One is trying in a general way to determine "realistic" economic forecasts, considering a number of typical values for the various parameters of importance. This will inevitably lead to an avalanche of cash flow tables, tables of calculated IRR on investment or equity in different time frames, tables of accummulated profits (or losses!), etc., all on the basis of different assumptions concerning plant capacity and efficiency, investments, financing schemes, depreciation models, taxations, different prices for raw materials, utilities, manpower, and products including different escalation rates of these prices, etc. - and different assumptions concerning plant utilization in the years considered. When one considers the amount of paper which may be required for such studies in order to "justify" investments in a specific case, then the possible volume of a general study becomes truly frightening.

There is a risk of ending in another pitfall if one decides to simplify matters by considering just one set of assumptions and to calculate e.g. the production cost of ammonia, assuming variations in plant capacity utilization. In this case all the tables, etc. shrink to almost nothing, and one is left with results so obvious that one is almost ashamed of presenting them.

In spite of its obvious drawbacks, the second approach was deliberately chosen for the present presentation. It was decided to consider the production costs as consisting of just two elements, "Fixed Costs" and "Variable Costs", and to evaluate on this basis the effect of capacity utilization.

"Fixed Costs" are assumed to be independent of production rate. The most important elements are debt service, depreciation, taxes other than corporate tax, insurances, salaries and wages including possible social services, management and marketing expenses, and maintenance costs. The "Fixed Costs" will be high when the plant is new because of the burdens of interest and debt repayment and relatively low - but certainly not zero - when the plant is old and loans have been paid back.

"Variable Costs" are assumed to be proportional to production rate and thus zero when the plant is not operating. Plant shut-down and start-up are assumed to have no influence on the variable costs - this is not a completely realistic assumption. The main element in the variable costs is the cost of feed + fuel; other elements are cost of electric power, water, and other utilities, and (also a debatable assumption) cost of catalysts and chemicals.

In order to quantify the impact of capacity utilization on production cost the assumptions summarized in Table 1 were made.

Table 1
Basic Assumptions

Nameplate capacity	1000 MTPD NH_3, 330 days/year
Fixed costs	10 MM US$/year 25 MM US$/year 40 MM US$/year
Variable costs	Cost of feed + fuel + 5 US$/MT NH_3
Consumption of feed + fuel	8 Gcal/MT NH_3
Cost of feed + fuel	2 US$/Gcal (0.5 US$/MM BTU) 10 US$/Gcal (2.5 US$/MM BTU)

Fixed Costs of 10 MM US$/year correspond roughly to a situation where all debt has been repaid. 40 MM US$/year are relevant for a new plant (total investments 150 MM US$, yearly debt service and other capital expenses assumed at 20% of investments = 30 MM US$/year). 25 MM US$ represents an intermediate situation (or a situation where either investments or capital expenses for one or the other reason are unusually low).

The total energy consumption of 8 Gcal/MT of ammonia may be typical as a yearly average for a relatively new natural gas based plant. It is of course unrealistic to assume that all plants - old and new - have the same energy consumption. The real situation is probably that a new plant consumes somewhat less (on the average and at full capacity), while the old plant consumes considerably more, and all plants have somewhat increased specific consumption when operating at reduced rates. Similar comments are relevant for the other variable costs, which have for simplicity been taken as 5 US$/MT in all cases.

Based on the simplified assumption outlined above the results shown in Figure 1 have been calculated.

Some general conclusions are obvious from the figure, considering that at present the world market price for ammonia is fluctuating around 100 US$/MT:

- It requires a capacity utilization well above 100% to produce ammonia at a competitive price in new plants - even if gas is cheap and capital is not expensive.

- It is very difficult to produce ammonia at a competitive price in areas where feed and fuel are expensive. It is barely possible in old, efficient plants and probably impossible in new plants.

- Plant reliability may be - and will in most cases be - essential for the financial survival of the ammonia producer. In a new plant operating on cheap feed + fuel, the difference in net income at an ammonia price of 150 US$/MT between 90% and 110% capacity utilization is about 8.5 MM US$/year. This may represent a change from an annual loss of 1.7 MM USD to an annual profit of 6.8 MM US$.

As mentioned above - these conclusions are simple and obvious. It may be appropriate, however, to add some comments on the apparent discrepancy between the general level of production costs indicated in Figure 1 and the present market price of about 100 US$/MT of ammonia. The situation is that the price level in the figure indicated for new plants with cheap feed + fuel is probably quite realistic. It is the present market price which is distorted, much too low, mainly because of the situation in CIS and other factors which will not be elaborated here. How do ammonia plants then survive? Mainly by selling downstream products, e.g. urea, DAP, or ammonium nitrate, which obtain more realistic prices. As an example it may be noted that at realistic conditions urea should cost 10-20% less than ammonia per ton in view of its lower nitrogen content. The actual situation, is, however, that the urea price is 10-20% above the ammonia price - again indicating that the ammonia price is depressed to a level about two thirds of what it should realistically be.

CAUSES OF LOST PRODUCTION TIME

The most comprehensive study of causes of lost production time in ammonia plants has been made by G.P. Williams and co-workers and has been published at five "Ammonia Safety Meetings" at the American Institute of Chemical Engineers. [1-5].

A series of surveys were made, first in the North American ammonia industry and, since 1978, worldwide (excluding the then socialist countries). Data are available up to 1985.

Figure 2 has been prepared on the basis of data from the surveys; only data for North American plants have been considered since only these are available for the whole period. The figure shows both number and duration of unscheduled ("avoidable") shutdowns - average per plant per year - due to various causes. There is, especially for the last 12 years covered, a very clear trend of declining number of shut-downs and number of days lost. This is probably partly due to a phase-out of old plants, partly to introduction of new, more reliable technology, both in existing plants by revamps and in new plants. In the whole period the main part of the shut-downs have been caused by equipment failures. The most unreliable equipment items - evaluated by the number of days lost due to failures - have been the primary reformer and the compressors and turbines.

These two equipment groups have in all the surveys been responsible for more than 60% of the unscheduled downtime caused by equipment failures. Also the secondary reformer including its waste heat boiler has caused a significant amount of downtime -with probably the waste heat boiler the most important in this respect. It is clear that a lot of information is lost in this very summaric presentation of failures. In many cases equipment failures may be a secondary effect, while the real cause is maloperation or failure in another part of the plants. Examples: Failure of feed desulphurization may cause reformer failure, and failure of boiler feed water treatment or malfunction of the instrumentation may cause boiler failure. Also, many of the cases reported as "equipment failure" are not the effect of poor workmanship or maloperation, but may go back to incorrect plant design in a general sense, e.g. lack of proper consideration of plant upset conditions. The clear downward trend in number of "equipment failure" cases to some extent reflects an improved "quality" of the process and plant engineering.

It is clear, however, from the above that in the past equipment failures, especially failures in reformer, compressors and turbines, and boilers caused significant unscheduled downtime in the ammonia industry. It is also clear that the trend has been towards a reduction in the time lost. This trend has continued, as it will be demonstrated later, to a point where the time lost in unscheduled downtime due to technical reasons is in many plants almost negligible. An important side effect of the better design and the improved reliability is that the duration of scheduled turn-arounds can be shortened, and moreover - a definite trend in the industry - the time span between turn-arounds can be extended from the conventional one year to 18 months or even two years.

The reasons for the improved reliability in ammonia plants are many; some of the most important are summarized in Table 2 and further discussed briefly below:

Table 2
Main Causes for Improved Reliability
in Ammonia Plants

- Improved engineering design
- Improved catalysts
- Improved equipment
- Improved training of operators
- Improved maintenance including preventive maintenance
- Sharing of experience in the industry

- Improved engineering design. There are today only four competitors in the supply of technology for ammonia plants (Topsoe, Kellogg, Uhde, and Brown and Root Braun, listed in order of number of recent contracts). All of these technology suppliers have a long experience and have teams of specialists who together ensure that the engineering is sound, that the most reliable types of equipment are selected, that the equipment is designed for the most critical conditions taking also upset situations into account, that instrumentation and control systems are designed properly, and that operating manuals are correct and complete.

- Improved catalysts. A natural gas based ammonia plant uses 8 to 9 different types of catalyst. All catalysts are constantly improved to obtain better activity, better resistance to poisoning and to effects of plant upsets, and better mechanical properties. The emphasis shifts constantly. Some years ago the most critical catalysts, i.e. those most often causing operational difficulties, were the primary reforming catalyst and the low temperature shift catalyst. New developments in shift catalysts (such as the Topsoe LSK/LK-821 combination) and in process technology (reduction in steam to carbon ratio) moved the problems in the shift section to the high temperature shift catalyst, and new types (such as the Topsoe SK-201 catalyst) were developed to restore the reliability of the shift section. In the reforming section catalyst developments (such as the shape optimized Topsoe catalyst type R-67-7H) has, together with improved understanding of catalyst poisoning and the mechanism of carbon formation, led to very robust reformer design. New technology, i.e. pre-reforming, which eliminates from the primary reformer all poisoning problems and all risk of carbon formation from higher hydrocarbons, is being introduced in the ammonia industry and will further increase the realibility of the reforming section. Improved knowledge about catalyst ageing and improved models for catalyst and converter performance makes predictions about remaining lifetime safer, thus reducing the risk of downtime caused by catalyst failure in the the constantly increasing time spans between scheduled turn-arounds.

- Improved equipment. As for catalysts, there is for the equipment used in ammonia plants a constant development to improve performance. Improved materials are used, e.g. in the hot parts of the primary reformer, mechanical design of e.g. boilers and reactors is optimized, corrosion incidents (e.g. metal dusting corrosion in reformed gas waste heat boilers) are analyzed and causes eliminated by change of mechanical design and process design, etc. Improved instrumentation and advanced control (i.e. computerized control of critical process parameters such as steam to carbon ratio, hydrogen to nitrogen ratio, reformer firing, etc.) reduce variations in operating conditions and therefore the risk of exposing equipment to adverse condition.

. Improved training of operators. Better tools for training of operators are becoming available through the development of dynamic plant simulators. Such installations allow simulation in real time of plant start-up and shut-down and of plant upsets so that the operators can be trained off-line and in advance in all types of incidents and therefore react correctly when the problem becomes real.

. Improved maintenance including preventive maintenance. New technology - e.g. new methods for non-destructive testing of equipment - has been introduced. This makes it possible to check the condition of equipment during - and in some cases between - scheduled shut-downs and to forecast the remaining lifetime, thus allowing sound decisions concerning preventive maintenance or equipment changeout.

. Sharing of experience in the industry. It is an important characteristic of the ammonia industry that open information and discussion about plant incidents is available. This may happen at open conferences as the present conference or the well-established "Safety Meetings", annual meetings arranged since the late 1950's by the American Institute of Chemical Engineers under the title: "Safety in Ammonia Plants and Related Facilities". Also more informal contacts or closed seminars, e.g. arranged by technology suppliers, contribute to this exchange of information. The result is that knowledge about operational difficulties and actions to prevent them is available to the whole industry, so that the reliability of the whole industry is improved.

PERFORMANCE OF AMMONIA PLANTS DESIGNED BY TOPSOE

Since 1980 construction of 17 ammonia plants based completely on Topsoe technology has been completed, and a further 9 units are being implemented.

To illustrate the development in design and performance a survey is given in the following for two of the plants completed since 1980:

. 1000 MTPD plant for Fauji Fertilizer Company Limited, Pakistan
. 1000 MTPD plant for P.T. Kalimantan Timur, Indonesia

These plants were selected because very complete records of performance are available in both cases. Furthermore both plants have avoided any significant loss of production due to external factors such as power failure or lack of feedstock.

The plants both use natural gas as feedstock and are basically using the same "conventional" series of process steps. Key data for each plant including performance during test run are given in Table 3.

Further data for these plants and other plants designed by Topsoe have been published in [6] - [11].

Table 3
Data for Two Ammonia Plants Designed by Topsoe

Plant Identification	FFCC	KALTIM
Nameplate capacity, MTPD	1000	1000
Contract effective date	June 1978	February 26, 1986
Date of first ammonia production	April 28, 1982	December 8, 1988
Time between contract date and first production, months	46	33
Time between first production and start of test run, months	2	1
Test Run		
Duration, days	7	15
Date of completion	June 18, 1982	February 3, 1989
Net energy consumption, Gcal/MT	8.85	7.02
Average production, MTPD	1063	1031
Cooling water temperature, °C	30	32

FFC Fauji Fertilizer Company Limited
KALTIM P.T. Pupuk Kalimantan Timur

FAUJI FERTILIZER COMPANY LIMITED

This plant is located in Goth Machhi, Pakistan. The ammonia plant was designed in the late 1970's and uses the technology of that period. As an example, the ammonia converter was a S-100 quench cooled radial flow converter. Urea technology is by Snamprogetti SpA. During the years Topsoe has remained in close contact with the client and has assisted in streamlining and optimizing the operation. Significant improvements in capacity utilization and energy efficiency have been obtained without any additional investments as illustrated in Figure 3 and Table 4.

Figure 3 shows a plot of the capacity utilization each month since start of commercial production in May 1982. It should be noted that the definition of 100% capacity utilization is based on calendar days. It is thus different from the normal definition which uses 330 days/year as basis. The data are for urea production; separate data for ammonia production are not available, but since all ammonia is converted to urea, they would within 1% be the same as for the urea plant.

It is seen that the plant has operated consistently at a high production rate, and that there is a trend towards improved capacity utilization through the years.

Table 4 shows the energy consumption in the ammonia plant, measured on specific dates as indicated.

Table 4
Energy Consumption in the FFC Ammonia Plant

	Gcal/MT NH_3
Average during test run (June 1982)	8.85
23/2 1984 (Just before turn-around)	8.52
26/3 1984 (Just before turn-around)	8.10
27/2 1986 (Just before turn-around)	8.36
17/3 1986 (Just before turn-around)	8.18

Also these data show that, contrary to what may be general belief, the performance of an ammonia plant may be significantly improved as the plant becomes older, just by optimization of operation and redress of minor mechanical faults, etc. This is of course quite natural because a lot of small improvements and adjustments will always be possible in a specific plant. The only prerequisites are a dedicated and well-qualified staff, both in operation and in maintenance, and a plant with some flexibility.

The ammonia plant has recently been revamped for further improvement of the operation. Th is revamp included installation of a S-200 basket in the original pressure shell and also additional steam superheating capacity together with other minor modifications. The urea section will also be modified mainly by additional urea solution evaporator capacity and one additional carbon dioxide compressor. This has not yet been fully implemented, and the improvement in performance, has, as a consequence, not yet been fully realized. The FFC plant has, through the first 9½ years of operation, had a total downtime of about 320 days. Out of this, about 140 days have been scheduled turn-around and about 50 days were caused by events outside the ammonia plant. A total of about 130 days of unscheduled downtime was caused by incidents in the ammonia plant.

The primary reformer has not caused unscheduled downtime in the FFC plant during the 9½ years of operation (this is a general result in plants designed by Topsoe; the good performance is credited to the proprietary Topsoe reformer design using the side fired concept). The waste heat boiler after the secondary reformer and the rotating machines (compressors, turbines, fans, and pumps) have caused about 35 and 50 days of downtime; the remaining 45 days have been due to a number of incidents involving heat exchangers, piping (corrosion), instruments, etc.

The performance of the FFC plant must be noted as very satisfactory. A second 1000 MTPD ammonia plant/1750 MTPD urea plant is at present under construction for Fauji Fertilizer Company limited for completion late 1992. The ammonia plant is based on updated low energy technology from the late 1980's - also supplied by Topsoe - and will have a net energy consumption of about 6.8 Gcal/MT NH_3.

P.T. PUPUK KALIMANTAN TIMUR

This plant is located in North Bontang, East Kalimantan, Indonesia. On the site are two older ammonia plants, and the new plant has therefore been referred to as the KALTIM-III plant.

The plant was constructed by Chiyoda Corporation in cooperation with P.T. Rekayasa Industri. The project comprises a 1000 MTPD ammonia plant using Topsoe technology and a 1725 MTPD urea plant based on Stamicarbon technology.

The design of the KALTIM-III ammonia plant reflects the state-of-the-art for low energy ammonia plants around 1985 with the modifications required for integration with an urea plant. This means that some energy saving features, e.g. the most energy efficient carbon dioxide removal process, cannot be used due to the requirement for full recovery of CO_2. A purge gas recovery unit has been installed to recover hydrogen from the purge gas from all three ammonia plants on the site. The plant is further described in [9] and [10].

The KALTIM-III plant produced its first ammonia in December 1988 and reached nameplate capacity just three days after first production. A successful 15 days test run was completed less than two months after start-up, and since then operation has been very stable with a minimum number of shut-downs and problems. Overall on-stream factor incluldinq turn-around has been 95% average at an average production rate of more than 104%, in all the three years of operation (based on 365 days/year). Downtime other than turn-around had been less than 8.2 days/year. The average net energy consumption over the years was around 7.40 Gcal (29.5 MM BTU) per ton NH_3 (based on lower heating value of gas streams and credit/debit of export/import steam at full calorific value). Performance data for the first three years of operation is shown in Figure 4. It will be noted that after the first turn-around one year after start-up, one and a half years of operation passed before the next turn-around.

The statistics for the KALTIM-III plant concerning unscheduled downtime are shown in Table 5 and Figures 5 and 6. It will be seen that out of 26 events causing a total of 19.65 days unscheduled downtime, only 14 events respectively 7.63 days were caused by the plant itself. 10 events out of these were caused by minor problems in the instrumentation, mainly related to faults in the electronics. This performance obtained in the first 3 years of operation must be rated as outstanding, and credit must go to the process licensor, the contractor, and not the least to the owner and operator of the plant.

Table 5
Downtime - Frequency and Total Duration

	Frequency			**Downtime (Days)**		
Cause	1989	1990	1991	1989	1990	1991
Natural gas supply	2	2	1	2.16	3.00	0.57
Power supply	3	2	2	3.32	1.65	1.32
Process	-	2	-	-	1.64	-
Instrument	5	9		2.59	-	1.32
Mechanical	-	1	5	-	1.02	-
Electric	-	1	-	-	1.06	-
TA	-	1	1	-	21.04	13.76

CONCLUSIONS

It has been illustrated that plant reliability is of major importance in production of ammonia. Satisfactory economic results cannot be achieved without a high capacity utilization.

Causes of unscheduled downtime are discussed with reference to published data. It is shown that equipment failures, especially in primary reformers, waste heat boilers, and in compressors and turbines were historically responsible for most of the downtime. The statistics will of course be different for different plants and different technologies. As an example, failures in the reformer have not been a major reason for loss of production in ammonia plants designed by Topsoe.

Performance data from two plants designed by Topsoe are presented. The plants have during 10 respectively 3 years of operation shown very satisfactory results.

High plant reliability is thus possible with today's technology and required in today's competitive market. This should be considered by owners of ammonia plants - also when they select technology for new plants.

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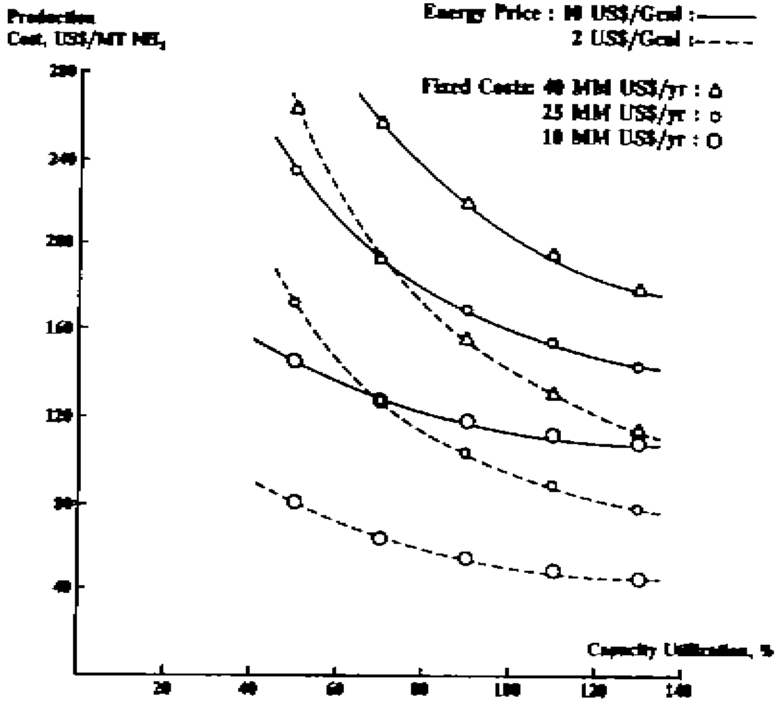

Figure 1
Production Cost of Ammonia as Function of Capacity Utilization

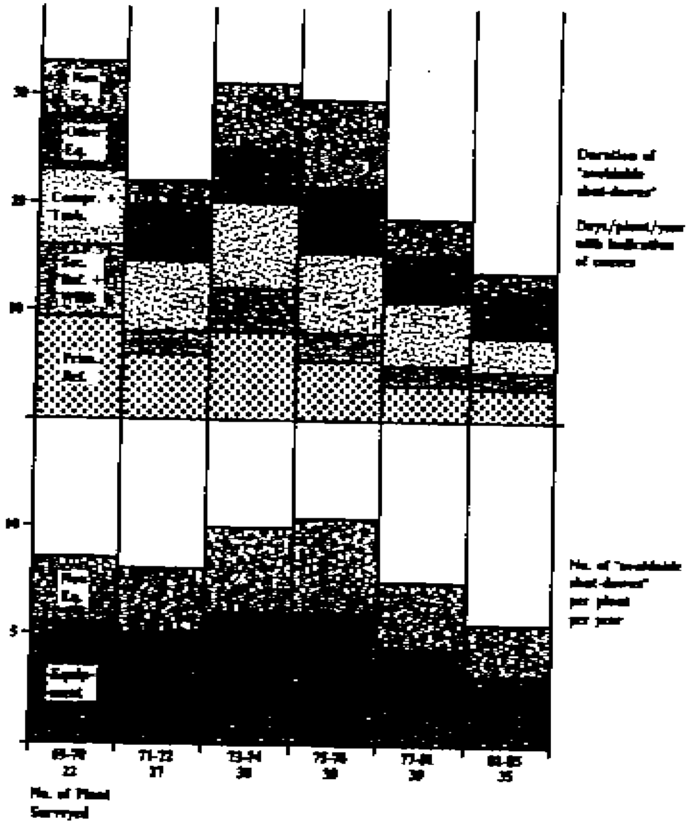

Figure 2
Causes of Unscheduled Ammonia Plant Shut-down
(Based on [1] - [5])

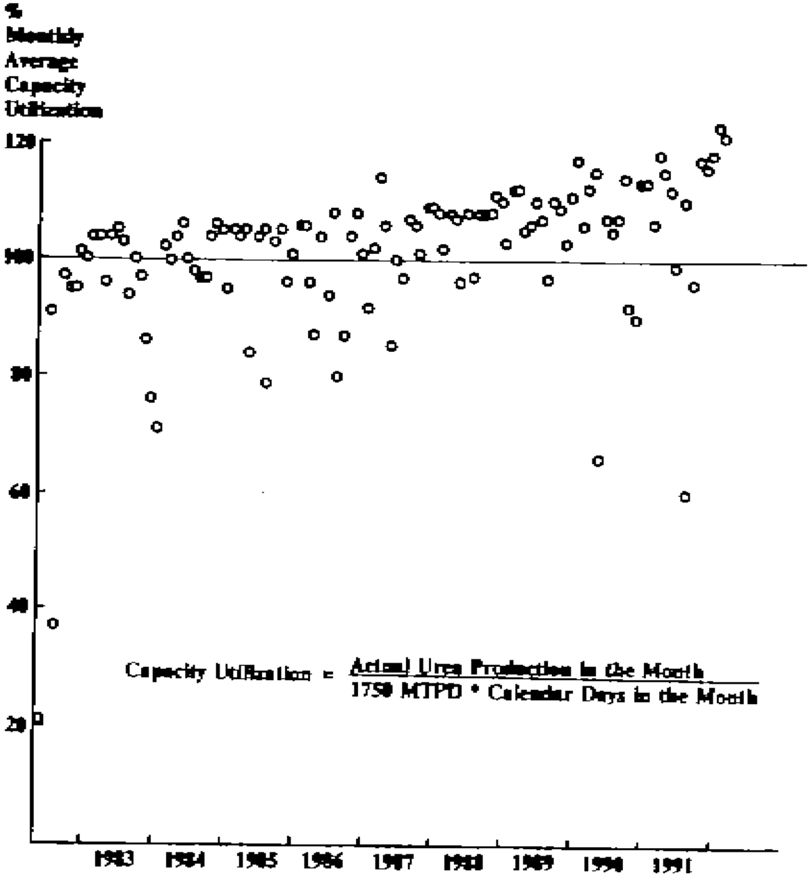

Figure 3
Monthly Capacity Utilization
FFC Urea Plant

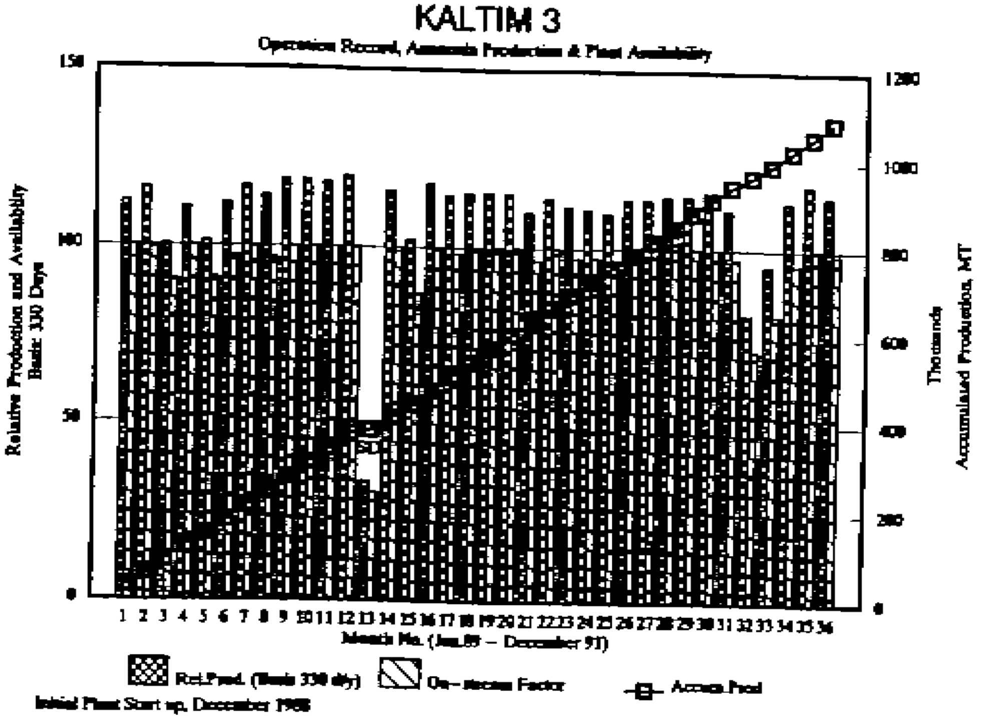

Figure 4
KALTIM-III Ammonia Plant - Ammonia Production
and Plant Availability

Figure 5
Number of Failures Causing Unscheduled Shut-down
in the Years 1989 through 1991
(Total Number of Events: 26)

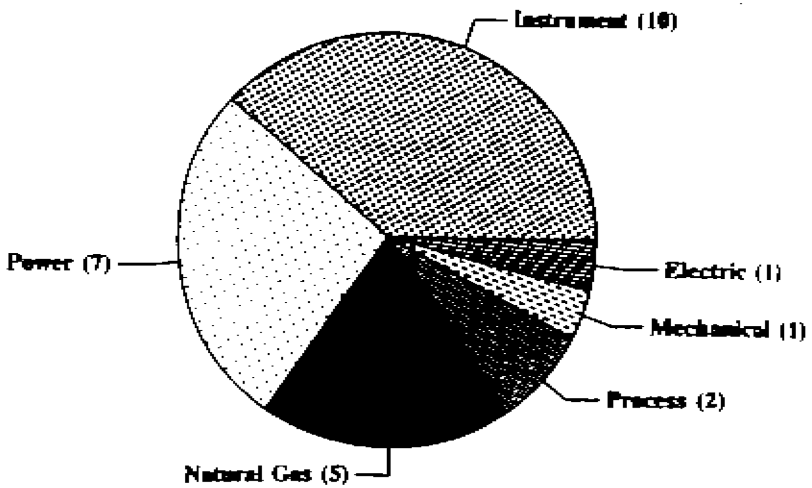

Figure 6
Contribution of Failures to Unscheduled Down Time
in the Years 1989 through 1991
(Total Downtime excluding Scheduled T.A. : 19.65 Days)