DEVELOPMENT OF OPERATIONAL RELIABILITY ASSESSMENT MODEL AND ITS APPLICATION TO A UREA FERTILIZER FACTORY

A Thesis

by

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Submitted to the Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Dhaka in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN INDUSTRIAL AND PRODUCTION ENGINEERING

September, 1983

BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY, DHAKA.

C E R T I F I C A T E

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BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY, DHAKA.

ACKNOWLEDGEMENTS

I wish to express my indebtedness and deep sense of gratitude to Dr. A.B.M. Zohrul Kabir, Asstt. Professor of the department of Industrial and Production Engg.,Bangladesh University of Engineering & Technology, Dhaka for his enlightened guidance, constant inspiration, numerous suggestions and all possible help throughout the course of this thesis. Both academically and personally, he has been more like a "guru" to me than a typical supervisor. I owe much to him.

My gratitude and heartiest thanks to Dr.A.F.M. Anwarul Hoque, Professor and Head of the deptt. of Industrial and Production Engg; BUET, Dhaka for his scholarly advice and valuable suggestions throughout the course of this research work.

I would like to express my deep appreciation to Dr. M. Anwarul Azim, Professor and Dean of the faculty of Mechanical Engineering,BUET, Dhaka for his kind interest in my research works.

Sincere gratitude and thanks to Dr. M. Mizanur Rahman, Associate Professor of the deptt. of Industrial & Production Engineering,BUET, Dhaka for his encouragement and valuable suggestions.

My indebtedness is due to my employer, Mr.A.K.M.Mosharraf Hossain, Chairman, Bangladesh Chemical Industries Corporation, Dhaka who kindly permitted me to undertake the Post-graduate study at BUET, Dhaka.

Indebtedness is also due to M. Siddiqur Rahman, General Manager, Urea Fertilizer Factory Limited, Ghorasal, Dhaka who kindly released me for a long time to complete the Post-graduate course at BUET, Dhaka.

I would also wish to convey my deepest gratitude and sincere thanks to Sree Bijoy Kumar Majumder, Chief Operation Manager and Mr. Faruque Ahmed Chowdhury, Addl. Chief Engineer of Urea Fertilizer Factory Limited, Ghorasal, Dhaka for providing facilities and rendering all possible help in collecting failure data of the factory (UFFL) required for this research work.

I am also thankful to my colleagues and Technicians of UFFL and Mr. Zahirul Hoque Bhuiyan, Typist of Machinery Maintenance Department, Urea Fertilizer Factory Limited, Ghorasal for his valuable assistance in carrying out and preparation of this Thesis work.

ABSTRACT

Operational reliability is a measure of equipment or system effectiveness, Usually, it is expressed as age-based reliability, but in a steady-state situation, it may be interpreted as meaning operational readiness and availability. The modeling for operational reliability of a complex system is done by decomposing the system into subsystems or components and thus generating a block diagram expression of system operation. A thorough study of various system configurations has been made. The model has been applied to assess the retiability of a fertilizer plant which helps in identification of critical equipments with low reliability. The causes of low reliability and various possibilities of improving reliabilities of critical equipments have been studied. Reliability improvements has been compared. In the calculation of reliability of individual equipment, Weibull reliability function has been used. The shape and scale parameters of this distribution has been estimated by Hazard Plotting, Maximum Likelihood Estimator and SEQLIM methods. Steady state availability and operational readiness have also been calculated for individual equipments as well for the whole plant.

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NOTATIONS

β = Shape parameter

η = Scale parameter

α' = Producer's risk

β' = Consumer's risk

d = Discrimination ratio

r = No. of failures

λ = Failure rate

A = Availability

A_I = Intrinsic availability

μ = Mean time between failure

μ_r = Mean time to repair

CHAPTER 1

INTRODUCTION

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1.1 General Introduction

The operation of a process plant involves many problems which causes shut down of the plant. Since most of the process equipments are complex mechanical units, their control and protective devices are very complicated.

During operation, failure of the plant may occure for many reasons, e.g.; previous incompetent (incomplete and incorrect) maintenance of mechanical, electrical, electronic and pneumatic equipments; fault signals of instruments and safety trip systems, poor design of the equipments, sudden and unexpected perturbation of voltage or currents etc. If the plant operates at high temperatures and pressures, then sometimes, it may go out of control which results failure of the plant. In addition to these causes failure of the plant may also happen due to wear and tear, random causes or wrong action taken by the operator.

In order to meet either safety or economic criteria, large and complex plants must have a potential high reliability of operation. This is generally achieved by the re-design of existing equipment, installation of redundant equipments, duplicating the safety trip systems, improving the maintenance policy, increasing the rate of periodic inspection etc. But these various means of reliability improvement must be cpmpared on the basis of implementation cost. In otherwords, Cost-Optimal reliability must be ensured.

In the general sense, Operational reliability is the quantative measure of system performance or system effectiveness. Mathematically; Operational reliability is a time dependent function indicating that the reliability of equipment or plant will decrease with operating time. But steady state measure of operational reliability can usually be indicated by operational readiness, availability and intrinsic availability. All of these measures are expressed as simple ratios considering operating time, idle time, down time and active repair time.

However simple the above measures may seem to be, in reality, the reliability analysis of a complex system is extremely difficult if it is treated in its entirety. So, the logical approach is to decompose the system into subsystems or components, thereby generating a block diagram description of system operation. Then the calculus of probability is applied to calculate system reliability.

1.2 Fertilizer Factory to be Studied.

Irrespective of the nature of Operation, the treatment of reliability analysis is same for any type of fertilizer factory or so to say for any complex plant in general. So, for this study, Urea Fertilizer Factory Limited, Ghorasal, Dhaka had been chosen because of its importance to the national economy. This is one of the modern complex and continuous production Chemical Plants in the Country.

This plant operates closer to its trip limit run at very high temperatures and pressures and use potentially dangerous chemicals. More over, most of its installed equipments and machineries are single unit in a flow train except few small units where stand-by redundancy is available. This plant produces about 1,000 tons of Urea per day. If the plant is shut-down for any minor troubles, it will take minimum 2 to 3 days to restart production which leads to great loss in production volum. So, when the plant goes into operation then the main objective is to avoid the failure of the plant by taking all possible preventive measures.

Review of the plant life history indicates that the plant suffers frequent shut-downs due to various troubles of equipments and machineries. The troubles might be reduced considerably if it is possible to identify the critical equipments and the potential trouble areas for which major shut-down of the plant occurs and improving the situation by installing redundant equipments or duplicating the system of the trouble areas.

1.3 Objective of the Study.

The objectives of this research are the following:

i) To develop a model for assessing operational reliability by decomposing the whole layout of the system into block diagram representation.

ii) To assess the operational reliability of each individual components and the overall reliability of the factory.

iii) To identify the critical components and major trouble areas.

iv) To suggest a policy to improve operational effectiveness of the factory.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 Reliability theory and definition

In its useful sense reliability theory is a method of assessing the performance of equipment that complements the familiar criteria of performance. Applied to processing operations, reliability techniques allow alternative plant configurations or processes to be compared objectively in terms of their ability to perform the allotted task. Similar techniques may be applied to the provision of maintenance and services. The systematic analysis of failure modes of itself leads to the discovery of danger points, and in combination with adeuate failure rate data allows quantitative estimates of such loss quantities as down-time to be made.

Chemical plants operate continuously in time; reliable plant only rarely fails or operates improperly. This suggests that the following definition of reliability given by Fresh water and Buffham (1) is suitable:

The reliability is the probability that the plant operates successfully within a desired band of operating variables for more than a specified time.

Clearly the reliability is a function of the time specified and depends on the nature of the plant and its environment. The reliability function R (t) may be defined more formally:

$$R(t) = Pr\,(\text{ no failure in } (0,t))$$

where Pr(A) is used to denote the probability of event A occuring, and failure is synonymous with operations outside the desired band of conditions. The concepts of reliability and failure rate are intimately related. If a large number of identical plants operating under identical conditions, The plants will have a distribution of life times in much the same way that the material entering a chemical process has a distribution of residence times :

$$f(t)\,dt = Pr(\text{Plant fails in } (t,t+dt))$$

The density function f(t) may be regarded as the failure rate at time t based on the number of plants put into operation at time zero.

2.2 Failure Types, Failure Rate and Hazard Rate

2.2.1 Failure Types

Failure is defined as The termination of the ability of an item to perform its required function. Three types of failures are recognized in system and component reliability studies by Aird(2), namely early failures, random and wear out failures.

2.2.1.1. Early Failures

In the early life of a plant these failures can be identified as commissioning problems and are usually caused by one of the following :

(i) Design faults - failure caused by inadequate design which will continue until the design is modified.

(ii) Manufacturing faults - the use of substandard components due to lack of quality control or poor workmanship in the assembly of units will produce early failures.

(iii) Construction faults - the initial assembly and setting up of plant items can produce additonal stresses over and above the design values resulting in premature failure.

In plant and equipment which has been in use for several years and is obviously past its initial life period, it is still possible to get early failure characteristics. This is due to the maintenance activity it-self whether in response to a breakdown or for preventive reasons. The most obvious reasons for these early failure characteristics are :

(a) Incorrect fault identification - usually because the symptom of failure has been corrected but not the underlying cause. This may be simply for expediency to get the plant operationas as quickly as possible or because there is a multiplicity of possible causes which are difficult to seperate.

(b) Disturbance of equipment - this may lead to one or more secondary failures such as the loosening of accumulated deposits which can then produce blockages or opening seals which then leak.

(c) Poor maintenance work - whilst this is the most difficult of categories to eliminate it is unfortunately one of the more common causes of early failure. Many examples can be quoted including using similar but incorrect replacement parts; allowing dirt and other matter to get into equipment ; or physically damaging replacement parts by using incorrect maintenance procedures.

It is desirable that all early failure modes are eliminated by appropriate action. In each case it is necessary to investigate the cause carefully so that one failure mode is not simply replaced by another. Where maintenance induced failures are occuring then it may be necessary to provide more formal diagnostic procedures or retraining as necessary.

2.2.1.2 Random Failures

Randomness of failure times occurs when the probability of failure does not vary with the age of a unit (the hazard rate is constant). From, an engineering point of view it would be expected that mechanical equipment would show wear out characteristics. With complex mechanical equipment there can be many different modes and although these may individually follow normal distributions with different means and standard deviations, when considered altogether these can produce on apparent exponential or even early failure distribution. In addition many faults can interact; for example, the failure of one component could lead to additional stresses on others through overheating, unbalance, or vibration.

In general it would be cautious to assume that all equipment has an underlying wear out distribution and to examine any data that do not produce this type of result with extreme care. Unfortunately this is frequently impossible to carry out because the original data are not available through the lack of a good recording system.

2.2.1.3 Wear out Failures

From a maintenance point of view it is desirable to have equipment with a wear out type of failure distribution since this gives a much longer mean time between failures (MTBF), is much more predictable in the sense that the variation between the lives of the individual units is small, and it can be used as the basis of a preventive maintenance policy. Since the equipment services a much greater length of time there are likely to be several dominant modes of failure contributing and it is important to isolate these. If one particular failure mode is causing a significant reduction in the overall MTBF then steps can be taken to design out this mode or at least improve the units performance. Possible causes of this type of distribution include wear, erosion, corrosion, fatigue or deposition of material causing failure due to blockages, ot of balance, or local overheating.

2.2.2 Failure Rate

The failure rate of a system is defined as the number of failures per unit time. The failure rate is not constant for the entire life of an equipment.

Jardine(3) has described that when making a graph of the failure rate for the whole life, the failure rate would be high at the begining and would show a decreasing tendency. It would usually become constant in a comperatively short time, i.e., when the equipment or system reaches a state of operational maturity (Fig-2.1). The period of decresing failure rate is called the " burn-in" period, during which infantile (early) failures are inherent in the new product.

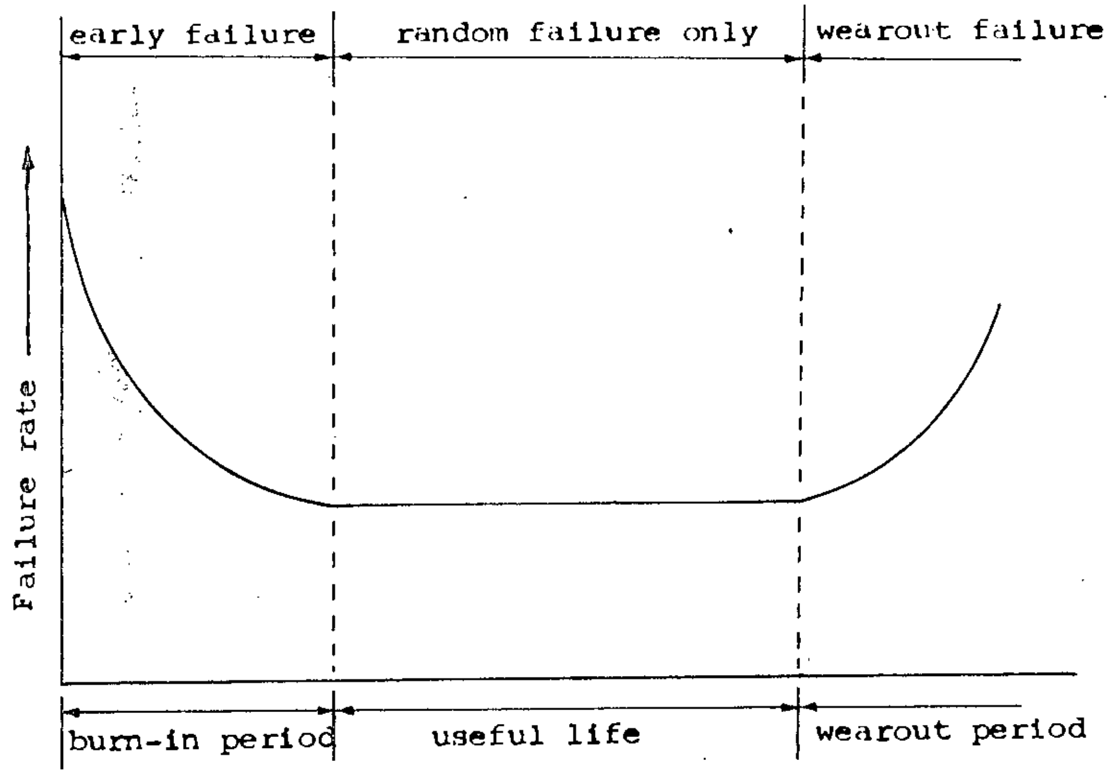


Fig-2.1 Failure rate curve

When the curve straightens and funs essentially parrallel to the abscissa, the failure rate is approximately constant and the product has reached its period of useful life where only chance failures occurs at rando. Later the failure rate assumes an increasing tendency and degradation failures begin to appear as a cpmseqiemce pf age (Wear-out), when the equipment is reaching its "rated life."

Herd(4) has defined that the probability of failure in a given time interval, t_1 to t_2 can be expressed in terms of either unreliability functions or reliability functions. The relationships are as follows :

$$\int_{t_1}^{t_2} f(t)\, dt = F(t_2) - F(t_1)$$
$$= R(t_1) - R(t_2)$$

The rate at which failures occur in the interval t_1 to t_2, naturally called the failure rate, will be defined as the ratio of the probability that failure occurs in the interval, given that it has not occured prior to t_1, the start of the interval to the interval length. Thus the expression for the failure rate is

$$\frac{R\,(t_1) - R\,(t_2)}{(t_2 - t_1)\, R(t_1)}$$

2.2.3 Hazard Rate

The hazard rate or instantaneous failure are, is defined as the limit of the failure rate as the interval length approacehs Zero. Then the hazard rate is :

$$h(t) = \underset{t' \to 0}{\text{Limit}} \left\{ \frac{R(t) - R\,(t+t')}{t'\,R(t)} \right\}$$

$$= \frac{f(t)}{R(t)}$$

2.3 Selection of Probability Distributions

The probability that something will fail at a prescribed instant is zero. Thus failure distributions are represented by functions of time f(t), such that when integrated over a specified time interval t_1 to t_2, the probability of at least one failure during the time interval is obtained.

$$F(t_1,t_2) = \int_{t_2}^{t_1} f(t)\, dt$$

There are many functions used to represent probability density distributions(5); for example, the hyper exponential, the negative exponential, the log-normal, the normal, the Gamma and the weibull distributions etc.

To provide flexibility in matching different density shapes and for easier analytical manipulation it is common in reliability studies to use the weibull distribution, which has a density function f(t) given by

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \exp\left\{-\left(\frac{t}{\eta}\right)^{\beta}\right\}$$

where f(t) is the probpotion of failures per unit time, t is time in appropriate units, β is the shape parameter and η is the scale parameter. The scale parameter η is also referred to as the characteristic age of the equipment. A high value of η indicates a good designed system, good quality control or large factors of safety. The shape parameter β defines the type of distribution. When β is equal to 0.5. 1.0, 2.0 and 3.4 the weibull distribution simulates the hyper exponential, the negative exponential, the log-normal and the normal distributions respectively.

The cumulative density function F(t) and Reliability function R(t) are given as follows :

$$F(t) = 1 - \exp\left\{-\left(\frac{t}{\eta}\right)^{\beta}\right\}$$

$$R(t) = \exp\left\{-\left(\frac{t}{\eta}\right)^{\beta}\right\}$$

2.4 Estimation of Weibull Distribution parameters.

The published methods for the estimation of the parameters β and η include :

1. The maximum likelihood estimators (MLE)
2. The best linear invariant estimators (BLIE)
3. The good linear unbiased estimators (GLUE) and
4. The least squares estimators.

In addition to these methods, some graphical techniques such as hazard plotting and Weibull paper plotting are available also.

1. MLE Method

For life testing situations, where r failures have been observed from a sample of n items, Bain(6) gives the following equation for estimating β:

$$\frac{\sum_{i=1}^{r} t_{i:n}^{\beta} \ln t_{i:n} + (n-r)\, t_{i:n}^{\beta} \ln t_{i:n}^{\beta}}{\sum_{i=1}^{r} t_{i:n}^{\beta} + (n-r)\, t_{r:n}^{\beta}} - \frac{1}{\beta} = \frac{1}{r} \sum_{i=1}^{r} \ln t_{i:n} \qquad \ldots \quad \ldots \quad (2.4.1)$$

After determining β, the scale parameter η can be estimated by :

$$\eta = \left[\frac{\sum_{i=1}^{r} t_{i:n}^{\beta} + (n-r)\, t_{r:n}^{\beta}}{r} \right]^{\frac{1}{\beta}} \qquad \ldots \quad \ldots \quad (2.4.2)$$

From equation (2.4.1), it is clear that β cannot be obtained with a single failure, in a life testing situation. The major problem with MLE is that the estimate of β is highly biased when there are only a few failures.

2. BLIE Method

This method has been developed by Mann, et al (7). They have given the following relationship for evaluating estimates β and η

$$\eta = \sum_{i=1}^{r} A(n,r,i)\ t_i \qquad \ldots \quad \ldots \quad (2.4.3)$$

and $$1/\beta = \sum_{i=1} C(n,r,i)\ t_i \qquad \ldots \quad \ldots \quad (2.4.4.)$$

Mann, et al. have given the weighting factors $A(n,r,i)$ and $C(n,r,i)$ for $n \geq 2$ and $r \geq 2$; r is the number of observed failures and n is the number of items on test. Obviously these formulations are valid for life-testing situations only. The main disadvantages of this method are that it cannot be used before the second failure and the estimate β is highly biased for the first few failures.

3. GLUE method

The method of good linear unbiased estimators have been discussed by Bain. The equations to be solved are :

(i) For $r < n$ (incomplete data),

$$1/\beta = \frac{r \ln t_{r:n} - \sum^{r} \ln t_{i:n}}{n\, k_{r,n}} \quad \ldots \quad \ldots \quad \ldots \quad (2.4.5)$$

$$\ln\eta = \ln t_{r:n} - (C_{r,n} / \beta) \quad \ldots \quad \ldots \quad \ldots \quad (2.4.6)$$

where the constants $K_{r,n}$ and $C_{r,n}$ are given in tabular forms for $n \geq 5$ or may be calculated by quadratic approximations provided by Bain.

(ii) For $r = n$ (complete data),

$$1/\beta = \frac{-\sum_{i=1}^{s} \ln t_{i:n} + S/(n-S) \sum_{i=S+1}^{n} \ln t_{i:n}}{nK_n} \quad \ldots \quad \ldots (2.4.7)$$

$$\ln\eta = \frac{1}{n} \sum_{i=1}^{n} \ln t_{i:n} + r^*/\beta \quad \ldots \quad \ldots (2.4.8)$$

where K_n is an uniasing constant given in tabular form, $S = [0.84n]$ is the largest integer $\leq 0.84n$, and $r^* = 0.5772$ is the Euler constant.

This method provides a good estimate of β for few failures. But, it also cannot be used before the seoond failure. Another shortcoming with GLUE is that it is inapplicable when replacements are carried out on failure; because there is no single value of $t_{r:n}$.

4. Least squares method

The method of least squares is applicable only after all the equipments in the sample have failed; i.e., no censories is allowed. Neverthless, the method is effective in dealing with few failures within engineering approximations. The determination of β and η by this method, is based on the inversion and double logarithmic transformation of the equation for the cumulative distribution function F(t) given by

$$F(t) = 1 - \exp\left\{ \left(\frac{t}{\eta}\right)^{\beta} \right\}$$

which on transformation becomes

$$\ln \ln \frac{1}{1-F(t)} = \beta \ln t - \beta \ln \eta \qquad \ldots\ldots\ldots \quad (2.4.9)$$

This is of linear from $Y = M X - Z$.

where $Y = \ln \ln \dfrac{1}{1-F(t)}$

$M = \beta$

$X = \ln t$

$Z = \beta \ln \eta$

Hinds et al.(8) gives that there are several ways of calculating $F(t_i)$ for the ith failure; three of which are as follows :

Choice	$F(t_i)$
Mean rank	$i/(n+1)$
Benard's approximation	$(i-0.3)/(n+0.9)$
Symmetrical sample cdf	$(i-0.5)/n$ .... (2.4.10)

Estimates of β and η can be obtained either graphically or by asing a computer programme. In the programme, equations(2.4.9) and (2.4.10) can be solved by the least squares technique to estimate β , while the scale parameter η is estimated by the following equation

$$\eta = \exp \left\{ Y(\text{at } 63.2\%) + z \right\} / \beta \quad \ldots \quad \ldots \quad (2.4.11).$$

Equation (2.4.9) can also be solved graphically.

<u>Weibull paper plotting</u> - Some special graph papers called "Weibull probability" papers are commonly used for plotting Y Vs. X. In using such papers, the usual technique is to produce a best fit line by eye. As an aid to this type of fitting, it should be noted that the line must pass through ($\overline{X}$, $\overline{Y}$), where

$$\bar{X} = \frac{\sum_{i=1} \ln t_i}{n}$$

$$\overline{Y} = \frac{\sum_{i=1}^{n} \ln \ln \left[\frac{1}{1-F(t_i)} \right]}{n}$$

like all other methods mentioned before, the least squares method also can not be used for $n < 2$.

<u>Hazard plotting</u> : Another graphical technique for estimating the Weibull parameters is 'hazard plotting' which has been developed by nelson (9). The main difference of this method from the earlier one is that it uses cumulative hazard function $H(t)$, instead of cumulative distribution $F(t)$ for a linear fit.

The hazard function $h(t)$ for a distribution of times t to failure is defined in terms of the cumulative distribution function $F(t)$ and its derivative, which is the probability density $f(t)$, as follows :

$$h(t) = f(t) / \{1-F(t)\} \quad \ldots\ldots \quad \ldots\ldots \quad (2.4.12)$$

The cumulative hazard function $H(t)$ of a distribution is the integral of the hazard function up to time t; is :

$$H(t) = \int_{\infty}^{t} h(t).\, dt = -\ln \{1-F(t)\} \quad \ldots\ldots\ldots \quad (2.4.13)$$

Again for the Weibull distribution,

$$F(t) = 1-\exp\left\{-\left(\frac{t}{\eta}\right)^{\beta}\right\}$$

$$H(t) = -\ln\left[1-1+\exp\left\{-\left(\frac{t}{\eta}\right)^{\beta}\right\}\right]$$

i.e., $H(t) = (t/\eta)^{\beta}, \quad t > o$

This can be rewritten to express time as a function of the comulative hazard, namely :

$$\ln t = (1/\beta) \ln H + \ln \eta \qquad \ldots \qquad \ldots \qquad (2.4.14)$$

By this relationship, lnt is a linear function of ln H. Thus, Weibull hazard paper is simply log-log graph paper from equation (2.4.14), it is obvious that the slope of the straight line plot equals $1/\beta$, this fact is used to estimate β with the aid of the shape parameter scale from a Weibull hazard plot For H = 1(100%) the corresponding time t equals η.; this fact is used to estimate η graphically.

For hazard plotting, the basic steps infolved are as follows :

(i) collect a number of failure dates/times for the same equipment (or a number of similar equipments)

(ii) Determine hours run between failures and order the times (both failed and unfailed times) from smallest to largest.

(iii) Level the times with reverse ranks, that is, the first time is levelled n, the second n - 1, and the n this levelled 1.

(iv) Mark the failure times to distinguish from the unfailed times, because the hazard value is colculated involving the failed items only.

(v) Calculate the hazard value for each failure, omitting unfailed items, as 1/K, where K is its reverse rank.

(vi) Calculate the cumulative hazard value for each failure as the sum of its hazard value and the hazard values of all preceeding failure times.

(vii) Plot cumulative hazard values Vs. sample failure times on a log - log graph paper.

(viii) By eye, fit a straight line through the data points. If the plot is reasonably straight, one may conclude that the distribution adequately fits the data.

(ix) In the Weibull model d log H/d log t is β and when $H = 1$, $t = \eta$

5. SEQLIM METHOD

This new method SEQLIM has been given by Kabir & Lihou (10). Although the method was developed primarily for safety systems, its application is not limited to those systems only, rather it can be used for analysing data from almost any system, provided there are not a large number of items on test or in service.

The method SEQLIM utilizes the basic acceptance principles of Sequential probability ratio test' (SPRT) to estimate sets of Weibull distribution pramaters (β η); and then the theory of probability limits is used to select the most suitable values of these parameters. The acceptance point V_r for SEQLIM is calculated as

$$V_r = r \frac{\ln d^{\beta}}{d^{\beta} - 1} - \frac{\ln B}{d^{\beta} - 1} \qquad \ldots\ldots\ldots\ldots \quad (2.4.15)$$

where, $B = \beta'/(1-\alpha')$

α' = Producer's risk = 0.10

β' = Consumer's risk = 0.05

d = disorimination ratio = 2.0

r = No. of failures

The accepted estimate of η is obtained as

$$\hat{\eta} = \left\{\left(\sum_{i=1}^{n} t_i^{\beta}\right)/v_r\right\}^{\frac{1}{\beta}} \qquad \cdots\cdots \qquad \cdots\cdots \qquad (2.4.16)$$

for any value of β

where t_i denotes the operating time for the ith item on test (including failure time if any), and n is the total number of items on test.

Now, for a set of β values, one can obtain a set of (β, η) pairs. Having obtained a set of (β, η) pairs one now needs to compute t_r/η for r observed failure times and to check whether these values are within the desired pbobability limits. The pair that has no "outlier" is accepted as the best estimate of β and η.

With SEQLIM the fundemental approach for applying probability limits is the same as explained above, but it has been proposed by Dubey (11) that one should first use the 40% (lower) - 60% (upper) limits (double sided). If at this stage, no pair (β, η) can be selected, then the limits should be increased stepwise, to 30%-70%, 20% - 80%, 10% - 90%, 5% - 95%, and so on, until a pair can be selected. It may happen that there are a number of pairs within the selection zone. In that case, the pair with the smaller value of β should be selected.

2.5 System Reliability prediction and Models

In performing the reliability analysis of a complex system, it is almost impossible to treat the system in its entirety. The logical approach is to decompose the system into functional entities composed of units, subsystems, or components. Each entirety is assumed to have two states, one good and one bad. The subdivision generates a block-diagram description of system operation. Models are then formulated to fit this logical structure and the calculus of probability is used to predict the system reliability in terms of the subdivision reliabilities. Series and parallel structures often occur, and their reliability can be described very simply. In many cases the structure is of a more complicated nature and more general techniques are needed. It is assumed that each functional entity is independent of the others in the forementioned models, but in many cases this is untrue. Dependent failures occur in standby systems, and systems which respond to a common environmental change. The models which govern these cases contain time-dependent conditional probabilities.

The formulation of a structural reliability model can be difficult in a large, sophisticated system and requires much approximation and judgment. The basic configurations of some reliability models are developed by carter (12), shown below :

2.5.1 System reliability - Components in Series

A series system is one which operates only if all its components are operating. For a series system the reliability is the products of the reliabilities of the components. Figure 2.2 shows the series arrangement of a number of components which have respective reliabilities R_1 , R_2 , R_3 . . . . etc.

Figure 2.2 components in series.

The system reliability, R_s is given as

$$R_s = R_1 \times R_2 \times R_3 \times \ldots\ldots\ldots R_n$$

where n = No. of components.

when the reliabilities of several series components are equal then

$$R_s = (R_e)^n$$

where R_e = reliability of several components when their reliabilities are equal to each other.

Again their may be n_1 components of R_1 reliability and n_2 components of R_2 reliability etc., in this case the overall reliability of the system.

$$R_s = (R_1)^{n_1}, (R_2)^{n_2}, (R_3)^{n_3},$$

2.5.2 System Reliability - Components in parallel.

A parallel system is one which fails to operate only components fail to operate. For a parallel system, the unreliability (probability of failure) is the product of the unreliabilities of the components. The reliability block diagram for a parallel system is shown in figure - 2.3.

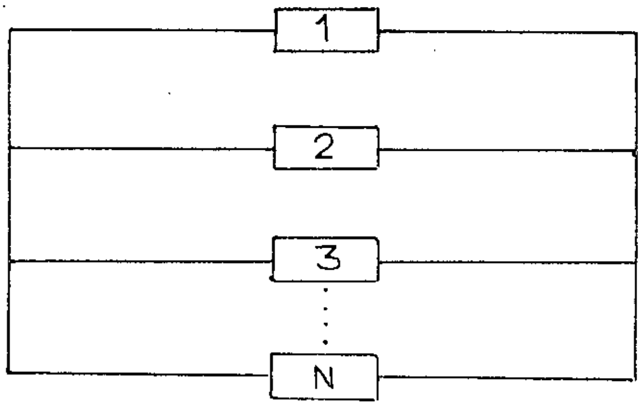


Figure 2.3 - Components in parallel

If n units are in parallel with an unreliability $F_1, F_2, F_3 \ldots\ldots F_n,$ then unreliability of the system,

$$F_p = F_1 \times F_2 \times F_3 \ldots\ldots F_n$$

if $F_1 = F_2 = F_3 = \ldots\ldots F_n$

then $F_p = F_1^n$

But $R + F = 1$ or $R = 1 - F$

Hence the system reliability R_p is given by

$$R_p = 1 - F_1^n$$

In analysing a parallel system in this fashion it is implied theat all sub-systems are activated when the system is activated and that failures do not influence the reliability of the surviving sub-systems.

2.5.3 System Reliability - Components in Series/Parallel.

The reliability of the system can be determined from the failure probability of the arrangement as a consequence of $R+F = 1$, $R = 1 - F$.

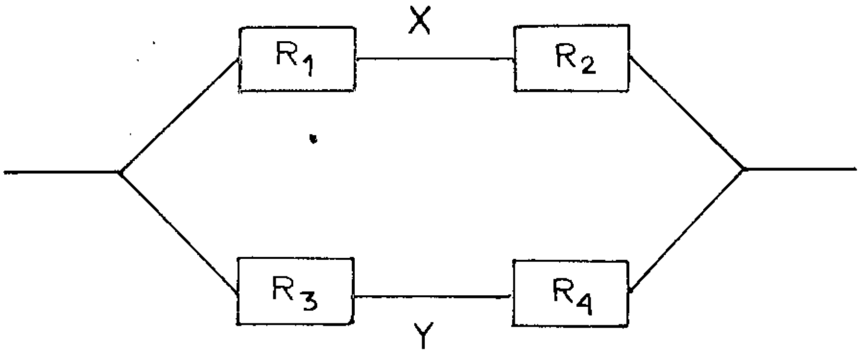


Figure 2.4 Components in Series/Parallel.

Considering the arrangement in figure 2.4, reliability of the series path X is given as

$$R_X = R_1 \times R_2$$

Therefore, unreliability of the series path X is given as

$$F_X = 1 - R_X = 1 - R_1 \times R_2$$

similiarly,

$$R_Y = R_3 \times R_4$$

and $$F_Y = 1 - R_3 \times R_4$$

Now unreliability of the system F_s is given by

$$F_s = (1 - R_1.R_2) (1 - R_3.R_4)$$

Hence, reliability of the system R_s is given by

$$R_s = 1 - (1 - R_1.R_2) (1 - R_3.R_4)$$

2.5.4 r- out-of-n parallel systems.

For a system which has n components in parallel and operates as long as r survive, the Binomial distribution is applicable. The system reliability is obtained by summing the probabilities that n, n - 1, ... r + 1, r components, will survive.

$$R = \sum_{k=r}^{n} \frac{n!}{k!(n-k)!} R_x^K (1 - R_x)^{n-k}$$

where R = System reliability

R_x = Components reliability

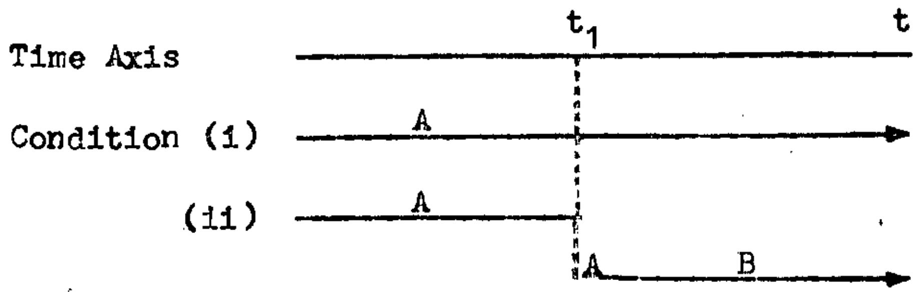
2.5.5 Stand-by Redundancy

In a system with redundant elements that are completely on stand-by, no time is accumulated on stand-by elements until the primary element fails. For simplicity, it will first be assumed that stand-by elements cannot fail if de-energized, and that the necessary switching devices are failure free. If the system contains two elements, A and B, the reliability function has been given by Welker (13) as follows : The system will be successful at time t if either of the following two conditions holds (letting A be the primary element):

i) A succeeds up to time t, or

ii) A fails at time $t_1 \angle t$ and B operates from t_1 to t.

The following diagram represents these two conditions:



Translation of the two conditions above to time dependent probabilities gives

$$R(t) = \int_t^{\infty} f_a(t)\ dt + \int_0^t \left\{ f_a(t_1) \int_{t-t_1}^{\infty} f_b(t)\ dt \right\} dt_1$$

where f(t) is the time-to-failure density function of an element. The first term of this equation represent the probability that element A will succeed until time t. The second term, excluding the outside integral, is the density function of a failing exactly at t_1 and B succedding for the remaining $(t-t_1)$ hour. Since t_1 can range from 0 to t, t_1 is integrated over that range. For exponential case where the element failure rates are λ_a and λ_b ,

$$R(t) = \frac{\lambda_b}{\lambda_b-\lambda_a} \exp(-\lambda_a t) - \frac{\lambda_a}{\lambda_b-\lambda_a} \exp(-\lambda_b t) \ .$$

which is a form of the mixed exponential. It can be shown that it does not matter whether the more reliable element is used as the primary or the standby element.

if $\lambda_a = \lambda_b = \lambda$,

$$R(t) = \exp(-\lambda t)\ (1+\lambda t)$$

For n elements of equal reliability

$$R(t) = \exp(-\lambda t) \sum_{r=0}^{n-1} \frac{(\lambda t)^r}{r!} .$$

2.6 System Effectiveness and Its Measures.

2.6.1 System Effectiveness

System effectiveness (14) is the probability that the system can successfully meet an operational demand within a given time when operated under specified conditions.

Effectiveness is obviously influenced by the way the equipment is designed and built. However, just as critical are the ways in which the equipment is used and maintained. In other words, system effectiveness can be materially influenced by the design engineer, the production engineer, the operator and the maintenance man. It can also be influenced by the logistic system that supports the operation and by the administration through personnel policy, rules governing equipment use, fiscal control, and many other administrative policy decisions.

The definition imply that the system fails (i) if it is in an inoperable condition when needed, or (ii) if it is operable when needed but fails to complete the assigned mission successfully. The expression "specified conditons" implies that system effectiveness must be stated in terms of the requirements placed upon the system, indicating that failure and use conditions are related. As the operational stresses increase, failure frequence may also be expected to increase.

If continous operation is required, any ceasation due to failure or scheduled maintenance reduces system effectiveness. If the demands on the equipment are such that an on-off use cycle profides significant free time for maintenance, system effectiveness is ehhanced.

2.6.2 System Effective Measures.

The following are the various measures of system effectiveness. For example, Serviceability, Maintainability, Repairability, Operational readiness, Availability, Intrainstic Availability etc. In this context, some of the important measures are defined by Kapur (15) as follows:

Operational Readiness:

The term operational readiness is defined as the probability that either a system is operating or can operate satisfactorily when the system is used under stated conditions.

The operational readiness (O. R.) would be estimated by

$$\text{O.R.} = \frac{\text{Operating time + idle time}}{\text{Operating time + idle time + down time}}$$

where operating time is the time during which the system is operating in a manner acceptable to the operator.

Availability:

Availability is defined as the probability that a system is operating satisfactorily at any point in time and considers only operating time and down time, thus excluding idle time. Availability in a measure of the ratio of the operating time of the system to the operating time plus the down time. Thus it includes both reliability and maintainability.

The availability function (A) would be estimated as

$$A = \frac{\text{Operating time.}}{\text{Operating time + down time}}$$

The availability function would also be derived by the following way :

Let μ = Mean Time Between Failure (MTBF)

μ_r = Mean time to Repair (MTTR)

N = Number of failures.

then μ = (Total operating times/number of failures)

μ_r = (total repair time/number of failures)

Therefore, for N failures

time lost = $\mu_r \cdot N$

time elapsed = (total operating time + total repair time.

$$= \mu N + \mu_r N$$

Availability, $$A = \frac{\mu N}{\mu N + \mu_r N} = \frac{\mu}{\mu + \mu_r}$$

i.e. $$A = \frac{MTBF}{MTBF + MTTR}$$

Intrinsic Availability

Intrinsic availability is defined as the probability that a system is operating in a satisfactory nammer at any point in time when used under stated conditions. In this contest, time is limited to operating and active repair time. Intrinsic availability is a more restictive measure that availability; hence the availability will always be less than or equal to the intrinsic availability. The decrease will be caused by the administrative and logistics time connected with the repair cycle, which is included in the availability measure.

For instance, the unavailability of spare parts will decrease the availability measures bu not the intrinsic availability measure. The intrinsic availability is estimated as

$$A_I = \frac{\text{Operating time}}{\text{Operating time + active repair time}}$$

where active reapir time is that portion of down time during which one or more technicians are working on the system to effect a repair. This time includes preparation time, fault location time, fault correction time and final check-out time for the system.

CHAPTER 3

DESIGN FEATURE OF UREA FERTILIZER FACTORY LIMITED, GHORASAL, DHAKA

CHAPTER 3

DÉSIGN FEATURE OF UREA FERTILIZER FACTORY LTD., GHORASAL DHAKA

3.1 Production Capacity

This plant is designed to produce 660 Metric Tons per day of liquid ammonia and about 18,000 NM^3 per hour of carbon dioxide for Urea Plant.

The raw material used in this plant is natural gas

3.2 Process Description of Ammonia plant.

The processes utilized in Ammonia production from natural gas in this factory are summerzed (16) below. The process flow diagram of Ammonia Plant are shown in figure 3.2.

<u>Scrubing of natural gas</u>

The cleaning of natural gas is done through dust seperator, Venturi, Scrubber and filter. After being cleaned, a certain part of this natural gas is sent to the compression unit as feed stock for ammonia production and the rest without any compression is used as fuel in ammonia plant, power plant, steam generation plant and others.

<u>Compression of Natural Gas feed stock</u>

The natural gas is supplied at 24.5-28.0 kg/cm^2G. and compressed to about 35 kg/cm^2G before it is sent to the desulfu-rization unit because high pressure reforming process is adopted in this plant.

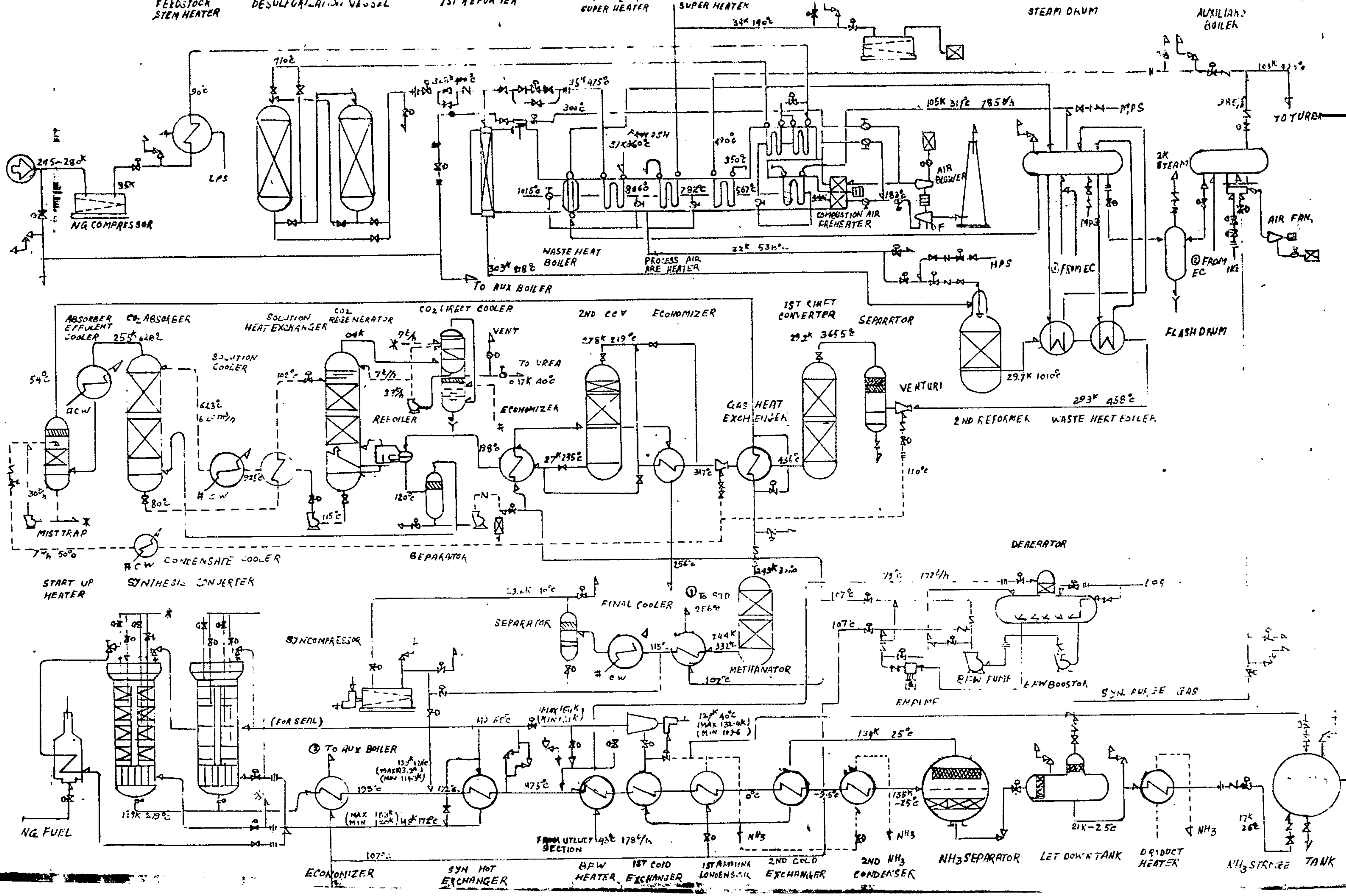


Figure 3.2 Process Flow Diagram of Ammonia Plant

Desulfurization Process.

It is necessary to reduce sulfur content of the natural gas feed stock to less that one ppM because sulfur would act as a poison on the reforming catalysts. Therefore the sulfur in the natural gas feed stock is almost completely removed by using zinc oxide catalyst.

Reforming process

The natural gas form the desulfurization vessles is mixed with the superheated steam and then enters the primary reformer. The steam reforming reaction is basically the reaction between the hydrocarbons and steam to produce hydrogen, methane, carbon dioxide and carbon monoxide. This steam reforming occurs in the preasence of vickel catalyst under high temperature. The reaction is shown below :

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

The reformed gas from the primary reformer is mixed with process air from the air compressor (A-GB 101) preheated. Through process air preheater is sent to the secondary reformer (A-DC 101) where methane and steam further react to produce hydrogen and carbon monoxide and required Nitrogen for Ammonia synthesis is also supplied.

The gas from the secondary reormer passes through the reformed gas waste heat boilers (A-EC 107) and the process gas procedds to the shift conversion process.

Shift conversion process.

In shift conversion, carbon monoxide reacts with steam to from hydrogen and carbon dioxide and this hydrogen is used in ammonia synthesis reaction.

This shift reaction occurs under the proper temperature and pressure conditions with suitable catalyst.

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

CO_2 removal process

For removal of CO_2 the converted gas enters the CO_2 removal process wich is based on GIAMMARCOVETROCOKE (G.V) CO_2 removal process.

The process gas from CO conversion unit enters the process gas reboiler (A-EA 301), providing the heat required for regeneration of the G.V. solution, then it is seperated from process condensate in the process gas K.O. drum (A-FA 301).

The gas leaving the process gas K.O. drum is passed to the CO_2 absorber (A-DA 301), where CO_2 is removed, contacting counter currently with G.V. solution. Passing through the absorber effluent cooler (A-EA 304), the process gas is washed in the mist trap (A-DA 303) where the mist is removed and is sent to the methanation unit as a purified gas with the CO_2 concentration of $0.1 \sim 0.3\%$

The G.V. solution which absorbed CO_2 is extracted out from the bottom of the CO_2 absorber and after being heated through the solution heat exchanger (A-EA 302) it is supplied to the top of the CO_2 regenerator (A-DA 302).

The regenerated G.V. solution is delivered out through the bottom of the CO_2 regenerator and after being pressurized by the solution pump (A-GA 301) is colled by passing through solution heat exchanger and solution cooler (A-EA 303 A-C) successively and then Circulated to the top of the CO_2 absorber.

The gas released from the top trays of the CO_2 regenerator where it is washed by condensate, enters the washing part to the CO_2 direct cooler (A-DA 304), here the mist is further removed by circulating water and condensate from the mist trap. The washed CO_2 is sent to the Urea plant with a purity of above 98.5%

Methanation process

In order to complete the removal of CO_2 and CO gases from synthesis gas by hydrogenating into steam and methane, methanation is used as the final process for gas purification. These reactions as explained by the following equations are reversible and also each of them being exothermic.

$$3H_2 + CO \rightleftharpoons CH_4 + H_2O$$

$$4H_2 + CO_2 \rightleftharpoons CH_4 + 2H_2O$$

The gas from CO_2 removal unit enters the process gas heat exchanger (A-EA 201) of the shift conversion unit and is heated to 300°C by 1st shift converter outlet gas and then enters the methanator. The process gas after the removal of carbon oxides in the methanator heats up the boiler feed water in the methanator effluent economizer (A-EA 401) and is then cooled to ambient temperature in the gas final cooler (A-EA 402).

The condensed water in the gas is removed in systhesis gas K.O. drum (A-FA 401) and the gas is sent to the synthesis gas compressor.

Ammonia synthesis Unit.

Ammonia synthesis reaction occurs on the iron catalyst promoted with various kinds of methals and is indicated by the following equation.

$$3H_2 + N_2 \rightleftharpoons 2\ NH_3$$

Incrasing the pressure results in an increase in Ammonia concentration at the equilibrium condition.

Decreasing the systhesis temperature results in an increase in ammonia content at the equilibrium condition, but results in decreasing the rate constant of reaction. Moreover, the better the catalyst, activity is, the lower the synthesis pressure can be. Therefore there is an optimum temperature for ammonia synthesis system.

In addition to nitrogen and hydrogen with a ratio of about 1 : 3, the refined synthesis gas has about 1.2% of methane and argon.

The process gas compressed by synthesis gas compressor is mixed with the effluent recycle gas from the synthesis converter through synthesis economizer (A-EB 501). After cooling in different stages, the synthesized ammonia present in the gas in condensed.

The product liquid ammonia from seperator is sent to the product let down tank (A-FA 502) and its pressure is decreased. Finally it is sent to the ammonia storage tanks (A-FA 501A,B), which are designed to store liquid ammonia of about 20 Kg/cm^2G.

3.3 Process Description of Urea Plant

The following processes are adopted in Urea Proauction in this plant. The process flow diagram of Urea Plant are shown in figure 3.3

Synthesis Section

Urea is synthesized in the reactor from liquid ammonia and carbon dioxide. CO_2 gas is compressed by CO_2 main compressor (U-GB 102) upto 230 kg/cm^2 and is directly fed with gasous state into the Reactor (U-DC 101). Liquid ammonia from recovery ammonia reservior (U-FA 401) is pumped upto 230 kg/cm^2 by liquid ammonia feed pump (U-GA 101), and fed in to reactor.

The first reaction in the reactor is formation of ammonium carbamate from ammonia and carbon dioxide.

$$2NH_3 + CO_2 = NH_4\ COO\ NH_2$$

This reaction release to large heat, and rapidly total CO_2 reacts to be ammonium carbamate. Next, a part of ammonium carbamate dehydrates, to be Urea and water.

$$NH_4\ CO_2\ NH_2 = NH_2CO\ NH_2 + H_2O$$

Equilibrium reaction of Urea and Biuret is shown below which is also reversible.

$$2NH_2\ CONH_2 \rightleftharpoons NH_2CONHCONH_2 + NH_3$$

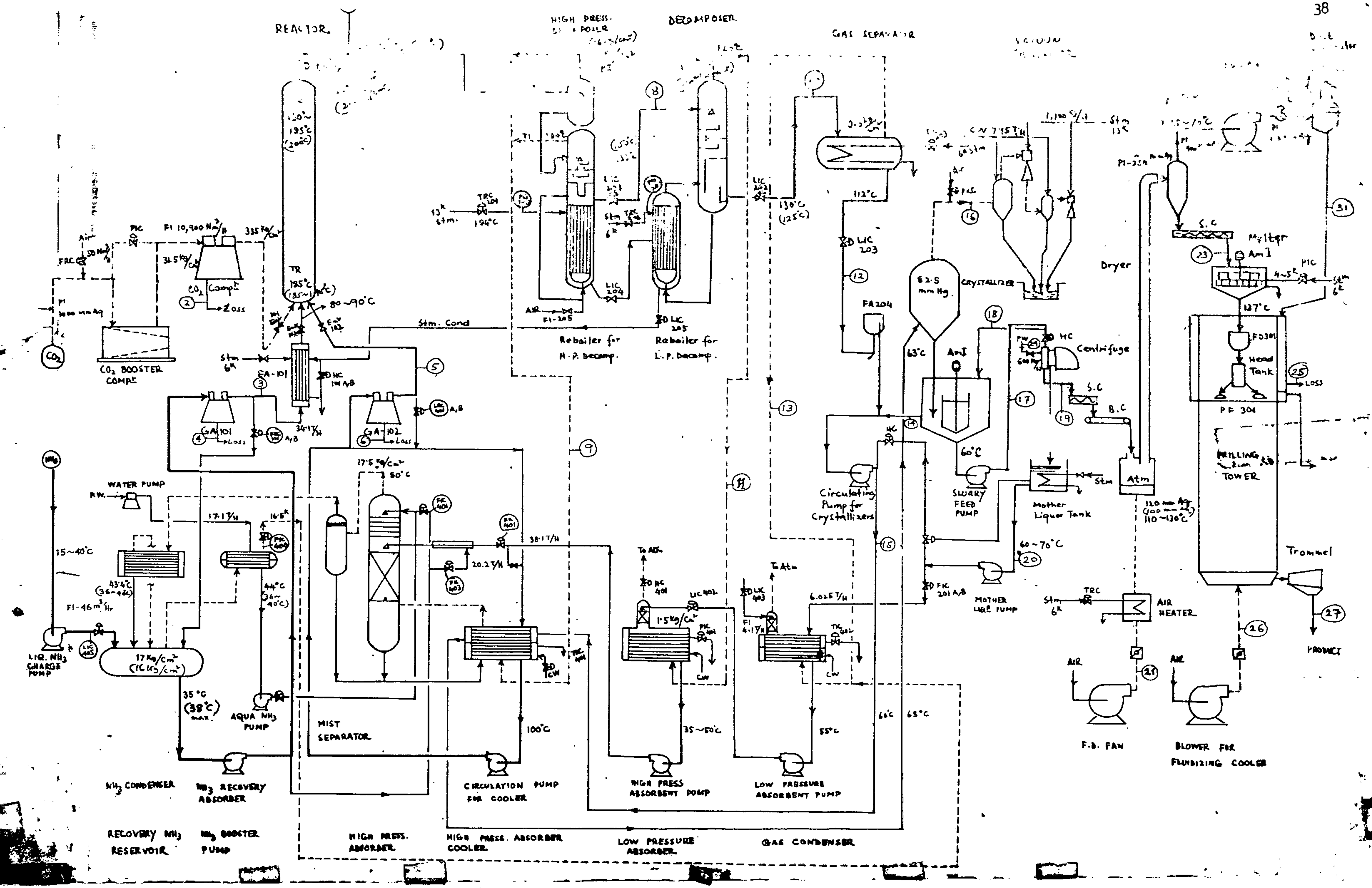


Figure 3.3 Process Flow Diagram of Urea Plant

The reaction product leaving the reactor consists of Urea, ammonium carbamate, ammonia and water and these materials except Urea and water are decomposed and seperated in the purification stage.

Decomposition and purification Section

The reaction product reduced its pressure through pressure control valve from 230 kg/cm^2 to 18 kg/cm^2, and enter into the high pressure decomposer (U-DA 201). Entering into high pressure decomposer, nearly 90% of free ammonia and carbamate will vaporize and decompose to ammonia and CO_2 gas. On the other hand, small quantity of Urea hydrolyzes to ammonia and carbon dioxide.

The gas consisting of ammonia, carbon dioxide and water from high pressure decomposer, enters in to high pressure absorber cooler (U-EA 401).

The liquid from high pressure decomposer (U-DA 201) enter into low pressure decomposer (U-DA 202) through LCV. The composition product, which is mixture gas of NH_3, CO_2, H_2O flows in low pressure absorber (U-EA 402) from low pressure decomposer (U-DA 202). The liquid of low pressure decomposer enters in to Gas seperator (U-DA 203) through L.C.V.

In gas seperator, NH3, CO_2 and little water is vaporized and sent to gas condenser (U-EA 403).

Crystallizer (U-FA 201).

The Urea solution enters into concentrator through the circulation pump for crystallizer. Almost all water in the supplied Urea solution are vaporized at this condition. Crystal Urea deposits in concentrator, and grows in crystallizer.

An agitator is installed in crystallizer to prevent agglomeration of Urea crystal. Best condition for crystal grouth in crystallizer is maintained by adequate recirculation of Urea slurry and enough residence time. Urea slurry having nearly 35% of crystal Urea is sent to centrifuge (U-GF 201) by slurry feed pump (U-GA 202). Urea solution enters in to centrifuge and slurry is devided into crystal and mother liquid by centrifugal force. Mother liquid is gathered in the mother liqour tank (U-FA 203), and about 90% is returned back to concentrator and remaining 10% is recycled to recovery section as absorbent. Crystal Urea from centrifuge contains 1.0~1.5 % of H_2O and 0.10~0.15% of biuret.

Drying.

Crystal Urea sent to dryer (U-FF 301) and dried by hot air of about 110°C and dried up to 0.10~0.20% of moisture and then caught in the cyclones (U-FC 301).

5. Prilling

The crystals Urea from the cyclone are fed to Melter(U-EA 301) by screw conveyor (U-JD 301). Crystalls Urea fed in the melter are sprayed uniformly on the heating tube surface by agitator. In the melter the crystals are melted and the molten Urea flows to head tank (U-FA 301) through strainer (U-FD 301).

Head tank is installed to keep necessary head to the molten urea falling down from distributor (U-PF 301). The liquid in head tank falls down from distributor as rain drops. During falling down in the tower, the molten Urea is prilled and colled by the ascending air, which comes from blower for fluidizing cooler(U-GB 303) and from the bottom of prilling tower as natural draught. The prills are further cooled on fluidizing cooler (U-FD 302) at the bottom of the tower and sent to the Urea storage through weighing conveyor and through Trommel (U-FD 303) which sperates big block of Urea from products.

CHAPTER 4

DATA COLLECTION AND DATA ANALYSIS

CHAPTER 4

DATA COLLECTION AND DATA ANALYSIS

4.1 Failure History of Urea Fertilizer Factory Ltd., Ghorasal

In plant failure history, date and time of failure and Start-up, causes of failure or troubles, repairing time taken for the remedial measures as well as down time resulted for the failure of the equipments and machineries, etc are included. These are collected from related departments (17) of the plant. Such failure records of Ammonia and Urea Plant for four years (July 1977 to June 1981), are shown in Appendix A and B respectively. The proforma used in recording failure data are shown below :

Failure time		Start-up time		Down time	Repair time
Date	Time Hrs.	Date	Time Hrs.	Days	Days
1	2	3	4	5	6

Causes of failure		Remedial measures/ Remarks
Equipment failed	Causes	
7	8	9

4.2 Operating Time Calculations of Equipments.

In calculating operating time, the running periods for each items are seperated from the period considered (July 1977 to June 1931) in the failure history of the Plant. It is noted here that at every running period i.e. between start-up and failure of an equipment, there exist some idle time due to the troubles of the other equipments. These idle times are summed for every running period and consequently actual operating time of an equipment is calculated by subtracting the idle time fromthe running period. By this way, operating times in between failures of each equipment of the Ammonia and Urea Plants are calculated and are shown in Table 4.2.1 and 4.2.2. respectively.

The symbols used in column 3 & 9 of Tables 4.2.1 and 4.2.2 are as follows:

F.S. - Faults signal(Instrument), E.F.- Electrical Fault, M.F.-Mechanical Faults, I.F.-Instrumental Fault, W.F. - Wear-out Fault, O.F. - Operational Fault, O.H.-Ovehauling and * - Failure.

Table 4.2.1 - Operating time calculation of equipments in Ammonia Plant.

Equipment	Running Date		Operating time calendar days	Idle time days	Actual Operating time days	Down time days	Repair time days	Causes of failures.
	From	To						
1	2	3	4	5	6	7	8	9
Gas Turbine (P-GT 101 A)	26-06-77	03-09-77*	73.00	0.00	73.00	5.48	5.00	F.S.
	09-09-77	12-10-77*	33.00	0.00	33.00	6.55	6.00	E.F.
	19-10-77	16-11-77*	28.00	0.00	28.00	3.00	2.50	E.F.
	19-11-77	27-01-78*	69.00	0.00	69.00	4.36	4.00	E.F.
	01-02-78	02-05-78 OH	90.00	0.00	90.00	78.00	15.00	O.H.
	19-07-78	08-08-79*	385.00	24.73	360.27	8.00	7.50	E.F.
	16-08-79	20-09-79*	35.00	0.00	35.00	49.00	48.50	O.H.
	08-11-79	30-04-80 OH	173.00	0.00	173.00	4.10	3.90	E.F.
	04-05-80	12-06-80	39.00	0.00	39.00	10.25	10.00	I.F.
	22-06-80	21-08-80	60.00	0.00	60.00	66.00	15.00	O.H.

Table 4.2.1 (Continued)

1	2	3	4	5	6	7	8	9
Boiler Feed Water Pump (A-GA 202)	16-7.77	8.3.78*	235.00	61.59	173.41	4.77	0.16	E.F.
	13.3.78	2.5.78^{OH}	50.00	9.00	40.70	78.00	7.00	O.H.
	19-7-78	17-7-80*	728.00	71.98	656.02	4.62	0.33	W.F.
	21.7.80	21.8.80^{OH}	31.00	0.00	31.00	66.00	7.00	O.H.
F.D.F. (A-GB 104T)	16-7-77	8.10.77*	84.00	23.34	60.66	2.77	0.00	O.F.
	11-10-77	2.5.78^{OH}	203.00	49.55	153.45	78.00	7.00	O.H.
	19-7-78	25-12-78*	159.00	4.00	155.00	2.65	0.00	F.S.
	29.12.78	21.8.80^{OH}	600.00	67.95	532.05	66.00	7.00	O.H.
	26-10-80	2-11-80*	7.00	1.00	6.00	3.50	0.50	F.S.
	6-11-80	21-6-81*	227.00	7.27	219.73	1.35	0.00	F.S.
Auxiliary Boiler (A-FA 101)	16-7-77	29-12-77*	166.00	42.81	123.19	3.00	0.25	F.S.
	1-1-78	8.2.78*	33.00	7.89	25.11	2.74	0.00	F.S.
	10-2-78	2.5.78^{OH}	81.00	14.37	66.63	78.00	20.00	O.H.
	19-7-78	6.9.78*	49.00	0.00	49.00	4.00	0.16	W.F.
	10.9.78	21.8.80^{OH}	710.00	72.90	637.10	66.00	20.00	O.H.

Table 4.2.1. (Continued)

1	2	3	4	5	6	7	8	9
A.T.B	16-7-77	2-1-78*	170.00	68.95	101.05	1.50	0.12	W.F.
	4.1.78	2.5.78 OH	118.00	33.35	84.65	78.00	9.00	O.F.
	19.7.78	21.8.80 OH	763.00	132.00	630.82	66.00	9.00	O.H.
	26.10.80	17.6.81*	234.00	17.26	216.74	3.41	1.50	E.F.
I.D.F. (A-GB	16-7-77	8.10.77*	84.00	25.07	58.93	10.33	0.00	O.F.
	11-10-77	2-5-78 OH	203.00	78.19	124.81	78.00	8.00	O.H.
	19-7-78	21-8-80 OH	763.00	130.18	632.82	66.00	8.00	O.H.
N.G. Booster Compressor (A-GB 106)	16-7-77	2-5-78 OH	290.00	103.80	186.20	78.00	12.00	O.H.
	19-7-78	7-11-79*	476.00	69.01	406.99	4.29	0.66	I.F.
	11-11-79	6-9-80*	210.00	37.88	172.12	1.70	0.12	O.F.
	11-6-80	21-8-80 OH	71.00	19.39	51.61	66.00	12.00	O.H.
	26.10.80	22.1.81*	88.00	8.37	79.63	1.82	0.16	F.S.
Waste heat boiler (A-EC 107)	16-7-77	2.5.78 OH	290.00	103.80	186.20	78.00	12.00	O.H.
	19-7-78	9.8.80*	751.00	129.47	621.53	2.71	2.71	W.F.
	11-8-80	21-8-80 OH	10.00	0.00	10.00	66.00	12.00	O.H.
Process Gas reboiler (A-EA 301)	16-7-77	2-5-78 OH	290.00	103.80	186.20	78.00	5.00	O.H.
	19-7-78	1-11-78*	105.00	17.37	87.63	6.13	3.80	W.F.
	7-11-78	21-8-80 OH	652.00	108.68	543.32	66.00	5.00	O.H.

Table 4.2.1 (Continued)

1	2	3	4	5	6	7	8	9
CO_2 absorber (A-DA 301)	16-7-77	22-10-77 *	98.00	34.73	63.27	21.57	19.90	W.F.
	12-11-77	2-5-78 OH	171.00	46.00	125.00	78.00	2.00	O.H.
	19-7-78	21-8-80 OH	163.00	132.18	630.82	66.00	2.00	O.H.
G.V. Solution Pump(A-GA 301)	16-7-77	4-4-78 *	262.00	96.68	165.32	3.00	1.20	M.F.
	6-4-78	2-5-78 OH	28.00	4.12	23.88	78.00	6.00	O.H.
	19-7-78	6-8-78 *	18.00	0.00	18.00	10.37	6.55	M.F.
	16-8-78	21-8-80 OH	735.00	121.81	613.19	66.19	6.00	O.H.
Mist trap (A-DA 303)	16-7-77	2-5-78 OH	290.00	103.80	186.20	78.00	5.00	O.H.
	19-7-78	2-2-80 *	563.00	89.25	473.75	11.85	4.50	W.F.
	14-2-78	21-8-80 OH	188.00	31.08	156.92	66.00	5.00	O.H.
Methanator Effluent Economizer(A-EA 401)	16-7-77	20-9-77 *	66.00	7.22	58.78	17.86	15.80	W.F.
	7-10-77	2-5-78 OH	207.00	78.72	128.28	78.00	7.00	O.H.
	19-7-78	21-8-80 OH	763.00	132.18	630.82	66.00	7.00	O.H.
Synthesis gas K.O. Drum (A-FA 401)	16-7-77	2-5-78 OH	290.00	103.80	186.20	78.00	3.00	O.H.
	19-7-78	17-2-80 *	578.00	101.10	476.90	2.30	2.30	W.F.
	19-2-80	21-2-80 OH	183.00	28.78	28.78	154.22	66.00	O.H.

Table 4.2.1 (Continued)

1	2	3	4	5	6	7	8	9
R.T.B.	16-7-77	19-8-77*	34.00	0.00	34.00	1.74	0.00	F.S.
	21-8-77	21-11-77*	92.00	6.087	31.13	3.34	1.70	W.F.
	24-11-77	29-3-78*	125.00	25.55	99.45	5.18	3.90	M.F.
	4-4-78	2-5-78 OH	27.00	7.12	19.88	78.00	9.00	O.H.
	19-7-78	16-1-79*	181.00	31.37	149.63	2.05	0.00	F.S.
	18-1-79	11-11-79*	297.00	38.79	258.21	2.00	0.00	O.F.
	13-11-79	14-3-80*	121.00	28.19	92.81	1.34	0.40	I.F.
	16-3-80	21-8-80 OH	158.00	27.44	130.56	66.00	9.00	O.H.
	26-10-80	13-6-81*	230.00	13.59	216.41	3.37	0.00	F.S.
	17-6-81	30-6-81*	13.00	7.03	5.97	0.68	0.00	F.S.
Hyper Turbine (A-GB 501 T&C)	16-7-77	2-5-78 OH	290.00	103.80	186.20	78.00	15.00	O.H.
	19-7-78	16-9-78*	59.00	14.37	44.63	3.00	3.00	E.F.
	19-9-78	31-12-78*	75.00	10.78	64.22	3.22	3.22	O.F.
	7-12-78	1-1-80*	390.00	46.84	243.16	4.85	4.85	M.F.
	6-1-80	16-5-80*	130.00	28.78	101.22	2.25	2.25	M.F.
	18-5-80	23-7-80*	66.57	16.57	49.43	1.81	1.81	O.H.
	25-7-80	21-8-80 OH	27.00	2.71	24.29	66.00	25.00	O.H.

Table 4.2.2 Operating time calculation of equipments in Urea Plant.

Equipment	Running date		Operating time calendar days	Idle time days	Actual Operating time days	Down time days	Repair tire days	Causes of failures
	From	To						
1	2	3	4	5	6	7	8	9
CO_2 Booster	16-07-77	03-12-77*	140.00	67.11	72.89	1.76	0.41	W. F.
Compressor	05-12-77	15-02-78*	72.00	33.73	38.27	0.98	0.33	W. F.
(U-GB 101 T&C)	16-02-78	02-05-78 OH	76.00	4.69	70.31	78.00	9.00	O. H.
	19-07-78	18-12-78*	152.00	23.50	128.50	0.21	0.00	M. F.
	18-12-78	01-10-79*	287.00	45.77	241.23	0.58	0.12	M. F.
	02-11-79	16-10-79*	14.00	00.00	14.00	0.54	0.10	M. F.
	17-10-79	14-11-79*	28.00	6.29	21.71	0.06	0.00	M. F.
	14-11-79	10-12-79*	26.00	0.00	26.00	1.95	0.80	M. F.
	12-12-79	29-12-79*	17.00	0.00	17.00	1.12	0.75	M. F.
	30-12-79	21-08-80 OH	233.00	59.29	172.71	66.00	9.00	O. H.
	26-10-80	11-02-81*	108.00	10.19	97.81	3.83	2.50	W. F.

Table 4.2.2. (Continued)

1	2	3	4	5	6	7	8	9
Gas turbine (P-GT101 B)	22-6-77	19-7-77*	27.00	0.00	27.00	0.80	0.70	F.S.
	19-7-77	3-9-77*	45.00	0.00	45.00	5.48	5.00	F.S.
	9-9-77	12-10-77*	33.00	0.00	33.00	6.55	6.00	E.F.
	19.10.77	16.11-77*	28.00	0.00	28.00	3.00	2.50	E.F.
	19-11-77	27-1-78*	69.00	0.00	69.00	4.00	4.00	E.F.
	1-2-78	2-5-78 OH	90.00	0.00	90.00	78.00	15.00	O.H.
	19-7-78	20-12-78*	153.00	0.00	153.00	0.35	0.00	F.S.
	21-12-78	8-8-79*	230.00	24.73	205.27	8.00	7.50	E.F.
	16-8-79	28-9-79 OH	35.00	0.00	35.00	49.00	49.00	O.H
	8-11-79	3-4-80*	146.00	0.00	146.00	1.94	1.50	E.F.
	5-4-80	30-4-80*	25.00	0.00	25.00	4.10	3.90	E.F.
	4-5-80	12-6-80*	39.00	0.00	39.00	10.25	10.00	I.F.
	22-6-80	21-8-80 OH	59.00	0.00	59.00	66.00	15.00	O.H.
CO_2 Main Compressor. (U-GB 102 A)	16-7-77	27-8-77*	35.00	2.90	32.10	3.37	3.00	W.F.
	31-8-77	2-5-78 OH	244.00	104.80	139.20	78.00	25.00	O.H.
	19-7-78	10-7-79*	356.00	62.05	293.95	0.10	0.00	M.F.
	10-7-79	27-9-79*	79.00	8.58	70.42	0.16	0.00	F.S.
	27-9-79	13-8-80*	320.00	71.23	248.77	0.41	0.20	W.F.
	13-8-80	21-8-80 OH	8.00	0.00	8.00	66.00	25.00	O.H.
	26-10-80	26-6-81*	243.00	28.52	214.48	1.35	1.10	W.F.

Table 4.2.2 (Continued)

1	2	3	4	5	6	7	8	9
CO_2 Main Compressor. (U-GB 102B)	16-7-77	18-7-77*	2.00	0.00	2.00	0.03	0.00	I.F.
	18-7-77	2-5-78 OH	288.00	107.70	180.30	78.00	25.00	O.H.
	19-7-78	20-12-78*	154.00	24.28	129.72	0.13	0.00	M.F.
	20-12-78	6-11-79*	321.00	46.89	274.11	0.58	0.38	W.F.
	6-11-79	12-4-80*	157.00	42.27	114.72	0.44	0.24	W.F.
	12-4-80	11-7-80*	90.00	19.28	70.72	0.04	0.00	M.F.
	11-7-80	13-8-80*	33.00	9.14	23.86	0.41	0.20	M.F.
	13-8-80	21-8-80 OH	8.00	0.00	8.00	66.00	25.00	O.H.
Suction common header valve of NH_3 Pump (U-GA 101)	16-7-77	21-12-77*	158.00	69.46	88.54	0.17	0.11	W.F.
	21-12-77	2-5-78 OH	132.00	39.40	92.60	78.00	0.10	O.H.
	19-7-78	13-12-78*	147.00	23.50	123.50	0.80	0.50	W.F.
	13-12-78	21-8-80 OH	616.00	120.08	495.92	66.00	0.10	O.H.
	26-10-80	28-6-81*	245.00	28.12	216.88	0.12	0.09	W.F.
Ammonia Preheater (U-EA 101 A)	16-7-77	2-5-78 OH	290.00	108.86	181.14	78.00	1.00	O.H.
	19-7-78	7-7-80*	718.00	135.54	582.46	0.21	0.20	W.F.
	7-7-80	21-8-80 OH	45.00	10.17	34.83	66.00	1.00	O.H.

Table 4.2.2 (Continued)

1	2	3	4	5	6	7	8	9
Ammonia Preheater (U-EA 101 B)	16-7-77	23-1-78*	191.00	73.96	117.04	0.20	0.10	O.H.
	23-1-78	2-5-78 OH	99.00	34.90	64.10	78.00	1.00	O.H.
	19-7-78	8-11-78*	112.00	23.50	88.50	0.80	0.60	W.F.
	8-11-78	21-8-80 OH	651.00	122.40	528.60	66.00	1.00	O.H.
Suction Common Header valve of R.C. Pump (U-GA 102)	16-7-77	8-9-77*	54.00	8.97	45.05	0.04	0.02	W.F.
	8-9-77	2-5-78 OH	236.00	101.64	134.36	78.00	0.10	O.H.
	19-7-78	21-8-80 OH	763.00	143.57	619.42	66.00	0.10	O.H.
Urea Reactor (U-DC 101 B)	16-7-77	5-2-78*	204.00	86.26	117.74	0.10	0.05	O.H.
	5-2-78	2-5-78 OH	86.00	21.09	64.91	78.00	15.00	O.H.
	19-7-78	29-7-80*	740.00	141.98	598.02	0.21	0.09	I.F.
	29-7-80	21-8-80 OH	23.00	2.71	20.29	66.00	15.00	O.F.
High Pressure decomposer (U-DA 201)	16-7-77	2-5-78 OH	290.00	108.86	181.14	78.00	15.00	O.H.
	19-7-78	29-8-79*	406.00	37.56	368.44	2.08	1.80	W.F.
	31-8-79	4-7-80*	307.00	62.87	244.13	1.03	0.50	M.F.
	5-7-80	21-8-80 OH	47.00	9.14	37.86	66.00	15.00	O.H.
Centrifuge (U-GF 201 A)	16-7-77	2-5-78 OH	290.00	107.11	182.89	78.00	5.00	O.H.
	19-7-78	21-4-79*	276.00	44.79	231.21	1.28	1.25	W.F.
	22-4-79	21-8-80 OH	486.00	100.31	385.69	66.00	5.00	O.H.

Table 4.2.2 (Continued)

1	2	3	4	5	6	7	8	9
Centrifuge (U-GF201 E)	16-7-77	2-5-78 OH	290.00	107.11	182.89	78.00	5.00	O.H.
	19-7-78	23-4-79 *	278.00	44.79	233.21	2.86	2.84	W.F.
	26-4-79	21-8-80 OH	282.00	100.31	381.69	66.00	5.00	O.H.
No. 2 belt conveyor (U-JD 204 B)	16-7-77	2-5-78 OH	290.00	108.86	181.14	78.00	2.00	O.H.
	19-7-78	15-3-79 *	239.00	33.98	205.02	1.04	1.00	W.F.
	16-3-79	25-7-79 *	131.00	27.50	103.30	0.35	0.30	W.F.
	26-7-79	6-12-79 *	133.00	17.92	115.08	0.25	0.24	W.F.
	6-12-79	21-8-80 OH	258.00	64.67	193.33	66.00	2.00	O.H.
Melter (U-EA 301 A)	16-7-77	2-5-78 OH	290.00	108.86	181.14	78.00	2.00	O.H.
	19-7-78	4-1-79 *	169.00	31.93	137.07	0.25	0.24	W.F.
	4-1-79	1-8-79 *	209.00	29.55	179.45	0.60	0.58	W.F.
	1-8-79	21-8-80 OH	358.00	83.62	301.38	66.00	2.00	O.H.
Bucket Elevator (B-JD 102)	16-7-77	2-5-78 OH	290.00	108.86	181.14	78.00	2.00	O.H.
	19-7-78	3-11-79 *	472.00	72.14	399.86	0.20	0.20	W.F.
	3-11-79	21-8-80 OH	291.00	72.68	218.32	66.00	2.00	O.H.
Belt conveyor to Bulk Storage (B-JD 103)	16-7-77	2-5-78 OH	290.00	108.86	181.14	78.00	3.00	O.H.
	19-7-78	4-8-79 *	381.00	61.48	319.52	0.08	0.08	W.F.
	4-8-79	21-8-80 OH	382.00	83.54	298.46	66.00	3.00	O.H.

4.3 Weibull Distribution Parameters Estimation of Equipments .

The published methods for the estimation of the Weibull distribution parameters β and η are described eleborately in section 2.4. In this section Hazard plotting method as well as MIE method are used for the estimation ofWeibull parameters. Graphical solutions of Hazard plotting method for individual equipment are shown in Appendix C. Computer programming (Shown in Appendix D) was used to estimate the parameters by MIE methods. It should be mentioned here that both of these methods are applicable only when number of Failures r 2. But in analyzing operating time it has been found that some of the equipments suffered only one failure during the period considered. In such cases Weibull parameters are estimated by using the SEQLIM METHOD (Calculation steps of SEQLIM method are shown in Appendix E with example). Application of all the methods mentioned above are shown in table 4.3.1 and 4.3.2 for the equipments of Ammonia plant and Urea plant respectively.

Table 4.3.1 Weibull Distribution parameters Estimation of Equipments of Ammonia Plant

Equipments	Method used									
	No. of failures	Hazard Plotting			MLE			SEQLIM		
		Shape parameter	Scale parameter	MTBF	Shape parameter	Scale parameter	MTBF	Shape parameter	Scale parameter	MTBF
Gas Turbine (P-GT 101 A)	7	1.12	130.00	124.76	1.23	139.85	130.85	-	-	-
Boiler feed water Pump (A-GA 202)	2	0.78	400.00	461.82	1.86	474.00	421.22	-	-	-
F.D.F. (A-GB 104 T)	4	0.91	200.00	209.24	0.72	291.86	358.37	-	-	-
Auxiliary boiler(A-FA 101)	3	0.97	122.00	123.39						
A.T.B (A-GB 101 T&C)	2	1.13	225.00	215.33	1.08	503.67	489.31			
I.D.F. (A-GB 102 T)	1	-	-	-	-	-	-	0.95	206.48	211.37
N.G.Booster Compr.(A-GB 106)	3	1.03	270.00	262.23	1.91	281.28	249.73	-	-	-
Waste heat boiler(A-EC 107)	1	-		-	-	-	-	3.40	744.96	669.98
Process gas reroiler(A-EA 301)	1	-	-	-	-	-	-	1.10	263.70	254.53
CO_2 absorber (A-DA 301)	1	-	-	-	-	-	-	1.00	228.57	228.64
G.V. Solution Pump(A-GA 301)	2	0.48	300.00	600.05	0.63	464.13	660.86	-	-	-
Mist trap (A-DA 303)	1	-	-	-	-	-	-	3.40	575.68	517.73
Methanator effluent economizer(A-EA 401)	1	-	-	-	-	-	-	1.30	342.43	316.40
Synthesis gas K.O. drum (A-FA 401)	1							3.40	579.07	520.78
R.T.B. (A-GC 501 T&C)	8	0.98	143.00	144.30	1.22	133.01	124.74	-	-	-
Hyper turbine (A-GB 501 T&C)	5	0.88	165.00	175.86	1.26	166.34	154.81	-	-	-

Table 4.3.2 Weibull Distribution Parameters Estimation of Equipments of Urea Plant

Equipments	No. of failures	Method used								
		Hazard Plotting			MLE			SEQLIM		
		Shape parameter	Scale parameter	MTBF	Shape parameter	Scale parameter	MTBF	Shape parameter	Scale parameter	MTBF
CO_2 booster compressor (U-GB 101 T&C)	9	0.88	95.00	101.25	-	-	-	-	-	-
Gas Turbine (P-GT 101B)	10	1.14	100.00	95.45	1.43	98.06	89.17	-	-	-
CO_2 main comp. (U-GB 102A)	5	0.94	205.00	210.94	1.74	206.54	184.09	-	-	-
CO_2 main comp. (U-GB 102B)	6	0.76	115.00	135.48	0.91	132.31	138.63	-	-	-
Suction common header valve of NH_3 pump(U-GA 101)	3	1.76	200.00	178.17	1.27	324.68	301.52	-	-	-
Ammonia preheater (U-EA 101 A)	1	-	-	-	-	-	-	3.40	698.61	628.29
Ammonia preheater (U-EA 101 B)	2	3.12	123.00	110.14	0.97	403.72	410.18	-	-	-
Suction common header valve of R.C. Pump (U-GA 102)	1	-	-	-	-	-	-	0.85	161.15	175.36

Table 4.3.2 (Continued)

Equipments	No. of failures	METHOD USED								
		Hazard Plotting			MIE			SEQLIM		
		Shape parameter	Scale parameter	MTBF	Shape parameter	Scale parameter	MTBF	Shape parameter	Scale parameter	MTBF
Urea reactor (U-DC 101 B)	2	0.68	330.00	429.86	1.59	412.73	370.50	-	-	-
High pressure Decomposer (U-DA 201)	2	2.69	320.00	284.79	-	-	-	-	-	-
Centrifuge (U-GF 201A)	1	-	-	-	-	-	-	2.10	414.06	367.00
Centrifuge (U-GF 201E)	1	-	-	-	-	-	-	2.10	414.06	367.00
No. 2 belt conveyor (U-JD 204 B)	1	2.76	167.00	148.76	3.20	199.98	179.31	-	-	-
Melter (U-EA 301 A)	2	3.32	210.00	188.63	2.42	283.56	251.62	-	-	-
Bucket elevetor (B-JD 102)	1	-	-	-	-	-	-	3.40	502.68	452.08
Belt conveyor to bulk storage (B-JD 103)	1	-	-	-	-	-	-	3.40	463.03	416.42

CHAPTER 5

RELIABILITY PREDICTION OF EQUIPMENTS

CHAPTER 5

RELIABILITY PREDICTION OF EQUIPMENTS.

5.1 Reliability Predictions

In this chapter the reliability of each equipment (which suffered at least one failure) of the factory are predicted for different time period in days (say 0, 10, 25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 450 and 500) by using the formula $R = \exp\left\{\left(-\frac{t}{\eta}\right)^{\beta}\right\}$ where β and η are the respective shape and scale parameters. Then the reliability of stand-by system where available and finally the overall reliability of the Ammonia and Urea Plants are predicted and shown in Tables 5.1.1 and 5.1.2 respectively.

The reliability block diagram and equvalent reliability diagram of Ammonia Plant are shown in figure 5.1.1 and 5.1.2 and that of Urea Plant are shown in figure 5.1.3 and 5.1.4 respectively. Such diagrams are very essential and facilitate in calculating overall reliability of the plant.

The formula used in reliability calculation of the stand-by systems are again depicted below:

For equipments	Formula used
Gas turbine (P-GT 101 A,B), CO_2 main compressor(U-GB 101 A,B), and Ammonia Preheater(U-EA 101A,B),	$R_s = 1 - (1 - R_1)(1 - R_2)$ R_1 and R_2 represents the reliability of equipment A and B respectively and R_s represents stand-by systems reliability.

For equipments	Formula used.
N.G.Booster Compressor(A-GB 106 A,B) Urea reactor(U-DC 101 A,B),No.2 belt conveyor(U-JD 204 A,B),and Melter(U-EA 301 A, B)	$R_s = 1 - (1 - R)^2$ Where R represents the reliability of both the equipment A and B respectively.
Centrifuge (U-GF 201 A-E)	$R = \sum_{k=3}^{5} \frac{5!}{k!(5-k)!} R^k (1 - R)^{5-k}$ Where R represents the reliability of each equipment.

The overall reliability of the plant are calculated by the formula $R_p = R_1 . R_2 R_3 R_4 . . . .$ where R_1 , R_2 , R_3 . . . . etc. are the reliability of each individual unit.

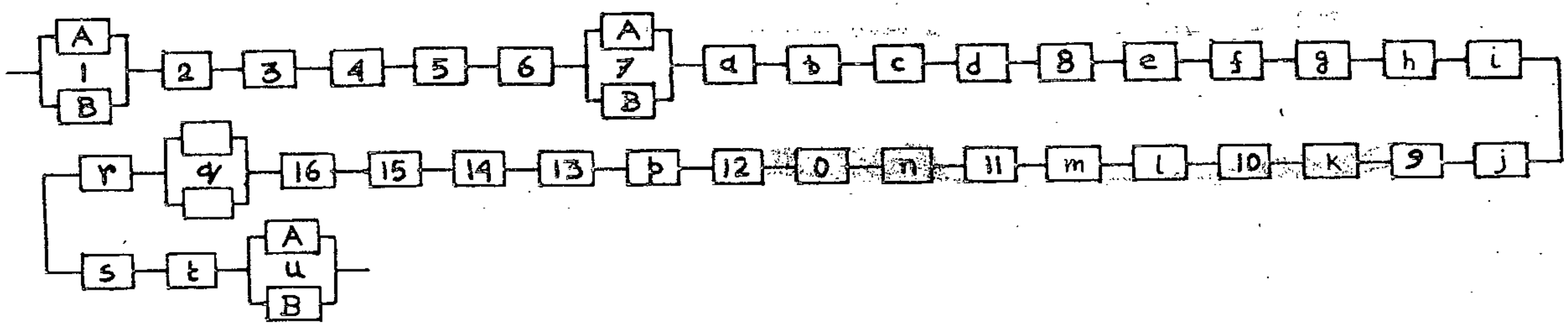


Figure 5.1.1 Reliability Block Diagram of Ammonia Plant.

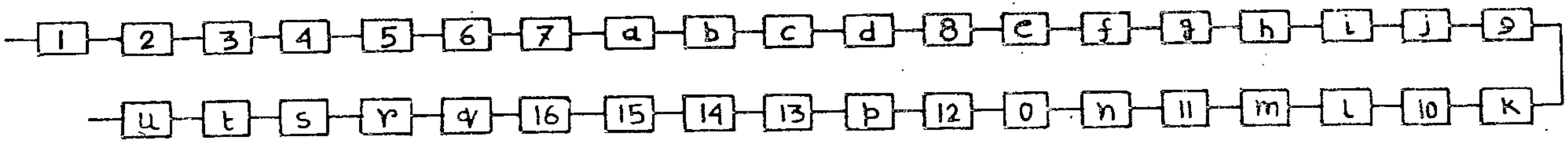


Figure 5.1.2 Equivalent Reliability Diagram of Ammonia Plant.

List of Equipments of Figure 5.1.2 are shown below :

1. Gas Turbine (P-GT 101 A,B)
2. B.F.W Pump (-GA 202)
3. F.D.F (A-GB 104-T)
4. Aux.Boiler (A-FA 101)
5. A.T.B (A-GB 101 T&C)
6. I.D.F (A-GB 102 T)
7. N.G.Booster Compressor (A-GB 106 A,B).
8. W.H.Boiler (A-EC 107)
9. P-G.Re-boiler (A-EA 301)
10. CO_2 absorber (A-DA 301)
11. G.V.Solution Pump (A-GA 301)
12. Mist.trap (A-DA 303)
13. M.E.Economizer (A-EA 401)
14. Syn.Gas K.O.Drum (A-FA 401)
15. R.T.B (A-GC 501 T&C)
16. Hyper Turbine (A-GB 501 T&C)

a. Desulfurization vessel (A-DA 101 A)
b. Desulfurization vessel (A-DA 101 B)
c. Ist.Reformer (A-BA 101)
d. 2nd Reformer (A-DC 101)
e. Q.G.Seperator (A-FA 201)
f. Ist.S.Converter (A-DC 201)
g. P.G.Heat exchanger (A-EA 201)
h. Ist.C.G.Economizer (A-EA 202)
i. 2nd shift Converter (A-DC 202)
j. 2nd C.G.Economizer (A-EA 203)
k. P.G. K.O.drum (A-FA 301)
l. S.H.Exchanger (A-EA 302)
m. CO_2 Regenerator (A-DA 302)
n. CO_2 direct cooler (A-DA 304)
o. Absorb. E.Cooler (A-EA 304)
p. Methanator (A-DC 401)
q. Synthesis Converter (A-DC 501 A,B)

Table 5.1.1 Reliability Prediction of Ammonia Plant.

Sl.no	Equipments	β	η	Time, days													
				0	10	25	50	75	100	150	200	250	300	350	400	450	500
				Reliability													
1A	Gas turbine (P-GT 101 A)	1.23	139.85	1	0.9617	0.8866	0.7541	0.6283	0.5158	0.3362	0.2116	0.1296	0.0775	0.0454	0.0261	0.0148	0.0082
1B	Gas turbine (P-GT 101 B)	1.43	98.06	1	0.9625	0.8679	0.6827	0.5058	0.3575	0.1593	0.0625	0.0220	0.0070	0.0020	0.0005	0.0001	0.00003
1	Gas turbine (P-GT 101 A,B)			1	0.9985	0.9850	0.9219	0.8163	0.6889	0.4419	0.2608	0.1487	0.0839	0.0473	0.0265	0.0148	0.0082
2	B.F.W. Pump (A-GA 202)	1.86	474.00	1	0.9992	0.9958	0.9848	0.9681	0.9461	0.8890	0.8179	0.7376	0.6524	0.5661	0.4822	0.4033	0.3314
3	F.D.F. (A-GB 104 T)	0.72	291.86	1	0.9156	0.8502	0.7552	0.6866	0.6297	0.5383	0.4668	0.4088	0.3605	0.3199	0.2851	0.2551	0.2291
4	Aux. boiler (A-FA 101)	0.97	122.00	1	0.9154	0.8066	0.6564	0.5359	0.4384	0.2946	0.1938	0.1345	0.0913	0.0620	0.0422	0.0288	0.0196
5	A.T.B (A-GB 101 T+C)	1.08	503.67	1	0.9855	0.9617	0.9207	0.8799	0.8399	0.7631	0.6915	0.6254	0.5647	0.5091	0.4585	0.4125	0.3707
6	I.D.F. (A-GB 102 T)	0.95	206.48	1	0.9452	0.8741	0.7710	0.6824	0.6052	0.4779	0.3790	0.3014	0.2402	0.1918	0.1534	0.1229	0.0985
7A	N.G. booster comp. (A-GB 106 A)	1.91	281.28	1	0.9982	0.9902	0.9637	0.9230	0.8704	0.7401	0.5937	0.4500	0.3227	0.2191	0.1409	0.0859	0.0497
7B	N.G. booster Comp. (A-GB 106 B)	1.91	281.28	1	0.9982	0.9902	0.9637	0.9230	0.8704	0.7401	0.5937	0.4500	0.3227	0.2191	0.1409	0.0859	0.0497
7	N.G. booster comp. (A-GB 106 A,B)			1	0.9999	0.9999	0.9986	0.9940	0.9832	0.9324	0.8349	0.6975	0.5412	0.3901	0.2619	0.1644	0.0969
8	W.H. boiler (A-EC 107)	3.40	744.96	1	0.9999	0.9999	0.9998	0.9995	0.9989	0.9957	0.9886	0.9758	0.9556	0.9262	0.8862	0.8351	0.7727

Table 5.1.1 Reliability Prediction of Ammonia Plant (Continued).

Sl. no	Equipments.	β	η	Time, days													
				0	10	25	50	75	100	150	200	250	300	350	400	450	500
				Reliability													
9	P.G. Reboiler (A-EA 301)	1·10	263·70	1	0·9730	0·9278	0·8516	0·7781	0·7088	0·5841	0·4781	0·3894	0·3158	0·2552	0·2056	0·1652	0·1324
10	CO_2 Absorber (A-DA 301)	1·00	228·57	1	0·9571	0·8963	0·8035	0·7202	0·6456	0·5187	0·4168	0·3349	0·2691	0·2162	0·1737	0·1396	0·1121
11	G.V. Sol^n. Pump (A-GA 301)	0·63	464·13	1	0·9147	0·8532	0·7821	0·7281	0·6837	0·6121	0·5552	0·5080	0·4678	0·4329	0·4022	0·3750	0·3506
12	Mist trap (A-DA 303)	3·40	575·68	1	0·9999	0·9999	0·9997	0·9990	0·9974	0·9897	0·9729	0·9430	0·8966	0·8317	0·7482	0·6468	0·5383
13	M.E. Economizer (A-EA 401)	1·30	342·43	1	0·9899	0·9672	0·9212	0·8703	0·8172	0·7103	0·6083	0·5146	0·4308	0·3574	0·2940	0·2401	0·1948
14	Syn.Gas K.O.Drum (A-FA401)	3·40	579·07	1	0·9999	0·9999	0·9997	0·9990	0·9974	0·9899	0·9734	0·9441	0·8986	0·8348	0·7525	0·6542	0·5449
15	R.T.B (A-GC 501 T+C)	1·22	133·01	1	0·9583	0·8779	0·7385	0·6082	0·4935	0·3141	0·1930	0·1153	0·0673	0·0385	0·0216	0·0119	0·0065
16	Hyper turbine (A-GB 501 T+C)	1·26	166·34	1	0·9714	0·9122	0·8025	0·6931	0·5905	0·4156	0·2832	0·1880	0·1221	0·0778	0·0487	0·0300	0·0182
	Ammonia Plant			1	0·6111	0·3106	0·0931	0·0259	0·0066	0·0003							

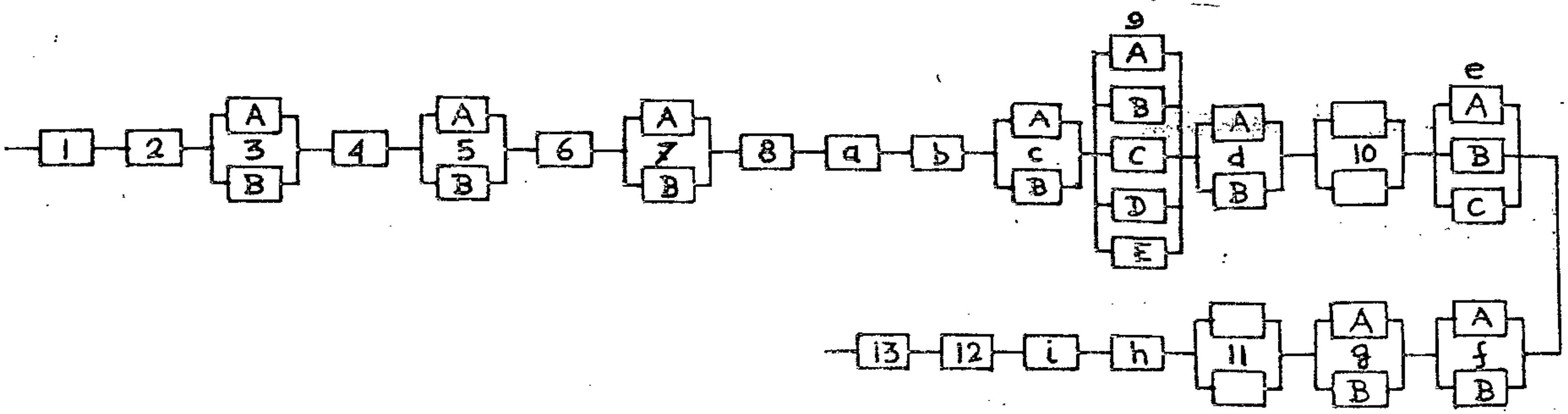


Figure 5.1.3 Reliability Block Diagram of Urea Plant.

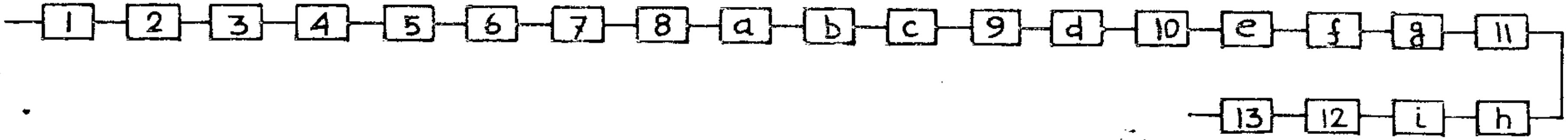


Figure 5.1.4 Equivalent Reliability Diagram of Urea Plant.

List of Equipments of Figure 5.1.4 are shown below :

1. CO_2 booster Compressor. (U-GB 101 T & C)
2. Gas Turbine(P-GT 101 B)
3. CO_2 Main Compressor. (U-GB 102 A,B)
4. S.C.H.Valve of NH_3 Pump (U-GA 101)
5. Ammonia preheater (U-EA 101 A,B)
6. S.C.H.Valve of R.C. Pump(U-GA 102)
7. Urea reactor (U-DC 101 A,B)
8. H.p.decomposer (U-DA 201)
9. Centrifuge(U-GF 201 A-E)
10. No.2 belt conveyor (U-JD 204 A,B)
11. Melter(U-EA 301 A,B)
12. Bucket elevator(B-JD 102)
13. Belt conveyor to bulk storage (B-JD 103)

a. L.P. decomposer(U-DA 202)
b. Gas Seperator(U-DA 203)
c. Crystallizer(U-FA 201)
d. Belt conveyor(U-JD 202,AB)
e. Dryer(U-FF 301 A-C)
f. Cyclone(U-FC 301 A-B)
g. Screw conveyor(U-JD 301)
h. Head tank (U-FA 301)
i. Belt conveyor(B-JD 101)

Table 5.1.2 Reliability Prediction of Urea Plant.

Sl.no.	Equipments	β	η	Time, days 0	10	25	50	75	100	150	200	250	300	350	400	450	500
				Reliability													
1	CO_2 booster comp. (U-GB 101 T+C)	0.88	95.00	1	0.8711	0.7342	0.5663	0.4438	0.3512	0.2243	0.1458	0.0960	0.0638	0.0428	0.0289	0.0196	0.0134
2	Gas turbine (P-GT 101 B)	1.43	98.06	1	0.9625	0.8679	0.6827	0.5058	0.3575	0.1593	0.0625	0.0220	0.0070	0.0020	0.0005	0.0001	0.00003
3A	CO_2 main comp. (U-GB 102 A)	1.74	206.54	1	0.9948	0.9749	0.9187	0.8423	0.7534	0.5637	0.3884	0.2480	0.1470	0.0817	0.0424	0.0207	0.0094
3B	CO_2 main comp. (U-GB 102 B)	0.91	132.31	1	0.9030	0.8029	0.6619	0.5507	0.4606	0.3259	0.2330	0.1679	0.1216	0.0886	0.0647	0.0475	0.0349
3	CO_2 main comp. (U-GB 102 A,B)			1	0.9995	0.9950	0.9725	0.9291	0.8669	0.7058	0.5309	0.3742	0.2509	0.1630	0.1043	0.0672	0.0439
4	S.C.H. Valve of NH_3 Pump (U-GA 101)	1.27	324.68	1	0.9880	0.9621	0.9112	0.8559	0.7992	0.6872	0.5824	0.4879	0.4047	0.3328	0.2716	0.2201	0.1772
5A	Ammonia preheater (U-EA 101 A)	3.40	698.61	1	0.9999	0.9999	0.9998	0.9994	0.9986	0.9946	0.9858	0.9700	0.9450	0.9090	0.8605	0.7992	0.7256
5B	Ammonia preheater (U-EA 101 B)	0.97	403.72	1	0.9727	0.9349	0.8764	0.8225	0.7723	0.6819	0.6029	0.5335	0.4724	0.4186	0.3711	0.3292	0.2921
5	Ammonia preheater (U-EA 101 A,B)			1	0.9999	0.9999	0.9999	0.9998	0.9996	0.9982	0.9943	0.9860	0.9709	0.9470	0.9122	0.8653	0.8057
6	S.C.H. Valve of R.C. pump (U-GA 102)	0.85	161.15	1	0.9101	0.8145	0.6908	0.5933	0.5134	0.3902	0.3007	0.2339	0.1834	0.1446	0.1146	0.0912	0.0729
7B	Urea reactor (U-DC 101 B)	1.59	412.73	1	0.9973	0.9884	0.9657	0.9357	0.9003	0.8187	0.7290	0.6372	0.5476	0.4632	0.3861	0.3174	0.2575
7A	Urea reactor (U-DC 101 A)	1.59	412.73	1	0.9973	0.9884	0.9657	0.9357	0.9003	0.8187	0.7290	0.6372	0.5476	0.4632	0.3861	0.3174	0.2575

Table 5.1.2 Reliability Prediction of Urea Plant (Continued).

Sl.no	Equipments	β	η	Time, days													
				0	10	25	50	75	100	150	200	250	300	350	400	450	500
				Reliability													
7	Urea reactor (U-DC 101 A,B)			1	0.9999	0.9998	0.9988	0.9958	0.9909	0.9671	0.9265	0.8683	0.7953	0.7118	0.6231	0.5340	0.4486
8	H.P. decomposer (U-DA 201)	2.69	320.00	1	0.9999	0.9989	0.9932	0.9800	0.9571	0.8778	0.7539	0.5976	0.4314	0.2801	0.1616	0.0819	0.0360
9A	Centrifuge (U-GF 201 A)	2.10	414.06	1	0.9995	0.9972	0.9882	0.9727	0.9506	0.8881	0.8049	0.7070	0.6015	0.4952	0.3945	0.3039	0.2262
9E	Centrifuge (U-GF 201 E)	2.10	414.06	1	0.9995	0.9972	0.9882	0.9727	0.9506	0.8881	0.8049	0.7070	0.6015	0.4952	0.3945	0.3039	0.2262
9	Centrifuge (U-GF 201 A~E)			1	0.9999	0.9999	0.9999	0.9998	0.9988	0.9882	0.9457	0.8460	0.6851	0.4910	0.3079	0.1682	0.0806
10B	No 2 belt conveyor (U-JD 204 B)	3.20	199.98	1	0.9999	0.9987	0.9882	0.9575	0.8968	0.6713	0.3677	0.1296	0.0257	0.0024	0.0001		
10A	No.2 belt conveyor (U-JD 204 A)	3.20	199.98	1	0.9999	0.9987	0.9882	0.9575	0.8968	0.6713	0.3677	0.1296	0.0257	0.0024	0.0001		
10	No.2 belt conveyor (U-JD 204 A,B)			1	0.9999	0.9999	0.9998	0.9981	0.9893	0.8919	0.6001	0.2424	0.0507	0.0047	0.0001		
11A	Melter (U-EA 301 A)	2.42	283.56	1	0.9996	0.9972	0.9851	0.9607	0.9228	0.8072	0.6507	0.4784	0.3178	0.1893	0.1003	0.0470	0.0193
11B	Melter (U-EA 301 B)	2.42	283.56	1	0.9996	0.9972	0.9851	0.9607	0.9228	0.8072	0.6507	0.4784	0.3178	0.1893	0.1003	0.0470	0.0193
11	Melter (U-EA 301 A,B)			1	0.9999	0.9999	0.9997	0.9984	0.9940	0.9628	0.8779	0.7279	0.5346	0.3427	0.1905	0.0917	0.0382
12	Bucket elevator (B-JD 102)	3.40	502.68	1	0.9999	0.9999	0.9996	0.9984	0.9958	0.9837	0.9573	0.9111	0.8412	0.7467	0.6313	0.5034	0.3745

Table 5.1.2 Reliability Prediction of Urea Plant (Continued).

Sl.no	Equipments	β	η	Time, days													
				0	10	25	50	75	100	150	200	250	300	350	400	450	500
				Reliability													
13	Belt conveyor to bulk storage (B-JD 103)	3.40	463.03	1	0.9999	0.9999	0.9994	0.9979	0.9945	0.9785	0.9440	0.8842	0.7956	0.6796	0.5444	0.4035	0.2729
	Urea Plant			1	0.7529	0.4958	0.2343	0.1025	0.0411	0.0046							

5.2 Reliability Vs. Time Curve of Equipments.

In this section predicted reliability Vs. time curve of various equipments of the Ammonia plant are shown in figure 5.2.1 to 5.2.5 and that of Urea plant are shown in figure 5.2.6 to 5.2.10 . Finally, over all reliability Vs.time curve of Ammonia plant as well as Urea plant are shown in figure 5.2.11.

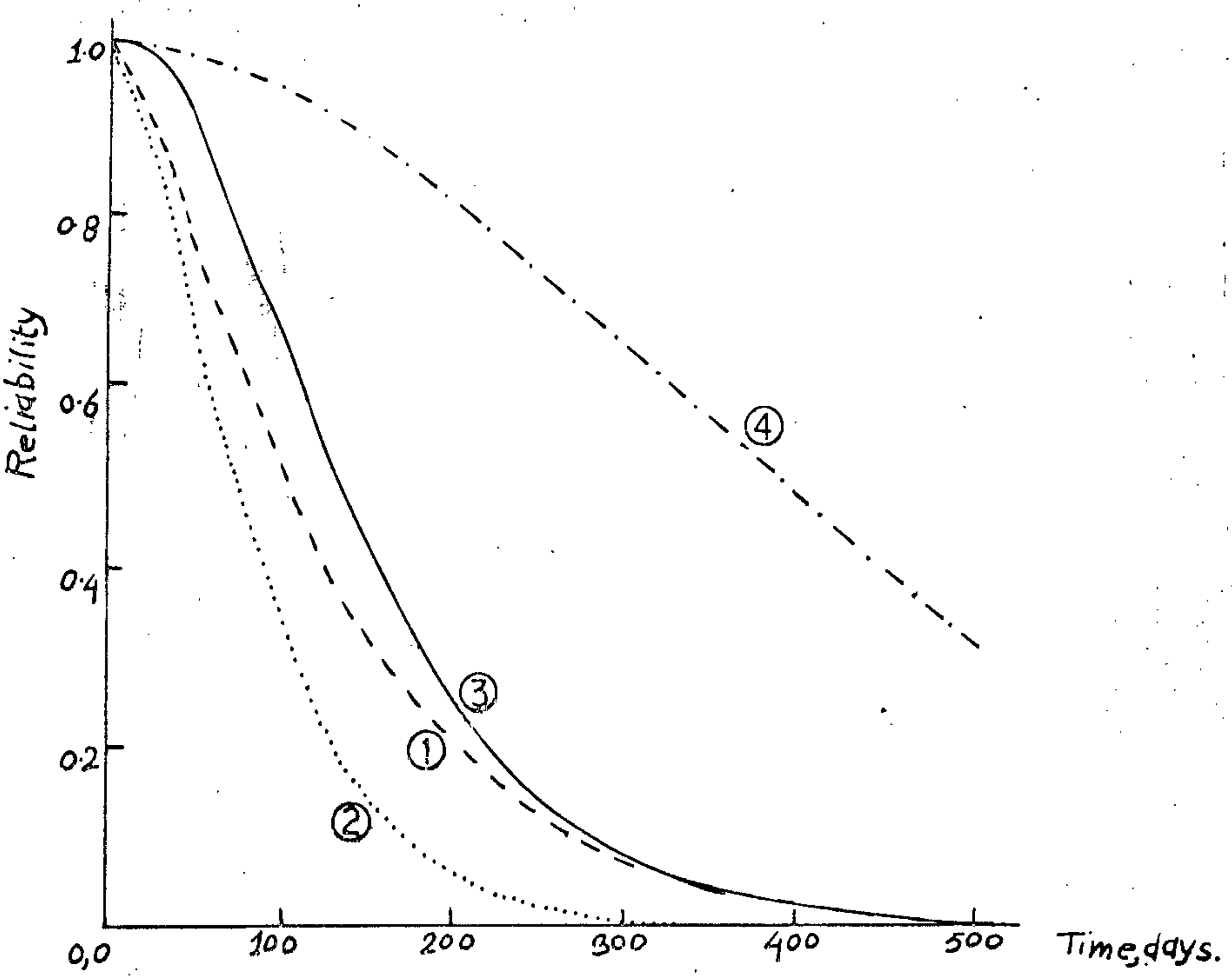


Figure 5.2.1 Reliability Vs. Time curves of Equipments :
(1) Gas turbine (P-GT 101 A); (2) Gas Turbine (P-GT 101 B); (3) Gas Turbine (P-GT 101 A,B); (4) Boiler feed water Pump (A-GA 202).

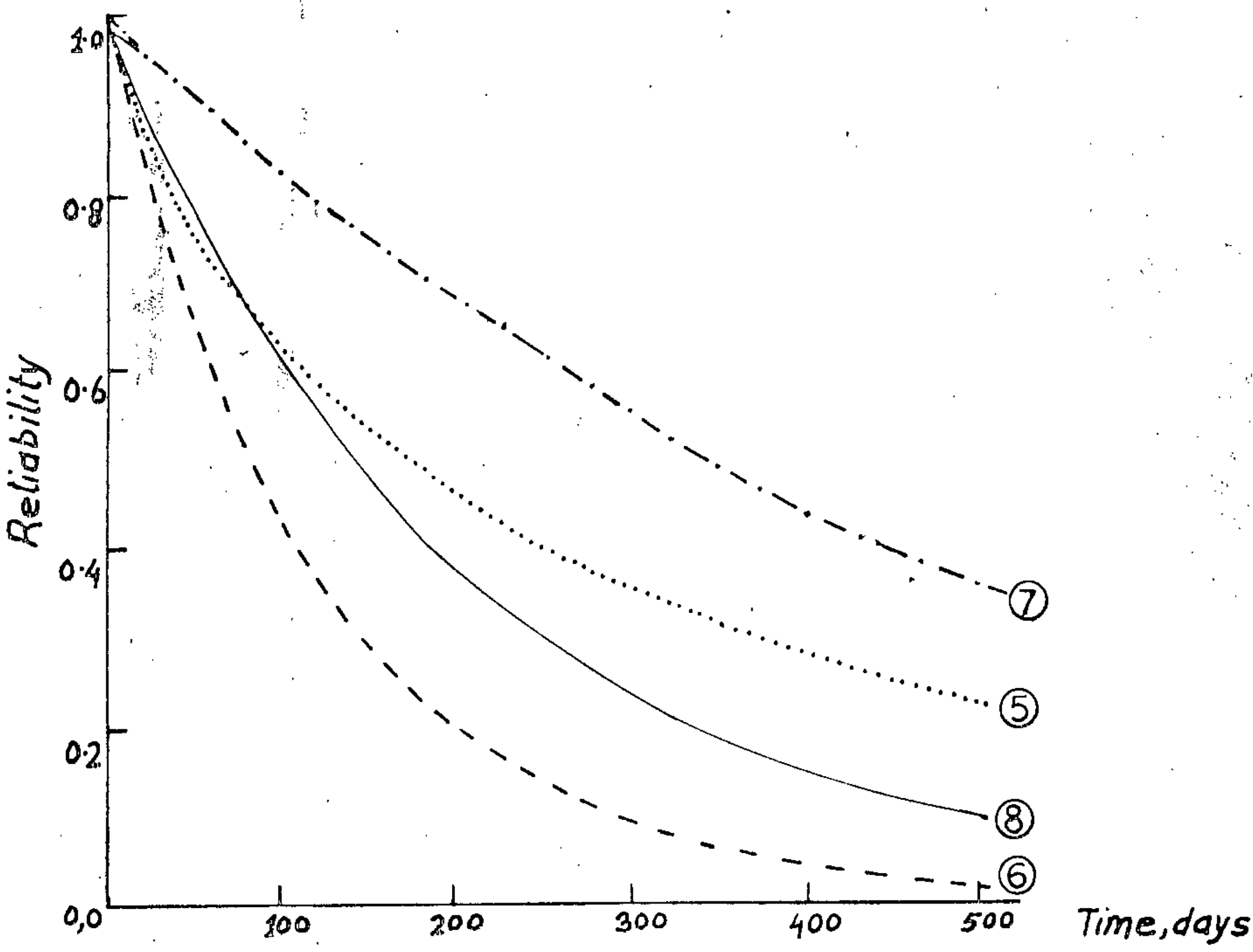


Figure 5.2.2 Reliability Vs. Time Curves of equipments : (5) F.D.F (A-GB 104 T); (6) Auxiliary boiler (A-FA 101) ; (7) A.T.B (A-GB 101 T & C); (8) I.D.F. (A-GB 102 T) ;

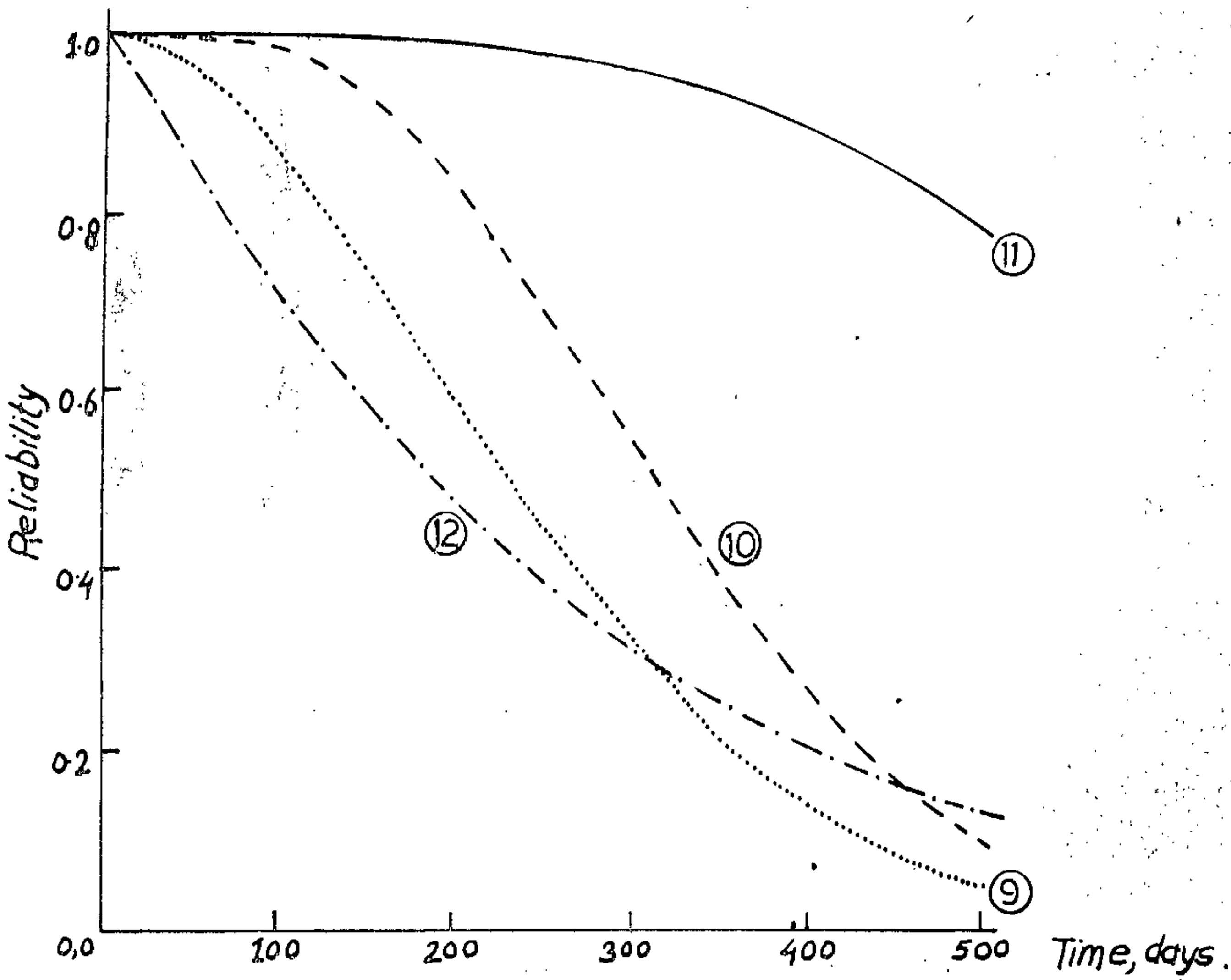


Figure 5.2.3 Reliability Vs. Time curves of Equipments :

(9) N.G. Booster Compressor(A-GB 106 A or B) :

(10) N.G.Booster Compressor(A-GB 106 A,B).

(11) Waste heat boiler (A-EC 107);

(12) Process gas Reboiler(A-EA 301).

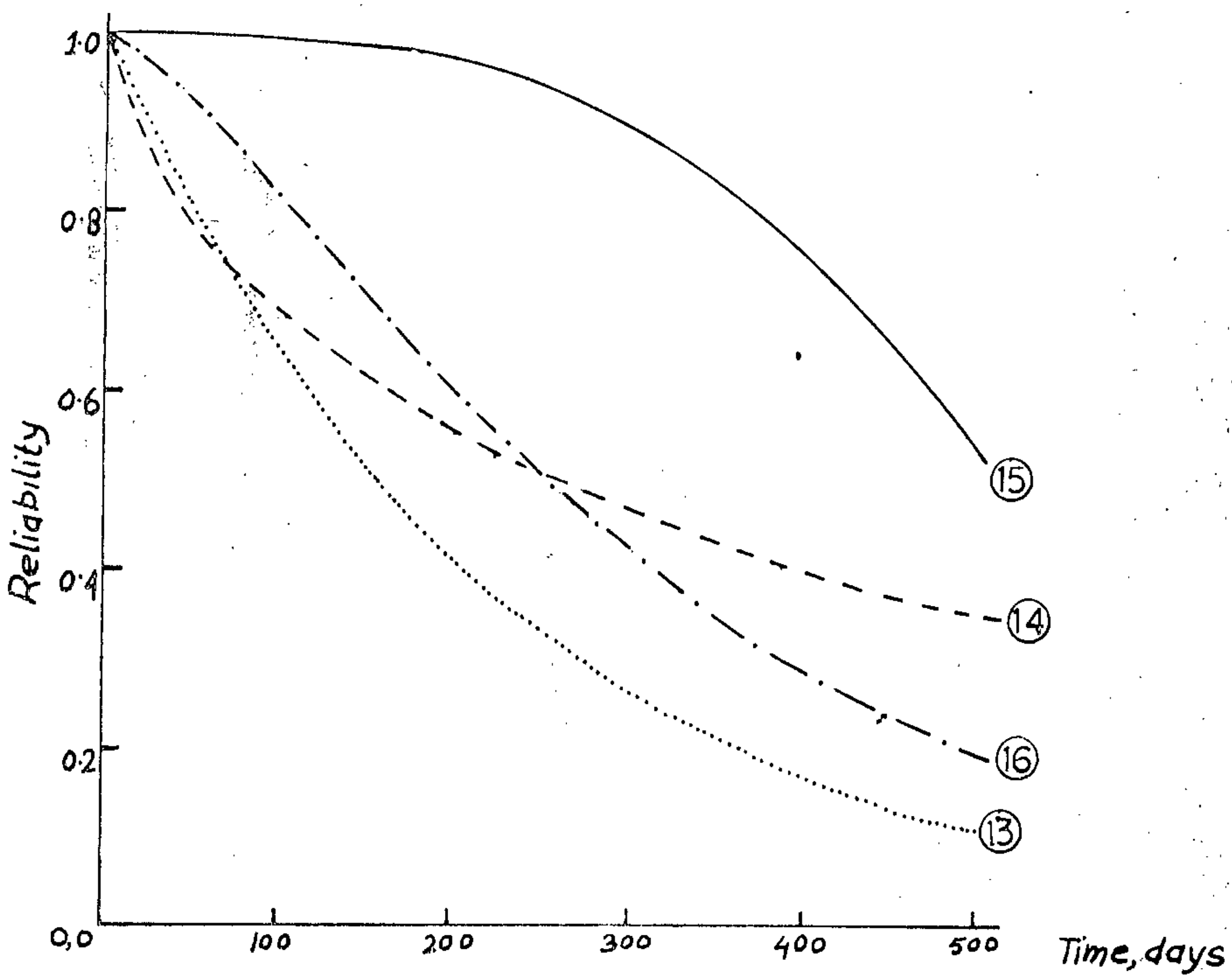


Figure 5.2.4 Reliability Vs. Time curves of Equipments : (13) CO_2 absorber(A-DA 301), (14) G.V.Solution Pump(A-GA 301) ; (15) Mist trap (A-DA 303) ; (16) Methanator effluent economizer(A-EA 401).

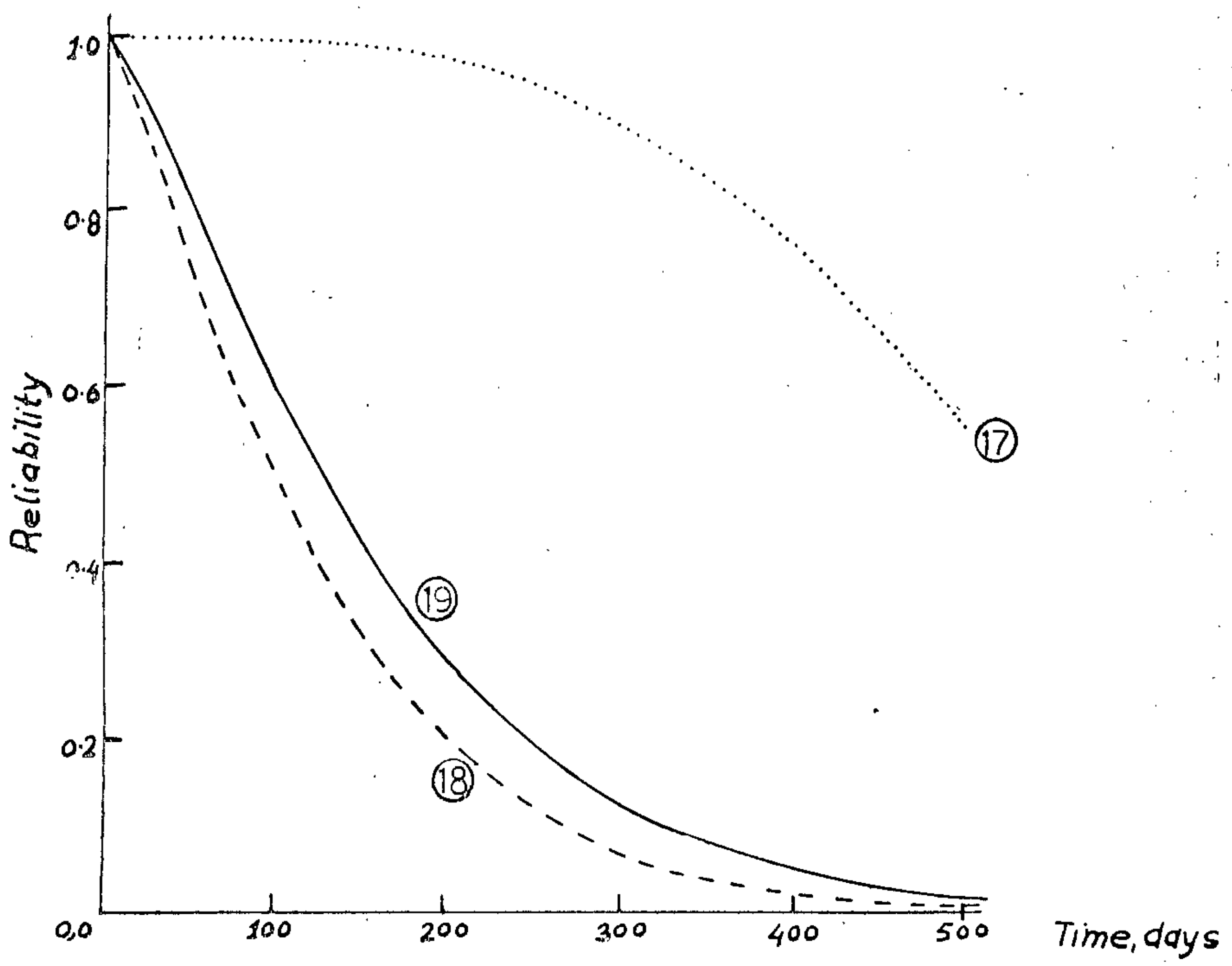


Figure 5.2.5 Reliability Vs. Time curves of Equipments : (17) Synthesis gas K.O. drum(A-FA 401); (18) R.T.B. (A-GC 501 T&C); (19) Hyper turbine (A-GB 501 T & C).

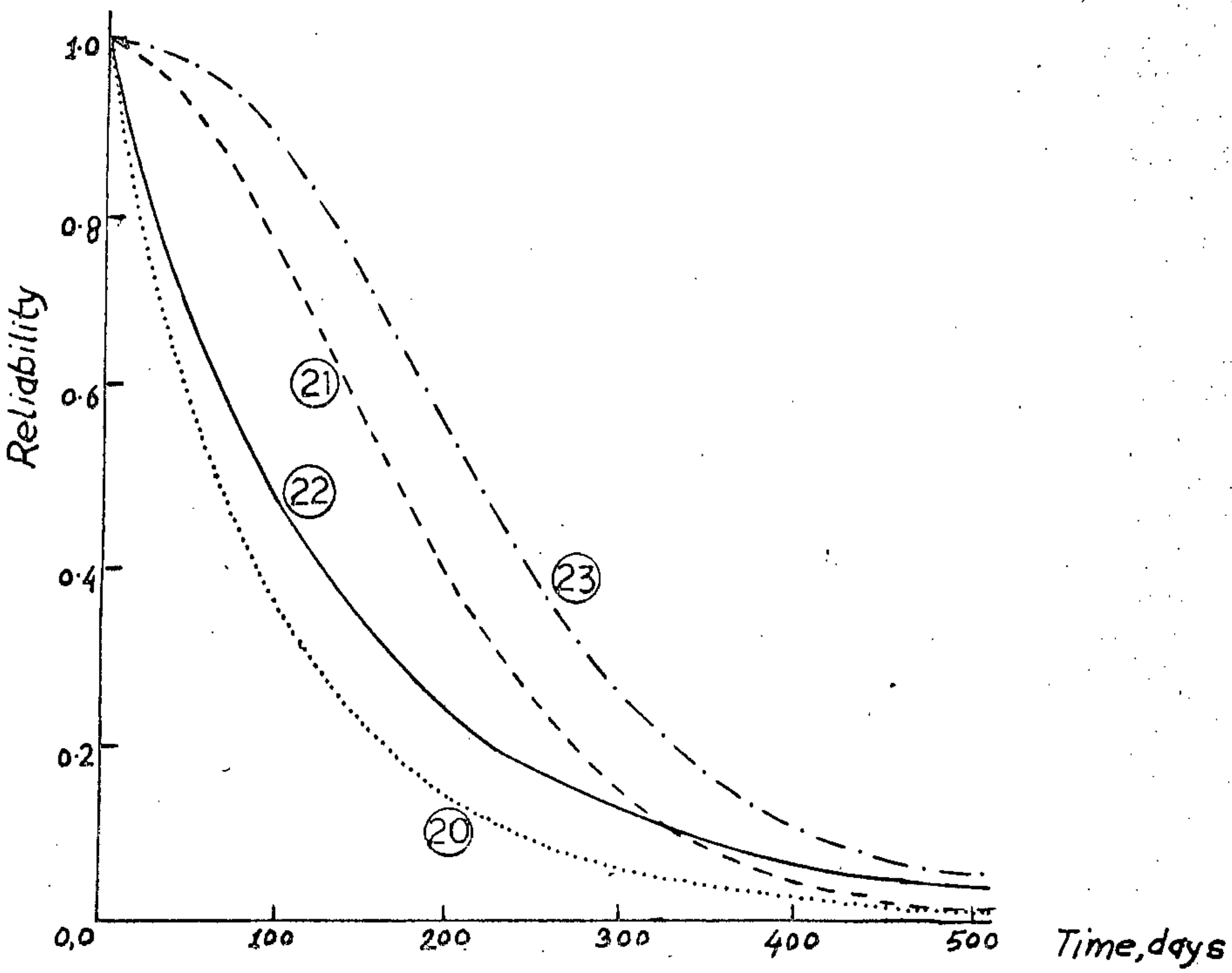


Figure 5.2.6 Reliability Vs. Time curves of Equipments :

(20) CO_2 booster Compressor(U-GB 101 T & C);

(21) CO_2 Main Compressor (U-GB 102 A) ;

(22) CO_2 Main Compressor(U-GB 102 B);

(23) CO_2 Main Compressor(U-GB 102 A,B).

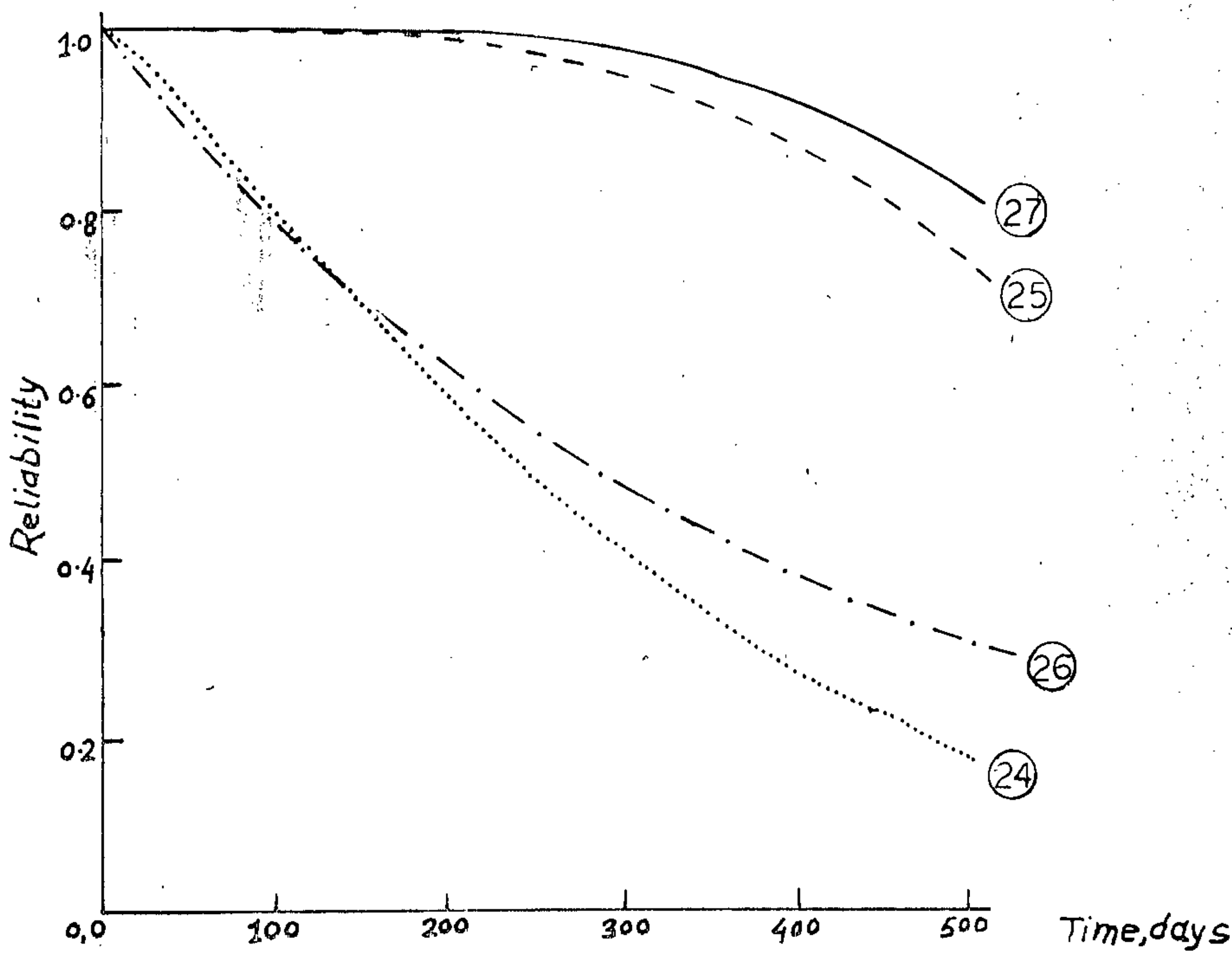


Figure 5.2.7 Reliability Vs. Time curves of Equipments :
(24) Suction common header valve of Ammonia Pump U-GA 101); (25) Ammonia preheater(U-EA 101 A);
(26) Ammonia preheater(U-EA 101 B);
(27) Ammonia preheater(U-EA 101 A,B).

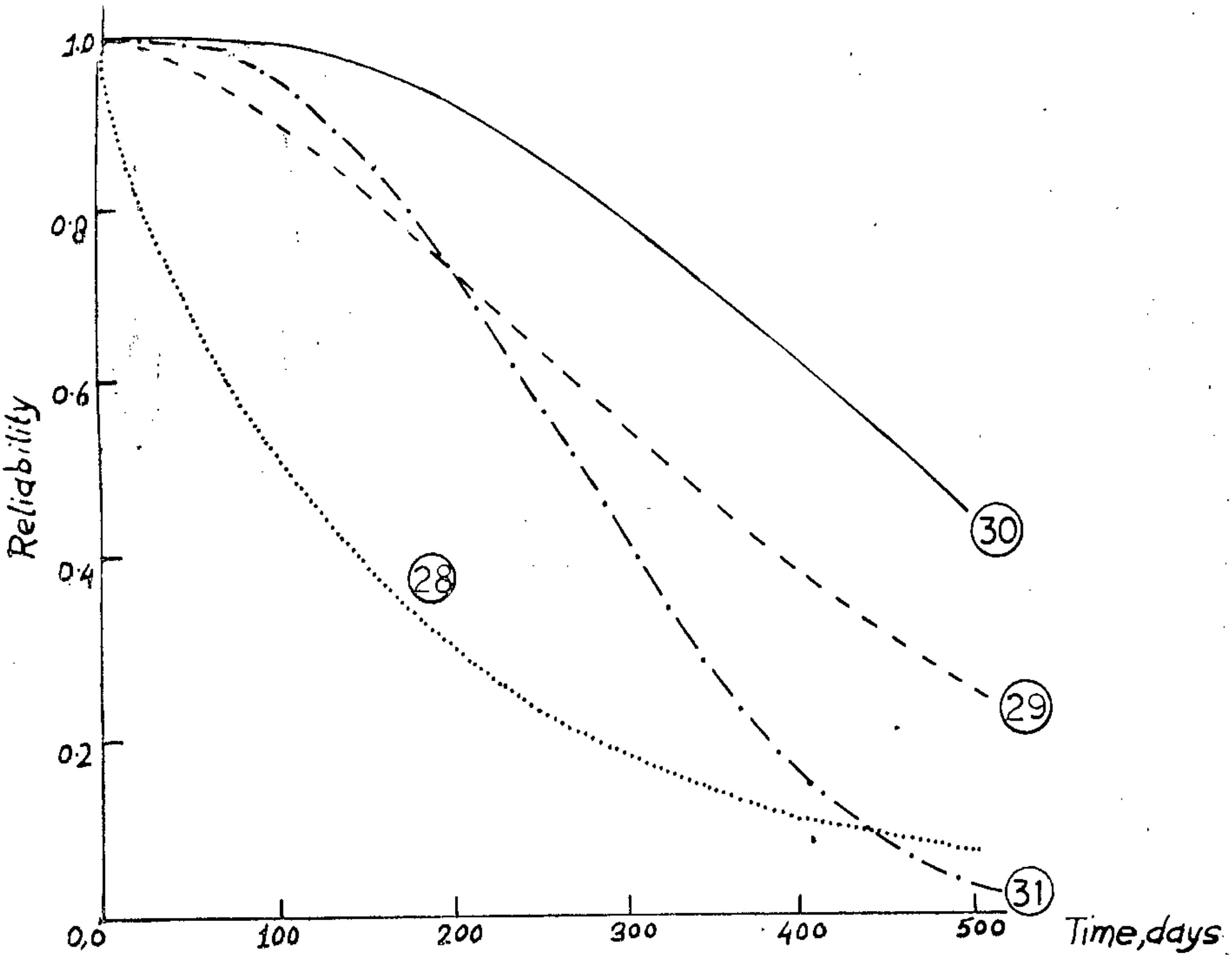


Figure 5.2.8 Reliability Vs. Time curves of Equipments :

(28) Suction common header valve of R.C.Pump(U-GA 102);

(29) Urea reactor(U-DC 101 A or B) ,

(30) Urea reactor(U-DC 101 A,B);

(31) High pressure decomposer(U-DA 201).

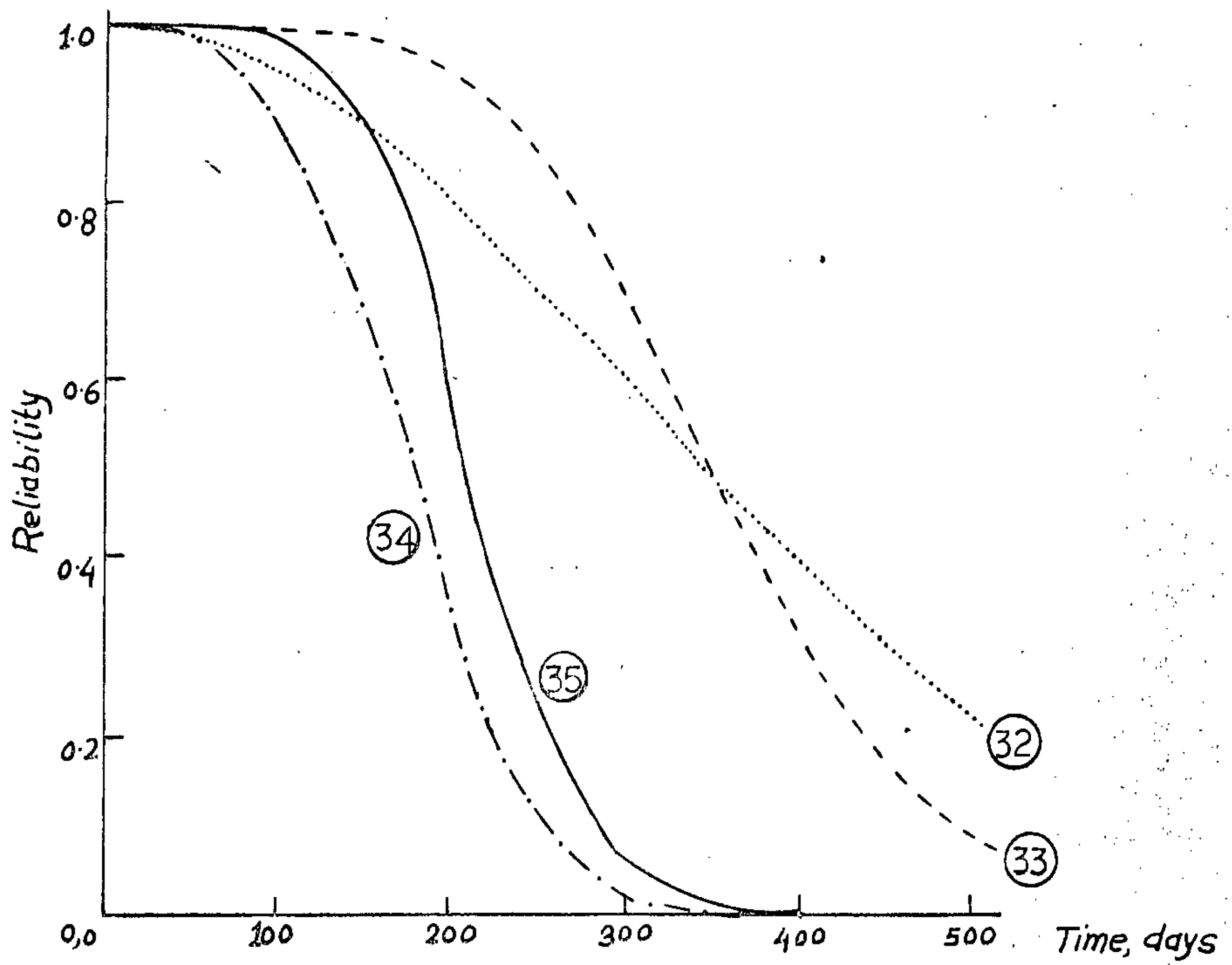


Figure 5.2.9 Reliability Vs.Time curves of Equipments : (32) Centrifuge (U-GF 201 A,B,C,D or E); (33) Centrifuge(U-GF 201 A-E); (34) No.2 belt conveyor(U-JD 204 A or B); (35) No.2 belt conveyor (U-JD 204 A,B).

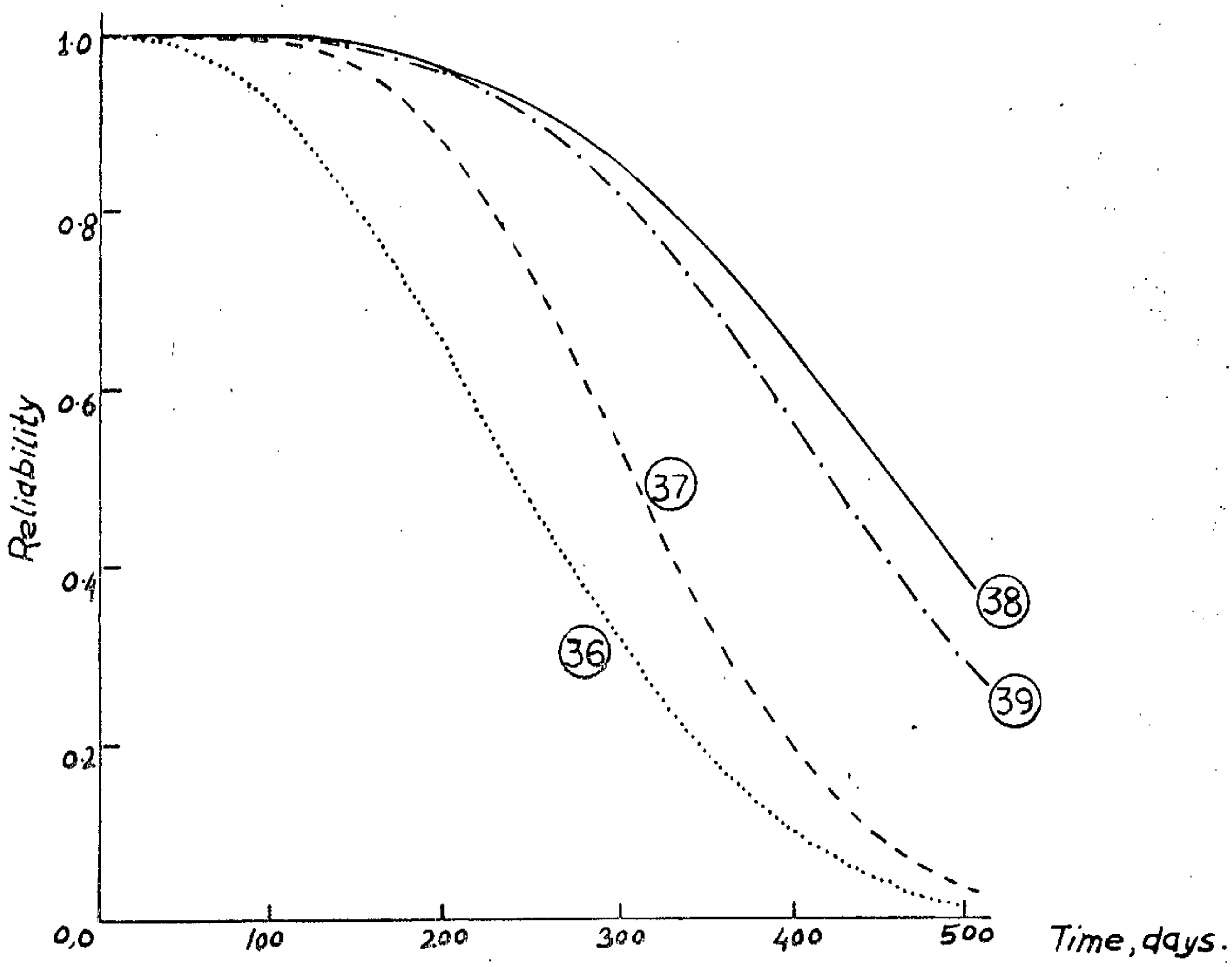


Figure 5.2.10 Reliability Vs. Time curves of Equipments :
(36) Melter(U-EA 301 A or B); (37) Melter(U-EA 301 A,B)
(38) Bucket Elevator(B-JD 102); (39) Belt Conveyor to
bulk storage (B-JD 103).

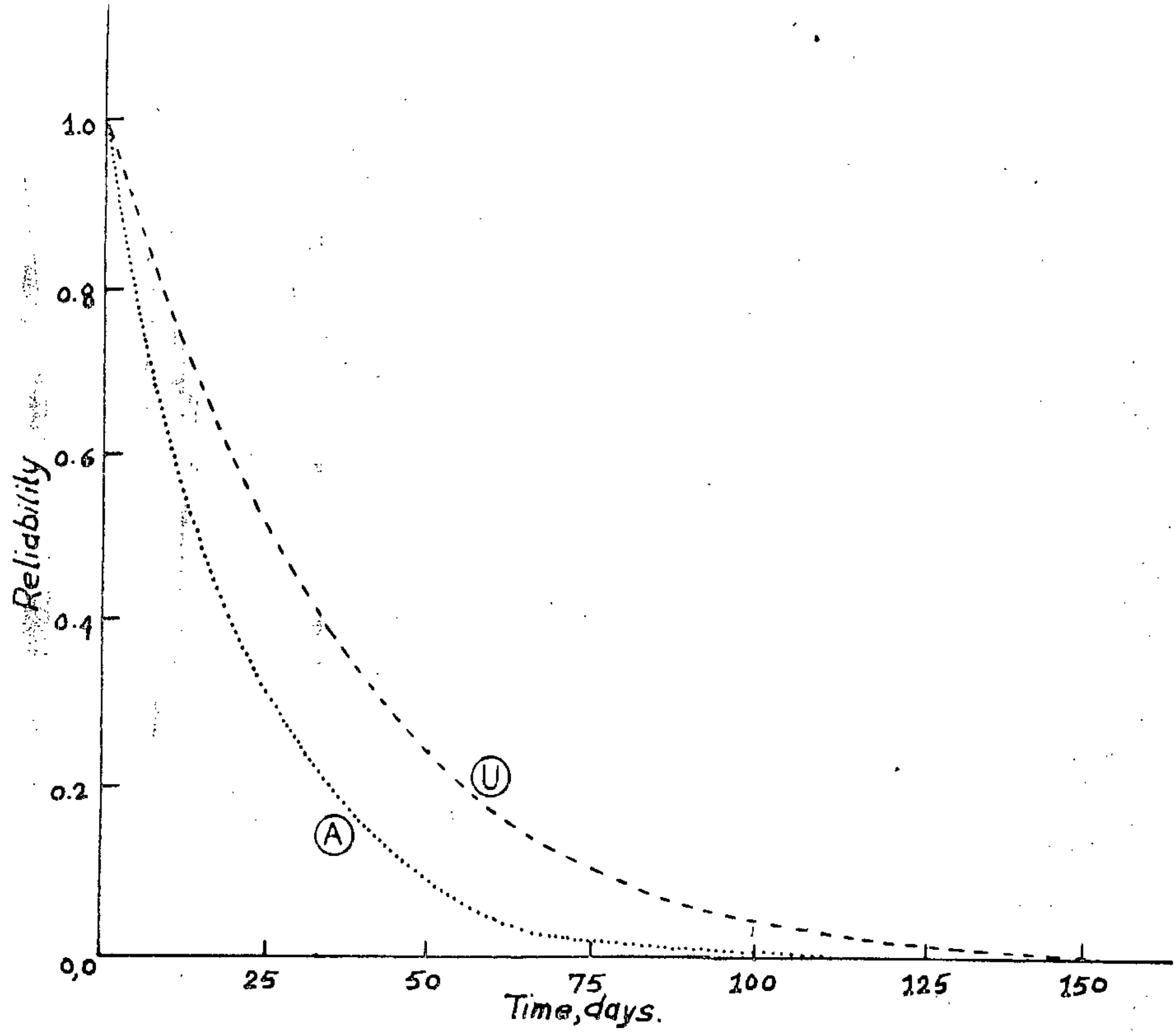


Figure 5.2.11 Reliability Vs. Time curves of plants :-

(A) Ammonia Plant; (U) Urea Plant.

CHAPTER 6

OPERATIONAL READINESS AND AVAILABILITY ASSESSMENT OF EQUIPMENTS

CHAPTER 6

OPERATIONAL READINESS AND AVAILABILITY ASSESSMENT OF EQUIPMENTS

6.1 Operational Readiness and Availability Assessment.

Availability and Operational readiness is an important consideration in relatively complex systems, such as Urea Fertilizer Factory Limited, Ghorasal, because high reliability of the system alone is not sufficient to ensure that the system will be available or ready to operate when needed. It is also necessary to ensure that it can be repaired quickly and that essential scheduled maintenance tasks can be performed quickly to reduce down time and consequently idle time of the system. So, in this chapter, Operational readiness and availability of each equipment and finally those of the Ammonia and Urea Plants are assessed. Results are shown in tables 6.1.1 and 6.1.2 respectively. The mean time between failures (MTBF) have been calculated by simple arithmatic averaging. In Tables 6.1.3 and 6.1.4 availability have been recalculated with MTBF from failure distribution parameters. Since this MTBF is slightly larger than MTBF by simple averaging, resulting availability is slightly greater.

Table 6.1.1 Operational Readiness And Availability Assessment of Ammonia Plant(by arithmatic averaging).

Equipments	Total Operating time (days) (1)	Total Idle time (days) (2)	Total down time (days) (3)	Total repair time (days) (4)	No. of repair (5)	No. of Failure (6)	M.T.T.R. (days) $(7)=\frac{(4)}{(5)}$	M.T.B.F. (days) $(8)=\frac{(1)}{(6)}$	Operational readiness $(9)=\frac{(1)+(2)}{(1)+(2)+(3)}$	Availability $(10)=\frac{(8)}{(7)+(8)}$
Gas turbine (P-GT101A)	960·27	24·73	234·74	117·40	10	10	11·74	96·02	0·8075	0·8910
Boiler feed water Pump (A-GA202)	901·13	142·57	153·39	14·49	4	4	3·62	225·28	0·8718	0·9841
F.D.F (A-GB104T)	901·16	144·84	149·42	14·00	2	4	7·00	225·29	0·8750	0·9698
Auxiliary boiler (A-FA101)	901·03	137·97	153·74	40·41	4	5	10·10	180·20	0·8711	0·9469
A.T.B (A-GB101T+C)	816·52	234·48	145·50	18·12	3	3	6·04	272·17	0·8783	0·9782
I.D.F. (A-GB102T)	816·56	233·44	154·33	16·00	2	3	8·00	272·18	0·8718	0·9714
N.G. booster compressor (A-GB106)	816·92	230·08	149·99	24·78	4	4	6·19	204·23	0·8746	0·9705
Waste heat boiler (A-EC107)	817·73	233·27	146·71	26·71	3	3	8·90	272·57	0·8775	0·9683
Process Gas reboiler (A-EA301)	817·15	229·85	150·13	13·80	3	3	4·60	272·38	0·8745	0·9833
CO_2 absorber (A-DA301)	819·09	212·91	165·57	23·90	3	3	7·96	273·03	0·8617	0·9716
G.V. Solution Pump (A-GA301)	820·39	222·61	157·37	19·75	4	4	4·93	205·09	0·8688	0·9765
Mist trap (A-DA303)	816·87	224·13	155·85	14·50	3	3	4·83	272·29	0·8697	0·9825

Table 6.1.1 (Continued)

Equipments	Total Operating time (days) (1)	Total Idle time (days) (2)	Total down time (days) (3)	Total repair time (days) (4)	No. of repair (5)	No. of failure (6)	M.T.T.R. (days) $(7)=\frac{(4)}{(5)}$	M.T.B.F (days) $(8)=\frac{(1)}{(6)}$	Operational readiness $(9)=\frac{(1)+(2)}{(1)+(2)+(3)}$	Availability $(10)=\frac{(8)}{(7)+(8)}$
Methanator effluent economizer (A-EA401)	817·88	218·12	161·86	29·80	3	3	9·93	272·62	0·8648	0·9648
Synthesis Gas K.O. drum (A-FA 401)	817·32	233·68	146·30	8·30	3	3	2·76	272·44	0·8778	0·9899
R.T.B (A-GC 501 T+C)	815·67	219·33	159·65	24·00	5	8	4·80	101·95	0·8663	0·9550
Hyper turbine (A-GB 501 T+C)	813·15	223·85	159·13	65·13	7	7	9·30	116·16	0·8669	0·9258
Ammonia Plant	813·15	0·00	384·71	267·19	37	44	7·22	18·48	0·6788	0·7190

Table 6.1.2 Operational Readiness And Availability Assessment of Urea Plant(By arithmatic averaging).

Equipments	Total operating time (days) (1)	Total Idle time (days) (2)	Total down time (days) (3)	Total repair time (days) (4)	No. of repair (5)	No. of failure (6)	M.T.T.R. (days) $(7)=\frac{(4)}{(5)}$	M.T.B.F. (days) $(8)=\frac{(1)}{(6)}$	Operational readiness $(9)=\frac{(1)+(2)}{(1)+(2)+(3)}$	Availability $(10)=\frac{(8)}{(7)+(\ )}$
CO_2 booster compressor (U-GB101T+C)	803.62	240.38	151.20	20.51	8	10	2.56	80.36	0.8734	0.9691
Gas turbine (P-GT 101B)	954.27	24.73	237.83	120.10	12	13	10.00	73.40	0.8045	0.8800
CO_2 main compressor (U-GB 102A)	792.47	249.56	148.04	53.30	4	6	13.30	132.07	0.8756	0.9085
CO_2 main compressor (U-GB102B)	803.43	249.56	145.63	50.82	5	8	10.16	100.42	0.8785	0.9081
Suction C.H. Valve of NH_3 Pump (U-GA101)	800.56	252.44	144.97	0.81	4	4	0.20	200.14	0.8789	0.9990
Ammonia Preheater (U-EA 101A)	798.43	254.57	144.21	2.20	3	3	0.73	266.14	0.8795	0.9972
Ammonia Preheater (U-EA 101B)	798.24	254.76	145.00	2.70	4	4	0.67	199.56	0.8789	0.9966
Suction C.H. Valve of R.C. Pump (U-GA102)	798.81	254.18	144.04	0.22	3	3	0.07	266.27	0.8796	0.9997
Urea reactor (U-DC 101B)	800.96	252.04	144.31	30.14	4	4	7.53	200.24	0.8794	0.9637
High Pressure decomposer (U-DA 201)	800.57	252.43	147.11	32.30	4	4	8.07	200.14	0.8774	0.9612
Centrifuge (U-GF 201A)	799.79	252.21	145.28	11.25	3	3	3.75	266.59	0.8786	0.9861
Centrifuge (U-GF 201E)	797.79	252.21	146.86	12.84	3	3	4.28	265.93	0.8772	0.9841

Table 6.1.2 (Continued)

Equipments	Total Operating time (days) (1)	Total Idle time (days) (2)	Total down time (days) (3)	Total repair time (days) (4)	No. of repair (5)	No. of failure (6)	M.T.T.R. (days) $(7)=\frac{(4)}{(5)}$	M.T.B.F. (days) $(8)=\frac{(1)}{(6)}$	Operational readiness $(9)=\frac{(1)+(2)}{(1)+(2)+(3)}$	Availability $(10)=\frac{(8)}{(7)+(8)}$
No 2 belt Conveyor (U-JD 204B)	798·07	252·93	145·64	5·54	5	5	1·10	159·61	0·8782	0·9931
Melter (U-EA 301A)	799·04	253·96	144·85	4·82	4	4	1·20	199·76	0·8790	0·9940
Bucket elevator (B-JD 102)	799·32	253·68	144·20	4·20	3	3	1·40	266·44	0·8795	0·9947
Belt conveyor to bulk storage (B-JD 103)	799·12	253·88	144·08	6·08	3	3	2·02	266·37	0·8796	0·9924
Urea Plant	800·57	192·37	205·08	116·50	28	39	4·16	20·52	0·8288	0·8314

Table 6.1.3 Availability Assessment of Equipments of Ammonia Plant by using MLE Method.

Equipments	(days) (7)	(MLE) (days) (11)	Availabity $(12) = \frac{(11)}{(7)+(11)}$
Gas turbine (P-GT101A)	11·74	130·85	0·9176
Boiler feed water Pump (A-GA202)	3·62	421·22	0·9914
F.D.F. (A-GB104T)	7·00	358·37	0·9808
Auxiliary boiler (A-FA101)	10·10	123·39	0·9243
A.T.B. (A-GB101T+C)	6·04	489·31	0·9878
I.D.F. (A-GB102T)	8·00	211·37	0·9635
N.G. booster compressor (A-GB106)	6·19	249·79	0·9758
Waste heat boiler (A-EC107)	8·90	669·98	0·9868
Process gas reboiler (A-EA301)	4·60	254·53	0·9822
CO_2 absorber (A-DA301)	7·96	228·64	0·9663
G.V. Solution Pump (A-GA301)	4·93	660·86	0·9925
Mist trap (A-DA303)	4·83	517·73	0·9907
Methanator effluent economizer (A-EA401)	9·93	316·40	0·9695
Synthesis gas K.O. drum (A-FA401)	2·76	520·78	0·9947
R.T.B. (A-GC501T+C)	4·80	124·74	0·9629
Hyper turbine (A-GB501T+C)	9·30	154·81	0·9433

Table 6.1.4 Availability Assessment of Equipments of Urea Plant by using MLE Method.

Equipments	M.T.T.R. (days) (7)	M.T.B.F. (MLE) (days) (11)	Availability (12)= $\frac{(11)}{(7)+(11)}$
CO_2 booster compressor (U-GB101T+C)	2.56	101.25	0.9753
Gas turbine (P-GT101B)	10.00	89.17	0.8991
CO_2 main compressor (U-GB102A)	13.30	184.09	0.9326
CO_2 main compressor (U-GB102B)	10.16	138.63	0.9317
Suction C.H.V. of NH_3 Pump (U-GA101)	0.20	301.52	0.9993
Ammonia Preheater (U-EA101A)	0.73	628.29	0.9988
Ammonia Preheater (U-EA101B)	0.67	410.18	0.9983
Suction C.H.V. of R.C. Pump (U-GA102)	0.07	175.36	0.9996
Urea reactor (U-DC101B)	7.53	370.50	0.9800
High pressure decomposer (U-DA201)	8.07	284.79	0.9724
Centrifuge (U-GF201A)	3.75	367.00	0.9898
Centrifuge (U-GF201E)	4.28	367.00	0.9884
No.2 belt conveyor (U-JD204)	1.10	179.31	0.9939
Melter (U-EA301A)	1.20	251.62	0.9952
Bucket elevator (B-JD102)	1.40	452.08	0.9969
Belt conveyor to bulk storage (B-JD103)	2.02	416.42	0.9951

CHAPTER 7

DISCUSSION ON RELIABILITY IMPROVEMENT

CHAPTER 7

DISCUSSION ON RELIABILITY IMPROVEMENT

7.1 Discussion on Reliability Improvement.

Comparing predicted values of reliability (Chapter-5) of individual equipment of the factory it has been observed that F.D.F. (A-GB 104 T), Auxiliary boiler (A-FA 101), GV solution pump(A-GA 301) and RTB (A-GC 501 T&C) in Ammonia Plant and Gas Turbine (P-GT 101 B), CO_2 booster compressor (U-GB 101 T&C) and CO_2 Main Compressor (U-GB 102 B) in Urea Plant Contributes relatively lower values of reliability. Now it necessitates the analysis of the failure history of the above mentioned equipments individually to find the causes for which poor reliability results. Actually in continuous production plant, failure free equipment are rarely feasible and failure may occur from various causes of troubles. So, it is advisable to find the sources of major faults and then preventive measures would be taken for the same to improve reliability.

In this context, a list of individual equipments showing different fauls during the period under consideration is prepared in table 7.1.1 for ammonia plant and in table 7.1.2 for Urea Plant. Total faults per equipment are also shown at the last column of the table. It is noted here that these tables are prepared by analysing the failure history of the factory.

Table 7.1.1 Troubles of Equipment in Ammonia Plant.

Equipments.	No.of Faults Instrumental	Electrical	Mechanical	Wear-out	Operational	Total faults for equipments
Gas Turbine(P-GT 101A)	2	5	-	-	-	7
Boiler feed water pump (A-GA 202).	-	1	-	1	-	2
FDF(A-GB 104 T)	3	-	-	-	1	4
Auxiliary boiler (A-FA 101).	2	-	-	1	-	3
ATB (A-GB 102T&C)	-	1	-	1	-	2
IDF(A-GB 102 T)	-	-	-	-	1	1
NG Booster Compressor	2	-	-	-	1	3
Waste Heat Boiler (A-EC 107	-	-	-	1	-	1
Process gas reboiler (A-EA 301).	-	-	-	1	-	1
CO_2 absorber(A-DA 301)	-	-	-	1	-	1
GV.Solution Pump (A-GA 301).	-	-	2	-	-	2
Mist trap(A-DA 303)	-	-	-	1	-	1
Methanator effluent Economizer(A-EA 401)	-	-	-	1	-	1
Synthesis gas K.O.drum (A-FA 401).	-	-	-	1	-	1
RTB (A-GC 501 T&C)	5	-	1	1	1	8
Hyper turbine (A-GB 501 T&C)	-	1	3	-	1	5
Total	14	8	6	10	5	43

Table 7.1.2 Troubles of Equipment in Urea Plant.

Equipments	No. of Faults					Total faults for Equipments.
	Instrumental	Electrical	Mechanical	Wear-out	Operational	
CO_2 booster compressor (U-GB 101 T&C)	1	-	5	3	-	9
Gas Turbine(P-GT 101B)	4	6	-	-	-	10
CO_2 Main Compressor (U-GB 102 A)	1	-	1	3	-	5
CO_2 Main Compressor (U-GB 102B)	1	-	3	2	-	6
Suction common header Valve of NH_3 Pump (U-GA 101)	-	-	-	3	-	3
Ammonia preheater (U-EA 101 B)	-	-	-	2	-	2
Ammonia preheater U-EA 101 A	-	-	-	1	-	1
Suction common header valve of R.C. Pump (U-GA 102)	-	-	-	1	-	1
Urea reactor(U-DC 101B)	1	-	-	1	-	2
High pressure decomposer(U-DA 201)	-	-	1	1	-	2
Centrifuge(U-GF 201E)	-	-	-	1	-	1
Centrifuge(U-GF 201A)	-	-	-	1	-	1
No.2 belt conveyor (U-JD 204 B)	-	-	-	3	-	3
Melter(U-EA 301 A)	-	-	-	2	-	2
Bucket elevator (B-JD 102)	-	-	-	1	-	1
Belt conveyor to bulk storage(B-JD 103).	-	-	-	1	-	1
Total	8	6	10	26	-	50

From tables 7.1.1 and 7.1.2, it has been found that major faults appeared in F.D.F. Auxiliary boiler and R.T.B. due to instrumental (including safety trip systems) troubles, in gas turbine due to Electrical troubles and in G.V. Solution Pump, CO_2 booster compressor and CO_2 Main Compressor due to mechanical troubles. Now question arises what would be the Optimal policy to improve reliability either utilizing proper technology to reduce major faults or installing stand by unit. Before coming to a conclusion, it will be useful to predict the reliability of each identified equipment for the following cases :

1. Excluding major faults of each identified equipment.
2. Considering stand by unit of each identified equipment.

Case - 1:

For predicting reliability of each above mentioned equipment after excluding major faults, it is first required to calculate the operating time and then Weibull parameters are to be estimated, all of which are shown in table 7.1.3. The reliability are then calculated with the parameters obtained in table 7.1.3 and shown in table 7.1.4.

Table 7.1.3 Weibull parameters estimation of identified equipments after excluding major faults (Original values are given in parenthesis).

Equipments	Running date From	Running date To	Operating time (days)	Idle time (days)	Down time (days)	Repair time (days)	Shape parameter	Scale parameter (days)	M.T.B.F. (days)	Standard deviation	Method applied	Remarks.
F.D.F. (A-GB 104T)	16-07-77	08-10-77	60.66	23.34	2.77	0.00						Excluding Instrument and safety system faults.
	11-10-77	02-05-78	153.45	49.55	78.00	7.00	0.95	228.88	234.30	246.61	SEQLIM	
	19-07-78	21-08-80	687.05	71.95	66.00	7.00	(0.72)	(291.86)	(358.37)			
Auxiliary boiler (A-FA 101)	16-07-77	02-05-78	216.03	63.97	78.00	20.00						
	19-07-78	06-09-78	49.00	0.00	4.00	0.16	0.90	207.37	218.25	242.81	-do-	-do-
	10-09-78	21-08-80	637.39	72.60	66.00	20.00	(0.97)	(122.00)	(123.39)			
R.T.B. (A-GC 501T&C)	16-07-77	21-11-77	65.13	60.87	3.34	1.70						
	24-11-77	29-03-78	99.45	25.55	5.18	3.90						
	04-04-78	02-05-78	19.88	7.12	78.00	9.00	1.42	267.06	242.93	173.03	MLE	-do-
	19-07-78	11-11-78	406.84	71.16	2.00	0.00	(1.22)	(133.01)	(124.74)			
	13-11-79	21-08-80	223.37	55.63	66.00	9.00						

Table 7.1.3 (Continued)

Equipments	Running date		Operating time	Idle time	Down time	Repair time	Shape parameter	Scale parameter	M.T.B.F.	Standard deviation	Method applied	Remarks.
	From	To	(days)	(days)	(days)	(days)		(days)				
CO_2 booster Compressor (U-GB 101T&C)	16-07-77	03-12-77	72.89	67.11	1.76	0.41						Excluding Mechanical faults.
	05-12-77	15-02-78	38.27	33.73	0.98	0.33						
	16-02-78	02-05-78	70.31	4.69	78.00	9.00	0.96	225.35	229.60	239.23	MIE	
	19-07-78	18-12-78	128.50	23.50	0.21	0.00	(0.88)	(95.00)	(101.25)			
	18-12-78	21-08-80	493.05	111.95	66.00	9.00						
	26-10-80	11-02-81	97.81	10.19	3.83	2.50						
Gas Turbine (P-GT 101B)	22-06-77	19-07-77	27.00	0.00	0.80	0.70						Excluding Electrical faults.
	19-07-77	03-09-77	45.00	0.00	5.48	5.00						
	09-09-77	02-05-78	220.00	0.00	78.00	15.00						
	19-07-78	20-12-78	153.00	0.00	0.35	0.00	1.22	225.63	211.56	174.50	MIE	
	21-12-78	20-09-79	240.27	24.73	49.00	49.00	(1.43)	(98.06)	(89.17)			
	08-11-79	12-06-80	210.00	0.00	10.25	10.00						
	22-06-80	21-06-80	59.00	0.00	66.00	15.00						
Co_2 Main Compressor (U-GB 102B)	16-07-77	02-05-78	282.30	107.70	78.00	25.00	1.12	318.51	305.67	273.20	MIE	
	19-07-78	06-11-79	403.83	71.17	0.58	0.38						
	06-11-79	12-04-80	114.72	42.27	0.44	0.24	(0.91)	(132.31)	(138.63)			
	12.04-80	21-08-80	102.58	28.42	66.00	25.00						

Table 7.1.4 Reliability Prediction of Identified Equipments After Excluding major faults.

Equipments.	β	η	Time, days.												
			0	25	50	75	100	150	200	250	300	350	400	450	500
			Reliability												
F.D.F. (A-GB 104 T)	0.95	228.88	1	0.8851	0.7900	0.7071	0.6342	0.5120	0.4148	0.3370	0.2744	0.2237	0.1827	0.1494	0.1223
Aux. boiler (A-FA 101)	0.90	207.37	1	0.8616	0.7573	0.6700	0.5952	0.4737	0.3798	0.3062	0.2480	0.2015	0.1642	0.1342	0.1099
R.T.B. (A-GC 501 T+C)	1.42	267.06	1	0.9659	0.9115	0.8481	0.7804	0.6435	0.5151	0.4023	0.3074	0.2303	0.1695	0.1227	0.0874
CO_2 booster comp. (U-GB 101 T+C)	0.96	225.35	1	0.8859	0.7900	0.7062	0.6322	0.5083	0.4099	0.3312	0.2681	0.2173	0.1764	0.1433	0.1165
Gas Turbine (P-GT 101 T)	1.22	225.63	1	0.9339	0.8529	0.7703	0.6903	0.5446	0.4218	0.3219	0.2427	0.1811	0.1338	0.0981	0.0713
CO_2 main comp. (U-GB 102 B)	1.12	318.51	1	0.9438	0.8818	0.8204	0.7609	0.6503	0.5522	0.4665	0.3925	0.3291	0.2750	0.2293	0.1906
Gas Turbine (P-GT 101 A.B)			1	0.9925	0.9638	0.9146	0.8500	0.6977	0.5441	0.4097	0.3013	0.2182	0.1564	0.1114	0.0789

Case - 2:

In reliability assessment of stand-by equipment, it is assumed that the failure pattern of this equipment will be similar to the principal equipment. So, both units will have identical failure distribution and reliability. The formula used in calculating the reliability of each proposed stand-by systems are given as

$$R_s = 1 - (1 - R)^2$$

Where R_s = Reliability of stand-by system

R = Reliability of existing unit.

The reliability calculations are shown in table 7.1.5.

Table 7.1.5 Reliability Prediction of Identified Equipments Assuming Standby Redundant System of Each.

Standby Redundant System of Equipment:	Time, days												
	0	25	50	75	100	150	200	250	300	350	400	450	500
	Reliability												
F.D.F (A-GB104T)	1	0.9775	0.9400	0.9017	0.8628	0.7868	0.7156	0.6504	0.5910	0.5374	0.4889	0.4451	0.4057
Aux. boiler (A-FA 101)	1	0.9625	0.8819	0.7846	0.6846	0.5024	0.3580	0.2509	0.1742	0.1201	0.0826	0.0567	0.0388
R.T.B. (A-GC501T+C)	1	0.9850	0.9316	0.8464	0.7434	0.5295	0.3487	0.2173	0.1300	0.0755	0.0427	0.0236	0.0129
CO_2 booster comp. (U-GB 101 T+C)	1	0.9293	0.8119	0.6906	0.5790	0.3982	0.2703	0.1827	0.1235	0.0837	0.0569	0.0388	0.0266
Gas turbine (P-GT 101B)	1	0.9825	0.8993	0.7557	0.5871	0.2932	0.1210	0.0435	0.0139	0.0039	0.0009	0.0001	0.00005
CO_2 main comp. (U-GB 102B)	1	0.9611	0.8856	0.7981	0.7090	0.5455	0.4117	0.3076	0.2284	0.1693	0.1252	0.0927	0.0685
CO_2 main comp. (U-GB 102A,B)	1	0.9990	0.9906	0.9681	0.9282	0.8017	0.6401	0.4793	0.3420	0.2371	0.1622	0.1114	0.0772

For comparison, reliability Vs. time curves of each identified equipment are drawn in figures 7.1.1 to 7.1.6. In each figure, there are three curves showing the following:

Curve - A : Reliability Vs. time curve of existing equipment.

Curve - B : Reliability Vs. time curve of existing equipment after excluding major faults and

Curve - C : Reliability Vs. time curve of stand-by system of the existing equipment.

Reliability Vs. time curve of F.D.F. (A-GB 104 T) are shown in figure 7.1.1, for different cases. It has been found that reliability (Curve -B) of the equipment is not sufficiently improved though major faults are excluded; rather after 100 days of Operation, reliability decreases below that of existing one (Curve - A), which is not expected; because in that particular case reliability should be improved, since major faults are excluded. The poor reliability resulted may be due to the fewer no. of failures used in estimating shape parameter for the equipment after excluding major faults.

But if a stand-by unit of F.D.F. is introduced, a sharp reliability improvement of the equipment is obtained (Curve-C). It should be pointed here that other factors e.g.; Cost involvement, availability of power, space facilities etc, are to be considered before installing any stand-by unit.

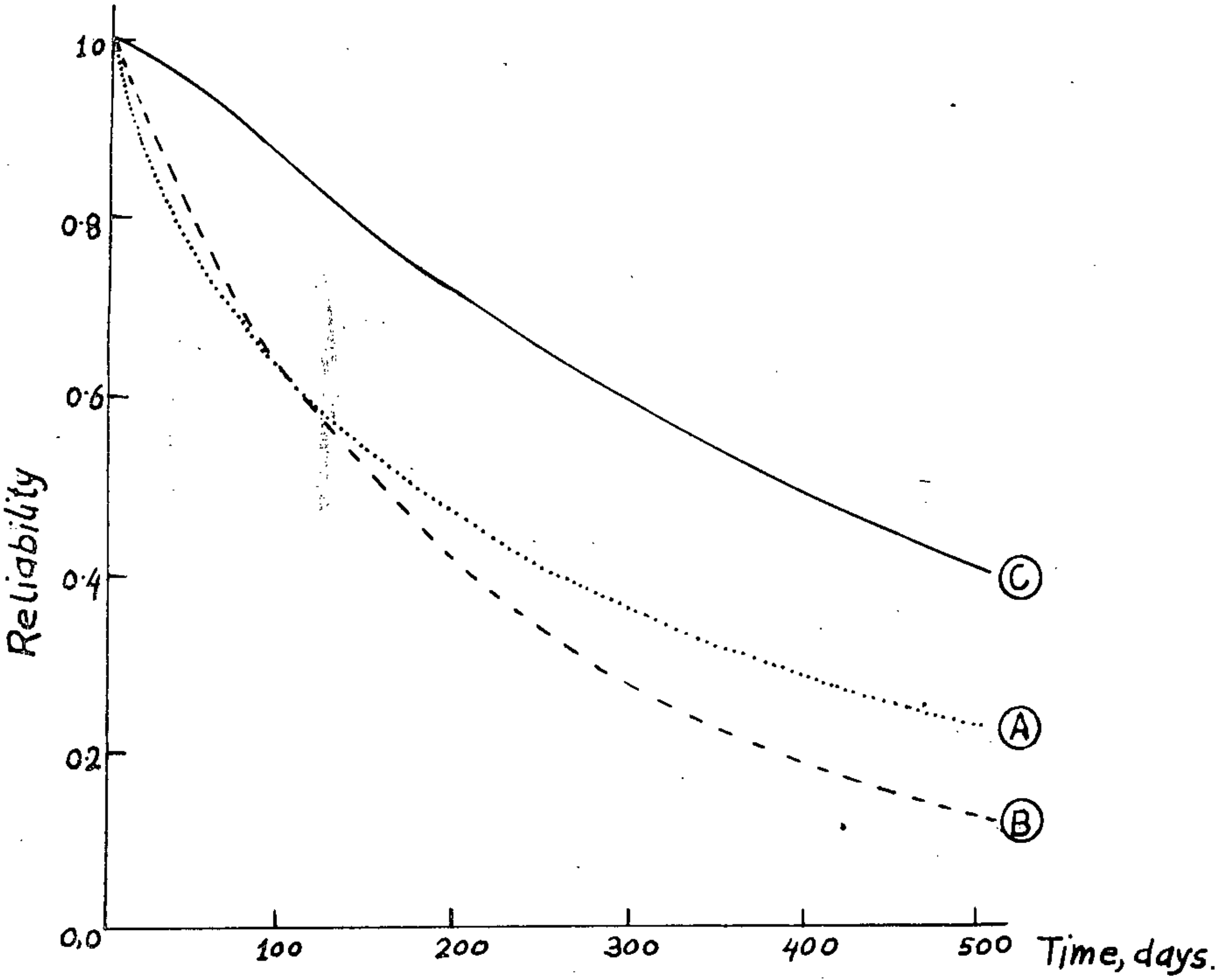


Figure 7.1.1 Reliability Vs. Time curve of F.D.F(A-GB 104 T): (A) Existing condition; (B) Excluding major Faults & (C) Standby system.

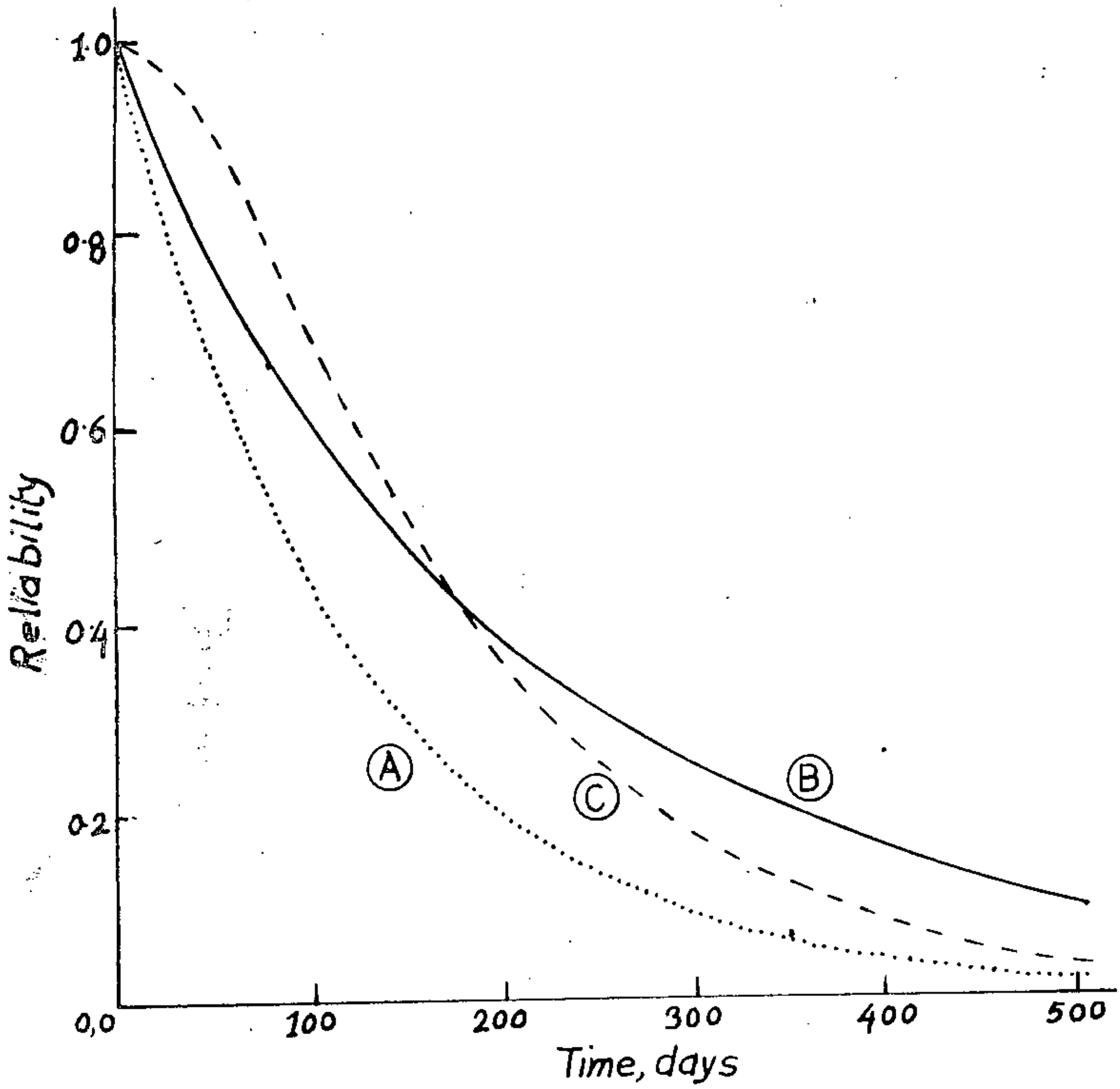


Figure 7.1.2 Reliability Vs. Time curve of Auxiliary boiler(A-FA 101) : (A) Existing condition; (B) Excluding major faults & (C) standby system.

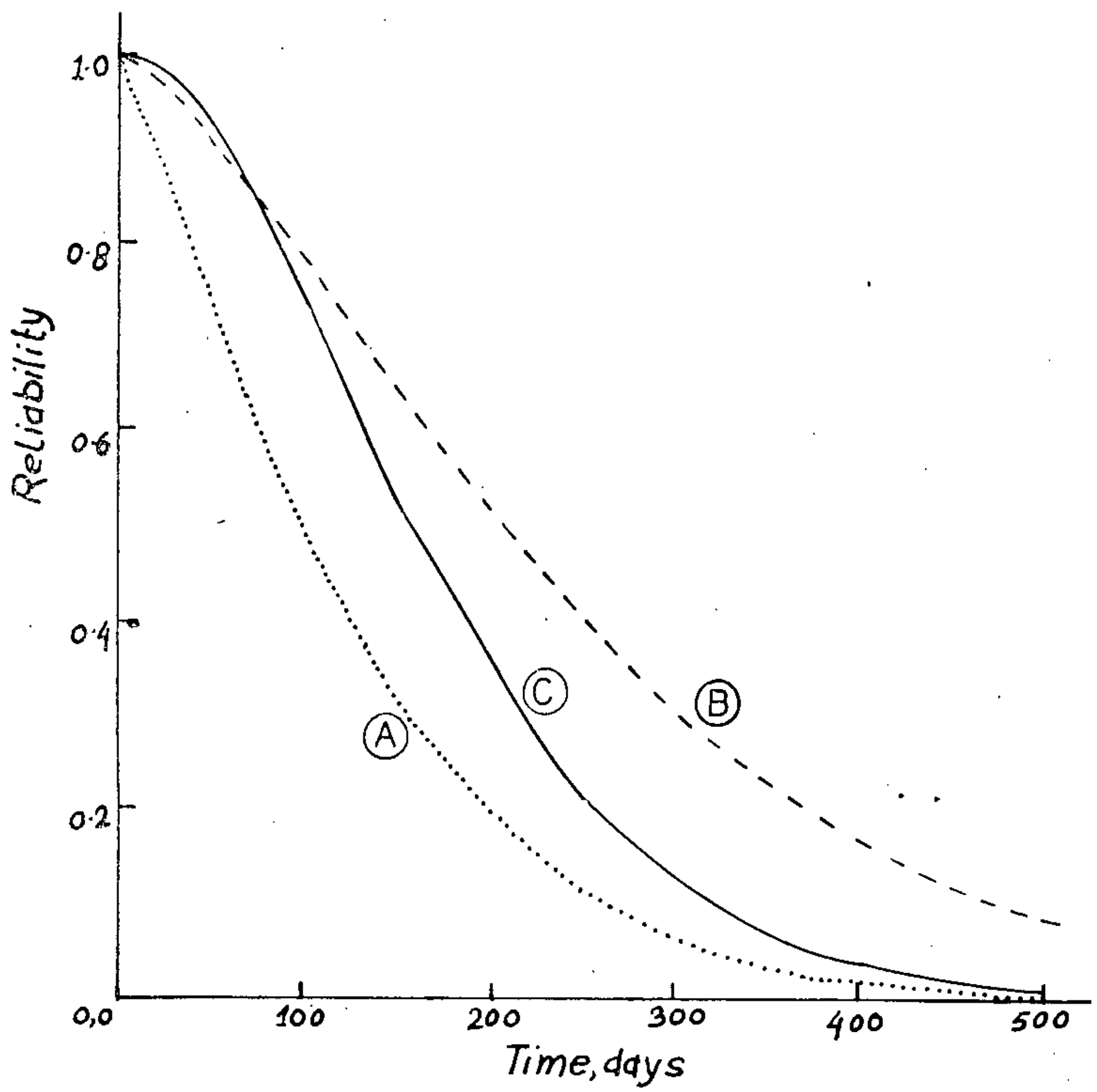


Figure 7.1.3 Reliability Vs. Time curve of R.T.B(A-GC 501T&C): (A) Existing condition; (B) Excluding major faults & (C) Standby system.

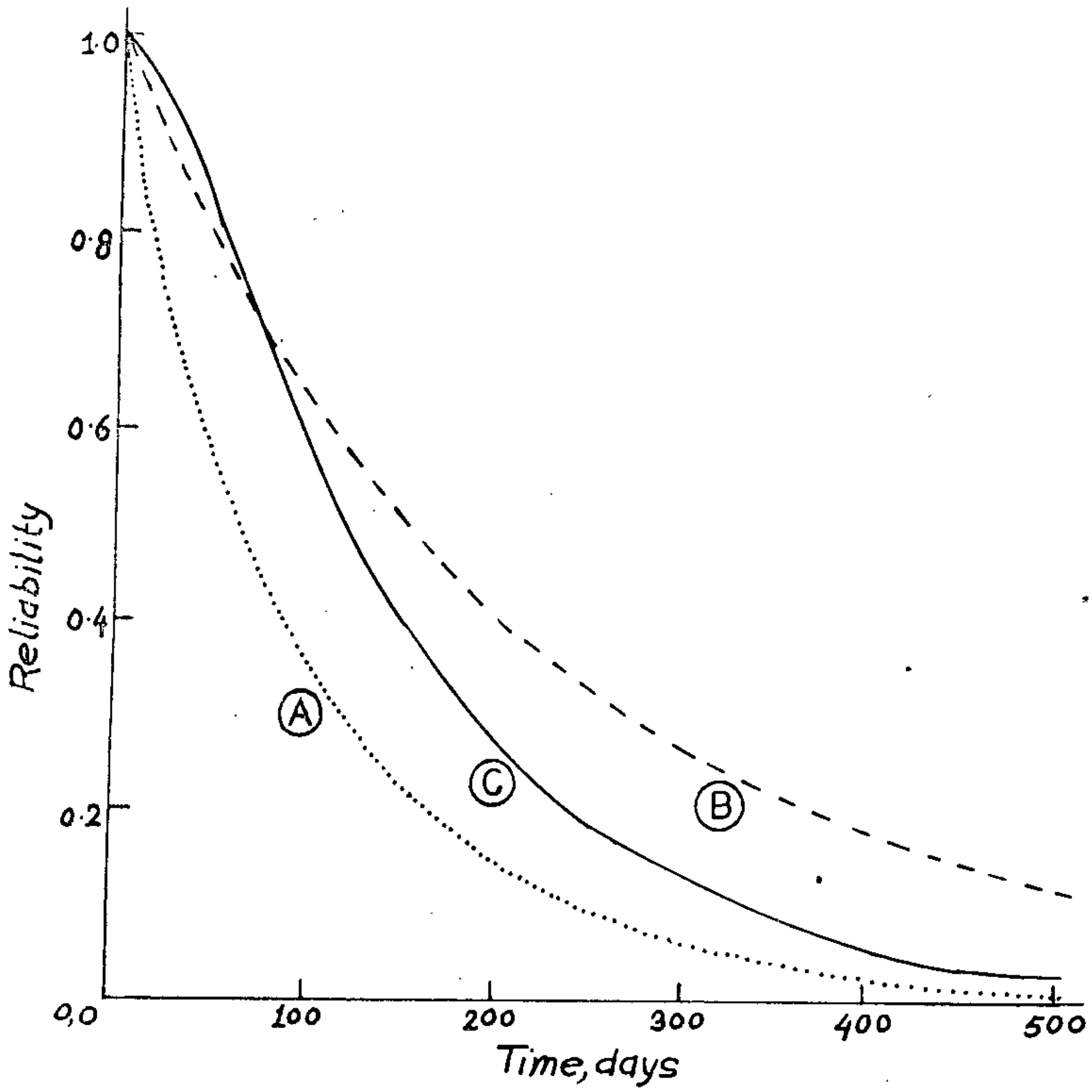


Figure 7.1.4 Reliability Vs. Time curve of CO_2 booster compressor(U-GB 101 T & C) : (A) Existing condition ; (B) Excluding major faults & (C) Standby system.

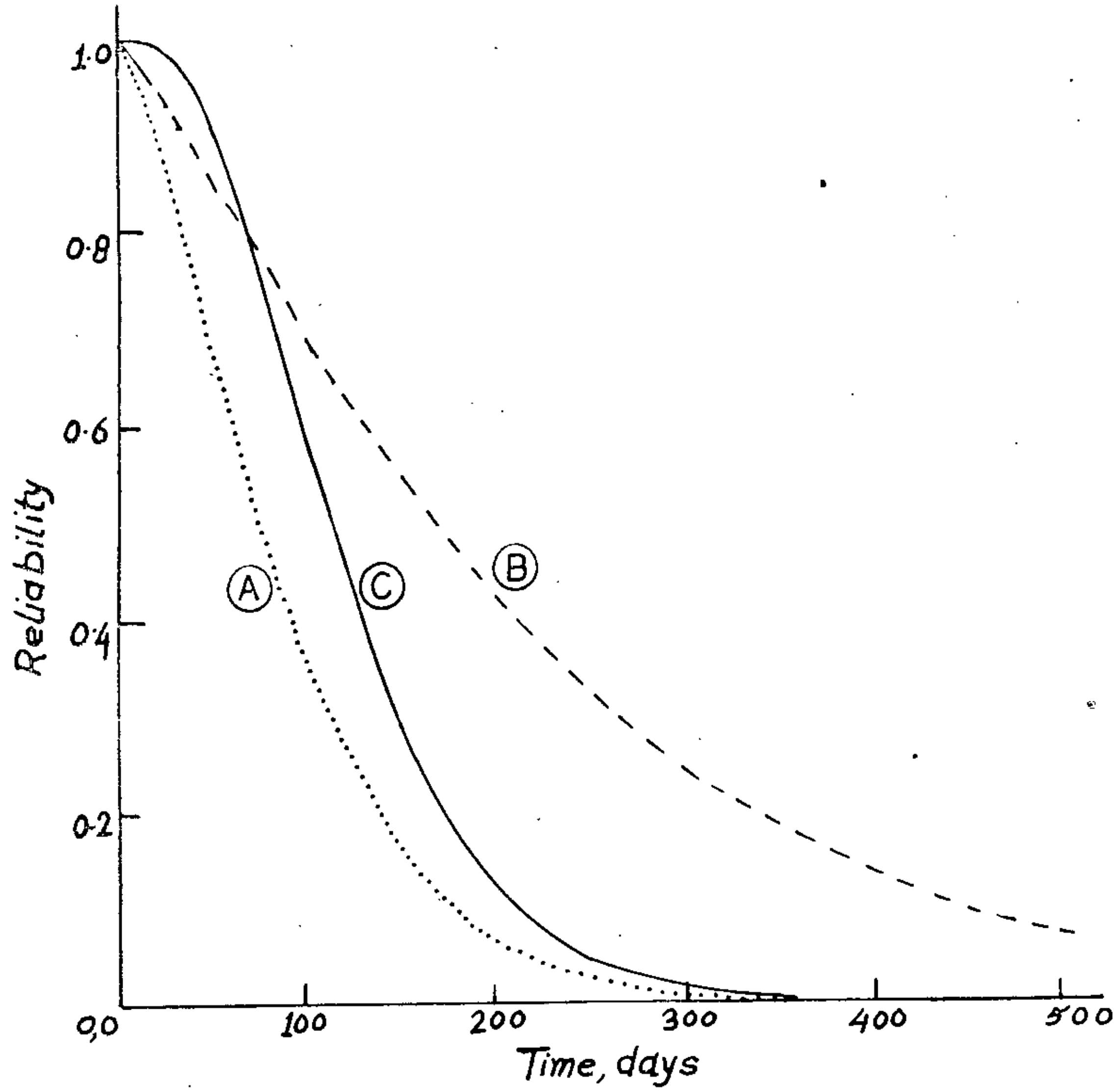


Figure 7.1.5 Reliability Vs. Time curve of Gas turbine (P-GT 101 B) : (A) Existing condition ; (B) Excluding major faults & (C) standby system.

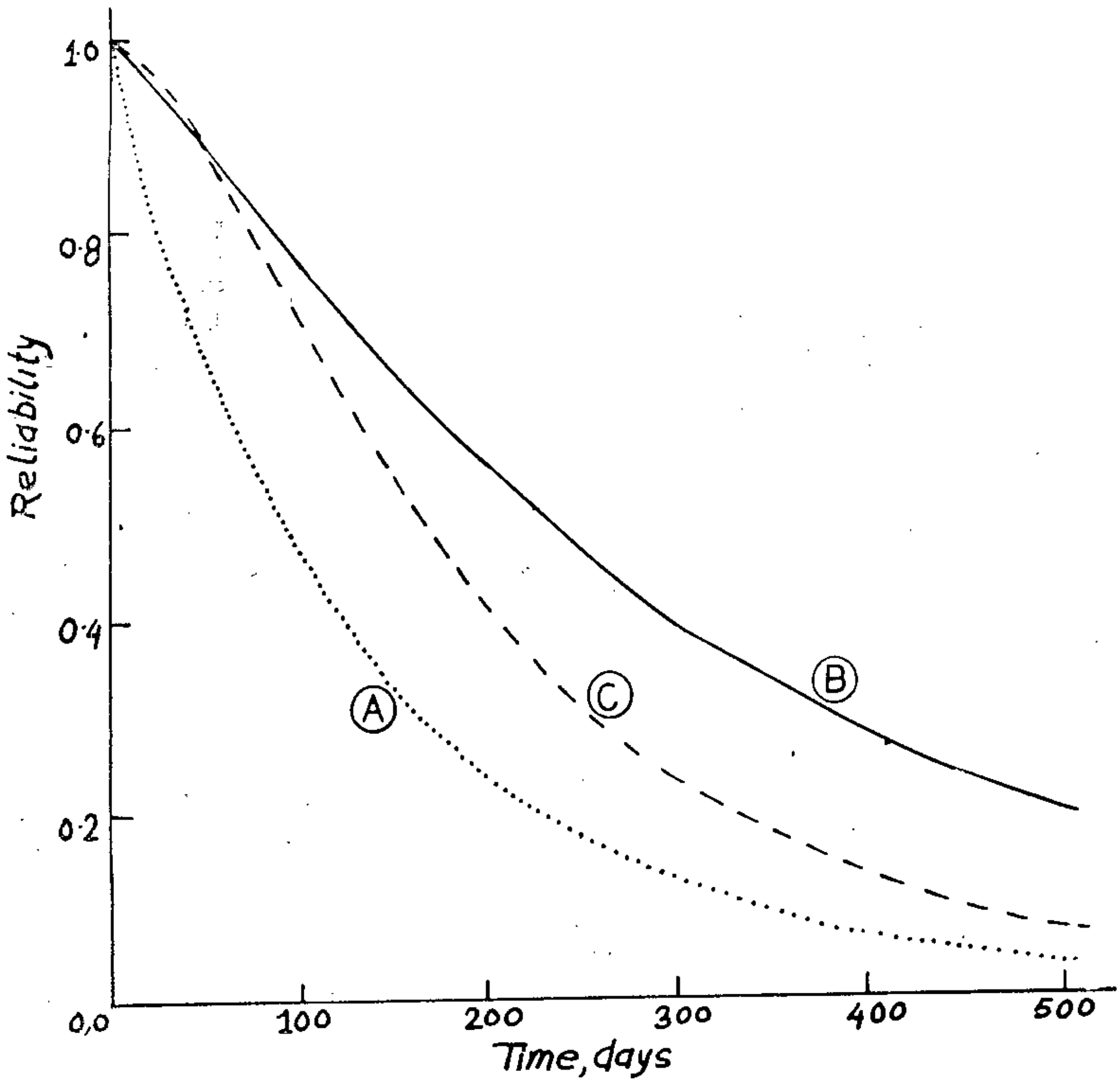


Figure 7.1.6 Reliability Vs. Time curve of CO_2 Main compressor (U-GB 102 B) : (A) Existing condition ; (B) Excluding major faults & (C) Standby system.

Referring to figures 7.1.2 to 7.1.6, it has been observed that reliability Vs. time curves after excluding major faults (Curve - B) of auxiliary boiler (A-FA 101), R.T.B. (A.-GC 501 T&C), CO_2 booster compressor (U-GB 101 T&C), Gas Turbine (P-GT 101 B), and CO_2 main compressor (U-GB 102 B) show satisfactory results. Although stand-by system of each indicates improved reliability (Curve -C), but after a certain period reliability decreases below that of curve- B, which has been obtained by excluding major faults. From the results obtained, it may be concluded that attention should be given to avoid the respective major faults rather than installing stand-by units.

In the case of GV. solution pump (A-GA 301), it has been found that only two mechanical faults occurred during the period under consideration. If it is possible to avoid such mechanical faults the pump would contribute to better reliability. Now it should be mentioned here that the GV. solution pump as well as the boiler feed water pump (A-GA 202) were originally designed to have a stand-by redundant unit with one motor driven and another steam turbine driven unit. But due to lack of steam, both the steam turbine driven units were out of service from the beginning of production of the factory. It is obvious that the reliability of GV. solution pump as well as boiler feed water pump will be improved by a considerable amount if original stand-by system of both the units can be restored either by installing motor or by increasing steam generation which will be required for operating existing steam turbine.

The reliability of both GV. solution pump and boiler feed water pump are now predicted by assuming stand-by redundant system of each machine and identical reliabilities for each unit. The calculations are shown in Table 7.1.6.

Table 7.1.6 Standby Redundant Systems Reliability of G.V. Solution Pump (A-GA 301) and Boiler Feed Water Pump (A-GA 202).

Equipments	β	η	Time, days												
			0	25	50	75	100	150	200	250	300	350	400	450	500
			Reliability												
G.V. Solution Pump (A-GA 301)	0.63	464.13	1	0.8532	0.7821	0.7281	0.6837	0.6121	0.5552	0.5080	0.4678	0.4329	0.4022	0.3750	0.3506
Standby redundant system of G.V. Sol^n. Pump.			1	0.9784	0.9525	0.9260	0.8999	0.8495	0.8021	0.7579	0.7167	0.6783	0.6426	0.6093	0.5782
Boiler feed water Pump (A-GA 202)	1.86	474.00	1	0.9958	0.9848	0.9681	0.9461	0.8890	0.8179	0.7376	0.6524	0.5661	0.4822	0.4033	0.3314
Standby redundant system of B.F.W. Pump.			1	0.9999	0.9997	0.9989	0.9970	0.9876	0.9668	0.9311	0.8791	0.8117	0.7318	0.6439	0.5529

7.2 Overall reliability prediction of the plants including proposed improve systems.

The reliability prediction tables and reliability Vs. time curves of Ammonia Plant and Urea Plant are shown in Chapter - 7.0. Now it is necessary to find to what extent the o overall reliability of the plant increases if the improved reliabilities of the identified critical equipments (i.e. the reliability of proposed stand-by systems as well as the reliability of those equipments after excluding major faults) are included in the calculations. In doing so, the reliabilities of stand-by redundant systems of F.D.F., G.V. Solution pump and Boiler Feed water pump and the predicted reliabilities of Auxiliary Boiler, R.T.B., CO_2 Booster Compressor, Gas Turbine(P-GT 101B) and CO_2 Main Compressor (U-GB 102 B) after excluding major faults are considered in place of their existing reliability. The overall reliability of the plants including improved systems are predicted in table 7.2.1. For comparison, the existing overall reliability of the plants are also shown in this table.

Table 7.2.1 Overall Reliability of the Plants including improved system.

Name of Plant.	TIME, DAYS					
	0	25	50	75	100	150
	RELIABILITY					
Ammonia Plant (Including)Proposed improve system	1	0.4869	0.2133	0.0872	0.0335	0.0041
Ammonia Plant (Existing condition)	1	0.3106	0.0931	0.0259	0.0066	0.0003
Urea Plant(Including Proposed improve system).	1	0.6464	0.4160	0.2590	0.1531	0.0411
Urea Plant(Existing Condition)	1	0.4958	0.2343	0.1025	0.0411	0.0046

The reliability Vs. time curve of Ammonia Plant for existing condition as well as including improved systems are shown in curves D and E of Figure 7.2.1 and those of Urea Plant are shown in curves F and G of figure 7.2.2.

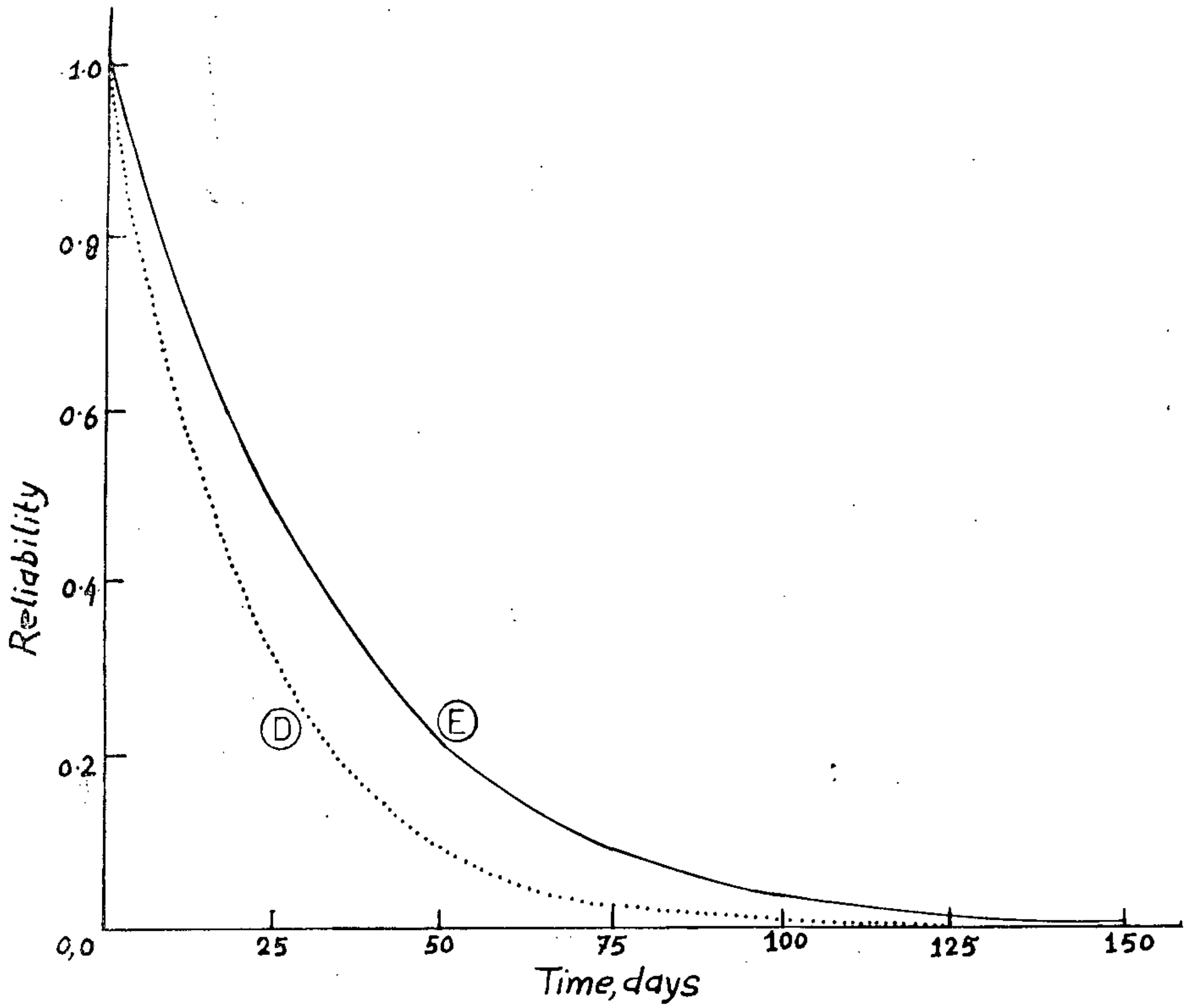


Figure 7.2.1 Reliability Vs. Time curve of Ammonia Plant :
(D) Existing condition & (E) Improved system.

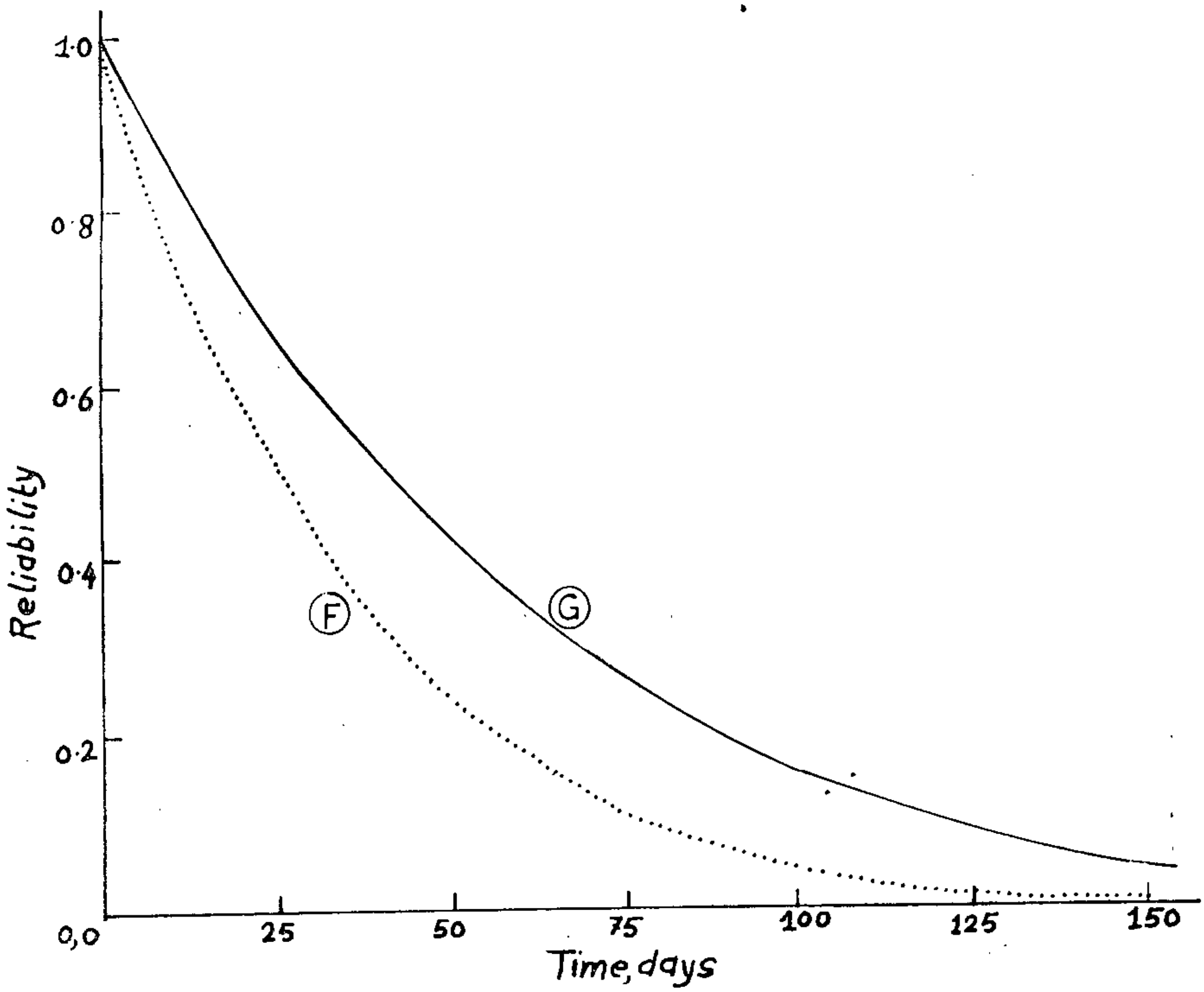


Figure 7.2.2 Reliability Vs. Time curve of Urea Plant :
(F) Existing condition & (G) Improved system.

CHAPTER 8

CONCLUSION AND FUTURE WORK

CHAPTER 8

CONCLUSION AND FUTURE WORK

8.1 Conclusion

From the study of this research, the following points are apparent.

i) From tables 5.1.1 and 5.1.2 and figure 5.2.11 it can be observed that the time-based reliability of both Ammonia and Urea Plants fall dramatically. The probabilities of encountering a failure within the first 25 and 50 days of operation of Ammonia Plant are 69% and 91% respectively; those for Urea Plant are 50% and 77% respectively. Since, the shut-down of Ammonia Plant will invariably cause the shut-down of Urea Plant, the maximum bound reliability figures are those for Ammonia Plant reliabilities.

From the reliability values of the individual equipments (Tables and figures of chapter 5), it can be seen that the main contributors to this low system reliability are F.D.F. (A-GB 104T), Auxiliary boiler (A-FA 101), G.V. solution Pump (A-GA 301) and R.T.B. (A-GC 501 T & C) in Ammonia Plant and Gas Turbine (P-GT 101 B), CO_2 booster compressor (U-GB 101 T & C) and CO_2 main compressor (U-GB 102 B) in Urea Plant.

ii) In chapter 6, Operational readiness and availability of individual equipments and plants have been calculated. The Operational readiness of individual equipments in Ammonia Plant very from 0.8075 to 0.8783 and for the plant itself, this value in 0.6788. The values for operational readiness for individual equipments in Urea Plant vary from 0.8045 to 0.8796 and that for plant itself is 0.8288.

The availability figures for both Ammonia and Urea Plants are 0.7190 and 0.8314 respectively. By similar reasoning, as in (i), it can be said that the upper bound of fertilizer factory availability for production is 0.7190. Since there are failures of Urea Plant as well, the actual availability is less than 0.7190.

iii) To improve the reliability of the plants, two alternatives were considered - eliminating major faults of each critical equipment as identified in (i) and considering installation of identical stand-by units of these critical equipments. In Tables 7.1.1 and 7.1.2, failure types and numbers of failures of each equipment in both Ammonia and Urea Plants have been listed. It has been found that major faults appeard in F.D.F., Auxiliary boiler and R.T.B. due to instrumental (including safety trip systems) troubles, in gas turbine - B due to electrical troubles and in G.V. solution pump, CO_2 booster compressor and CO_2 main compressor due to mechanical troubles.

Reliability figures have been, recalculated for both the cases mentioned above and tables and graphs have been presented (Tables 7.1.4 - 7.1.6 and figures 7.1.1 - 7.1.6). It can be observed that almost in all cases, installation of stand-by units would improve reliability situations considerably for the first 100 days of operation. But this would require comparatively much heavier capital investment and radical changes in plant layout. So, for Auxiliary boiler (A-FA 101), R.T.B.(A-GC 501 T & C), CO_2 booster compressor(U-GB 101 T&C), Gas turbine (P-GT 101B) and CO_2 main compressor (U-GB 102 B), measures to eliminate major faults have been considered, because this step will also improve reliability situations appreciably.

In Table 7.2.1 overall reliability values have been recalculated by considering the above mentioned improvement procedures. From the table as well as figures 7.2.1 and 7.2.2, it can be observed that for the first 25 and 50 days of operation of Ammonia Plant, the reliability has improved from 31% to 49% and from 9% to 21% respectively. The improvements in Urea Plant are from 50% to 65% for the first 25 days and from 23% to 42% for 50 days of operation.

8.2 Scope of Future Works

Since many failures were caused by Spurious trips, the reliability of the Safety system can be investigated. The possibility of duplicating trip systems or installing high integrity protective systems (HIPS) can be studied.

An optimal maintenance policy for mechanical equipments should be developed.

Fault diagnostics of the plant equipments should be prepared to minimize corrective measures by trial and error.

Maintenance procedures should be recorded and guide lines should be strictly followed to minimize maintenance induced failures.

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APPENDIX

APPENDIX-A Failure History of Ammonia Plant.

Failure time		Start-up time		Down time	Repair time	Causes of failure		Remedial measures/ Remarks
Date	Time hrs	Date	Time hrs	Days	Days	Equipment failed	Causes	
1	2	3	4	5	6	7	8	9
21-6-77	11.10	22-6-77	18.20	1.30	0.04	NG Booster Comp. (A-GB 106)	Pressure regulator troubles of Titas gas metering station	Regulator was replaced.
4-7-77	10.20	16-7-77	11.16	12.04	8.54	Whole plant	For repairing works.	
19-8-77	10.20	21-8-77	3.96	1.74	0.00	RTB(A-GC 501T&C)	Steam pressure extra low.	Wrong signal.
3-9-77	14.30	9-9-77	1.82	5.48	5.00	Gas turbine (P-GT 101 A,B)	Exhaust temperature high.	Wrong signal
20-9-77	0.90	7-10-77	21.54	17.86	15.80	Methanator effl-ent Economizer (A-EA 401)	Tube leakage	Defect tubes were plugged.
8-10-77	8.30	8-10-77	16.22	0.33	0.00	I.D.F.(A-GB 102T)	Lub.Oil pressure extra low	Operational faults.

APPENDIX-A (Continued)

1	2	3	4	5	6	7	8	9
8-10-77	15.45	11-10-77	9-93	2.77	0.00	F.D.F.(A-GB 104T)	Exhaust steam pressure extra high.	Operational faults
12-10-77	19.05	19-10-77	8.25	6.55	6.00	Gas Turbine (P-GT 101 A,B)	Fuse troubles	Fuse replaced.
22-10-77	9.30	12-11-77	22.98	21.57	19.90	Co_2 absorber (A -DA 301)	Differential pressure was high	R/Ring were changed.
14-11-77	9.35	17-11-77	16.79	3.31	1.50	(Ammonia & Urea Plant)	For repairing works.	
16-11-77	17.30	19-11-77	17.30	3.00	2.50	Gas Turbine (P-GT 101 A,B)	Fuse burnt due to reverse current.	Fuse replaced.
21-11-77	3.20	24-11-77	11.36	3.34	1.70	R.T.B.(A-GC 501 T&C).	Lub.Oil line leakage.	Pipe line replaced
03-12-77	7.25	05-12-77	1.49	1.76	0.41	CO_2 Booster compressor (U-GB 101 T&C).	Thrust bearing (Turbine) damaged	Thrust bearing replaced.
29-12-77	9.10	01-01-78	9.10	3.00	0.25	Auxiliary boiler (A-FA 101)	Drum level extra low	Faults signal.
02-01-78	13.50	04-01-78	1.50	1.50	0.12	ATB (A-GB 101T&C)	Blockage of air filter.	Filter replaced.

APPENDIX-A (Continued)

1	2	3	4	5	6	7	8	9
16-01-78	6.15	19-01-78	11.67	3.23	1.30	Whole plant	For repairing works.	
27-01-78	21.40	01-02-78	6.03	4.36	4.00	Gas Turbine (P-GT 101 A,B)	Due to reverse current.	Checked.
08-02-78	11.35	10-02-78	22.63	2.47	0.00	Auxiliary boiler (A-FA 101)	Drum level extra low	Faults signal.
08-03-78	8.45	13.03-78	2.93	4.77	0.16	Boiler feed water pump(A-GA 202)	Wrong maintenance by Electrical personnel.	
29-03-78	21.50	04-04-78	1.82	5.18	3.90	RTB(A-GC 501T&C)	Thrust brgs.damaged and also instrument air pressure extra low.	Bearing replaced
04-04-78	-	06-04-78	-	3.00	1.20	GV solution pump (A-GA 301)	Bearing temperature high.	Bearing replaced
15-02-78		16-02-78		0.98	0.33	CO_2 Booster compressor (U-GB 101 T&C).	Thrust bearing damaged.	Bearing replaced
07-04-78		10-04-78		4.12	2.25	Manual shutdown	For repairing works.	
02-05-78		19-07-78		78	72	Manual shut-down	For annual overhauling.	

APPENDIX-A (Continued)

1	2	3	4	5	6	7	8	9
06-08-78	11.25	16-08-78	20.13	10.37	6.55	GV solution pump (A-GA 301)	Coupling damaged	Coupling replaced
06-09-78	0.35	10-09-78	0.34	4.00	0.16	Auxiliary boiler (A-FA 101)	Air preheater coupling damaged.	Coupling repaired
16-09-78	14.32	19-09-78	14.32	3.00	2.30	Hyper turbine (A-GB 501 T&C).	Lub. oil pump stopped due to Electrical troubles.	Electrical circuit rectified.
01-11-78	17.20	07-11-78	20-32	6.13	3.80	Process gas reboiler(A-EA 301)	GV solution leakage.	Line repaired.
18-12-78		18-12-78		0.21	0.00	CO_2 Booster compr. (U-GB 101 T&C)	Mal.functioning of delivery check valve.	Checked.
25-12-78	19.00	27-12-78	10.60	2.65	0.00	FDF.(A-GB 104T)	Lub.oil pressure extra low.	Faults signal.
27-12-78	13.00	29-12-78	13.00	2.00	0.00	FDF.(A-GB 104T)	Mal.functioning of trip system.	Checked.
03-12-78	21.00	07-12-78	2.28	3.22	0.00	Hyper turbine (A-GB 501 T&C)	Due to fire on turbine insulation.	
16-01-79	20.25	18.01-79	21.45	2.05	0.00	RTB (A-GC 501T&C)	Low level of Economizer.	Wrong signal.

APPENDIX-A (Continued)

1	2	3	4	5	6	7	8	9
24-03-79	15.30	01-04-79	16.26	8.04	5.20	Manual shut-down	Short fall of raw material.	NG line repaired.
03.04-79	14.53	06-04-79	9.00	2.77	0.50	De-acrator bent valve(PCV 524)	Troubles of the valve.	Repaired.
03-06-79	21.52	20-06-79	14.00	16.69	12.20	Manual shut-down	Spared No. G. for P.D.B.	
08-08-79	5.30	16-08-79	5.40	8.00	7.50	Gas turbine (P-GT 101 A,B).	Gas turbine-A,was trip due to flame failure & that of'B' was trip. when synch-ronizing with PDB.	Checked.
01-10-79	17.30	02-10-79	7.22	0.58	0.12	CO_2 Booster compr. (U-GB 101 T&C)	High temperature of pinion side redial bearings.	Bearing checked.
16-10-79	15.35	17-10-79	4.30	0.54	0.10	- do -	- do -	- do -
07-11-79	9.15	11-11-79	16.25	4.29	0.66	NG Booster compr. (A-GB 106).	NG.pressure actua-tion.	PCV checked.
11-11-79	21.10	13-11-79	21.10	2.00	0.00	RTB (A-GC 501T&C)	RPM decreased suddenly.	Operational faults

APPENDIX-A (Continued)

1	2	3	4	5	6	7	8	9
14.11.79	13.50	14.11.79	15.00	0.062	0.00	CO_2 Booster compr. (U-GB 101 T&C).	Brg. temperature high at pinion side radial bearing.	No. action taken.
16-11-79	12.15	16-11-79	13.40	0.052	0.00	- do -	- do -	- do -
19-11-79	11.30	19-11-79	12.25	0.04	0.00	- do -	- do -	- do -
10-12-79	21.15	12-12-79	1.00	1.95	0.80	- do -	- do -	Alignment checked.
29-12-79	12.00	30-12-79	15.25	1.12	0.75	- do -	- do -	Bearing changed.
01-01-80	15.05	06-01-80	12.25	4.85	3.50	Hyper turbine (A-GB 501 T&C)	Failure of Askania controller.	Checked.
14-1-80	15.00	15-01-80	22.00	1.29	0.80	CO_2 Booster compr. (U-GB 101 T&C).	High temperature of pinion side radial bearing.	Alignment checked.
24-01-80	15.15	02-02-80	20.00	9.19	7.00	W-DA 302 B.	Saron cloth damaged	Saron cloth of filter was replaced.
02-02-80	22.35	14-02-80	19.15	11.85	4.50	Mist trap (A-DA 303).	Extra high level of GV solution.	Rectified.
17-02-80	1.40	19-02-80	9.00	2.30	0.66	Synthesis gas K.O. Drum(A-FA 401)	High level.	Checked and repaired.

APPENDIX-A (Continued)

1	2	3	4	5	6	7	8	9
14-03-80	18.15	16-03-80	2.40	1.34	0.40	RTB(A-GC 501T&C)	Local instrument panel troubles.	Repaired.
30-04-80	20.50	04-05-80	23.04	4.10	3.90	Gas turbine (P-GT 101 A, B)	Unbalanced load sharing.	Checked.
16-05-80	9.50	18-05-80	16.00	2.25	1.40	Hyper turbine (A-GB 501T&C)	Failure of Askania controller.	Checked.
09-06-80	20.16	11-06-80	13.15	1.70	0.12	NG Booster compr. (A-GB 106)	Abnormal NG press drop.	Titas gas supply troubles.
12-06-80	10.45	22-06-80	11.00	10.25	10.00	Gas turbine (P-GT 101 A,B).	Due to load rejection by gas turbine-'A'.	Checked.
17-07-80	7.15	21-07-80	22.15	4.62	0.33	Boiler feed water pump (A-GA 202)	Down stream line leakage.	Line repaired.
23-07-80	17.10	25-07-80	12.54	1.81	1.10	Hyper turbine (A-GB 501 T&C).	Inter cooler tube leakage.	Leakage tube were plugged.
09-08-80	4.20	11-08-80	21.24	2.71	0.33	Waste heat boiler (A-EC 107)	Leakage in up stream welding joint.	Repaired.

APPENDIX - A (Continued).

1	2	3	4	5	6	7	8	9
21-08-80	10.10	26-10-80		66.00	60.00	Manual shut-down	For annual over-hauling.	
01-11-80	5.40	02-11-80	5.40	1.00	0.00	Auxiliary boiler (A-FA 101)	Closure of NG Emergency valve.	Instrumental faults.
02-11-80	20.20	06-11-80	8.19	3.50	0.50	FDF (A-GB 104T)	Low lub. oil pressure.	Faults signal.
08-11-80	17.35	12-11-80	14.23	3.87	0.25	Auxiliary boiler (A-FA 101)	Low instrument air pressure.	Instrumental faults.
22-01-81	10.05	24-01-81	5.73	1.82	0.00	NG Booster compr. (A-GB 106)	Low lub oil pressure.	Faults signal.
11-02-81	7.35	15-02-81	3.27	3.83	2.50	CO_2 Booster compr. (U-GB 101 T&C).	Abnormal vibration at compressor side.	Rotor replaced.

APPENDIX - A (Continued)

1	2	3	4	5	6	7	8	9
10-04-81	14.05	13-04-81	23.90	3.40	0.00	Manual shut-down of NH_3 Plant.	NG supply stopped by titas.	
13-06-81	9.05	17-06-81	2.00	3.67	0.00	RTB (A-GC 501T&C)	Low indication of thrust pressure relay switch.	Faults signal.
17-06-81	11.20	20-06-81	21.04	3.41	1.50	ATB (A-GB 101 T&C)	Failure of condensate pump.	Electrical faults.
21-06-81	9.30	25-06-81	0.18	3.62	0.00	FDF(A-GB 104T).	Mal. functioning of Governor linkage.	Faults signal.
30-06-81	9.20	01-07-81	1.52	0.68	0.00	RTB(A-GC 501T&C)	Low thrust pressure.	Faults signal.

APPENDIX-B Failure History of Urea Plant.

Failure Time		Start-up time		Down Time	Repair time	Causes of failures		Remedial measures /Remarks.
Date	Time hrs.	Date	Time hrs.	Days	Days	Equipment failed	Causes.	
1	2	3	4	5	6	7	8	9
16-07-77	8.00	16-07-77	16.00	0.07	0.00	Urea reactor (U-DC 101 A,B).	Abnormal suction flow fluctuation.	Checked.
18-07-77	7.00	18-07-77	7.72	0.03	0.00	CO_2 main compr. (U-GB 102 B)	Oil pressure switch troubles.	Pressure switch replaced.
19-07-77	0.50	19-07-77	19.70	0.80	0.70	Gas turbine (P-GT 101 B)	Exhaust temperature high.	Checked and repair.
21-07-77	20.55	22-07-77	0.33	0.36	0.30	- do -	- do -	Checked.
22-7-77	9.00	22-07-77	21.48	0.52	0.25	Urea reactor (U-DC 101 A,B)	Heavy leakage of 13 kg/ cm^2 steam line leading to LPD.	Line repaired.
27-08-77	23.00	31-08-77	7.88	3.37	3.00	CO_2 main compr. (U-GB 102 A)	Packing temperature abnormally high.	Checked & rectified.
08-09-77	13.00	08-09-77	13.96	0.04	0.02	Suction common header valve of RC. pump(U-GA102)	Valve flange and seat leakage.	Repaired.

APPENDIX-B (Continued)

1	2	3	4	5	6	7	8	9
21-12-77	9.30	21-12-77	13.36	0.17	0.11	Suction common header valve of NH_3 pump (U-GA 101).	Leakage between flange and seat.	Repaired
23-01-78	10.15	23-01-78	14.95	0.20	0.10	Ammonia preheater(U-EA 101A)	Tube leakage.	Leakage tubes were plugged.
05-02-78	20.00	05-02-78	22.40	0.10	0.05	Urea reactor (U-DC 101 B).	Line cracked	Repaired.
26-07-78	0.25	27-07-78	13.93	0.57	0.00	Gas turbine (P-GT 101B).	Flame failures.	Faults signal.
08-11-78	0.15	08-11-78	19.15	0.80	0.60	Ammonia preheater(U-EA 101B)	Leakage.	Tube bundles. replaced.
13-12-78	0.80	13.12.78	20.00	0.80	0.10	Suction common header valve of NH_3 pump (U-GA 101).	Leakage.	Repaired.
04-01-79	13.15	04-01-79	19.15	0.25	0.24	Melter(U-EA301A)	Bearing damaged.	Bearing replaced.
21-04-79		22-04-79		1.28	1.25	Centrifuge (U-GF 201A).	Over load trip.	Main bush changed.

APPENDIX-B (Continued)

1	2	3	4	5	6	7	8	9
23-04-79		26-04-79		2.86	2.84	Centrifuge (U-GF 201 E)	Motor troubles.	Repaired.
20-12-78	8.45	20-12-78	11.57	0.13	0.00	CO_2 main compr. (U-GB 102 B)	Abnormal sound in stuffing box.	Checked.
20-12-78	19.50	21-12-78	3.90	0.35	0.00	Gas turbine (P-GT 101 B)	Over speed trip.	Faults signal.
15-03-79		16-03-79		1.04	1.00	No. 2 belt conveyor (U-JD 204 B)	Bearing worned-out	Checked and replaced.
10-07-79	10.25	10-07-79	14.00	0.10	0.00	CO_2 main compr. (U-GB 102 A)	Abnormal sound.	Checked.
25-07-79	16.30	26-7-79	1.15	0.35	0.30	No.2 belt conv-eyor (U-JD 204B)	Bearing troubles.	Bearing changed.
01-08-79	9.30	01-08-79	14.20	0.60	0.58	Melter(U-EA101A)	Leakage.	Repaired.
04-08-79	15.45	04-08-79	18.00	0.08	0.08	Belt conveyor to bulk storage (B-JD 103).	Motor chain worned out.	Replaced with new one.
29-08-79	13.15	31-08-79	15.30	2.08	1.80	High pressure decomposer (U-GB 102 A)	Leakage.	Repaired.

APPENDIX - B (Continued)

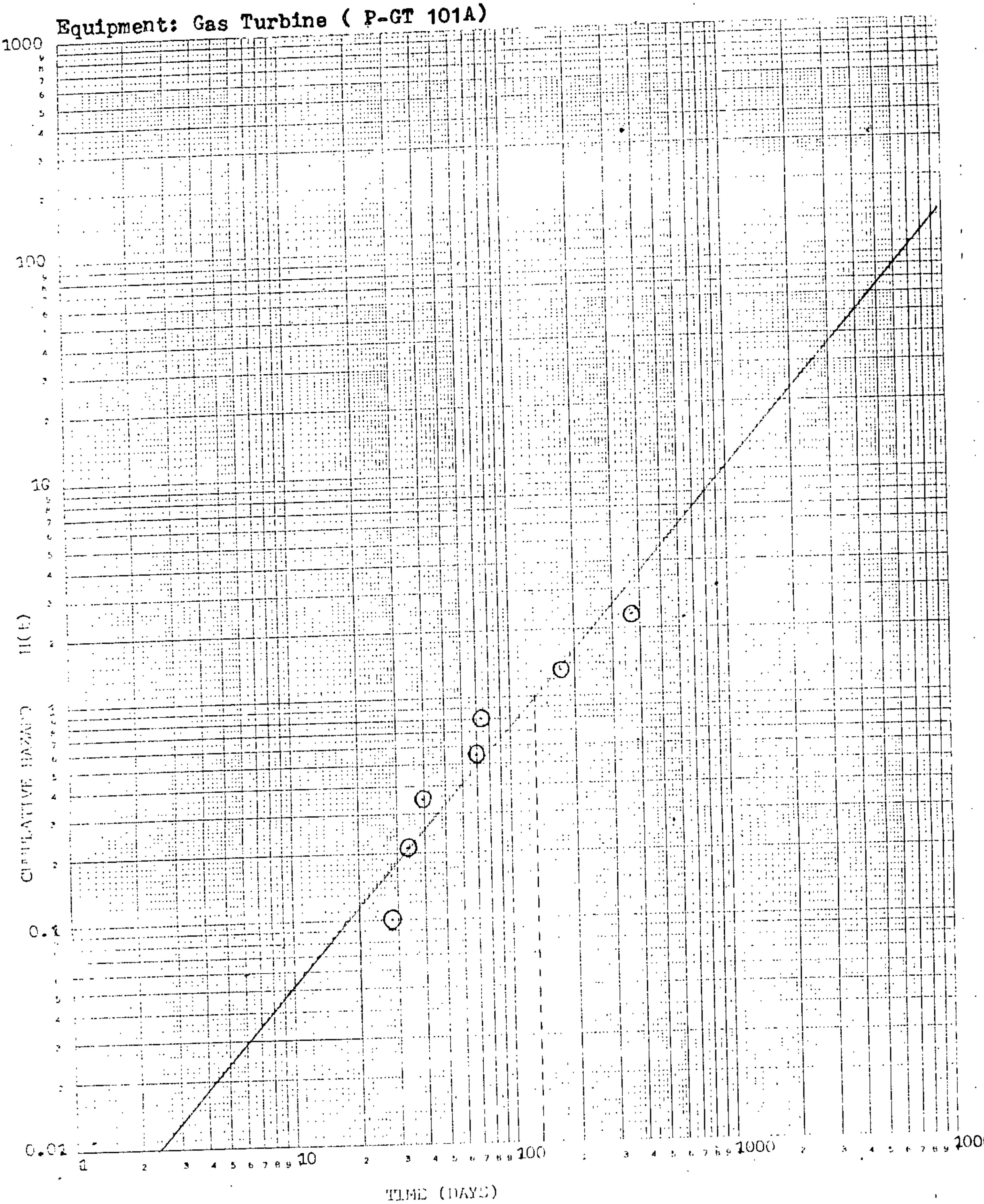
1	2	3	4	5	6	7	8	9
27-09-79	8.45	27-09-79	13.10	0.16	0.00	CO_2 main compr. (U-GB 102 A)	High temperature of Ist stage delivery.	Checked.
03-11-79	8.20	03-11-79	13.00	0.20	0.20	Bucket elevator (B-JD 102)	Worned-out of driving chain.	Repaired.
06-11-79	9.35	06-11-79	23.50	0.58	0.38	CO_2 main compr. (U-GB 102 B)	High temperature of packing box.	Checked and repaired.
06-12-79	4.10	06-12-79	10.10	0.25	0.24	No.2 belt conv-eyor (U-JD 204 B)	Worned out of sprocket teeth.	Replaced with one
03-04-80	3.30	05-04-80	2.30	1.94	1.50	Gas turbine (P-GT 101 B)	Load hunting.	Checked.
12-04-80	8.30	12-04-80	19.15	0.44	0.24	CO_2 main compr. (U-GB 102 B)	High temperature of Ist stage delivery.	Checked & Repaired.
24-06-80	11.25	25-06-80	11.00	0.98	0.80	Gas turbine (P-GT 101 B)	Load rejection by gas turbine-'A'.	Checked.
04-07-80	15.45	05-07-80	16.20	1.03	0.50	High pressure decomposer (U-DA 201).	Sight glass blown out	Replaced.
07-07-80	12.45	07-07-80	17.53	0.21	0.20	NH_3 preheater (U-EA 101 A)	Tube leakage.	Tube bundle replaced.

APPENDIX - B (Continued)

1	2	3	4	5	6	7	8	9
11-07-80	12.10	11-07-80	13.23	0.04	0.00	CO_2 main compr. (U-GB 102 A,B).	High temperature of packing box.	Checked.
29-07-80	3.15	29-07-80	12.31	0.21	0.09	Urea reactor (U-DC 101 B)	Failure of pressure controller.	Replaced.
06-08-80	16.30	06-08-80	20.95	0.19	0.00	- do -	Mal. functioning of pressure control valve.	Checked.
13-08-80	12.15	13-08-80	22.11	0.41	0.20	CO_2 main compr. (U-GB 102 A,B).	Compressure-A, stopped due to high temperature of Ist stage delivery & that of 'B' stopped due to high temperature of packing box.	Thoroughly checked and rectified.
26-06-81	8.45	27-06-81	16.91	1.35	1.10	CO_2 main compr. (U-GB 101 A).	High temperature of Ist and 2nd stage delivery.	Checked and repaired.
28-06-81	14.45	28-06-81	17.40	0.12	0.09	Suction common header valve of NH_3 feed pump. (U-GA 101)	Flange leakage.	Repaired.

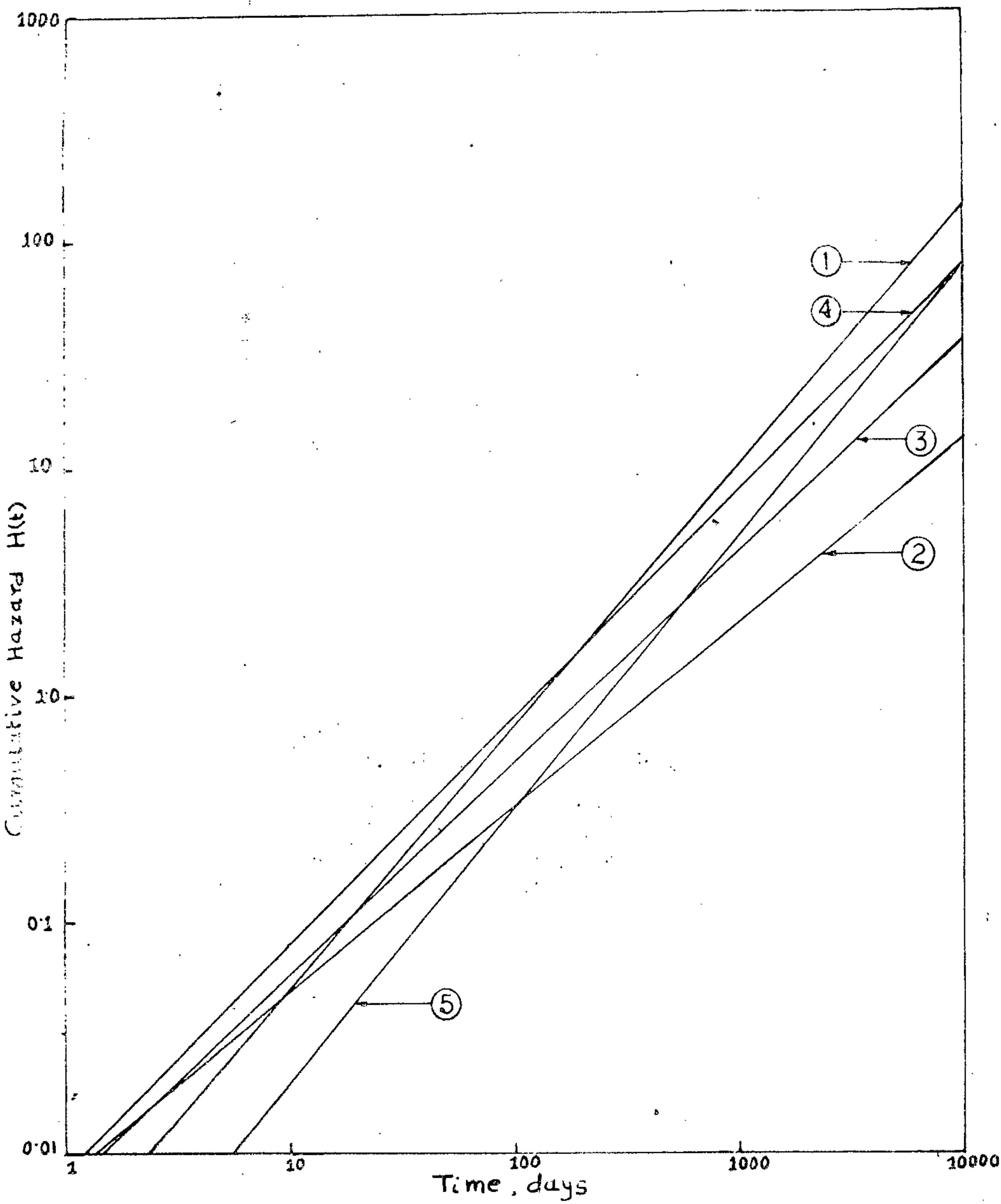
APPENDIX - C. Graphical Solutions of Hazard Plotting Method

Equipment: Gas Turbine (P-GT 101A)



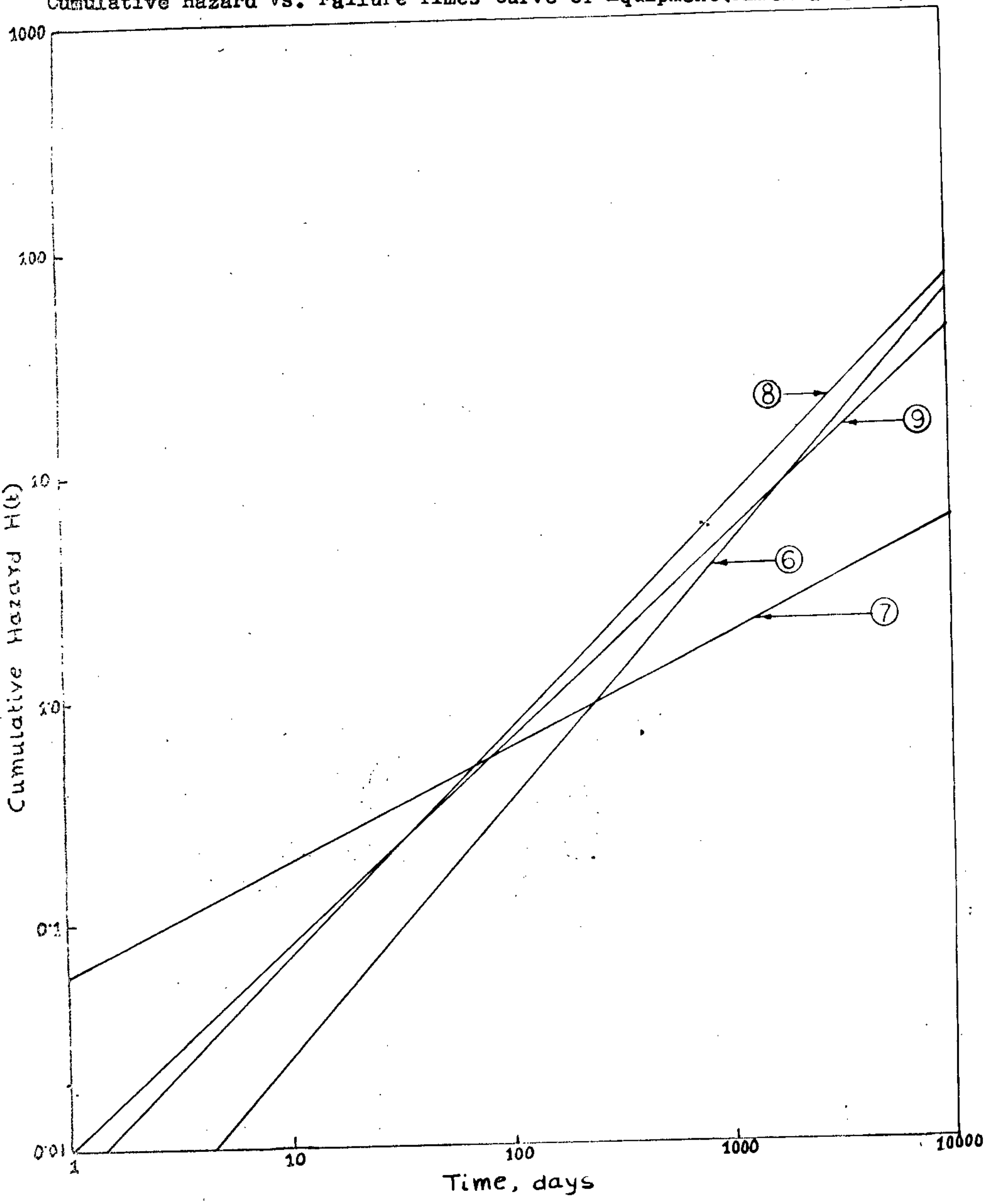
APPENDIX - C_1

Cumulative Hazard Vs. Failure Times curve of Equipment(Ammonia Plant).



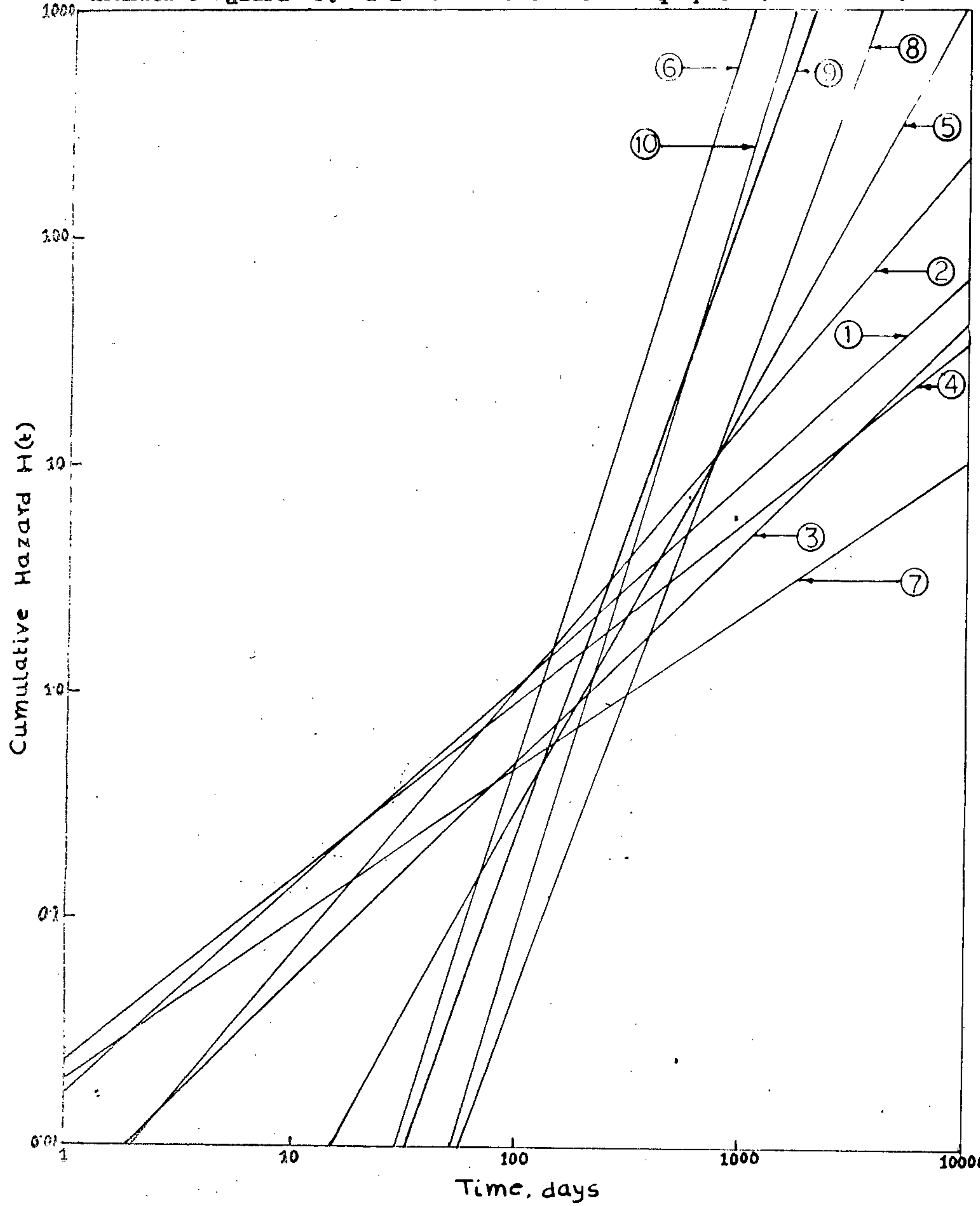
APPENDIX - C_1

Cumulative Hazard Vs. Failure Times Curve of Equipment(Ammonia Plant)



APPENDIX - C_2

Cumulative Hazard Vs. Failure Times curve of Equipment(Urea Plant)



Equipments of Appendix C_1 are as follows :

1. Gas turbine (P-GT 101 A)
2. Boiler feed water pump (A-GA 202)
3. F.D.F. (A-GB 104 T).
4. Auxiliary boiler (A-FA 101).
5. A. T. B. (A-GB 101 T & C).
6. N. G. Booster Compressor (A-GB 106).
7. G.V. Solution pump (A-GA 301).
8. R. T. B. (A-GC 501 T & C).
9. Hyper turbine (A-GB 501 T & C).

Equipments of Appendix C_2 are as follows :

1. CO_2 Booster Compressor (U-GB 101 T & C).
2. Gas Turbine (P-GT 101 B)
3. CO_2 Main Compressor (U-GB 102 A).
4. CO_2 Main Compressor (U-GB 102 B).
5. Suction common header valve of Ammonia Pump (U-GA 101).
6. Ammonia preheater (U-EA 101B)
7. Urea reactor (U-DC 101 B).
8. High pressure decomposer (U-DA 201)
9. No. 2 belt conveyor (U-JD 204 B).
10. Melter (U-EA 301 A)

APPENDIX - D

MLE Method for the Estimation of Weibull distribution (W.D.) Parameters.

The Computer programme used for the estimation of Weibull distribution parameters is shown below:

```
C     PROGRAMME FOR EVALUATING WEIBULL DISTRIBUTION
C     PARAMETERS
      DIMENSION T(40), X(40), Y(40), XY(40), YS(40), XYS(40), YF(40),
     1TF(40)
      READ (1,900)  N1
  900 FORMAT(I2)
      DO 999 IX=1,N1
      READ (1,100) N, IR
  100 FORMAT(2I2)
      READ (1,101) (T(I), I=1, N)
      READ (1,101) (TF(II),II=1,IR)
  101 FORMAT(13F6.2)
      B1=1.0
      B=B1
      WRITE (3,110)IX
  110 FORMAT (5X,'EXAMPLE',I2,/,5X,9('*'))
      DO 102 J=1,N
      Y(J)=ALOG(T(J))
  102 YS(J)=Y(J)**2
      DO 103 J2=1,IR
  103 YF(J2)=ALOG(TF(J2))
      S3=0.0
      DO 105 K1=1,IR
  105 S3=S3+YF(K1)
      P3=(1.0/FLOAT(IR))*S3
  108 DO 106 J1=1,N
      X(J1)=T(J1)**B1
      XY(J1)=X(J1)*Y(J1)
  106 XYS(J1)=X(J1)*YS(J1)
      S1=0.0
      S2=0.0
      S4=0.0
      DO 104 L=1,N
      S1=S1+XY(L)
      S2=S2+X(L)
  104 S4=S4+XYS(L)
      G=(S1/S2)-(1.0/B1)-P3
      GP=(((S2*S4)-(S1**2))/(S2**2))+(1.0/(B1**2))
      R=G/GP
      IF(ABS(R).LT.0.001) GO TO107
      B1=B1-R
      IF(B1.LE.0.0)GO TO111
      GO TO113
  111 B1=B+1.0
      B=B1
      GO TO 113
  113 GO TO 108
  107 ETA=(S2/IR)**(1.0/B1)
      FMT=ETA*YY(1.0+(1.0/B1))
      SD=SQRT((ETA**2)*(YY(1.0+(2.0/B1))-((YY(1.0+(1.0/B1)))**2)))
      WRITE(3,109)B1,ETA,FMT,SD
  109 FORMAT(5X,'SHAPE PARAM=',F5.2,5X,'SCALE PARAM=',F10.3,5X,
     1'MEAN LIFE=',F8.3,5X,'STD DEV=',F10.3)
  999 CONTINUE
      STOP
      END

      FUNCTION YY(T)
      YY=(T**T)*EXP(-T)*SQRT((2.0*3.1416)/T)*(1.0+(1.0/(12.0*T))+
     1(1.0/(288.0*(T**2))))
      RETURN
      END
```

APPENDIX - E

Calculation Steps For Estimation of the Weibull Distribution Parameters by the SEQLIM Method.

η is calculated by eqn. (2.4.16) ; t_r/η is the ratio of the observed failure time to η, for rth failure; t.40 and t.60 indicate the 40% lower and 60% upper probability limits; " — " indicates that the observed failure time is not an outlier, while "*" indicates an outlier; checks of outliers and nonoutliers are made from the tables given by Kabir (18); " → " on the left side of β indicates an incoming pair. An example of estimations of β and η for I.D.F. (A.GB 102 T) by SEQLIM method are shown below. Failures data of I.D.F. are shown in chapter - 4.

	β	η	t_1/η	$t_{.40}$	$t_{.60}$
	1.0	227.24	0.25928	-	-
→	0.95	206.48	0.28535	-	-
	0.90	185.82	0.31708	-	*

Estimates for single failure : β = 0.95, η = 206.48