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# RELIABILITY OF AMMONIA PLANTS

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## 1. INTRODUCTION

The operation continuity of ammonia plants, particularly of those with a single stream, is one of the main factors contributing to the reduction of production costs. On the other hand, costs can be increased due to shut-down and start-up.

It had also been proved in the past that high operation temperatures, pressures, and every accidental shut-down can be a potential cause of further failures which will lead to a plant shut-down.

From the reliability statistics of the ammonia plants operating throughout the world it has been found that for the reciprocating plants there are 60.2 days per year of inactivity with an average 16.5 shut-downs/year.

General maintenance is carried for 31 days every 17 months.

This report shows how it has been possible to raise the level of efficiency of our plant thus making it possible to save considerably in energy, to carry out the turnaround once every five years, and to develop the already well-established know-how in terms of:

- non-destructive tests and routine checks;
- intervention as preventive maintenance or failure maintenance;
- management.

## 2. PLANT DATA

Single stream ammonia plant, in operation since 1967:

| | |
|---|---|
| Original capacity: | 400 te $NH_3$/day |
| Present capacity: | 500 te $NH_3$/day |
| Initial feedstock: | Virgin naphta |
| Present feedstock: | Natural gas |
| Reforming: | Selas patent |
| $CO_2$ absorption: | Gianmarco-Vetrocoke patent<br>(glycine now used instead of arsenic) |
| Synthesis: | Fauser patent |
| Compressor: | Reciprocating |

## 3. PERFORMANCE SUMMARY OF THE ENICHEM PORTO MARGHERA AMMONIA PLANT

| | |
|---|---|
| Service factor: | 94.7% |
| Frequency and duration of maintenance: | 60 months/49 days |
| Downtime due to equipment failure: | 7.9 |
| Downtime due to instrumental failure: | 0.0 |
| Downtime due to electric failure: | 0.0 |

Two comparisons were made to verify the validity of the strategy adopted:

- plant reliability with maintenance carried out at intervals of four and five years;
- reliability of our plant compared with other similar ones throughout the world, the information for which was taken from AIChE paper n. 50c "Causes of Ammonia Plant Shutdowns Survey V".

It is to be noted that for reciprocating plants, which generally have two parallel reciprocating compressors for syn gas, each with a capacity of 50%, the stoppage of a compressor for one day is considered the same as a shutdown of half a day.

## 4. OVERALL PERFORMANCE

Table I shows the overall performance for all the plants including the periods of inactivity and the number of shutdowns.

The onstream factor of our plant is superior to others principally because it is not compromised by the dramatic increase in inevitable periods of inactivity due to feedstock curtailment and inventory control as recorded in various parts of the world and indicated in Table III "Classification of Downtime for Unavoidable Shutdown".

The number of shutdowns greater than the average, of the reciprocating plants, is basically caused by frequent valve changes in the reciprocating compressors.

## 5. SERVICE FACTOR

This represents the level of reliability of the plants and is defined as :

1 - (days per year - days of total downtime) / (days per year - avoidable downtime)

Table II shows how the plants, in comparison, despite having a low onstream have, on the other hand, a high service factor due to the high unavoidable downtime. In our case only a small difference is noted.

It should also be pointed out that in many plants advantage is taken of long shutdowns caused by feedstock curtailment or inventory control to carry out maintenance.

When this had happened the reason for plant inactivity was not completely attributed to maintenance but also to unavoidable causes (see Table IV), which changed the service factor value, thus no longer giving the correct measurement of plant reliability.

## 6. CLASSIFICATION OF DOWNTIME AND SHUTDOWNS

The causes of the ammonia plant shutdowns, shown in Table III and IIIB, are divided into two categories : avoidable and unavoidable.

In the unavoidable shutdown category the most significant value for the days of inactivity is determined by a load reduction due to trade union problems.

These, however, along with the other causes, with the exception of electrical failure, have never caused plant shutdown.

It can be seen that for avoidable shutdowns the total of days for maintenance are considerably lower than for other plants.

This result becomes more significant when we consider that in the interval between two overhauls there are no intermediate shutdowns for other causes where intervention is possible to eliminate potential critical points in order to promote the continuity of plant operation.

Tables IV & V give the relative data about maintenance.

In our plant the turnaround is carried out once every five years.

This leads to a considerably lower average number inactive days per year than for others.

The values for plant inactivity due to delay during the completion of automatization work carried out as an exceptional case during the 1990 overhaul, are given under the heading "Shutdowns for other causes".

Also during failure maintenance optimum results were obtained which become even more relevant when we consider the long interval between turnarounds and the absence of temporary intermediate shutdowns due to unavoidable causes.

## 7. EQUIPMENT FAILURES

The reliability of the equipment in the gas line has reached an excellent degree, as Tables VIa and VIb show.

From these it can be seen that in the space of nine years there have been no primary or secondary reforming shutdowns, with the exception of one shutdown in 1990, caused by a rupture in a flexible process air hose at the secondary.

In the compression and synthesis area higher downtime values are recorded, due to repeated failures concentrated in a brief time-lapse for the same equipment that at times prevented a definitive solution from being found to the problem.

However, with the 1985 overhaul these problems were already solved.

The results obtained in the instrumentation and electrical sector were even more satisfying.

As can be seen in Tables VII and VIII, in the 1986-1990 period there were no plant shutdowns caused by instrumental or electrical equipment failures.

As regards, on the other hand, the shutdowns due to electrical power failure on interventions were carried out with the intention of protecting above all the reforming operation in order to avoid thermic shocks which, as has been seen in the past, lead to further failures.

## 8. MAINTENANCE ENGINEERING

In 1980 the maintenance engineering group was formed with the following aims:

- To supply the maintenance group with adequate technical instruments to carry out maintenance interventions properly.
- To indicate plant modifications so as to increase plant reliability.
- To coordinate non-destructive tests carried out by contractors.
- To carry out non-destructive tests for vibrational diagnosis.
- To determine the condition of the rotating equipment.

The philosophy behind the make-up of this group is based on concentrating in one logical and physical place the information relative to:

- materials for building equipment and machines
- non-destructive inspections and control techniques for the plant components
- welding problems
- eventual plant failures
- vibrational diagnosis
- specifications of inspection material
- calculation methods for mechanical verifications

In parallel to the engineering activity an supporting operative activity run by company personnel has been formed over the years for the following sectors:

- execution of non-destructive controls
- execution of vibrational inspections
- execution of manufactural tests at the suppliers

The approach that led to the union of theory and practice was determined by the following factors:

- the drawing up of inspection plans carried out with the direct participation of the operators that led to improvement of the non-destructive control methods, developed for the qualification and quantification of defects caused by particular operating conditions of each piece of equipment.
- continuous communication with the factory plant operator groups that has facilitated maintenance of each component. This has allowed a critical revision of projects for modifications, keeping in mind future inspections.
- the direct experience with defects which emerged during inspections that has permitted the correct modelling of calculation simulation specifically for the search for further critical points and for the eventual re-design of the components themselves.

- The experience described in the previous points that has allowed tests and construction specifications to be drawn up that in many cases are more rigorous than the laws in force and which have contributed to the increase in the MTBF (Mean Time Between Failures) and the MTTR (Mean Time To Repair).

- The continuous contact between suppliers of components with regard to tests at the suppliers premises which have led to their sensitization towards the constructive methods to be used in the manufacturing of components.

- The same contact with the suppliers that has allowed us to identify the most suitable suppliers of critical components.

- The work field of the group which is not just limited to the Porto Marghera factory but also to other main factories of the company, acquiring different know-how for various construction types of plants.

## 9. APPROACH TO PROGRAMMED SHUTDOWNS

The illustrated operation results were obtained after the following actions:

**1980**

- Constitution of maintenance engineering group

- Drawing-up of inspection programme for the ammonia plant for a comprehensive evaluation of its state of conservation

**1981**

- Programmed maintenance shutdown with execution of control plan to verify the general state of the plant

- Repair interventions following discovery of defects discovered during inspection

**1982**

- Analyses of results which emerged during the course of the inspection plan carried out during the programmed shutdown of 1981

**1983**

- Preparation of programmed maintenance shutdown of 1985

- Analyses of crisis point which came up during the previous inspection, evaluation of the constructive modifications to be made on equipment and machines.

**1984**

- Institution of periodical vibrational inspection of rotating equipment and reciprocating compressors

- Issue of control and supply specifications of materials foreseen during the previous analyses

- Execution of tests at the supplier's of particularly critical parts to be used in the ammonia plant

- Drawing up of the inspection plant for the ammonia plant to form a comprehensive evaluation of both the state of conservation and the appropriateness of the interventions carried out during the 1981 shutdown.

**1985**

- Turnaround with the execution of the control plan to verify the general state of the plant.

- Repair interventions following the discovery of defects during inspections.

The same course of action was repeated in the period 1985 to 1990, with particular emphasis given to detailed issue of supply and control specifications following experience gained from the previous period.

## 10. CASE HISTORY

The previously defined points have made it possible to define recurring critical operative situations.

### *PRIMARY REFORMING OVEN*

The 1981 programmed shutdown revealed a considerable number of defects in the weldings between the catalyst tubes and pigtails and between pigtails and weldolets of the outlet header.

These defects were revealed with the penetrating liquid test before grinding of the areas to be inspected.

The defects were mapped out then removed, followed, when necessary, by further welding where the defect affected the thickness significantly.

The main cause of damage was the inadequate material used in the construction phase.

The 1985 programmed shutdown revealed similar defects to those found in the previous shutdown. In the meantime a 3-part operation spread over time has been underway to verify the external stresses on the pigtails:

**1985:** First support modification

**1990:** Elimination of support

**1992:** Comprehensive re-design of support using the finite elements method for thorough verification of stress deriving from operation: this re-design will be carried out on the company's twin plant at S. Giuseppe di Cairo (SV).

### *TRANSFER LINES*

The transfer lines made of INCOLOY 800H have in the past proved to have weak points in the welding joining the secondary reforming made of low moly steel: the repairs of these weldings were done in the 1981 and 1990 programmed shutdowns.

After these interventions the joint-reducer was redesigned in order to obtain a more balanced distribution of tension and to create optimum conditions for a systematic inspection during operations with ultrasound.

In the 1985 programmed shutdown the subsidence of one of the pipeline supports was found: the subsidence had particularly affected the welding between the support plate and the pipe.

The anchorages were re-designed with positive results that were confirmed by the inspections carried out during the 1990 programmed shutdown.

*STEAM SUPERHEATER*

The steam superheater is composed of a 15 m long exchanger positioned horizontally on elastic supports. In the past the critical point has been traced to the welding between the shell and the hot tube plate, the point subjected to the most mechanical stress. In fact in the load change phase the exchanger moves noticeably horizontally and vertically as well as the natural axis movement caused by thermic dilation, movement due to the uneven distribution of temperature on the shell.

The first action was carried out at the re-startup after the 1985 programmed shutdown when continuous regulations were carried out on the elastic supports with variable loads intended to minimize the external stress on the welding mentioned above.

This proved successful as shown by the programmed shutdown of 1990.

With these results the support system was re-designed using suitable supports with constant load.

*RECIPROCATING COMPRESSORS SYN GAS*

During the latest production campaign there have been a high member of failures due to valve disc ruptures. These fatigue ruptures occurred before expected. On closer analysis of the material it was found that there was a considerably wide range of distribution of hardness, which indicated for the material of the valve disc (martensitic stainless steel) a drastic decrease of the mechanical properties resistant to fatigue.

This fact is also confirmed by the poor results obtained when carrying out modifications to only the mechanical machining cycle of the discs themselves, and obtaining no change in the valve performance.

On the other hand, material from different suppliers gave decidedly different results thus justifying the effect of hot treatment on the material constituting the valve discs.

*SYNGAS CIRCULATOR*

Since 1980 the MTBF has risen from 4000 to 12000 hours through accurate balancing of the impellers and the use of bearings in a bronze cage subjected to a through check before their installation.

*UPPER BASKET OF SYNTHESIS VESSEL*

The upper basket of the synthesis vessel is replaced at each five-year shutdown. The basket is reconditioned and kept as a spare part for the installed equipment. During the following reconditionning, the constructive techniques which were improved with weldings that guarantee a better seal, were confirmed by tests carried out by the suppliers before despatch.

This equipment had defects caused by incorrect welding procedures.

*SYNTHESIS VESSEL*

The synthesis vessel is multilayer type which therefore limits inpection exclusively to the sheet constituting the most internal and most external shells apart from the forgings constituting the base, the upper flange and the cap.

During the programmed shut-down of 1981, defects in the internal sheet of the shell were found corresponding to the mounting brackets; these defects were removed completely.

Controls carried out in subsequent shutdowns proved the interventions to be successful, with no further defects being found.

*ROTATING EQUIPMENT*

All the rotating equipment is subjected to a weekly systematic vibrational inspection. The information gleaned from this control system is used to carry out correctly the reconditioning of machines with spare parts and to diagnose any eventual failures of these machines which require considerable intervention time which can lead to production loss.

In the latter case the correct use of vibration diagnosis techniques has made it possible to concentrate on only the indispensable interventions for the right management of machinery and reducing the MTTR.

**TABLE I**

**OVERALL PLANT PERFORMANCE**

**AICHE SURVEY V**

Period 1982-85 1985-85 1985-90

Large Tonnage Plants Reciprocating Plant

| | North America | Europe | ROW | World | Enichem P.Marghera | Enichem P.Marghera |
|---|---|---|---|---|---|---|
| Downtime-Days/Yr/Plant | 71,11 | 48,63 | 84,52 | 60,17 | 24,77 | 26,62 |
| Shutdowns-N°/Yr/Plant | 6,7 | 6,25 | 11,62 | 16,48 | 15,5 | 12 |
| **Onstream Factor ( % )** | **80,52** | **86,68** | **76,84** | **83,52** | **93,21** | **92,71** |

**TABLE II**

**PLANT SERVICE FACTOR**

**( Days/Yr/Plant )**

**AICHE SURVEY V**

Period 1982-85 1985-85 1985-90

Large Tonnage Plants Reciprocating Plant

| | North America | Europe | ROW | World | Enichem P.Marghera | Enichem P.Marghera |
|---|---|---|---|---|---|---|
| TOTAL DOWNTIME | 71,11 | 48,63 | 84,52 | 60,17 | 24,77 | 26,62 |
| | | | | | | |
| Unavoidable Downtime | 47,06 | 11,19 | 39,36 | 35,44 | 4,1 | 7,64 |
| Net Avoidable | 24,05 | 37,44 | 45,16 | 24,73 | 20,67 | 18,98 |
| **SERVICE FACTOR ( % )** | **92,44** | **89,42** | **87,69** | **92,5** | **94,27** | **94,69** |

**TABLE III**

**CLASSIFICATION OF DOWNTIME**

**(Days/Yr)**

**AICHE SURVEY V**

Period 1982-85 1982-85 1985-90

Large Tonnage Plants Reciprocating Plant

| | North America | Europe | ROW | World | Enichem P.Marghera | Enichem P.Marghera |
|---|---|---|---|---|---|---|
| **UNAVOIDABLE SHUTDOWNS** | | | | | | |
| Feedstock Curtailment | 0,8 | 0,55 | 19,97 | 11,19 | 0,09 | 0,25 |
| Inventory Control | 45,37 | 8,69 | 15,16 | 20,82 | 0 | 0,78 |
| Electrical Failure | 0,18 | 0,63 | 1,7 | 2,05 | 0,9 | 0 |
| Other | 0,71 | 1,42 | 2,53 | 1,38 | 3,11 | 6,61 |
| **TOTAL UNAVOIDABLE** | **47,06** | **11,19** | **39,36** | **35,44** | **4,1** | **7,64** |
| | | | | | | |
| **UNAVOIDABLE SHUTDOWNS** | | | | | | |
| Turnarounds | 10,64 | 14,57 | 20,78 | 13,96 | 11,5 | 9,8 |
| Failure Maintenance | 13,33 | 22,74 | 23,96 | 10,71 | 8,72 | 7,98 |
| Other | 0,18 | 0,13 | 0,42 | 1,35 | 0,45 | 1,2 |
| **TOTAL UNAVOIDABLE** | **24,05** | **37,44** | **45,16** | **24,73** | **20,67** | **18,98** |
| | | | | | | |
| **TOTAL DOWNTIME** | **71,11** | **48,63** | **84,52** | **60,17** | **24,77** | **26,62** |

**TABLE IIIB**

**CLASSIFICATION OF DOWNTIME**

**(N°/Yr)**

**AICHE SURVEY V**

Period 1982-85 1982-85 1985-90

Large Tonnage Plants Reciprocating Plant

| | North America | Europe | ROW | World | Enichem P.Marghera | Enichem P.Marghera |
|---|---|---|---|---|---|---|
| **UNAVOIDABLE SHUTDOWNS** | | | | | | |
| Feedstock Curtailment | 0,14 | 0,08 | 0,74 | 0,31 | 0 | 0 |
| Inventory Control | 0,34 | 0,07 | 0,23 | 0,29 | 0 | 0 |
| Electrical Failure | 0,36 | 0,17 | 1,37 | 2,31 | 1,75 | 0,6 |
| Other | 0,27 | 0,11 | 0,19 | 0,46 | 0 | 0 |
| **TOTAL UNAVOIDABLE** | **1,11** | **0,43** | **2,53** | **3,37** | **1,75** | **0,6** |
| | | | | | | |
| **UNAVOIDABLE SHUTDOWNS** | | | | | | |
| Instrument Failure | 1,16 | 1,42 | 1,87 | 0,8 | 1,5 | 0,2 |
| Equipment Failure | 3,21 | 3,48 | 5,53 | 10,65 | 11,25 | 11,2 |
| Turnarounds | 0,5 | 0,4 | 0,68 | 0,52 | 0,25 | 0,2 |
| Electrical Failure | 0,22 | 0,2 | 0,35 | 0,61 | 1 | 0 |
| Other | 0,5 | 0,32 | 0,66 | 0,53 | 0 | 0 |
| **TOTAL UNAVOIDABLE** | **5,59** | **5,82** | **9,09** | **13,11** | **11,25** | **11,2** |
| | | | | | | |
| **TOTAL SHUTDOWNS** | **6,7** | **6,25** | **11,62** | **16,48** | **15,5** | **12** |

## TABLE IV
## DOWNTIME MAINTENANCE
### (Days/Yr/Plant)
### AICHE SURVEY V

| Period | 1982-85 | | | | 1982-85 | 1985-90 |
|---|---|---|---|---|---|---|
| | Large Tonnage Plants | | | | Reciprocating Plant | |
| PREVENTIVE MAINTENANCE | North America | Europe | ROW | Recip. Plant | Enichem P.Marghera | Enichem P.Marghera |
| TOURNAROUNDS | | | | | | |
| Shutdown for Overhaul | 10,54 | 14,57 | 20,78 | 13,9 | 11,5 | 9,8 |
| Shutdown for Other Causes | 0,41 | 4,94 | 8,81 | 7,99 | 0,45 | 1,2 |
| Total | 10,95 | 19,51 | 29,59 | 21,94 | 11,95 | 11 |
| | | | | | | |
| OTHER PREVENTIVE MAINTENANCE | | | | | | |
| Shutdown for PM | 0,08 | 0 | 0,33 | 0,02 | 0 | 0 |
| Shutdown for Other causes | 0,03 | 2,38 | 2,76 | 2,71 | 0 | 0 |
| | | | | | | |
| TOT. PREVENTIVE MAINTENANCE | 11,06 | 21,89 | 32,68 | 24,67 | 11,95 | 11 |
| | | | | | | |
| FAILURE MAINTENANCE | | | | | | |
| Equipment | 11,44 | 20,75 | 20,33 | 9,08 | 6,97 | 7,88 |
| Instrumentation | 1,05 | 1,41 | 1,11 | 0,35 | 0,63 | 0,1 |
| Electrical | 0,49 | 0,19 | 1,7 | 0,54 | 1,12 | 0 |
| Other | 0,35 | 0,39 | 0,82 | 0,74 | 0 | 0 |
| | 5,59 | 5,82 | 9,09 | 13,11 | 11,25 | 11,2 |
| | | | | | | |
| TOTAL FAILURE MAINTENANCE | 13,33 | 22,74 | 23,96 | 10,71 | 8,72 | 7,98 |
| | | | | | | |
| TOTAL DOWNTIME MAINTENANCE | 24,39 | 44,63 | 56,64 | 35,38 | 20,67 | 18,98 |

## TABLE V
## TURNAROUNDS

| | Large Tonnage Plants | | | | Reciprocating Plant |
|---|---|---|---|---|---|
| | North America | Europe | ROW | World | Enichem P.Marghera |
| Days per Turnarounds | 21,74 | 33,24 | 33,71 | 30,8 | 49 |
| Actual Frequency-Months | 24 | 20,5 | 13,58 | 17 | 60 |
| Desidered Frequency-Months | 23,5 | 25 | 14,5 | 16 | 60 |

**TABLE VI A**

**CLASSIFICATION OF DOWNTIME**

**Downtime (Days/Yr)**

**AICHE SURVEY V**

| Period | 1982-85 | | | | 1982-85 | 1985-90 |
|---|---|---|---|---|---|---|
| | Large Tonnage Plants | | | | Reciprocating Plant | |
| | North America | Europe | ROW | World | Enichem P.Marghera | Enichem P.Marghera |
| **Primary Reformer** | 3,01 | 3,04 | 4,84 | 1,1 | 0 | 0 |
| **Secondary Reformer** | 1,25 | 5,36 | 1,25 | 0,77 | 0 | 1,32 |
| **Purification** | 1,11 | 1,9 | 1,9 | 1,58 | 0,15 | 0,66 |
| **Feed Gas Compressor** | 0,06 | 0,17 | 0,04 | 0 | 0 | 0 |
| **Air Compressor** | 0,8 | 0,32 | 1,67 | 0,25 | 0 | 0,41 |
| **Total** | **6,23** | **10,79** | **9,7** | **3,7** | **0,15** | **2,39** |
| **Syn Gas Compressor** | 1,49 | 2,33 | 3,7 | 0,28 | 2,71 | 0,94 |
| **Syn Gas Circulator** | 0,01 | 0 | 0,02 | 0,05 | 0 | 0 |
| **Refrigeration Compressor** | 1,13 | 0,25 | 0,63 | 0 | 0,06 | 0,96 |
| **Total** | **2,63** | **2,58** | **4,35** | **0,33** | **2,77** | **1,9** |
| **Syn Loop & Refrig.** | | | | | | |
| **Exchangers** | 0,72 | 0,26 | 0,81 | 0,25 | 0,65 | 0,8 |
| **Piping & Valves** | 0,39 | 1,51 | 0,3 | 0,1 | 0,35 | 0,39 |
| **Vessels** | 0,07 | 0,4 | 0,01 | 0,23 | 0 | 0 |
| **Miscellaneous** | 0,1 | 0 | 0 | 0,24 | 0 | 0 |
| **Total** | **1,28** | **2,17** | **1,12** | **0,82** | **1** | **1,19** |
| **Misc. Equipment** | | | | | | |
| **Auxiliary Boiler** | 0,48 | 0,31 | 0,45 | 0,68 | 0 | 0 |
| **Piping & Valves** | 0,27 | 0,63 | 0,9 | 0,58 | 0,3 | 0,2 |
| **Exchangers** | 0,17 | 2,59 | 3,31 | 1,21 | 1,8 | 1,1 |
| **Vessels** | 0,06 | 1,4 | 0,19 | 0,53 | 0 | 0 |
| **Pumps & Drivers** | 0,08 | 0,17 | 0,23 | 0,03 | 0 | 0 |
| **Reciprocating Compr.** | | | | 1,14 | 0,75 | 0,8 |
| **Miscellaneous** | 0,2 | 0,12 | 0,08 | 0,06 | 0,2 | 0,3 |
| **Total** | **1,26** | **5,22** | **5,16** | **4,23** | **3,05** | **2,4** |
| **GRAND TOTAL** | **11,4** | **20,76** | **20,33** | **9,08** | **6,97** | **7,88** |

**TABLE VI B**

**CLASSIFICATION OF DOWNTIME**

**Shutdowns (N°/Yr)**

**AICHE SURVEY V**

| Period | 1982-85 | | | | 1982-85 | 1985-90 |
|---|---|---|---|---|---|---|
| | Large Tonnage Plants | | | | Reciprocating Plant | |

| | North America | Europe | ROW | World | Enichem P.Marghera | Enichem P.Marghera |
|---|---|---|---|---|---|---|
| **Primary Reformer** | 0,7 | 0,52 | 0,78 | 0,5 | 0 | 0 |
| **Secondary Reformer** | 0,14 | 0,24 | 0,27 | 0,1 | 0 | 0,2 |
| **Purification** | 0,44 | 0,39 | 0,68 | 0,59 | 0,25 | 0,2 |
| **Feed Gas Compressor** | 0,04 | 0,03 | 0,04 | 0 | 0 | 0 |
| **Air Compressor** | 0,31 | 0,21 | 0,39 | 0,15 | 0 | 0,2 |
| **Total** | **1,63** | **1,39** | **2,16** | **1,34** | **0,25** | **0,6** |
| **Syn Gas Compressor** | 0,65 | 0,57 | 1,57 | 0,24 | 1,75 | 0,8 |
| **Syn Gas Circulator** | 0,02 | 0 | 0,03 | 0,07 | 0 | 0 |
| **Refrigeration Compressor** | 0,18 | 0,1 | 0,29 | 0,02 | 0,25 | 0,8 |
| **Total** | **0,85** | **0,67** | **1,89** | **0,33** | **2** | **1,6** |
| **Syn Loop & Refrig.** | | | | | | |
| **Exchangers** | 0,24 | 0,09 | 0,15 | 0,24 | 0,25 | 0,2 |
| **Piping & Valves** | 0,2 | 0,24 | 0,19 | 0,19 | 0,25 | 0,2 |
| **Vessels** | 0,03 | 0,01 | 0 | 0,04 | 0 | 0 |
| **Miscellaneous** | 0,48 | 0,34 | 0,36 | 0,52 | 0,5 | 0,4 |
| **Total** | **0,48** | **0,34** | **0,36** | **0,52** | **0,5** | **0,4** |
| **Misc. Equipment** | | | | | | |
| **Auxiliary Boiler** | 0,02 | 0,03 | 0,07 | 0,15 | 0 | 0 |
| **Piping & Valves** | 0,1 | 0,44 | 0,49 | 0,47 | 0 | 0 |
| **Exchangers** | 0,02 | 0,51 | 0,59 | 0,45 | 0,5 | 0,2 |
| **Vessels** | 0,01 | 0,04 | 0,04 | 0,06 | 0 | 0 |
| **Pumps & Drivers** | 0,04 | 0,05 | 0,14 | 0,07 | 0 | 0 |
| **Reciprocating Compr.** | | | | 7,22 | 8 | 8,4 |
| **Miscellaneous** | 0,05 | 0,03 | 0,03 | 0,03 | 0 | 0 |
| **Total** | **0,24** | **1,1** | **1,36** | **8,45** | **8,5** | **8,6** |
| **GRAND TOTAL** | **3,2** | **3,5** | **5,67** | **10,75** | **11,25** | **11,2** |

**TABLE VII**

**INSTRUMENT FAILURES**

| Downtime | Days/Yr | 1.982 | 1.983 | 1.984 | 1.985 | | AVERAGE |
|---|---|---|---|---|---|---|---|
| Total | 1ˆ Reformer | 0,85 | 0 | 0 | 1 | | 0,47 |
| Partial | 2ˆ Reformer | 0 | 0 | 0,21 | 0 | | 0,05 |
| Partial | Methanation | 0,15 | 0 | 0,1 | 0,2 | | 0,11 |
| Partial | Synthesis | 0 | 0 | 0 | 0 | | 0 |
| Partial | Compressors | 0 | 0 | 0 | 0 | | 0 |
| TOTAL | DOWNTIME | 1 | 0 | 0,31 | 1,2 | | 0,63 |
| | | | | | | | |
| Downtime | Days/Yr | 1.986 | 1.987 | 1.988 | 1.989 | 1.990 | AVERAGE |
| Total | 1ˆ Reformer | 0 | 0 | 0 | 0 | 0 | 0 |
| Partial | 2ˆ Reformer | 0 | 0 | 0 | 0 | 0 | 0 |
| Partial | Methanation | 0 | 0 | 0 | 0 | 0,5 | 0,1 |
| Partial | Synthesis | 0 | 0 | 0 | 0 | 0 | 0 |
| Partial | Compressors | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | DOWNTIME | 0 | 0 | 0 | 0 | 0,5 | 0,1 |
| | | | | | | | |
| Shutdowns | N°/Yr | 1.982 | 1.983 | 1.984 | 1.985 | | AVERAGE |
| Total | 1ˆ Reformer | 1 | 0 | 0 | 1 | | 0,5 |
| Partial | 2ˆ Reformer | 0 | 0 | 1 | 0 | | 0,25 |
| Partial | Methanation | 1 | 0 | 1 | 1 | | 0,75 |
| Partial | Synthesis | 0 | 0 | 0 | 0 | | 0 |
| Partial | Compressors | 0 | 0 | 0 | 0 | | 0 |
| TOTAL | SHUTDOWNS | 2 | 0 | 2 | 2 | | 1,5 |
| | | | | | | | |
| Shutdowns | N°/Yr | 1.982 | 1.983 | 1.984 | 1.985 | 1.990 | AVERAGE |
| Total | 1ˆ Reformer | 0 | 0 | 0 | 0 | | 0 |
| Partial | 2ˆ Reformer | 0 | 0 | 0 | 0 | | 0 |
| Partial | Methanation | 0 | 0 | 0 | 0 | 1 | 0,2 |
| Partial | Synthesis | 0 | 0 | 0 | 0 | | 0 |
| Partial | Compressors | 0 | 0 | 0 | 0 | | 0 |
| TOTAL | SHUTDOWNS | 0 | 0 | 0 | 0 | 1 | 0,2 |

## TABLE VIII
## INTERNAL ELECTRICAL FAILURES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Downtime | Days/Yr | 1.982 | 1.983 | 1.984 | 1.985 | | AVERAGE |
| Total | | 1,25 | 0 | 1,2 | 0 | | 0,61 |
| Partial | Centrifugal compr. air | 0,45 | 0 | 0 | 1,6 | | 0,51 |
| TOTAL | DOWNTIME | 1,7 | 0 | 1,2 | 1,6 | | 1,12 |
| | | | | | | | |
| Downtime | Days/Yr | 1.986 | 1.987 | 1.988 | 1.989 | 1.990 | AVERAGE |
| Total | | 0 | 0 | 0 | 0 | 0 | 0 |
| Partial | | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | DOWNTIME | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | |
| Shutdowns | N°/Yr | 1.982 | 1.983 | 1.984 | 1.985 | | AVERAGE |
| Total | | 1 | 0 | 1 | 0 | | 0,5 |
| Partial | Centrifugal compr. air | 1 | 0 | 0 | 1 | | 0,5 |
| TOTAL | SHUTDOWNS | 2 | 0 | 1 | 1 | | 1 |
| | | | | | | | |
| Shutdowns | N°/Yr | 1.986 | 1.987 | 1.988 | 1.989 | 1.990 | AVERAGE |
| Total | | 0 | 0 | 0 | 0 | | 0 |
| Partial | | 0 | 0 | 0 | 0 | | 0 |
| TOTAL | SHUTDOWNS | 0 | 0 | 0 | 0 | 0 | 0 |

## TABLE IX
## EXTERNAL ELECTRICAL FAILURES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Downtime | Days/Yr | 1.982 | 1.983 | 1.984 | 1.985 | | AVERAGE |
| Total | | 0,75 | 0,82 | 0 | 0 | | 0,39 |
| Partial | Centrifugal compr. air | 0 | 0,46 | 1,58 | 0 | | 0,51 |
| TOTAL | DOWNTIME | 0,75 | 1,28 | 1,58 | 0 | | 0,9 |
| | | | | | | | |
| Downtime | Days/Yr | 1.986 | 1.987 | 1.988 | 1.989 | 1.990 | AVERAGE |
| Total | | 0 | 1,02 | 0 | 0 | 0 | 0,2 |
| Partial | | 0 | 0 | 0 | 0,31 | 0,51 | 0,17 |
| TOTAL | DOWNTIME | 0 | 1,02 | 0 | 0,31 | 0,51 | 0,3 |
| | | | | | | | |
| Shutdowns | N°/Yr | 1.982 | 1.983 | 1.984 | 1.985 | | AVERAGE |
| Total | | 1 | 1 | 0 | 0 | | 0,5 |
| Partial | Centrifugal compr. air | 0 | 1 | 4 | 0 | | 1,25 |
| TOTAL | SHUTDOWNS | 1 | 2 | 4 | 0 | | 1,75 |
| | | | | | | | |
| Shutdowns | N°/Yr | 1.986 | 1.987 | 1.988 | 1.989 | 1.990 | AVERAGE |
| Total | | 0 | 1 | 0 | 0 | 0 | 0,2 |
| Partial | | 0 | 0 | 0 | 1 | 1 | 0,4 |
| TOTAL | SHUTDOWNS | 0 | 1 | 0 | 1 | 1 | 0,6 |

**TABLE X**

**STATISTIC FOR PLANT SHUTDOWNS IN THE 1981-1990 PERIOD**

| Year | Plant Shutdown | Cold Shutdown | Date | n. days of operation | Notes |
|---|---|---|---|---|---|
| 1981 | 0 | 0 | 08.15.81 | | Re-start-up of plant |
| 1982 | 1 | 1 | 03.12.82 | 209 | |
| 1983 | 1 | 1 | 09.13.83 | 550 | |
| 1984 | 0 | 0 | | | |
| 1985 | | | 04.20.85 | 585 | |
| Total | 2 | 2 | | | |

**Average** = 0,5 cold shutdowns/year in 4 years

**Loss from reformer pipes** = 2

**Average** = 0.5 losses/year in 4 years of operation

| Year | Plant Shutdowns | Cold Shutdowns | Date | n. days of operation | Notes |
|---|---|---|---|---|---|
| 1985 | <br>1 | <br>0 | 06.16.85<br>10.19.85 | <br>125 | Re-start-up of plant |
| 1986 | 1 | 0 | 06.18.86 | 242 | |
| 1987 | 1<br>1<br>1 | <br><br>1 | 05.19.87<br>07.03.87<br>10.10.87 | 335<br>45<br>99 | |
| 1988 | 1 | 1 | 04.10.88 | 183 | |
| 1989 | 1 | 1 | 04.25.89 | 380 | |
| 1990 | 0 | 0 | 03.01.90 | 310 | |
| Total | 7 | 3 | | | |

**Average** = 0,6 cold shutdowns/year in 5 years

**Loss from reformer pipes** = 0

**Average** = 0.0 losses/year in 5 years of operation