AMMONIA PLANT OPERATIONS:

What Causes Ammonia Plant Shutdowns?

According to the second AIChE survey on ammonia plant shutdowns, major equipment failures are still the major cause of downtime.

G. P. Williams, Cooperative Farm Chemicals Association, Lawrence, Kan.,
J. G. Sawyer, Allied Chemical Corp., Hopewell, Va.

Operating efficiency in large tonnage, single-train ammonia plants is showing an improvement. However, major equipment failures continue to be the dominant cause of shutdowns.

These are two conclusions drawn from a recent survey to identify shutdown causes in such facilities. Other observations will also be in this article.

A total of 27 plants participated in the survey: eight at 600 ton/day, three at 750, thirteen at 1,000, and three at 1,500 ton/day. These facilities represent 75% of the large tonnage ammonia plants in North America. The survey covers the operational histories of these plants for the two year period, 1971 and 1972, and updates the 1969–70 survey of 22 plants presented at the 1971 Atlantic City AIChE meeting. Six additional plants and all but one of the '69–'70 survey plants are included in the '71–'72 survey. Data from both survey periods are presented separately to provide a comparison of changes in downtime, equipment failures, and other performance criteria. A distinction was maintained between the "pre-'68" or "older" plants (those plants initially brought onstream in 1963 through 1967) and the "newer" plants because of differences in their performance characteristics.

The causes of shutdowns have been divided into five general categories, i.e., instrument failures, electrical failures, major equipment failures, preventative maintenance, and "other." A more detailed analysis of major equipment failures is presented since this category still accounts for a large portion of the downtime.

The "average" ammonia plant, representative of all plants surveyed during the '71–'72 operational period, displayed a significant improvement in plant performance over the '69–'70 period because total downtime was reduced by 4½ days and number of shutdowns by one.

Total survey average of annual downtime and number of shutdowns is shown in Table 1. A comparison of older and newer ammonia plants for the two survey periods is shown in Table 2. Most improvement in onstream time occurred in the pre-1968 plants, where downtime was reduced by 6½ days per year and the number of shutdowns by 1½ per year. However, downtime of these pre-1968 plants is still higher than the average of all plants and seven days greater than that of the newer plants. The newer plants continued to post the same downtime as they did in the '69–'70 survey. Moreover, the number

Table 1. Average annual downtime and number of shutdowns.

	1969–70 Survey (22 plants)	1971–72 Survey (27 plants)
Days of Downtime	50	45½
Number of Shutdowns	9½	8½

Table 2. Comparison of performance by older and newer plants.

	1969–70 Survey (annual basis)	1971–72 Survey (annual basis)
Pre-1968 Plants:		
Days of Downtime	54	47½
Number of Shutdowns	10	8½
1968–71 Plants:		
Days of Downtime	40½	40½
Number of Shutdowns	7	8½

Table 3. Annual downtime for large tonnage ammonia plants (1971–1972 survey).

Downtime Days*	Number of Plants Pre-1968	1968–71	Totals
10	1	0	1
20	1	1	2
30	3	4	7
40	3	1	4
50	3	2	5
60	4	0	4
70	1	0	1
80	1	0	1
90	1	1	2
100+			
average days	47½	40½	45½

*Downtime days/yr./plant ± 5 days of indicated number of days.

of shutdowns is the same for both the older and newer plants, even though the downtime is significantly different.

The distribution of downtime indicated in Table 3 clearly shows the difference between the performance of the older and newer plants: 40% of the pre-'68 ammonia plants have annual downtime in excess of 50 days, whereas only 10% of the newer plants exceed 50 days. Nevertheless, 75% of the pre-'68 plants in the '69-'70 survey had less downtime during the '71-'72 period.

Five classifications of shutdown causes

Causes of shutdowns and their associated downtime have been divided into five classifications. The number of shutdowns is shown in Table 4. The number of shutdowns of plants participating in the survey ranged from three to 14 per year. A comparison between the two survey periods indicates a slight improvement in the number of shutdowns suffered by the "average" ammonia plant, but the frequency of 8½ shutdowns per year is still far from desirable. In a broad sense, only those shutdowns classified as "preventative maintenance" or "other" can be considered as "intentional" shutdowns. This amounts to one shutdown per year. The difference is 7½ shutdowns per year caused by electrical, instruments, and equipment failures, which are clearly unintentional or unwanted shutdowns.

It is significant that most of the shutdowns—5 per year—are caused by major equipment failures and that there has been little improvement since the '69-'70 survey period. Instrument failures are the second most frequent cause of shutdowns, and their frequency has doubled from one to two per year since the first survey. Electrical failures have been cut 50% in the pre-'68 plants, effecting a reduction to one shutdown every two years for the "average" ammonia plant. Although instrument and electrical failures account for a small portion of the total downtime (3-4%), the number of failures increases the exposure of major equipment to potential damage. Failure of a key control loop can easily result in a plant "crash-down."

Most operators appear to be scheduling a major maintenance turnaround every 12 to 18 months. Although one-third of the plants reported only one turnaround during the '71-'72 period, the remaining plants reported two. Because the frequency of equipment failures is rather high, most plants maintain a high degree of turnaround "readiness" to take advantage of the downtime created by an equipment failure. In fact, one-half of the turnarounds during the '71-'72 period were initiated by a major equipment failure. The distribution of downtime in both survey periods due to all classes of causes is shown in Table 5.

Less downtime needed to make repairs

As mentioned earlier, the pre-'68 plants have appreciably reduced their downtime by 6½ days per year, while the newer plants continued their fairly respectable downtime of 40½ days per year.

One of the most notable changes between the two survey periods has been the reduction in downtime to repair major equipment failures. Both the older and newer plant groups show a 30% reduction in downtime to repair the same number of major equipment failures. There are certainly a number of factors contributing to the quicker repair times and one of the more important ones is that there has been less failure of the type of equipment which inherently requires long repair times, such as primary waste heat boilers.

Table 4. Number of shutdowns of large tonnage ammonia plants.

Classification	'69–'70 Survey Period Plants No/Yr./Plant: Pre-'68 (16 Plants)	'68–'69 (6 Plants)	Totals (22 Plants)
I. Instrument Failures	1	1	1
II. Electrical Failures	1	½	1
III. Major Equipment failures	6	4	5½
IV. Turnarounds*	1	1	1
V. Other	1	½	1
Totals	10	7	9½

Classification	'71–'72 Survey Period Plants No/Yr./Plant: Pre-'68 (18 Plants)	'68–'71 (9 Plants)	Totals (27 Plants)
I. Instrument Failures	1½	2	2
II. Electrical Failures	½	½	½
III. Major Equipment failures	5½	4½	5
IV. Turnarounds*	½	½	½
V. Other	½	1	½
Totals	8½	8½	8½

*Half of the maintenance turnarounds shown in the '71-'72 data are included under "Major Equipment Failures."

Perhaps even more important are the factors derived from experience, such as: better awareness of potential problem equipment, higher quality and quantity of spare parts inventory, refined clearance procedures, better maintenance familiarity with equipment, improved repair techniques and procedures, and quicker management response time in establishing a repair program.

For example, during the '69-'70 survey period 7½ days were required to repair tube and riser leaks and 23 days for a primary waste heat boiler; during the last survey period this repair time was reduced to about five and ten days, respectively.

Another significant change between the two survey periods has been the 45% increase in "preventative maintenance" downtime. This now accounts for 52% of the total downtime versus 32% during the '69-'70 period. "Preventative maintenance" downtime is defined as the downtime remaining after subtracting electrical, instrument, equipment failure, and "other" downtime from the total downtime. For the most part it represents "turnaround" downtime.

It is difficult to account satisfactorily for this increase because maintenance activities and other problems falling under this heading were not requested on the survey questionnaire. For instance, there were 19 maintenance turnarounds lasting more than 25 days and most of these were initiated by major equipment failures requiring less than seven days repair time.

Perhaps spare parts availability, high ammonia inventory, or even feedstock availability played an important role in these extended outages. However, in many cases, it can be surmised that much of the increase in scheduled

Table 5. Downtime in large tonnage ammonia plants.

Classification	'69–'70 Survey Period[1] Plants Days[2] Pre-'68 (16 Plants)	'68–'69 (6 Plants)	Total (22 Plants)
I. Instrument Failures	1	1	1
II. Electrical Failures	1	1	1
III. Major Equipment Failures	32	22	29½
IV. Other	3	1½	3
V. Preventative Maintenance	16½	14½	16
Totals	54	40½	50

Classification	'71–'72 Survey Period Plants Days[2] Pre-'68 (18 Plants)	'68–'71 (9 Plants)	Total (27 Plants)
I. Instrument Failures	1	½	1
II. Electrical Failures	½	—	½
III. Major Equipment Failures	21½	16	19½
IV. Other	1	1	1
V. Preventative Maintenance	24	23	23½
Totals	47½	40½	45½

[1]This survey data covers a period from January 1, 1969, to May 1, 1971 (28 months).
[2]Downtime days/yr./plant.

Table 6. General classification of major equipment failures.

Classification	'69–'70 Survey Period Plants Days* Pre-'68 (16 Plants)	'68–'69 (6 Plants)	Total (22 Plants)
I. Primary Reforming	13	½	9½
II. Secondary Reforming	6	7	6½
III. Purification	2	5	3
IV. Syn Loop & Refrigeration (excluding compressors & turbines)	2	½	1
V. Major Compressors and Turbines	7	6	7
VI. Miscellaneous	1		1
Totals	31	19	28

Classification	'71–'72 Survey Period Plants Days* Pre-'68 (18 Plants)	'68–'71 (9 Plants)	Total (27 Plants)
I. Primary Reforming	8	2½	6
II. Secondary Reforming	2½	2	2
III. Purification	2½	2½	2½
IV. Syn Loop & Refrigeration (excluding compressors & turbines)	½	5	2
V. Major Compressors and Turbines	7½	4	6½
VI. Miscellaneous	½	½	½
Totals	21½	16½	19½

*Average number of downtime days/yr./plant to repair major equipment item causing shutdown.

outage time can be attributed to an enlargement of various maintenance programs such as: more tube replacements, greater exchanger and compressor maintenance, and perhaps more upgrading and replacements of transfer headers and convection section coils. In general, it appears that the "average" ammonia plant operator is spending less time "putting out fires" and more time preventing them.

Major equipment downtime associated with plant process areas is shown in Table 6. Comparing equipment downtime of the two survey periods, the "average" ammonia plant dramatically reduced "Primary" and "Secondary Reforming" downtime by 3½ and 4½ days, respectively, which accounts for most of the 8½ days difference in total equipment downtime between the two survey periods. In fact, there was a slight improvement in all categories except "Syn Loop and Refrigeration." This latter category is somewhat distorted because 80% of the outage time was due to two ammonia converter problems in two of the newer plants requiring a total of 80 days downtime (one involved a basket replacement and the other, a flange repair).

There is still a major difference between the older and newer plants in primary reforming downtime. Plant age, especially important for reformer tubes, transfer headers, convection section coils, and waste heat boiler tubes and insulation, favors the newer plants. But the newer plants included in the first survey are now, of course, two to four years old and are experiencing more failures in these areas. For instance, during the '69-'70 survey none of the newer plants reported a tube, riser, or manifold failure; now they have 0.3 failures per year. In contrast, the older plants had 1.0 failures per year during the earlier survey and now have 0.9, a slight reduction.

The reduction in "Secondary Reforming" downtime for both age group plants is a result of quicker repair time, fewer waste heat boiler shell failures (which require more time than tube failures to repair), and a slight reduction in the total number of failures. There were 13 failures, about half of which were shell failures, reported on the first survey of 22 plants vs. 11 failures for this survey of 27 plants with only one shell failure.

Specific equipment failures

A listing of the "top 6" major equipment failures in terms of downtime is shown on Table 7. This table is a summary of the detailed data presented in Table 8. Tube, risers and manifold leaks, followed closely by the syn gas compressor, and the air compressor lead the list of major equipment failures causing the most downtime for all plants. They account for 44% of the major equipment downtime. Waste heat boilers, which headed the '69–'70 list, have dropped to fourth place in the ranking.

The addition of tube, riser, and manifold leaks to the newer plant's problem list has pushed this category into first place. However, as mentioned above, this problem has "leveled off" for the older plants and may even diminish in the future as operators better define an optimum tube replacement program for their plant. Almost all the ammonia plants are still running on all or a portion of their original reformer tubes, and the end of this first cycle is rapidly approaching for many of the plants. This "leveling off" in the older plants indicates that their preventative maintenance programs, including design and material changes as well as improved reforming catalysts, are having a favorable impact.

The synthesis gas compressor (including its driver turbines) continues to be a major problem item, having moved from third to second place on the downtime list. More shutdowns have been caused by the syn gas compressor than any other single equipment item. In terms of number of shutdowns, no improvement has been made since the first survey. The "average" ammonia plant still has just under one shutdown per year attributed to this machine. Of the 47 failures reported by the 27 plants participating in the '71–'72 survey, the causes fall into 16 basic categories, some of which were: replaced compressor bearings (11), replaced compressor seals (3), replaced thrust bearing (3), repaired crack in gas balance line (4), lost buckets on condensing turbine (2), bad governor worm gear (2), changed out rotor (2), balance piston failed (1).

The newer plants are having more syn gas compressor shutdowns than the older plants. Just the reverse was true during the first survey. The older plants are now averaging 0.7 shutdowns per year vs. 1.1 for the newer plants. In addition, 23% of the instrument failures are associated with the syn gas compressor. A total of 22 incidents were reported and the causes widely varied, e.g.: kick-back valve would not close (1), governor oil pressure regulator broke (1), faulty oil switch (4), seal oil pressure regulator valve broke (1), governor malfunctioned (1), pneumatic/hydraulic transducer failed (2), faulty trip circuit (2), seal oil differential transmitter failed (1), etc.

The air compressor fails about once every 2½ years in the "average" ammonia plant, and this frequency has increased slightly since the '69–'70 survey. Its catalog of problems reads about the same as the syn gas machine, except that it does not have a seal oil system.

While the refrigeration compressor operates at somewhat lower speeds and pressures, its operation is remarkably trouble-free in comparison to the previous two compressors. A total of seven failures were reported during the past two years which is equal to one failure every eight years in the "average" ammonia plant.

Included under the term "Exchangers" in Table 7 are all the synthesis loop exchangers, surface condensers, CO_2 removal system exchangers, compressor intercoolers, and those exchangers commonly associated with the catalytic conversion vessels in the purification section of the plant. There has been significant reduction in the number of failures in CO_2 removal system exchangers. Since the last survey, the failure frequency has been cut in half. Whereas some of the plants with MEA systems reported using an inhibitor system during the '69–'70 survey, all of the 17 MEA users participating in this survey are now using an inhibitor. While exchangers only rank fifth on the "top six" list they are undoubtedly a serious maintenance problem. This survey only reports on failures causing shutdowns and it is probably conservative to say that less than one-third of the exchanger problems show up in this type of survey.

One of the basic objectives of this survey was to identify hazardous conditions arising from failures. Although there were fewer fires reported, the areas in which they occurred are about the same as reported in the first survey. Specifically, fires were associated with an oil leak near the syn gas compressor turbine, ammonia converter outlet flange, secondary waste heat boiler flange, packing gland leak on a purge gas separator level float chamber, transfer header rupture, and a process gas line rupture due to erosion from quench water.

Case and thoroughness in the inspection and maintenance of piping and flanges in hydrogen rich gas service is of utmost importance and cannot be over-emphasized.

Miscellaneous data

A brief summary of some miscellaneous information brought out in the survey is as follows:

1. The average "longest run time" for all 27 plants was 179 days, which is slightly higher than the 171 day average for the '69–'70 survey. Seven of the plants reported continuous runs greater than 200 days. The highest "longest run time" reported was 361 days.

2. In the "average" ammonia plant, 24% of the routine and 55% of the turnaround maintenance is performed by contract maintenance personnel. Four of the plants use 100% contract maintenance for both types of maintenance while 60% of the plants use less than 10% contract maintenance for routine. All plants use some degree of contract maintenance for turnarounds.

3. A breakdown of the reported effect of gas curtailments on plant operations is as follows: five plants experienced gas curtailments between 18 days and 251 days per year; five reported less than five days per year; 14 reported no gas curtailments; and three did not reply. Three plants said they had the capability of using No. 2 fuel oil as an alternate fuel source.

Table 7. Major equipment failures causing the most downtime.*

'69–'70 Survey Period Plants

	Pre-'68 (16 Plants)	'68–'69 (6 Plants)	Totals (22 Plants)
1.	Tube, Riser, & Manifold Leaks (22.6)	Waste Heat Boilers (36.0)	Waste Heat Boilers (20.6)
2.	Waste Heat Boilers (17.2)	Exchangers (25.5)	Tube, Riser, & Manifold Leaks (18.5)
3.	Syn Gas Compressor (12.4)	Syn Gas Compressor (18.0)	Syn Gas Compressor (13.4)
4.	Transfer Hdr. (7.5)	Air Compressor (6.7)	Exchangers (9.5)
5.	Exchangers (6.0)	Refrigeration Compressor (5.6)	Transfer Hdr. (6.2)
6.	Convection Sect. & Piping (5.5)	Convection Sect. & Piping (2.6)	Convection Sect. & Piping (5.0)

'71–'72 Survey Period Plants

	Pre-'68 (18 Plants)	'68–'71 (9 Plants)	Totals (27 Plants)
1.	Tube, Riser, & Manifold Leaks (19.3)	Ammonia Converter (27.7)	Tube, Riser, & Manifold Leaks (16.7)
2.	Syn Gas Compressor (16.7)	Syn Gas Compressor (15.1)	Syn Gas Compressor (16.2)
3.	Air Compressor (11.8)	Waste Heat Boilers (11.1)	Air Compressor (11.1)
4.	Waste Heat Boiler Leaks (10.2)	Tube, Riser, & Manifold Leaks (10.0)	Waste Heat Boiler Leaks (10.4)
5.	Exchangers (9.6)	Air Compressor (9.3)	Exchangers (9.2)
6.	Transfer Hdr. (6.9)	Exchangers (8.1)	Ammonia Converter (7.5)

*Percentage of major equipment downtime is shown in parentheses.

Acknowledgment

The authors would like to thank those companies and individuals who participated in the survey and who took the time to provide answers to a lengthy questionnaire. #

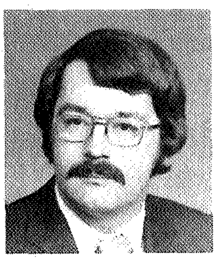
Literature cited

1. Sawyer, J.G., Williams, G.P., and Clegg, J.W., "Causes of Shutdowns in Ammonia Plants," CEP Technical Manual, 14 pp. 62-6, Ammonia Plant Safety, New York (1971).

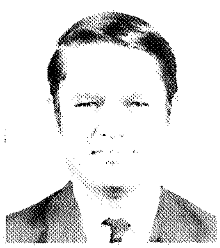
Table 8. Equipment failures in large tonnage ammonia plants.

Classification of Failure	'63–'67 Ammonia Plants (18 Plants) No.	Days	Days/Yr.*	'68–'71 Ammonia Plants (9 Plants) No.	Days	Days/Yr.*	Totals (27 Plants) No.	Days	Days/Yr.*
I. Primary reforming:									
(a) Tube leaks	18	105		1	7.4		19	112.4	
(b) Riser leaks	6	20.5		2	6.6		8	27.1	
(c) Manifold leaks	6	21.4		2	10.8		8	37.2	
(d) Pigtail leaks	1	2		1	4		2	6	
Sub-totals	31	148.9	(4)	6	28.8	(1½)	37	177.7	(3½)
(e) I.D. Fan	5	7		2	2		7	9	
(f) Transfer header	5	53.5		0	0		5	53.5	
(g) Catalyst	5	16.8		1	5		6	21.8	
(h) Conv. sect. coils	5	49		2	6		7	55	
(i) Misc.	1	4		0	0		1	4	
Sub-totals	21	130.3	(3½)	5	13	(½)	26	143.3	(2½)
Totals	52	279.2	8	11	41.8	2½	63	321	6
II. Sec. Reforming & WHB's:									
(a) WHB tube leaks	4	56		6	32		10	88	
(b) WHB shell leaks	1	20		0	0		1	20	
(c) WHB fouling	7	2.2		0	0		7	2.2	
(d) Piping & flange leaks	4	8.9		1	.5		5	9.4	
Totals	16	87.1	2½	7	32.5	2	23	119.6	2
III. Purification:									
(a) Catalyst	0	0		2	12		2	12	
(b) Exchangers	11	33.1		1	3.9		12	37	
(c) CO_2 Removal—Circ. pumps	6	16.8		6	10.5		12	27.3	
—Exchangers	15	28.5		3	11		18	39.5	
—Piping & flgs.	3	1.9		0	0		3	1.9	
—Other	5	11.5		3	10.8		8	22.3	
Totals	40	91.8	2½	15	48.2	2½	55	140	2½
IV. Syn Loop & Refrigeration:									
(a) Exchangers	5	10.4		2	4.5		7	14.9	
(b) Converter	0	0		2	80		2	80	
(c) Piping & flanges	5	2.8		3	.3		8	3.1	
Totals	10	13.2	½	7	84.8	5	17	98	2
V. Compressors:									
(a) Compressors & Turbines:									
—Feed gas	4	5		0	0		4	5	
—Air	16	90.7		7	26.9		23	117.6	
—Syn gas	28	128.6		19	43.6		47	172.2	
—Refrigeration	6	25.4		1	4		7	29.4	
(b) L.O. & S.O. systems	9	23.2		2	.5		11	23.7	
Totals	63	272.9	7½	29	75.0	4	92	347.9	6½
VI. Miscellaneous:									
(a) Pumps	4	7.5		1	.2		5	7.7	
(b) Piping, valves, flgs.	7	16.1		8	2.9		15	19	
(c) Surface condenser	1	2		5	4		6	6	
Totals	12	25.6	½	14	7.1	½	26	32.7	½
Grand Totals	193	769.8	21½	83	289.4	16	276	1059.2	19½

*Average number of downtime days/yr./plant to repair equipment item causing a plant shutdown. Figures are rounded-off to nearest 1/2.



G.P. Williams, presently project manager for Cooperative Farm Chemicals Assn., was with Allied Chemical Corp. for eight years as superintendent, technical, project engineer, and senior process engineering primarily in the fertilizer processes area. Williams earned his B.S.Ch.E. from Pennsylvania State University.



J.G. Sawyer is presently plant manager of Allied Chemical Corp. He has worked for Allied Chemical for seven years as superintendent, ammonia plant and superintendent, technical and process engineering. Sawyer earned his B.S.Ch.E. from the University of Washington.

DISCUSSION

JEFF WILLIS, American Cyanamid Co.: I just wanted to comment on heat exchanger failures. We have seen a sharp increase in tube failures in the synthesis and purification heat exchangers. We want to warn you all to be looking for this in the older plants.

WILLIAMS: This is true. Several of these exchanger failures showed up on the survey. However, I know of 6 or 7 shutdowns caused by leaks in high pressure syn gas/water cooled exchangers. I believe some of these occurred before the survey period, but there have been a few in the past year.