OPERATING EXPERIENCE - HELIUM EXTRACTION AND LIQUEFACTION EXPANSION DEVICES

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1. INTRODUCTION

The Energy Doubler Program at the National Accelerator Laboratory and activities proposed by other National Laboratories will require low temperature helium refrigerators that are about the same size as the largest helium liquefiers in this country. For all of these developing programs, it is very important that the refrigerators be highly reliable and capable of continuous operation. Of equal importance is that the cooling system operate properly when first installed-rework is very time consuming and expensive.

With these objectives in mind, NBS personnel visited five helium extraction facilities which have on-site the four largest helium liquefiers in the U. S. Although the primary intent was to determine how successfully the rather sophisticated helium expansion devices operated in the field, we also questioned the supervisors, operators and maintenance personnel about the other major components of the process plants since the refrigerators will also have the same sort of vacuum insulation systems, purifiers and compressors which must function reliably.

Even if records had been made available, searching through logs covering 10 years of operation was not practical. The information in this report was gathered by questioning facility personnel. The authors have made no attempt to evaluate or compare the equipment. Only facts as reported by facility personnel are given. The failure history for the past 2 to 3 years is probably fairly reliable. At each facility, there was at least one person who vividly remembered the details of the initial startup. The failure history in the middle years is hazy.

A word of caution must be injected. While every effort was made to find out all details of the failures experienced, different interpretations of the word 'failure' may bias the data. To those who in the past had catastrophic mechanical breakdowns, a 2-hour packing replacement every 2 months now may not be judged failure, only an inconvenience.

All of the plants had difficulty to some degree at startup. In some cases, there were basic design problems; in others, the problems were inherent to new construction. Basic design or fabrication problems have affected both turbines and reciprocating expanders, heat exchangers, insulation systems, purifiers, and compressors. At this time, at all the facilities, the necessary revisions have been made although some of the machinery still requires more than ordinary careful operation.

All of the helium liquefiers are precooled to liquid nitrogen temperature. Each of the liquefiers have expansion turbines operating at below liquid nitrogen temperature and all but one have reciprocating, two phase exhaust expansion engines at the lowest temperatures.

2. FACILITIES VISITED

Keyes Helium Plant - No liquefaction
Keyes, Oklahoma

Phillips Greenwood Plant - One liquefier
Elkhart, Kansas

Cities Service Jayhawk Helium Plant - Two liquefiers
Satanta, Kansas

National Helium Corporation - No liquefaction
Liberal, Kansas

Kansas Refined Helium Company - One liquefier
Otis, Kansas

These facilities will be referred to by the mailing address city. Detailed plant and equipment descriptions are given in the appendices.

3. RECENT EXPERIENCE SUMMARY - EXPANSION MACHINES

Expansion machine failures over the past 2 or 3 years (or more when documented), are summarized in this section and in table 1. Our definition of failure was any instance when an expansion device stopped or was stopped for unscheduled repair, replacement or maintenance. As mentioned, all such "failures" are probably not recorded here. Therefore, the numbers given will tend to be optimistic.

A. Keyes

1. Rotary - About one nitrogen turbine bearing and seal failure occurs each year. There are a total of six turbines, four of which are normally operated at one time. These machines require careful operation.
2. Reciprocating - At any one time, three of the high pressure nitrogen reciprocating machines are operated. There are a total of ten such units. The impression is that maintenance is almost continuous among the ten machines. No failure rate could be determined.

B. Elkhart

1. Rotary - There are two helium expansion turbines in this facility which run full time without redundancy. Three turbines have failed in the last 2 years--1.3 operating years per failure. The two nitrogen turbine expanders have been virtually trouble-free since the plant was commissioned.

2. Reciprocating - In the past 18 months, there have been about six instances of oil seeping down the low temperature cylinders, freezing and cutting out seals. There have been no other failures of these new expansion machines which exhaust two phase helium.

C. Satanta

1. Rotary, original liquefier - About one helium turbine of the two fails per year. These units require very careful operation and are sensitive to plant upsets, power failures, etc.
2. Rotary, new liquefier - In service for 1.5 years, there have been three failures among the two turbines, none of which can be attributed to the bearing or rotating assembly design. These units are tolerant of changes in process conditions and operator adjustments.
3. Reciprocating, new liquefier - Three failures have also occurred in the two cylinders of the two phase exhaust helium reciprocating expander. Once a screw dropped into a cylinder; another time frozen impurities caused a piston seizure. The remaining seizure is unexplained. Both the screw backing out and worn cams at 3000 hours require materials changes.

D. Liberal

While there are no helium expanders or liquefaction equipment at this plant, the operating record is impressive--50 days down in 10 years with no impurity freeze plugging.

E. Otis

1. Rotary - Ten turbines (two operate full time) have failed in 7.5 years. The primary reason has been contaminants in the process stream. These units are easy to operate.
2. Reciprocating - Two failures have occurred in 4800 hours of operation. Both times, screws fell into the cylinders. Worn cams were replaced at 3000 hours.

Table 1

Recent Experience Summary - Expansion Machines

		TURBINE			RECIPROCATING			
	Years in Operation	Number of Turbines Operating	Failures	Mean Turbine Operating Hours per Failure	Number of Cylinders	Maintenance Interval	Failures	Mean Cylinder
Keyes	13	N_2 - 4 6 total	1 per year	35,000	3 (10 total)	continuous	Not appropriate for this study	
Elkhart	8	He-2 N_2-2	He-3 in 2 years N_2-?	He 11,400	2	6 months	6 in 18 months Oil freezing	43
Satanta (original liquefier)	5	He-2	1 per year	17,500	-			
Satanta (New liquefier)	1.5	He-2	3 in 1.5 years	8,760	2		3 in 1.5 years	8
Otis	7.5	He-2	10 in 7.5 years	23,700	2		2 in 4800 hours	4

4. DISCUSSION

A. General

Contaminants in the process stream were universally cited by the facility personnel as a source of trouble. Of course, the liquefier feed stream continually brings trace amounts into the process, a situation that presumably will not exist for the Energy Doubler refrigerators except in the small amount of make up helium. None-the-less, the advice offered at all the facilities--good purifiers are the key to trouble free operation--should be carefully heeded.

The advantage of redundant components which allow continuous operation lies in the fact that a majority of the expander failures occur during startup or shutdown either because of pressure disturbances or the migration of contaminants as temperatures change along the process stream.

Several of the plant managers stressed the necessity of adequate instrumentation and the difficulty in trouble shooting if the proper instruments and sample taps were not installed.

All of the plant managers emphasized the need for competent maintenance and repair personnel. Two maintenance managers said that the ordinary mechanic was not capable of making measurements accurately enough to satisfactorily determine the clearances in the turbines--special talent is necessary.

B. Expanders

The choice between turbine or reciprocating expansion devices may well be decided by the flow rates involved rather than the apparent difference in failure free operating time shown in table 1. The warm expansion devices, turbines in all the liquefiers visited, handle a flow roughly ten times larger than the cold reciprocating expanders. For good turbine efficiency, as the diameter is decreased for lower flow rates, the speed must be increased. There is an upper surface speed limit for oil lubricated bearings. In some of the plants, the turbo expanders were the smallest that the manufacturer had built at that time. Thus, the option of using turbines at the lowest temperatures with two phase exhaust and lower flow rates may require gas bearings and some development. On the other hand, reciprocating expanders to handle the higher flow rate at the higher temperatures will be quite large.

At some of the facilities, the personnel felt that not enough attention had been given to designing for turbine stop - start transcients. They emphasized the need for high quality control

hardware for the bearing oil systems and that emergency control functions should be provided for all plant malfunctions. For example, if the high pressure helium flow is interrupted, the turbine should automatically shut down but in addition the oil flow should be stopped when the turbine stops to avoid pumping oil into the process piping.

For the properly designed expanders, the most significant factor contributing to failure is contamination, either oil, wear particles from compressor rings or frozen contaminants in the process stream.

C. Compressors

Dry lubricated reciprocated helium compressors eliminate oil contamination but inspection and replacement of worn rings is required. The typical inspection interval is 90 days while typical ring life varied from 90 days to about 1 year. Ring life varied between different brands of compressors at the same plant. No mention was made of any other problems such as short valve life or oil breakdown.

The diaphragm compressors are higher maintenance items but do provide high pressures in only a few stages and are oil-free.

5. EXPANSION DEVICES AT OTHER FACILITIES

The United States facilities listed below are those known by the authors to have low temperature expansion devices although not necessarily operating on helium. There are many expanders in air separation plants located throughout the country which are not listed.

Brookhaven National Laboratory
Argonne National Laboratory
Los Alamos Scientific Laboratory
Lawrence Livermore Laboratory
Langley Research Center
Mississippi Test Facility
West Palm Beach, Florida
Long Beach, California
Sacramento, California
Ontario, California

(Some of the older hydrogen liquefiers may have been dismantled.)

(Reported by T. R. Strobridge and C. F. Sindt)

APPENDIX A.

I. GENERAL

1. FACILITY: Keyes Helium Plant
U. S. Bureau of Mines, Helium Operations
Keyes, Oklahoma 73947
Telephone: 405 546-2411
(53 employees)

2. CONTACTS: Herbert Kalman - Helium Operations, Amarillo, Texas
Robert Woods - Helium Operations, Amarillo, Texas
Carl Schegel - Plant Superintendent
Gurnell Gamblin - Assistant Plant Superintendent

3. DATE OF VISIT: 12/10/73

4. PRINCIPAL PRODUCT: Grade "A" helium as gas only

5. PRINCIPAL CUSTOMER: U. S. Government

6. NATURAL GAS PROCESSING CAPACITY: 70×10^6 SCFD

7. HELIUM CONTENT IN NATURAL GAS: 2 percent

8. COST: $\$11 \times 10^6$

9. HISTORY AND PROCESS: The Keyes plant was built as part of the Helium Conservation Program to extract helium from the natural gas passing through a commercial pipeline. Construction was finished in late 1959; full production was reached 8 days after startup. The operating schedule is 24 hours per day, 365 days per year and is met at least with partial production mainly due to over design and redundant equipment.

The natural gas diverted from the pipeline is first stripped of water and CO_2 in a liquid chemical process. The remainder of the water is adsorbed in desiccant beds. So called "crude helium" (about 70 percent helium) is produced by liquefaction and phase separation of the feed stream. Refrigeration for the liquefaction is provided by Claude cycle nitrogen refrigerators which use two turbo expanders in series. The crude helium stream is compressed to much higher than the feed stream pressure and is further purified by two phase separations at low temperature, finally passing through an adsorber at liquid nitrogen temperature. Again, the refrigeration is provided by a Claude cycle refrigerator, this time using reciprocating expanders. Thus, this facility has operated

both types of expanders for a number of years. The grade A helium is pumped to as high as 4000 psi with diaphragm compressors. The other compressors are oil lubricated; these are used to compress the helium free natural gas back to the pipeline pressure, for the nitrogen refrigerators, and to compress the crude helium prior to final purification. There is no helium liquefaction capability at this site.

II. EQUIPMENT

1. EXPANDERS

A. Rotary - Two turbo expanders per cold box for crude helium production, total of six.

Design specifications:

Flow - 106,000 SCFH of nitrogen
Isentropic efficiency - 75 percent
Tip speed - 700 to 730 ft/s
Inlet - 600 psia, 177 K
Outlet - 0-2 psig in two stages
Maximum speed - High pressure unit 67,000 rpm
Low pressure unit 35,000 rpm
(Variable 25 to 100 percent of limit)
Power dissipation - Air blower
Wheel sizes - High pressure unit - 2.63 in.
Low pressure unit - 5.99 in.
Bearings - Pressure lubricated oil journal and thrust bearings
Wheel and nozzle - Radial inflow, axial outflow, fixed nozzle, full admission
Seals - Labyrinth and seal gas

Operating conditions at time of visit:

	High Pressure	Low Pressure
Inlet pressure, psig	400	105
Discharge pressure, psig	105	1.5
Inlet temperature, K	186.5	148.2
Discharge temperature, K	148.2	111
Typical speed, rpm	35-40,000	15-20,000

Maintenance schedule - None

B. Reciprocating - Two reciprocating (one redundant) per cold box for final helium purification, total of 10.

Design specifications:
Flow - About 10^6 SCFD
Isentropic efficiency - About 85 percent
Inlet - 600 psia, 162 K
Outlet - 0-2 psi, 78 K (2 to 6 percent wet)
Maximum speed - 250 - 300 rpm
Power dissipation - Oil pump
Bore and stroke - About 5 x 9 in.
Piston rings - Micarta

Maintenance schedule - None

2. COLD BOXES AND HEAT EXCHANGERS

Insulation - Rock wool with pure nitrogen purge
Heat exchangers - Giauque - Hampson coiled tube

3. COMPRESSORS

A. Natural gas
Three, reciprocating, 2000 hp, single stage.
Integral natural gas motor drive, supercharged, V6, two cycle. 160 to 500 psi

B. Nitrogen
Three reciprocating, 2500 hp, three stage.
Integral natural gas motor drive, V10, two cycle. 3 to 600 psi

C. Crude helium
Three, reciprocating, 240 hp, three stage.
Integral natural gas motor drive, V8, four cycle. 50 to 2700 psi

Maintenance schedule for A, B, and C above:
Annual overhaul of compressor cylinders is done when motors are serviced.

D. Grade A helium
Three, reciprocating, diaphragm, single stage.
Electrically driven. 2700 to 4000 psi

Maintenance schedule - Diaphragms are changed at 1000 hours.

III. OPERATING EXPERIENCE

1. EXPANDERS

A. Rotary - Normally, two of the three sets of turbines are operated with the third cold box and pair of turbines on reserve. The normal failure rate is about one turbine per year out of the six although there have been two in the past few months. The typical mode of failure is bearing and seal destruction although the impression was that the failure was not sudden but progressive. The indication is an increase in seal gas flow. The most frequent problem is with the high pressure turbine where thrust loads are probably highest. A ruined bearing usually has some of the babbitt metal pulled from the surface. Some of the problems have been caused by operator error. During the first startup, an operator error flooded the piping with desiccant dust which ruined the turbine bearings. Pressure surges in the process streams have caused problems at times, but on the whole after operating personnel were trained, the turbines give fairly satisfactory service. At first, the turbines were returned to the manufacturer for repair. This procedure was found to be very expensive and time consuming so now all repairs are made in the Bureau of Mines central shops. Two spare complete rotating assemblies are kept on hand. There has not been any technical help from the manufacturer for a number of years.

B. Reciprocating - These expansion engines are not of modern design. While there is no scheduled maintenance program, the impression is that maintenance is continuous. The common wear items are the valve seals, the rocker and bearings and the piston rings. All of those operating were leaking around the seals. Undesirable features are fixed valve cams which limit flexibility and difficulty in controlling speed. The energy adsorbtion device is an oil pump. The units were delivered with oil pumps that were too small and it took two iterations before the right size was installed.

2. COLD BOXES AND HEAT EXCHANGERS

There have been few problems with the cold boxes and heat exchangers although some of them had large frost and ice build-up areas.

3. COMPRESSORS

The natural gas, nitrogen and crude helium compressors (originally all metal rings) are relatively trouble free. Recently, however, the crankshaft on one of the 2000 hp units failed. Measurements showed the crankcase was bowed so that the crankshaft bearings were not aligned. The reason given is that the thermal gradient in the foundation was sufficient to produce the bending.

The grade A helium compressors originally were equipped with cast rings. Since then one unit has been fitted with chrome rings and another with nonmetallic rings. The latter change may be in preparation for nonlubricated operation.

The high pressure diaphragm compressors require diaphragm replacement at 1000 hour intervals as preventative maintenance. Infrequently, the compensating pumps must be replaced and there have been several connecting rod replacements over the past 14 years. There has not been a significant problem with the valves.

IV. GENERAL ADVICE BY FACILITY PERSONNEL

1. When writing specifications, be sure to require instrumentation sufficient to measure equipment performance.
2. Protection devices, for instance turbine over speed, must be of high quality or inadvertent shutdowns will occur.
3. Silicon oils will adsorb large amounts of helium and lose lubricating qualities.
4. Blower loaded turbines are good, but loading characteristics are critical at startup.

APPENDIX B.

I. GENERAL

1. FACILITY: Phillips Greenwood Plant
Elkhart, Kansas 67950
Telephone: 316 592-2501
(32 employees)

2. CONTACTS: Paul Farrell - Plant Superintendent
J. D. Carson - Operations Supervisor
L. B. Jones - Maintenance Supervisor

3. DATE OF VISIT: 12/11/73

4. OWNER: Alamo Chemical, a Phillips Petroleum subsidiary, and Gardner Cryogenics

5. PRINCIPAL PRODUCTS: Liquid helium
Liquefied petroleum gases

6. HELIUM LIQUEFACTION CAPACITY: 630 liter/hour

7. PRINCIPAL HELIUM CUSTOMER: Gardner Cryogenics

8. NATURAL GAS PROCESSING CAPACITY: 65×10^6 SCFD

9. HELIUM CONTENT IN NATURAL GAS: 0.55 percent

10. HISTORY AND PROCESS: Helium is extracted from natural gas in a Colorado Interstate Gas Company pipeline. Construction was completed in 1965 and full production was reached in 1966. There is no redundant equipment at this facility so production is interrupted whenever any unit breaks down. Crude helium is extracted from the gas stream with a closed propane refrigeration cycle and a closed cycle nitrogen turbo expander refrigerator. Further refinement to produce grade A helium uses another closed cycle nitrogen turbo expander refrigerator. The helium liquefaction process is a Claude cycle, liquid nitrogen precooled. The warm expansion turbines are in series. The JT valve is bypassed with two reciprocating, wet exhaust, expanders. Helium feed to the liquefier is purified with activated alumina and charcoal at liquid nitrogen temperature and again on activated alumina at about 23 K. The helium compressors for the liquefaction cycle are dry lubricated. High pressure compressors for filling cylinders are diaphragm or dry lubricated. We were allowed to inspect only the helium liquefaction equipment; the company is sensitive about the separation process and equipment.

II. EQUIPMENT (Incomplete - proprietary)

1. EXPANDERS

A. Rotary

Helium - Two turbo expanders in series

Design specifications:

Flow - 87,500 SCFH
Inlet - High pressure unit - 150 psig, 78 K
Discharge - Low pressure unit - 2 psig, 6 K
Maximum speed - 72,000 rpm
(Variable from 20 to 100 percent)
Power dissipation - Oil brake
High pressure unit - 6.16 hp
Low pressure unit - 3.7 hp
Wheel sizes - High pressure unit - about 1.75 in.
Low pressure unit - about 2.25 in.
Bearings - Pressure lubricated oil journal and thrust bearings (Babbit)
Wheel and nozzle - Radial inflow, axial outflow, adjustable nozzle blades, full admission
Seals - Labyrinth and seal gas

Maintenance schedule - None

Nitrogen - Two turbo expanders
No details

Maintenance schedule - None

B. Reciprocating

Helium - Two single stage, two phase, exhaust in parallel

Design specifications:

Flow - About 250,000 SCFD each
Inlet - 150 psig, 6 K
Discharge - 2 psig, 4.4 K
Speed - 200 - 800 rpm
Power dissipation - Electric generator
Bore and stroke - 2 in. by 4 in.
Piston rings - Teflon

Maintenance schedule - Warm up about every 6 months for oil removal at cold end.

2. COLD BOX AND HEAT EXCHANGERS

Insulation - Vacuum and multi-layer, 78 K shield
Heat exchangers - Plate-fin

Maintenance schedule - None

3. COMPRESSORS

A. Natural gas and propane

Two reciprocating, integral natural gas motor drive, 1670 hp, dry lubricated compressor cylinders

Maintenance schedule - 60 days

B. Helium

One reciprocating, integral natural gas motor drive, 550 hp, four cycle, dry lubricated compressor cylinders, 2 to 150 psig

One reciprocating, integral natural gas motor drive, 600 hp, two cycle, dry lubricated compressor cylinders, 2 - 150 psig

Maintenance schedule - 60 days

C. Helium

Two, diaphragm, two stage, electrically driven, 250 to 3300 psig

Maintenance schedule - 60 days

III. OPERATING EXPERIENCE

1. EXPANDERS

A. Rotary - At the time of our visit, the helium turbines had been running for about 1 year except during the annual shutdown. When the plant was first built, these were two types of problems. First, there was turbine wheel erosion due to either dirt in the piping or solid neon. The cause was never really pinpointed but the combination of a larger cold adsorber and more operating time has alleviated the problem. Secondly, bearings and seals had a very short life at the plant startup. This difficulty was traced to bearing oil return lines that were too small and did not slope enough. Since the return oil flow was impeded, the bearing cavities would flood and force oil into the process stream causing unbalance, bearing interference and shutdown.

Since the proper revisions were made in 1971, three sets of bearings have been replaced.

The two nitrogen turbines have been virtually trouble free.

As opposed to the early days of the plant, there has been no outside technical assistance for several years. Spare parts carried are a complete rotating assembly for each machine, spare shafts, heat barrier walls, expander wheels, brake wheels, and one set of the adjustable nozzle blades.

B. Reciprocating - The original wet exhaust expanders were design-deficient with weak room temperature running gear. Broken items include, but are not restricted to, bellows, valve stems, connecting rods, cams, and bearings. The new machines are much more substantially constructed and at this time have run for 18 months with no failures. There is a small oil seep from the crankcase which wicks onto the connecting rods and valve stems. The units are shut down about every 6 months for oil clean up to prevent migration to the cold sections. These units are easy to remove and replace; additionally the design allows valve porting changes. There has been no outside technical assistance for 2 years. Spare parts carried are valves, valve pushrods, a piston rod and a connecting rod. The oil lubricated running gear will be replaced with dry lubricated running gear in the first part of 1974.

2. COLD BOX AND HEAT EXCHANGERS

There have been few problems in the vacuum insulated cold box. At one time, there was evidence of a process line leak which turned out to be four leaks but no further difficulties have developed.

3. COMPRESSORS

Some trial and error was required to find a ring material for the dry lubricated compressor with a useful service life. Rider ring design changes also were made. At this time, the rings are changed at the annual overhaul; at about 6 months, the pistons are rotated one half turn to turn the unworn section of the rider ring to the bottom of the cylinder. Several companies now market graphite impregnated Teflon rings that are satisfactory.

The Greenwood facility has not had good experience with diaphragm compressors. There has been short diaphragm life (2 weeks), wrist pin bearing wear, cross head bearing wear, failures in the limiting valves and compensating pump and even broken cylinder heads.

IV. GENERAL ADVICE BY FACILITY PERSONNEL

1. Lack of redundant equipment has hurt the operation. Several smaller machines in place of one large one are much preferred.
2. Oil supply to turbine bearings should automatically shut off in case of compressor or high pressure failure.
3. Inspector should be in shop during fabrication if for nothing more than to keep weld slag and grinding dust out of process piping.
4. Do not shut down unless mandatory. Startup and shutdown causes contaminate carryover and freeze-up.

(Reported by T. R. Strobridge and C. F. Sindt)

APPENDIX C.

I. GENERAL

1. FACILITY: Cities Service Jayhawk Helium Plant
Route 1, Box 42
Satanta, Kansas 76801
Telephone: 316 657-2211
(56 employees)

2. CONTACTS: Dick Davis - Plant Superintendent
Glen Chernohan - Operation Superintendent
Jack Horn - Technical Services Supervisor
(New telephone: 918 586-2211)

3. DATE OF VISIT: 12/12-13/73

4. OWNER: Cities Service Oil Company

5. PRINCIPAL PRODUCT: Liquid helium
Liquefied petroleum gas

6. HELIUM LIQUEFACTION CAPACITY:
Original unit - 818 liter/hour design
727 liter/hour nominal
New unit - 818 liter/hour nominal
(Expandable to 1930 liter/hour)

7. PRINCIPAL HELIUM CUSTOMER: Linde, Air Products and Chemicals Inc., and Airco Cryogenics

8. NATURAL GAS PROCESSING CAPACITY: 500×10^6 SCFD

9. HELIUM CONTENT IN NATURAL GAS: 0.4 percent

10. HISTORY AND PROCESS: Helium is extracted from natural gas in a company owned pipeline. The helium separation plant was built as part of the U. S. Government Helium Conservation Program in 1963. There are two separate helium liquefaction facilities on site. The original liquefier was finished in November 1968; the heat exchangers were shipped for rework in December 1968 and liquid helium production commenced in early 1969. The second liquefier was commissioned in June 1972. The operating schedule is 365 days per year, 24 hours per day with 2 days down every 90 for compressor maintenance. A majority of the compressor drives at the facility are steam turbines with speed reduction gears for the reciprocating, dry lubricated machines. Yearly overhaul of the drives required by natural gas motors is eliminated. Feed to both liquefiers is Grade A helium at liquid nitrogen temperature. Differences in design philosophy of the two liquefiers are apparent. Experience with the older unit led the company to demand more complete instrumentation, process stream sample taps and selective warmup gas injection points. The result has been much smoother, reliable operation.

For the original liquefier, the manufacturers provided assistance at the startup and representatives have been on site to solve turbine problems. Additionally, there have been two other visits; once to deal with the cold box insulation and once to fix the storage dewar.

For the new liquefier, there has been no outside technical assistance since startup.

II. EQUIPMENT

1. EXPANDERS

A. Rotary - Helium, two turbo expanders in series

Design and operating conditions:

Flow
- High pressure unit - 198-206,000 SCFH
- Low pressure unit - 216-224,000 SCFH

Inlet
- High pressure unit - 120 psig, 36 K
- Low pressure unit - 46 psig, 17.6 K

Discharge
- High pressure unit - 45 psig, 29.3 K
- Low pressure unit - 4 psig, 17 K

Maximum speed
- High pressure unit - 95,000 rpm, 85,000 nominal
- Low pressure unit - 65,000 rpm, 54,000 nominal

Power dissipation - Oil brake

Wheel sizes - About 1.5 in.

Bearings - Pressure lubricated oil journal and thrust bearings (Babbit)

Wheel and nozzle - Radial inflow, axial outflow, fixed nozzle blades, full admission

Seals - Teflon labyrinth and seal gas (Seal gas for both turbines 5370 SCFD).

Maintenance schedule - None

2. COLD BOX AND HEAT EXCHANGERS

Insulation - Vacuum and Pearlite, 78 K shield

Heat exchangers - Plate fin

Maintenance schedule - None

3. COMPRESSORS

Helium

One reciprocating four stage, steam turbine drive, 1200 hp, dry lubricated compressor cylinders

Maintenance schedule - Teflon ring replacement 90 days. (100 days is too long).

Helium

Four, diaphragm, two stage, electric drive

Two, diaphragm, single stage, electric drive

III. OPERATING EXPERIENCE, ORIGINAL LIQUEFIER

1. EXPANDERS

A. Rotary - When the liquefier was first started, the turbine bearings failed with startling regularity. The thrust bearings were not strong enough making the high pressure unit very sensitive to back pressure fluctuations. Small fluctuations in the plant process conditions or an operator miscue meant a turbine failure. The failures were preceded by an increase in seal gas flow rate as the labyrinth was destroyed, followed by noise and seizure. The turbines are difficult to start and stop successfully, requiring three operators. However, since the initial problems, there is about one turbine failure per year. Redesign and operator experience are probably responsible for the increased running time but the liquefier still demands kid-glove handling. One each of the turbines are kept as spares with all repairs made by the manufacturer. The manufacturer is very responsive. There has been no outside technical assistance for the turbines for several years.

2. COLD BOX AND HEAT EXCHANGERS

Originally, the insulation was simply a 78 K shield with helium gas in the dewar. Excessive heat leak forced a change to evacuated perlite insulation. At the time of the visit, there was frost and ice at several locations on the dewar and top plate and around the turbines. At installation, there was poor flow distribution in the heat exchangers which were cut out and shipped to the heat exchanger manufacturer for rework. There have been several leaks over the years. The 34,000 gallon storage dewar insulation vacuum has been continually marginal.

3. COMPRESSORS

Replacement of the Teflon rings in the four stage reciprocating compressor is mandatory at 90 days and requires 2 days. This is fairly undesirable because the turbines are difficult to stop and start successfully. When first installed, steel baffles in the Admiralty tube intercoolers corroded out. Faulty cooling water treatment was the probable cause.

There has not been exceptional service from the diaphragm compressors. The valve plate wears on the guide stem allowing the plate to cock and hang up. In addition, the oil pressure limiting valves occasionally wear. Diaphragm life is 1.5 to 3 months. Presently, they are using 1/2 hard 301 stainless steel for the diaphragms.

IV. EQUIPMENT, NEW LIQUEFIER

1. EXPANDERS

A. Rotary

Helium, two turbo expanders

Design and operating conditions:

Flow
- High pressure unit - 198,000 SCFH
- Low pressure unit - 198,000 SCFH

Inlet
- High pressure unit - 270 psig
- Low pressure unit - 125 psig

Discharge
- High pressure unit - 125 psig
- Low pressure unit - 40 psig

Maximum speed
- High pressure unit - 127,000 rpm, 123,000 nominal
- Low pressure unit - 127,000 rpm, 100,000 nominal

Power dissipation - Oil brake

Wheel sizes -

Bearings - Pressure lubricated oil journal and thrust bearings

Wheel and nozzle - Radial inflow, axial outflow, fixed nozzle blades, full admission (The wheels are the same for both expanders, the nozzle plates are different.)

Seals - Labyrinth and seal gas

Maintenance schedule - None

B. Reciprocating
Helium - One, two cylinder, two phase exhaust

Design and operating conditions:
Flow - About twice the liquid production, 20,250 SCFH
Inlet - 270 psig
Interstage - 40 psig
Discharge - 1 psig
Speed - 125 rpm
Power dissipation - Electrical generator
Bore and stroke - 3 in. by 3 in.
Bearings - Roller and ball
Piston rings - Warm, one O-ring and three oil impregnated felt rings
Valve rod seals - Warm, stacked glands
Piston - Micarta

Maintenance schedule - None

2. COLD BOX AND HEAT EXCHANGERS
Insulation - High vacuum and multi-layer
Heat exchangers - Plate-fin - Trane
Maintenance schedule - None

3. COMPRESSOR
One five stage reciprocating, integral natural gas motor drive, 800 hp, dry lubricated compressor cylinders, 0.5 to 275 psig

Maintenance schedule - Check compressor rings, 90 days

V. OPERATING EXPERIENCE - NEW LIQUEFIER

1. EXPANDERS

A. Rotary- These turbines are much easier to operate than those in the older plant. They are very tolerant to variations in liquefier operating conditions and operator adjustments of those conditions. Compared to the older units, they are easier to install. Three turbines have failed since the liquefier was started in June 1972. One was inadvertently contaminated and frozen while shut down. When it was started,

three blades broke off one side of the wheel. Still it ran at 90,000 rpm until it was convenient to shut down and replace it. Another turbine seized after an electric motor in the oil lubrication system burned up and contaminated the oil with particulate matter. The third turbine seized during automatic shutdown following a power failure to the oil system. A room temperature valve did not function properly.

One spare shaft and wheel are kept on hand with all repairs made by the manufacturer.

B. Reciprocating - The two phase exhause reciprocating expander is run only when the resulting 25 percent increase in liquefier output is required to meet sales commitments. Generally, the facility supervisors are satisfied because failures do not stop liquid production, only decrease it. After 3000 hours of operation, the valve and piston cams were worn to the point that replacing was mandatory. Three other failures have occurred. A screw which served as a valve seal retainer dropped into the cylinder. The resulting split Micarta piston was repaired by sawing off the split portion and gluing on an additional section. The screws can of course be staked, pinned, or wired. Seizing has occurred twice; once perhaps due to faulty defrosting and another time for unknown reasons. In the last case, the piston was charred and a liquid of unknown nature was found in the cylinder. The presence of oxygen necessary for burning has not been explained.

2. COLD BOX AND HEAT EXCHANGERS

Difficulties in analyzing problems with the older liquefier prompted the company to require extensive instrumentation and process stream sample taps in this new unit. Selective defrosting is therefore easily accomplished and migration of impurities can be traced. There has been no trouble with the high vacuum-multilayer insulation which is very effective. The plate-fin heat exchangers are designed for about twice the present flow rate so the plant capacity can be increased by adding a compressor and modifying the turbine wheels.

Shop fabricated transfer line sections were field installed by the prime contractor and have been a source of trouble because of faulty field welds.

3. COMPRESSOR

A five stage instead of four stage helium compressor was chosen so that cylinder temperatures would not be so high. Also, very large intercoolers were chosen. The result has been longer ring life but until more operating experience is accumulated, the ring wear is checked at 90 day intervals.

VI. GENERAL ADVICE BY FACILITY PERSONNEL

1. Require adequate instrumentation for diagnosis.
2. Make sure that startup and shutdown operations are provided for by vendors.
3. Insure that welders for field erection are qualified.
4. Keep compression cylinder temperatures low in dry lubricated reciprocating compressors.
5. Make provisions for contaminant analysis and selective warmup.

(Reported by T. R. Strobridge and C. F. Sindt)

APPENDIX D.

I. GENERAL

1. FACILITY: National Helium Corporation
P. O. Box 1008
Liberal, Kansas 67901
Telephone: 316 624-7231
2. CONTACTS: Ross W. Wilson - President
3. DATE OF VISIT: 12/12/73
4. OWNERS: National Distillers and Chemical Corporation
Panhandle Eastern Pipe Line Company
5. PRINCIPAL PRODUCT: Liquefied petroleum gas
Crude helium (65 percent helium)
6. HELIUM LIQUEFACTION CAPACITY: None
7. PRINCIPAL HELIUM CUSTOMER: U. S. Government, Helium Conservation Program (Discontinued)
8. NATURAL GAS PROCESSING CAPACITY: 1×10^9 SCFD
9. HELIUM CONTENT IN NATURAL GAS: 0.4 percent
10. HISTORY AND PROCESS: This facility is the largest of the private industry helium extraction plants for the Helium Conservation Program. Dedicated September 24, 1963, operation has been virtually continuous although helium extraction was stopped when the Government contracts were cancelled. Thus, about 10^9 SCFY of helium are lost to the atmosphere. The facility continues to produce LPG.

The separation process employs stripping and fractionation rather than flash phase separation such as in the Keyes facility resulting in almost total helium extraction from the feed stream. Careful laboratory experiments and pilot plant studies led to the final design. Equipment selection and supervised construction coupled with design have resulted in continuous production with the exception of 50 days for the past 10 years. Propane, Methane and Nitrogen cycles supply refrigeration at descending temperature levels to the fractionation columns.

II. EQUIPMENT

(Note. This facility was not on the original itinerary. The visit was very short and in the early evening, resulting in incomplete acquisition of equipment nameplate data.)

1. EXPANDERS - None
2. COLD BOXES AND HEAT EXCHANGERS -

Insulation - Mineral wool at higher temperatures, expanded pearlite at low temperatures all with nitrogen purge

Heat exchangers - All copper tubing on stainless mandrels in stainless shells.

Maintenance schedule - None

3. COMPRESSORS

Eight centrifugal, electrically driven compressors for natural gas, propane, methane, and nitrogen

Two reciprocating electrically driven for helium.

Total installed drive power - 50,000 hp

Maintenance schedule

Centrifugal

Change oil pumps - Annually
Check high speed couplings - Annually
Check bearings - 5 years
Check motor bearings - 5 years
Check gear boxes - 5 years

III. OPERATING EXPERIENCE

1. COLD BOXES AND HEAT EXCHANGERS

Only once in 10 years has a cold box been opened for repair. Plant personnel attribute this to quality control during fabrication and the mechanical design. For instance, all possible joints are welded in the process piping. There are only three demountable joints in all of the cold piping. Knowing that workmen would have to be in the cold boxes to compact the mineral wool as it was installed, every process, instrument, and control line that would not stand a man's weight was protected by angle or channel structure.

Water is removed from the process stream by adsorbtion on activated alumina to less than 0.1 ppm. Good drying was considered important during the design process and there has been no freezing in 10 years of operation. (Tests have shown that a majority of the water is adsorbed at the outside surface of the alumina bed.) In fact, there has never been any plugging in the plant because of contaminants.

2. COMPRESSORS

Insufficient pipe support members led to vibration at startup. The machinery is very noisy and would not be tolerated near usual working or living areas. Workers must wear earmuffs in the vicinity. Very occasionally an oil seal will fail or wear out but not in a catastrophic manner so there is time to plan a shutdown of the machine. for repair. The maintenance schedule testifies to the trouble free operation of these compressors.

IV. GENERAL ADVICE BY FACILITY PERSONNEL

1. High quality equipment is necessary for continuous trouble-free operation.
2. Prototypes should be thoroughly tested.
3. Adequate instrumentation is necessary.
4. Adequate process stream clean-up is necessary for continuous trouble-free operation.

APPENDIX E.

I. GENERAL

1. FACILITY: Kansas Refined Helium Company
P. O. Box 312
Otis, Kansas 67565
Telephone: 913 387-2281

2. CONTACTS: Roy Kruger - Plant Manager
Al Pesisca - Plant Superintendent
Tom Lynch - Maintenance Manager
Jim Hamm - Chief Operator

3. DATE OF VISIT: 12/14/73

4. OWNER: George A. Engle

5. PRINCIPAL PRODUCT: Liquid helium

6. HELIUM LIQUEFACTION CAPACITY: 880 liter/hour. 1090 liter/hour with two phase exhaust reciprocating expander

7. PRINCIPAL HELIUM CUSTOMER: Airco

8. NATURAL GAS PROCESSING CAPACITY: 700,000 SCFH

9. HELIUM CONTENT IN NATURAL GAS: 1.5 percent. Can be as high as 3.5 percent with the addition of crude helium from Northern Natural Gas.

10. HISTORY AND PROCESS: Owned by an individual, the Otis plant was built to supply liquid helium to private industry. While the liquefier functioned properly, it took an extra year to solve problems with the extraction process. The prime contractor for the turnkey contract went out of business after full production was reached in May 1966. Since that time, liquid helium has been produced 97 percent of the scheduled operation time which is full time excluding scheduled maintenance. A two-phase exhaust, reciprocating expansion engine has been added to increase production by about 25 percent. At the time of our visit, liquid helium had been produced continuously for the past 17 months.

Grade A helium is fed to the liquefier at about 80 K at the highest pressure in the cycle. The feed helium does not pass through the two turbo expanders, thus eliminating contamination and unbalance problems there. There are four pressure levels in the process with the Joule-Thomson process (or the reciprocating expanders) operating between the highest and lowest pressures and the turbines operating between the intermediate and lowest pressures. (The reciprocating expander is operated only when necessary to meet sales commitments.)

There are no engineering personnel at the site; there has been no outside technical assistance for the past 17 months.

II. EQUIPMENT

1. EXPANDERS

A. Rotary

Helium, two turbo expanders in series

Design and operating conditions:

Flow

High pressure unit - 200,000 SCFH

Low pressure unit - 200,000 SCFH + some of 70,000 SCFH

Inlet

High pressure unit - 120 psig, 34.3 K

Low pressure unit - 45 psig, 14.3 K

Discharge

High pressure unit - 45 psig, 27.6 K

Low pressure unit - 4.4 psig, 9.83 K

Maximum speed

High pressure unit - 95,000 rpm, 80,000 nominal

Low pressure unit - 85,000 rpm, 54,000 nominal

Power dissipation - Oil brake

Wheel sizes

High pressure unit - 1.77 in.

Low pressure unit - 1.97 in.

Bearings - Pressure lubricated oil journal and thrust bearings

Wheel and nozzle - Radial inflow, axial outflow, fixed nozzle blades, full admission

Seals - Labyrinth and seal gas

Maintenance schedule - None

B. Reciprocating

Helium - One, two cylinder, two phase exhaust

Design and operating conditions

Flow

Warm cylinder - 70,000 SCFH

Cold cylinder - 27,000 SCFH plus flashing loss

Inlet

Warm cylinder - 210 psig

Cold cylinder - 45 psig

Discharge
Warm cylinder - 45 psig
Cold cylinder - 4.4 psig
Speed - Nominal 200 rpm
Power dissipation - Electrical generator
Bore and stroke - 3 in. by 3 in.
Bearings - Roller and ball
Piston rings - Warm, one O-ring and three oil impregnated felt rings
Valve rod seals - Warm, stacked glands
Piston - Micarta

Maintenance schedule - None

2. COLD BOX AND HEAT EXCHANGERS

Insulation - High vacuum
Heat exchangers - Plate-fin

Maintenance schedule - None

3. COMPRESSORS

Helium - Two, four stage, reciprocating, integral natural gas motor drive, 500 hp, dry lubricated compressor cylinders, 4 - 210 psig

Maintenance schedule -
Check compressor piston and rider rings - 90 days
Change interstage and final filters - 30-60 days

Helium
Two, single stage, diaphragm

Maintenance schedule - None

III. OPERATING EXPERIENCE

1. EXPANDERS

A. Rotary - There have been a total of ten turbine failures since the plant was started. The majority of these were due to contaminants in the process stream, both frozen contaminants and wear particles from the dry lubricated compressor rings. The remaining failures have been caused by oil pump failures, etc. None could be traced to faulty bearing or seal design. The addition of three sets of filters for the wear particles and careful attention to maintaining process stream purity have been the key for trouble free operation. The turbines are easy to stop and start and are tolerant to operator errors.

Two complete turbines are kept as spares along with seven sets of rotors and bearings. (The spare parts inventory at this facility was extensive for all the machinery.) Repairs are made by the manufacturer. Since the initial operation, there has been no outside technical assistance for the turbines.

B. Reciprocating - A total of 4840 operating hours have been accumulated on the two phase exhaust expansion engine. During that time, two valve seal retaining screws have fallen into the cylinders ruining pistons. At about 3000 hours, repairs to the valve cams were required. The cam repairs were made by the plant maintenance men who feel a wider key and keyway would alleviate the problem. The manufacturer has been very cooperative and in general, the machine is quite satisfactory. It is easy to start and stop, taking about 1.5 hours to cool down and bring on line.

2. COLD BOX AND HEAT EXCHANGERS

There have been no problems with the cold box and heat exchangers although the bottom 4 feet of the dewar were frosted as was part of the large storage dewar. Evidently, the production rate is satisfactory and the heat leak is not considered excessive.

3. COMPRESSORS

The dry lubricated helium compressors are shut down and inspected for ring wear every 90 days. Typical ring life is 9 months. Difficulties with wear particles traveling to the liquefier prompted the installation of three sets of filters--the last one is 10 μ, operating at 80 K. All of the natural gas motor-compressors were re-bored after 6 years of service.

Valve life on the diaphragm compressors was about 1 month. However, decreasing the valve plate travel has helped considerably. Diaphragm life is typically 2500 hours. Since the plant was started, one crankshaft was bent and one piston seized. The manufacturer assisted with the seized piston.

IV. GENERAL ADVICE BY FACILITY PERSONNEL

1. Adequate adsorption capacity is an absolute necessity. Impure process gas has been the biggest problem.
2. Good maintenance personnel and careful operators are the key to successful operation.
3. The plant equipment is well suited to the company's requirements.

Illustrations

1. Keyes - Nitrogen expansion turbine.

2. Keyes - Hall containing expansion devices, six turbines and crude helium cold boxes on right, five final purification cold boxes and ten reciprocating expanders on left.

3. Keyes - Cold boxes containing main heat exchangers.

4. Keyes - One of the three 2500 hp, three stage nitrogen compressors.

5. Elkhart - From left: Vertical stainless cylinder-neon adsorber; horizontal white dewar - vapor separator and liquid helium collection dewar; two story metal shack houses two reciprocating two phase exhaust expanders; tall white cylinder-main liquefier cold box.

6. Elkhart - Running gear for one of the reciprocating expanders.

7. Elkhart - Oil supply system for turbine bearings.

8. Otis - Turbine housings - have been outside for 7.5 years.

9. Otis - Running gear for reciprocating expander.

10. Satanta - One liquefier is housed in pitched roof building in shadow foreground. Other liquefier is near horizontal white helium dewar.

11. Satanta - Original liquefier cold box in foreground shadow extends almost to top of corrugated shack. Turbines are in shack.

12. Satanta - New liquefier cold box is behind middle sphere and extends almost to roof.

13. Liberal - Four electrically driven centrifugal compressors totaling 25000 hp.