INTEGRATED NITROGEN REJECTION FACILITY PRODUCES FUEL AND RECOVERS NGL'S

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Shortly after the discovery of the Block 31 field in 1945, ARCO Oil and Gas Company, then Atlantic Refining Company, started searching for ways to improve the ultimate recovery from the Devonian formation. Laboratory research showed that natural gas would become miscible with the crude at 3500 psi. Therefore, injection of the produced gas began in 1949. A processing plant was built in 1957 to extract liquids from the gas before reinjection. Eventually, the produced gas volume was not adequate to maintain miscibility pressure and additional gas was purchased to make up reservoir voidage. Further laboratory research showed that flue gas injection would maintain miscibility at a higher injection pressure. ARCO began flue gas injection in the Block 31 field in 1966 at a rate of 40 to 50 MMSCFD. In 1980, a favorable decision was handed down from the U.S. Department of Energy relative to the recoupment of investments made in tertiary recovery projects. This provided further incentive for an ongoing development program. Since 1966, continuous flue gas injection has sustained the miscible flood and, being predominantly nitrogen, caused a constant increase in nitrogen content of the produced gas. The inlet gas to the processing plant currently contains from 30 to 45% nitrogen. The processing plant consists of three lean oil absorption trains for propane and heavier recovery. Residue gas from the processing plant, which is used for fuel, has declined in BTU content to below 800 BTU/SCF. All the fuel users were designed for 950-1000 BTU fuel. The fuel had to be "spiked" with a high ethane stream to maintain a 950 BTU fuel stream. This blending was satisfactory for several years, but variations in nitrogen content and momentary imbalances in this blending cause operational problems in the gas-engines, power boilers, and flue gas generators.

Three alternatives were evaluated for solving the fuel problem: purchasing outside fuel, retrofitting existing equipment for low BTU fuel or building a nitrogen rejection facility. Nitrogen rejection was determined to be the preferred solution from an economic and reliability standpoint.

The nitrogen rejection facility (NRF), built in 1983, handles 94 MMSCFD of the highest BTU (lowest N_2) gas. This facility was designed to produce up to 38 MMSCFD of fuel gas while recovering 300,000 gal/day of NGL's.

DESIGN CONSTRAINTS

The design of this facility required consideration of several design conditions:

- Handle a wide range of compositions with a minimum of equipment changes,

- Fuel gas must be 1000 BTU/SCF HHV $\pm$ 25 BTU/SCF,

- High NGL recovery (75-80% ethane, essentially all C_3+),
- Turndown to 70% capacity,
- Recover NGL's without nitrogen rejection at turndown capacity,
- Capable of going to sales, fuel or injection with fuel gas stream,
- Capable of producing a nitrogen product pure enough for venting.

PROCESS DESIGN

The NRF was designed to process a feed stream whose composition could vary from a low of 19% nitrogen to a high of 62% nitrogen (Table 1). This changing composition results in product streams which change in composition and rate over time (Table 2). The nitrogen and methane production rates vary about four-fold over the life of this project. It is this variation that dictated much of the design.

The NRF facility is divided into three main process areas: inlet treating, NGL recovery and the Nitrogen Rejection Unit (NRU) as shown in Figure 1. Also, 14,000 BHP of reciprocating compressors were installed for reinjection of nitrogen and excess fuel.

INLET TREATING

The inlet treating removes H_2O, CO_2, and H_2S to prevent hydrate and solid CO_2 formation in the cryogenic section of the plant. Existing amine and glycol units were modified to remove the CO_2 to below 100 ppmv, H_2S to 4 ppmv, and water to 10 lb/MMSCF. These H_2O and CO_2 removal levels are not sufficient for plant operation, so a molecular sieve system was added to remove water to 0.1 ppmv and CO_2 to less than 5 ppmv. Also included in the inlet treating area is a compressor which is driven by the expander in the NGL section. This compressor boosts the gas to the NGL recovery section inlet pressure of 1050 to 1100 psig. Up to 10 MMSCFD of this gas was originally used to regenerate the molecular sieve beds, and was recycled to the amine unit. This internal regeneration gas recycle has recently been eliminated.

NGL RECOVERY

In the NGL recovery section (Figure 2) the gas is initially split into two approximately equal streams. One stream is exchanged with the cold NRU stream to -92^{O}F. This is fed to the top of the high pressure stripper. The second stream is exchanged with the demethanizer streams and propane refrigeration. This stream is then fed to the bottom of the high pressure stripper. This stripper was used in place of a flash drum for improved separation of the nitrogen from the NGL components.

The overhead from the high pressure stripper is expanded to 390 psig and sent to the low pressure stripper. The bottom product from the high pressure stripper is flashed to 400 psig in a lower flash section of the low pressure stripper. The residual liquid is fed directly to the demethanizer several trays from the top. The low pressure stripper bottom product is fed to the top of the demethanizer. The demethanizer operates at 230 psig and produces an NGL product stream with 0.03 moles of methane/mole of ethane. The net result of utilizing the strippers is a fuel stream from the top of the demethanizer which can go directly to fuel rather than being processed in the NRU.

NITROGEN REJECTION UNIT

The nitrogen rejection unit is the heart of this plant. The process must handle changes in the feed gas nitrogen to methane ratios from 0.4 to 3.22. Several process schemes were investigated to determine the optimum design. Serious consideration was given to a single tower design with a second tower to be added later. This posed many problems of redesign and retrofitting. Also, the timing of nitrogen concentration increase from the field is always difficult to predict.

The final design consists of an integrated two tower arrangement (Figure 3). A high pressure tower provides a rough nitrogen/methane split and a low pressure tower makes the specification products. The high pressure tower operates at a pressure a few psig less than the low pressure stripper. The subcooled bottoms product of this tower provides the main feed for the low pressure tower. The towers are linked by a condenser/reboiler. The condenser liquid is subcooled and fed to the top of the low pressure tower, thus providing reflux needed for this separation. The overhead vapor consisting primarily of nitrogen and inerts such as argon and hydrogen is fed to the top of the low pressure tower. A small expander is provided to control and shorten the tower cool-down time during startup.

The low pressure tower produces nitrogen at $-300^{o}F$ containing less than 1% methane. The bottom methane stream containing less than 1% nitrogen is pumped by cryogenic pumps to 250 psig. This stream is split before backexchange and the split streams are expanded to 130 psig and 5 psig, respectively. These streams are vaporized in a series of exchangers to near ambient temperature. The latent heat from these streams provides much of the refrigeration necessary in the separation steps.

PROCESS CONTROL

Process control for the NRF is accomplished by a central computer control system. This system provides supervisory control for 60 active control loops as well as data acquisition and logging for 500 points. A programmable controller handles the molecular sieve bed switching. A full analog backup to these systems is provided in case of computer failure.

An online process chromatograph continuously samples inlet and product streams. Additionally, open-loop analyzers monitor inlet CO_2 and H_2O content. Results of these analyses can be used by the operator to adjust operations or can be fed to the computer for automatic setpoint adjustments.

With these control systems the entire operation including compression is operated by one man per shift.

There are several key control points in the process.

1) Expander/compressor - The speed of the expander and the pressure ratio are set to control the throughput rate and temperature levels in the NGL Unit.

2) Front-end heat exchangers - Balancing of the heat exchangers is required to optimize gas chilling for maximum ethane recovery.

3) High pressure fuel pressure - The pressure level at which the high pressure fuel boils in the back exchangers is perhaps the key control point in the plant. This pressure determines the chilling capacity in all the primary heat exchangers.

4) NRU Tower Pressure - The pressure of the low pressure tower will be adjusted throughout the project life. As the nitrogen content of the feed increases, this pressure will be set at a higher level.

5) NRU Tower Bottom Temperature - The bottom temperature of the low pressure tower is controlled by the vapor draw rate from the bottom tray. During the early years this vapor draw rate decreases as nitrogen increases. For the high nitrogen feeds, a methane recycle stream is added to this column to increase the boilup.

LAYOUT AND CONSTRUCTION

Figure 4 shows the NRF plant layout. The NRU towers, NRU exchangers, and the NGL feed exchanger are housed in a cold box which are shop fabricated and shipped to the site in four sections. With the exception of the block-mounted fractionation towers and molecular sieve vessels, the plant was fabricated in skid-mounted modules. Two 100% capacity expander/compressor sets were installed to minimize shutdowns due to rotating equipment problems.

START-UP

The start-up was accomplished in several distinct phases. An overriding concern throughout the start-up was to avoid major upsets in other areas of the Block 31 Gas Plant, particularly disrupting the fuel supply to the numerous gas engines and boilers. The Pretreatment section was commissioned with absorber residue gas from the lean oil plant. This was necessary because the richest gas (normal NRF feed) was being used for plant fuel. The plant could not give up this dependable source of fuel until the NRU was fully operational and dependable.

PHASE 1, PRECONDITIONING

The commissioning of the Pretreatment Section was the initial phase of the start-up. The main purpose of bringing the Pretreatment Section on stream as early as possible was to condition the molecular sieve beds to produce a dry gas, which could be used for drying downstream equipment. Estimates were that several weeks could be used in drying equipment to the levels required, even though nitrogen had been used to pressure test instead of hydrotesting.

PHASE 2, PURGING AND DRYING

After the Pretreatment Section start-up, the NGL and NRU Sections were purged with low pressure, 5-10 psig, dry gas from the molecular sieve beds.

After purging, the NGL and NRU Sections were pressurized to operating pressures to check for piping leaks. After repairing leaks, the plant was dried out for approximately one week with low pressure gas. Water content was measured with a Panametrics Moisture Analyzer. The water content specification was 0.1 ppm; however, the measurements could be read to 0.2 ppm, with a $\pm$ 0.3 ppm accuracy. Therefore, the inlet and outlet water contents of the purge gas were monitored until no increase was detected for approximately 24 hours. The critical part of the drying out procedure was opening all bypass and vent lines to insure purge gas flow throughout the plant.

PHASE 3, NGL RECOVERY START-UP

At this point, the NRU was isolated and the cool-down of the NGL section began. First, the pressure of the high pressure and low pressure strippers was raised to 400 psi. Then the control valve which bypassed the expander was operated manually as a pressure throttling valve for a Joule Thomson cooling effect. The pressure upstream of the valve in the high pressure stripper was slowly raised to 950 psig to slowly lower the temperature downstream in the low pressure stripper. Cool-down on JT valve operation to operating temperatures and pressures was accomplished in approximately 48 hours. The main concern during cool-down was not exceeding a temperature difference of 100^{o}F across the plate/fin heat exchangers.

This was accomplished by controlling the cool-down rate. At this time the NRF feed was changed from plant residue gas to a plant inlet stream but still not the highest BTU gas. Due to reinjection compressor limitations, plant capacity was limited to 40 MMSCFD at this time. The NGL Recovery Section ran on JT valve operation for approximately one week while controllers were tuned. Under JT operation a 44% ethane recovery was achieved.

PHASE 4, EXPANDER-COMPRESSOR START-UP

The next phase of start-up was operation of the expander-compressor in the NGL Recovery Section. The expander-compressor lube oil and seal gas pressure control was not adequate to prevent lube oil entering the process streams. The units could not be operated without design modifications. Corrections were made in the field; however, the lube oil system continued causing occasional expander-compressor shutdowns. The NGL Recovery Section met design conditions with 86% ethane recovery when the expander was running.

PHASE 5, NRU START-UP

The final phase of the start-up began with the cool-down of the NRU. Liquid inventories collected on the third day, and on the fourth day an ice ball formed on the cold box skin. The NRU was shut down to repair leaks. It took 22 days to warm the cold box, remove the Perlite insulation, locate the leaks, repair the leaks and reload the Perlite. From the location of the leaks, it appeared that the shop-fabricated piping was damaged during field construction.

When the NRU was restarted, it was quickly brought to conditions which produced specification products with 33-36 MMSCFD feed; however, control of the system was lost when the flow was increased further. With fuel available from the NRU, the feed was switched to the highest BTU gas in the plant. Since the flue gas plant was shut down during NRF startup, the plant could not use all of the fuel produced by the NRU. The excess fuel produced had to be compressed for reinjection. The extra gas overloaded the reinjection compressors, causing back-pressure in the headers and making pressure control of the NRU difficult.

Due to mechanical problems the start-up expander was never used. However, its absence did not affect the start-up, as its purpose was only to facilitate rapid cool-down.

When trying to depressurize one of the inlet expander-compressors to clean a screen, it was found that a new expander discharge valve leaked. To reseat the valve, it was cycled repeatedly. To cycle the valve required satisfying the expander's permissive start logic which pressurized the lube oil and seal gas systems. As was later discovered, each time the valve was opened, lube oil flowed into the process piping, eventually totaling approximately 100 gallons. This oil solidified in the top of the low pressure stripper and blocked off all flow. The NGL Recovery Section was shut down and the NRU was isolated, maintaining liquid levels. A 50-50 mixture of diesel and xylene was trucked in and circulated to clean out the system.

In addition to the backpressure problem with the product headers, a varying feed rate from the NGL Recovery Section delayed stabilization of the NRU. Originally, the expander speed was controlled by a compressor suction pressure-speed cascade loop. Inlet flow was to be controlled by three parallel flow control valves upstream of the Pretreatment Section which controlled the flow rates to three existing amine absorbers. However, flow control was poor with this system. The speed-pressure control was changed to speed-flow control to stabilize inlet flow rate. The three flow control valves were put on manual control.

The start-up phase was accomplished with a 33% nitrogen feed. Process conditions for this feed (Figures 5 and 6) matched well with computer simulations. All of the products were within design specifications and also matched predicted values well (Table 3).

NRF EXPANSION

The throughput rate of the original NRF design was limited by the inlet amine unit, the inlet compressor/expander units and by the injection compression capacity. The NRF was upgraded in 1984 to maximize the capacity of the NGL Recovery section, thereby processing gas which would otherwise be injected with no liquid recovery. Throughput in the NGL recovery area was increased with the following minor equipment additions and process changes. (Figure 5)

Originally, molecular sieve regeneration gas was taken off of the inlet compressor discharge. This internal recycle was eliminated by taking the regeneration gas off of the LP Stripper overhead stream. A regen gas compressor and aftercooler were added, as well as a TEG dehydration system to dry the regen gas before injection compression.

In the original design, all of the LP Stripper overhead gas was fed to the NRU. Addition of a flow control valve to send only the volume to the NRU needed to satisfy fuel demand allows operation of the NGL section at full capacity without dropping all the LP Stripper overhead to nitrogen rejection pressure. The LP Stripper overhead not processed for fuel or used for molecular sieve regen gas now goes to injection compression at the 400 psi level. A plate-fin exchanger was added to cool inlet gas with the LP Stripper gas not processed in the NRU.

Other systems were upgraded to handle the increased flows. An additional amine contactor, amine cooler and hydrocarbon and acid gas compressors were added to increase the capacity of the existing systems. The expander-compressor in the NGL recovery section was re-wheeled for the increased volume.

The above changes increased the Pretreating and NGL Recovery sections' capacity to approximately 96 MMSCFD, producing 385,000 gallons of liquid product per day.

CONCLUSION

The start-up of this Nitrogen Rejection Facility represents the first facility for handling a feed with such a wide variation in composition. The process worked according to design and has met or exceeded all the original design criteria. The plant is currently processing 96 MMSCFD and producing 385,000 gal/day of NGL's. As with most start-ups, the main problems were with the rotating equipment items, especially the expander/compressor units. The NRF is providing a reliable source of fuel and should increase plant production and field life.

Table 1
NRF Feed Composition (Mole %)

	Year A	Year B	Year C
N_2	19.05	31.02	62.53
CH_4	54.63	48.06	21.16
CO_2	3.09	3.61	6.48
C_2H_6	13.59	9.97	5.54
H_2S	.05	.05	.04
C_3H_8	6.06	4.35	2.48
C_4+	3.53	2.94	1.77
	100.0	100.0	100.0

Table 2
NRU Products - Design Basis

	Year A	Year B	Year C
N_2 Product			
Flow Rate, MMSCFD	11.7	19.4	42.4
Purity ($\%N_2$)	93.2	94.9	95.3
HP & LP Fuel			
H.P. Fuel, MMSCFD	27.0	27.6	15.2
L.P. Fuel, MMSCFD	11.3	6.2	0
HHV, BTU/SCF	1020	1015	1024
N_2 Mole %	3.0	2.9	2.8
C_2 Mole %	4.8	4.4	5.6
Liquid Product			
Gallons/Day	330,000	256,000	156,000
% C_2 Recovery	78.7	77.4	77.7
Moles C_1/Mole C_2	.02	.018	.018

Table 3
Material Balance at Design Capacity

	1 NGL Feed MOL %	2 NGL Product MOL %	3 Demeth. Overhead MOL %	4 NRU Feed MOL %	5 N_2 Product Mol %	6 NRU C1 Product Mol %
H_2	0.59	-	-	0.77	2.11	-
O_2,Ar	0.30	-	0.16	0.39	0.51	0.31
N_2	32.20	-	6.23	45.5	96.04	2.55
CO_2	-	-	-	-	-	-
C_1	49.48	0.82	88.02	51.0	1.34	93.72
C_2	9.68	53.0	5.51	2.28	-	3.42
C_3	4.62	30.4	0.08	0.06	-	-
iC_4	0.39	2.5	-	-	-	-
nC_4	1.46	9.2	-	-	-	-
iC_5	0.31	1.6	-	-	-	-
nC_5	0.48	1.3	-	-	-	-
C_6	0.49	1.18	-	-	-	-
	100.00	100.00	100.00	100.00	100.00	100.00
MMSCFD	63.0	-	-	-	19.4	22.6
		274,320 gal/D				

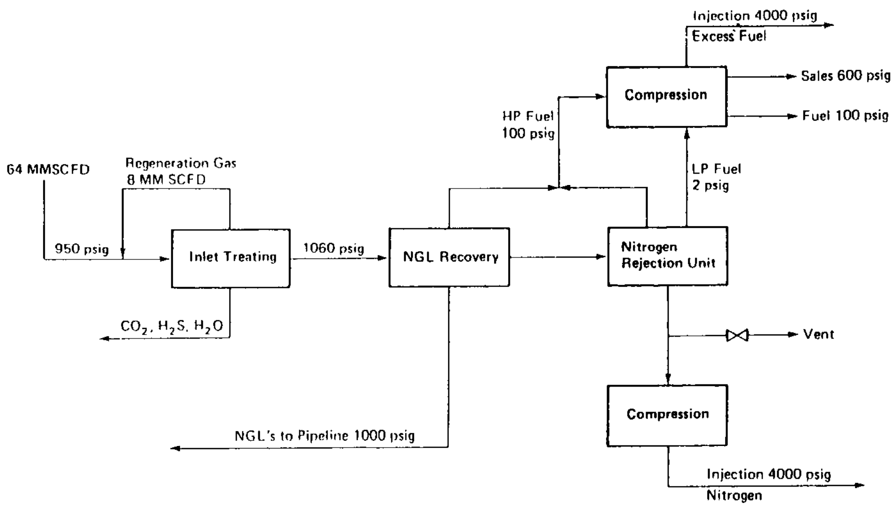


Figure 1 - Nitrogen rejection facility, block flow diagram

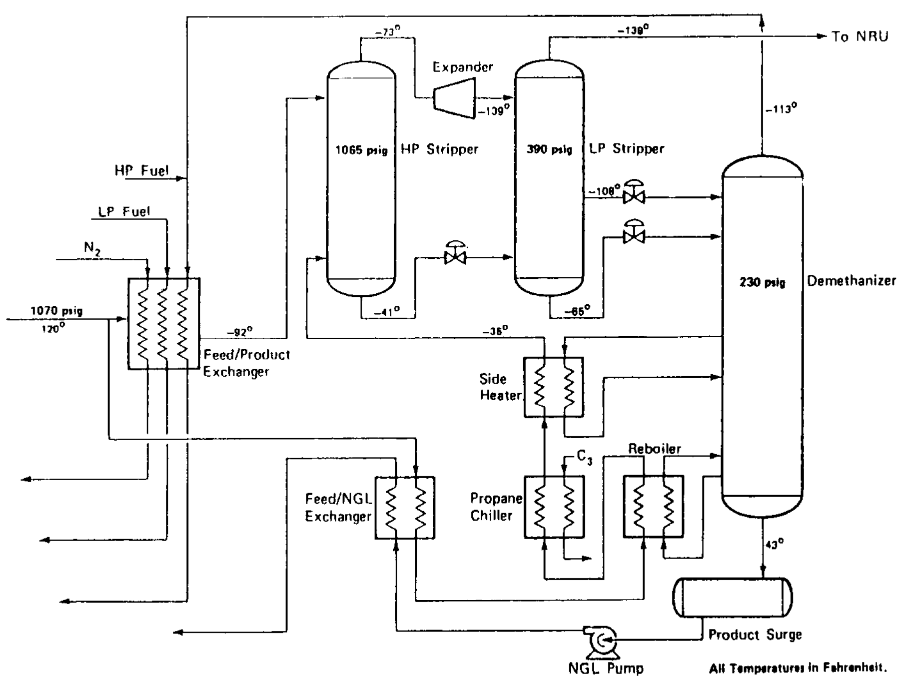


Figure 2 - NGL recovery section design (typical)

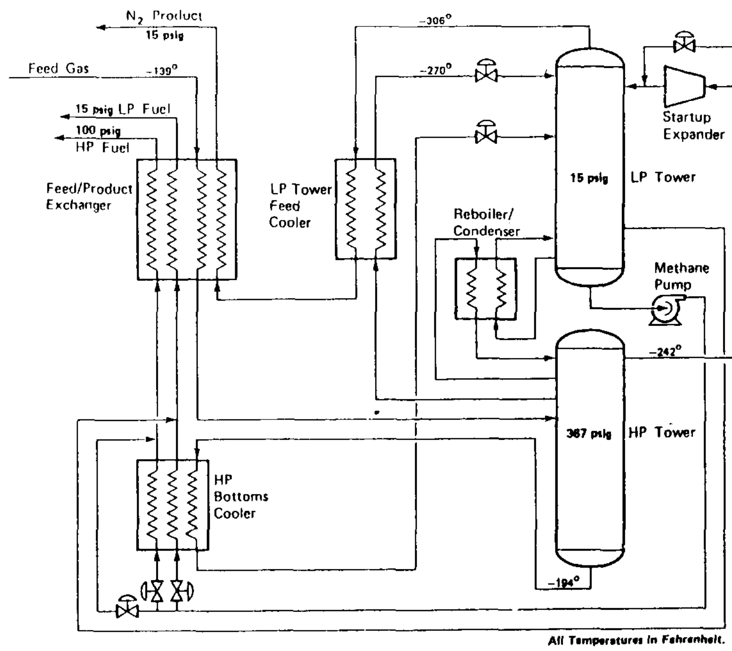


Figure 3 - NRU section design (typical)

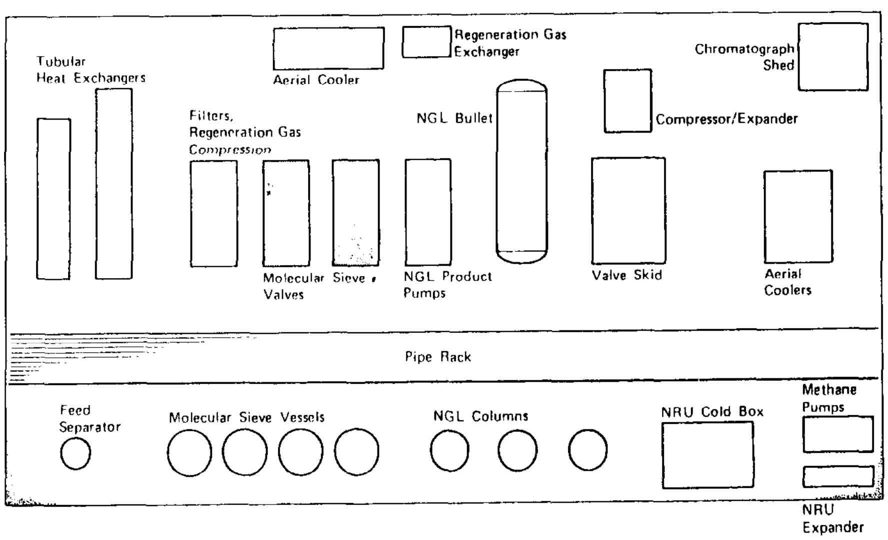
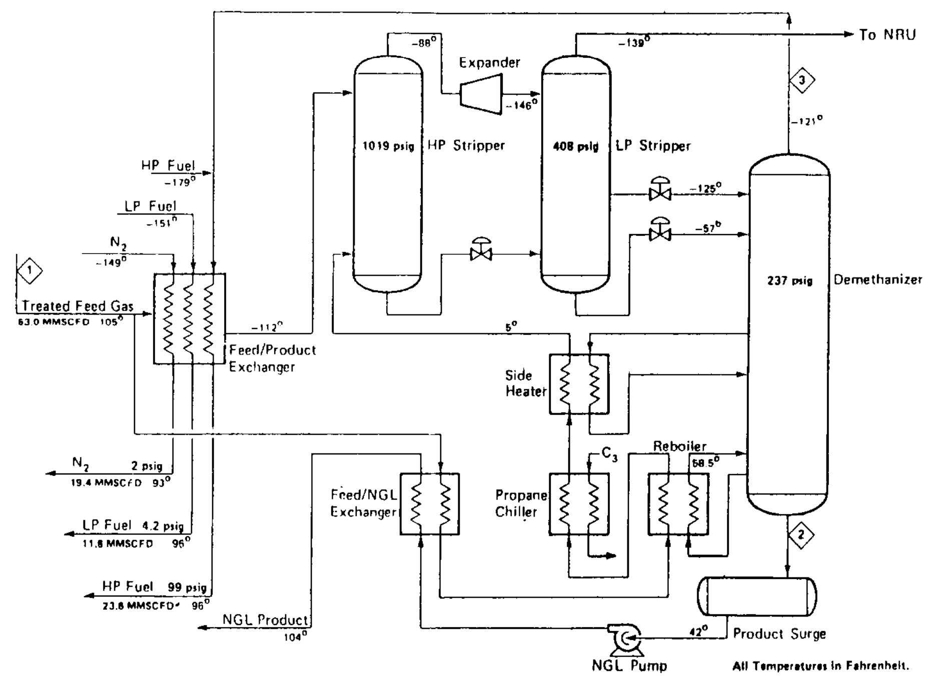
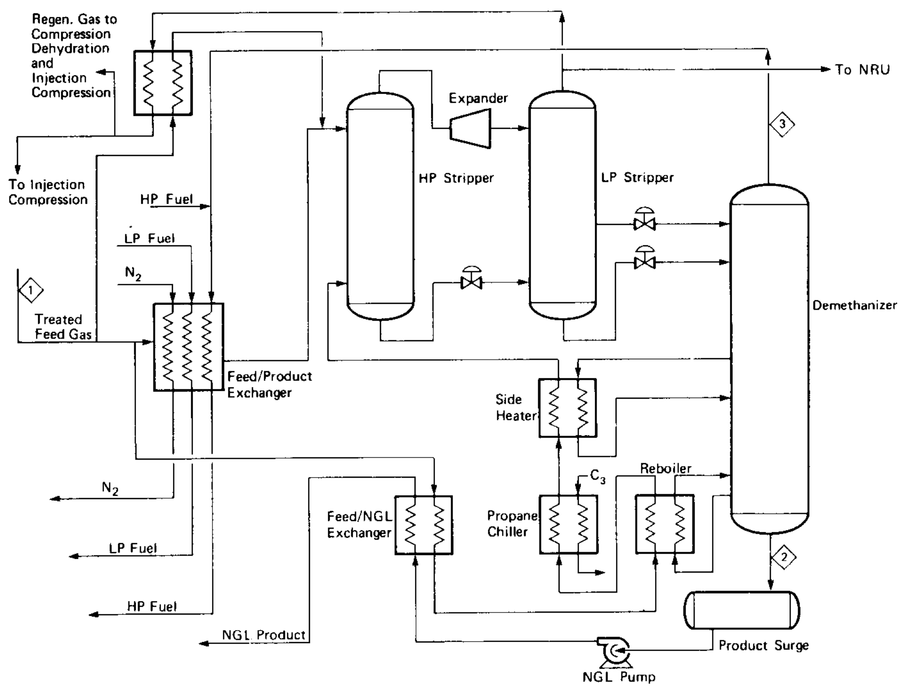


Figure 4 - Facility plot plan.



NGL RECOVERY SECTION STARTUP DATA



NGL RECOVERY SECTION AFTER 1984 UPGRADE

Figure 5

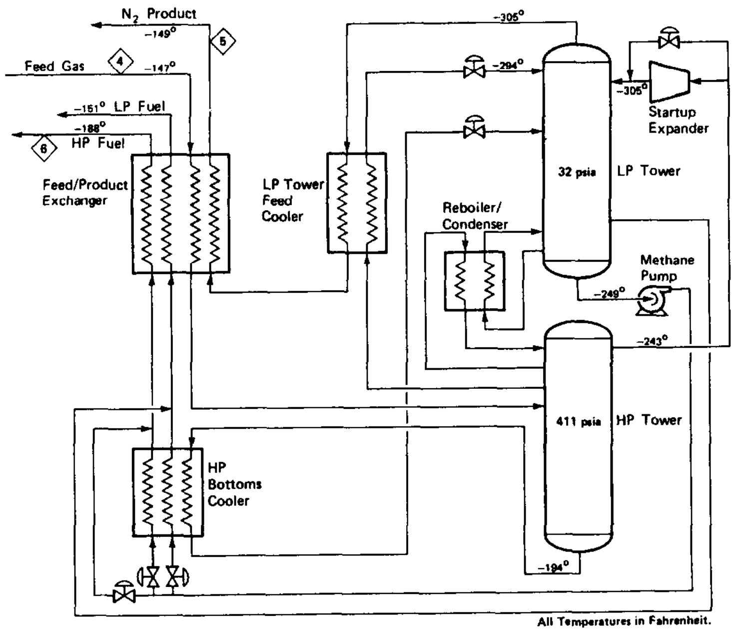


Figure 6 - NRU section startup data