International Fertilizer Industry Association

IFA Technical Conference

Johannesburg, South Africa
30 September-4 October 1996

International Fertilizer Industry Association - Secretariat: 28 rue Marbeuf - 75008 Paris - France
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Date of Receipt: 26 June 1996

KELLOGG ADVANCED AMMONIA PROCESS (KAAP): REVIEW OF COMMERCIAL EXPERIENCE

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RESUME

Le procédé Kellogg avancé de production d'ammoniac (KAAP), qui repose sur l'emploi d'un catalyseur de synthèse à haute activité, fonctionne avec succès industriellement à Pacific Ammonia Company (autrefois Ocelot Ammonia) depuis novembre 1992. Pacific Ammonia Company a augmenté avec succès sa capacité de production d'ammoniac de 40 % par l'emploi de KAAP et du système échangeur de reforming Kellogg (KRES).

Cette communication présente l'expérience industrielle de KAAP à Pacific Ammonia et fournit une mise à jour d'autres projets KAAP. La communication insistera sur le fonctionnement et la performance du procédé KAAP à Pacific Ammonia. Le procédé avancé de fabrication d'ammoniac de M.W. Kellogg Company fournit la conception économique d'unités d'ammoniac construites à partir de zéro. Le procédé KAAP est également utilisé pour de nombreuses réhabilitations dans le monde en vue d'augmenter la capacité et de diminuer l'énergie.

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INTRODUCTION

On November 10, 1992, for the first time, ammonia, one of the world's most important and leading bulk-commodity chemicals and the building-block of the world's fertilizer industry, was produced on a commercial scale using a non-iron catalyst. This breakthrough, the Kellogg Advanced Ammonia Process (KAAP), represents the first significant advance in ammonia synthesis catalyst technology since the development of the iron-based catalyst more than 80 years ago. KAAP technology is based on the use of a new, precious metal high activity ammonia synthesis catalyst, which makes possible the design of lower cost and lower energy ammonia facilities. In 1992, the Ocelot Ammonia Company, now Pacific Ammonia Incorporated (PAI), located in Kitimat, British Columbia, Canada, became the site of the first commercial application of the Kellogg Advanced Ammonia Process.

The new KAAP process has been in successful operation at Pacific Ammonia almost four years. This paper provides an update on the commercial experience of Kellogg's KAAP technology at Pacific Ammonia. The KAAP catalyst has demonstrated excellent performance and stability; meeting or exceeding all expectations of the PAI KAAP-based synthesis loop retrofit expansion. Implementation of KAAP at Pacific Ammonia has not only resulted in significant energy savings, but has allowed for a cost-effective increase in ammonia production capacity of more than 40% once additional synthesis gas was made available in 1994, through the implementation on another Kellogg advanced ammonia technology, the Kellogg Reforming Exchanger System (KRES).

This paper will also show how the experience at Pacific Ammonia has been incorporated into Kellogg's latest ammonia plant design. The benefits of the new technology have been clearly demonstrated at Pacific Ammonia. The new technology from Kellogg, having been commercially proven, is gaining wide acceptance, allowing the user to be the low cost ammonia producer. The KAAP technology is being used in the Farmland MissChem and Nitrogen Leasing ammonia plants to be located in Trinidad. These plants, which are scheduled to start-up in 1998, each have a nameplate capacity of 1850 MTPD (2040 STPD), which we believe will make them the largest single-train nameplate ammonia plants built to-date. KAAP technology is also being implemented on a number of retrofits, including expansion projects for Ampro Industries in Donaldsonville, Louisiana and for Incitec Industries in Morningside (Brisbane), Queensland, Australia.

KELLOGG ADVANCED AMMONIA PROCESS (KAAP)

The Kellogg Advanced Ammonia Process (KAAP) is a breakthrough in ammonia synthesis technology. Successful commercialization of KAAP represents the first significant advance in ammonia synthesis catalyst technology since the iron catalyst was first used for ammonia manufacture over 80 years ago. KAAP is based on the use of a novel precious-metal ammonia synthesis catalyst. The KAAP catalyst is a co-promoted, ruthenium-metal catalyst, supported on a proprietary graphitic structure. KAAP catalyst was co-developed by M.W. Kellogg and British Petroleum.

An intense development program, which lasted more than 10 years, established the optimum catalyst formulation, the effects of poisons, optimum process conditions, catalyst activation and passivation procedures, a rigorous kinetic model and a basis for predicting catalyst life. The development program established and confirmed the significant benefits and properties of the KAAP catalyst. These characteristics include an intrinsic activity of up to 20 times higher for ammonia synthesis than that exhibited by conventional iron-based catalysts currently available. The KAAP catalyst maintains a high activity at relatively low temperatures and low pressures, as well as at high ammonia concentrations. Additionally, the KAAP catalyst can operate over a wide range of hydrogen-to-nitrogen ratios, with the optimum being lower than stoichiometric.

Engelhard Industries Inc., a prominent catalyst manufacturer with extensive precious-metal catalyst experience, was sublicensed by Kellogg to manufacture the new KAAP catalyst.

PACIFIC AMMONIA KAAP EXPERIENCE

The Pacific Ammonia plant was originally designed to produce nominally 544 MTPD (600 STPD) of ammonia and was commissioned in December of 1986. Purge gas from an adjacent 1250 MTPD (nameplate) methanol plant was used as feedstock. The ammonia plant was designed using Kellogg's reduced energy ammonia technology. Implementation of KAAP at Pacific Ammonia in 1992 has not only resulted in significant energy savings, but has allowed for a cost-effective increase in ammonia production capacity of more than 40% once additional synthesis gas was made available from the new KRES-based front-end in 1994.

The KAAP process has been in successful operation at Pacific Ammonia for almost four years. This application at Pacific Ammonia has met or exceeded all flowsheet requirements. Also, importantly, Kellogg's main objectives: to substantiate catalyst activity, stability and life and to technically confirm the new radial flow ammonia converter in an actual industrial environment, have all been confirmed.

PAI KAAP PROCESS DESIGN

The first commercial demonstration of KAAP ammonia synthesis technology at Pacific Ammonia utilizes a full flow converter installed downstream and in-series with the existing magnetite converter. This approach not only made optimum use of KAAP catalyst's ability to achieve high conversions even with a feed containing a significant level of ammonia, but also demonstrated the converter design which is being used on current grassroots KAAP projects. The Pacific Ammonia retrofit design embodies the following key features.

- Low pressure drop, radial flow, in-series KAAP converter
- A retrofitted synloop now capable of efficiently operating at a reduced H/N ratio
- A synloop now capable of a minimum 40% increase in ammonia production
- Reduced energy operation

Figure 1 gives a block flow diagram of the current Pacific Ammonia plant following the expansion with KAAP and KRES. The original plant took all of its feed from purge gas from the adjacent Methanex methanol facility. With the installation of a new natural gas based KRES front-end in 1994, additional synthesis gas was made available to the synthesis loop.

Figure 2 displays a simplified flowsheet of the Pacific Ammonia retrofitted synloop. The synthesis loop operates at around the original design pressure of 2000 psia (141 kg/cm^{2}a). Compressed fresh feed plus recycle exits the existing 103-J syngas machine and is blended with additional syngas from other compression facilities before passing to the 121-C feed/effluent exchanger. Partially preheated converter feed then passes directly from 121-C to a 2-bed Kellogg horizontal converter (105-D) loaded with magnetite catalyst. Converter effluent exits the horizontal converter in a normal manner before passing on to a steam superheater and generator, respectively, which generates medium pressure 3000 KPa(g) (30.6 kg/cm^2 (g)) steam for driving the 103-J compressor turbine and for export. The gas exiting the boiler is then ready for feeding to the KAAP section of the synloop.

All of the 105-D effluent, containing nominally 15% ammonia, passes directly to the 2-bed radial flow KAAP converter (105-D1) for additional syngas conversion. The main flow stream enters the reactor through a side inlet and is preheated in the tubes of the KAAP reactor integral interchanger 122-C1. An outside bypass line around this exchanger is provided for first bed inlet temperature control. Gas then passes through the first bed, the shell side of the interchanger and the second bed of KAAP catalyst, where the exit ammonia concentration is increased to about 19%. Hot 105-D1 effluent is first cooled in a new medium pressure steam generator 123-C1 before passing on to the shell side of the 121-C feed/effluent exchanger.

The 121-C shell side effluent is first cooled in a water cooled exchanger where ammonia condensation begins. Final product condensation occurs in a 4-stage exchanger, 120-C, called the « unitized chiller ». All ammonia product from the plant is removed as a liquid at -33^{0}C before being sent to offsites storage. Refrigeration duties are handled by the 105-J motor-driven 2-case, 4-stage centrifugal ammonia compressor. Recycle gas then passes back through the tubes in 120-C and following liquid NH_3 disengagement is returned to the last wheel of the 103-J syngas compressor and additional parallel recycle compression facilities provided as part of the KRES front-end expansion project.

The original synloop had such a minor amount of inerts present in the make-up gas (primarily argon) that a voluntary purge was not necessary. The expanded plant has more inerts in the feedgas due to the process nature of the front-end expansion (reforming based rather than purge gas based) and therefore a continuous purge is required. The expanded plant purge gas is processed in a membrane hydrogen recovery unit where 85-90% of the purge H_2 is recovered for recycle. Waste gas exiting the membrane separation facilities is blended with refrigeration compressor purge gas and 107-F flash gas before exiting the plant battery limits as a supplemental fuel stream.

PAI KAAP REACTOR DESIGN

Figure 3 displays a simplified analytical diagram of the PAI two bed radial flow KAAP converter. Because KAAP catalyst is so reactive (up to 20 times more active than magnetite), thin beds of catalyst are used to stay within prescribed operating temperatures. The AI KAAP converter was designed to fully meet capacity expansion expectations as a 2-bed unit. Kellogg uses 3 and 4 bed designs for grassroots installations.

Operating temperatures are such that a hot wall design is possible with external insulation. The vessel and exchanger were manufactured by Kawasaki Heavy Industries (KHI).

Most radial flow designs are concerned with sealing the upper portion of the bed with excess, unutilized catalyst to prevent gas-bypassing after catalyst settling has occurred. The Kellogg design utilizes a unique/proprietary sealing arrangement which avoids hot spots within the catalyst bed due to maldistribution while providing for 100% utilization of the loaded catalyst volume.

Access to the top bed for maintenance or catalyst loading/unloading is via a full opening top head closure. A side manway provides access to the bottom bed.

PAI KAAP START-UP

The Pacific Ammonia KAAP Reactor System was successfully started-up in November of 1992. As with most catalysts, the KAAP catalyst was loaded in its oxidized state; however, it is only active in the reduced state. The reduction was carried out with fresh synthesis gas, basically consisting of heating up the catalyst beds to around 300^{0}C. Overall, the reduction process went smoothly and slightly faster than anticipated. The entire reduction process took only 19 hours to complete. KAAP catalyst can be activated faster than iron-catalyst because only a small amount of water is generated by the catalyst during reduction, because of the relatively small amount of metals used. Once KAAP catalyst reduction was complete, the magnetite converter was brought on-line and stabilized and then syngas was routed through the KAAP unit and brought into full operation. First ammonia was produced from the KAAP reactor on November 10, 1992.

PAI KAAP OPERATION

The operation and performance of KAAP at Pacific Ammonia was closely monitored and extensively evaluated by Kellogg. A number of tests were conducted to confirm the results established during the development phase and to provide feedback to future designs. In all cases, the KAAP catalyst operation and performance at Pacific Ammonia has met or exceeded the commercialization criteria.

The Pacific Ammonia KAAP Reactor System has been very easy to operate. The KAAP unit installed downstream of the magnetite converter, improves the overall efficiency of the synthesis loop and allows for more flexibility and a wider range of operation. With KAAP, Pacific Ammonia can run the ammonia synthesis loop efficiently over a wide range of H/N ratios. The addition of KAAP has also resulted in milder synloop operating conditions (e.g., lower pressure, less recycle flow, lower speed on synthesis gas compressor, etc.).

The highlights of the first four years in service at PAI give a good testimonial of the excellent KAAP catalyst performance. The catalyst was operated under various planned and unplanned conditions. Over the four years of successful operation, the KAAP catalyst was accidentally exposed to extremely high levels of CO and O_2 poisons and was operated under various inerts, H/N ratio, pressure and space velocities. The new radial flow reactor and the catalyst were operated under full pressure and temperature cycles as the plant went through planned and unplanned shutdowns.

CATALYST POISONS

The feedstock to the ammonia plant is methanol purge gas containing carbon monoxide. Nitrogen is supplied from an air separation plant and it serves to purify the methanol purge gas feed through a nitrogen wash unit. Breakthroughs of CO and O_2 have occurred on several occasions due to accidental upsets in the air separation and/or nitrogen wash units. In December 1993, there was a massive CO quantity inadvertently admitted to the synthesis loop for several hours as a planned shutdown was initiated. Unfortunately, the methanol purge gas was not diverted to fuel after the nitrogen wash unit was shutdown. CO level reached about 4000 ppmv at near design reactor operating temperatures. Upon restart of the plant, the KAAP catalyst was deactivated. It took several days, but, following re-reduction, the KAAP catalyst fully recovered its activity. It should be noted that the upstream magnetite catalyst was also deactivated during this incident and also recovered several days later.

The KAAP catalyst has since been exposed to higher than normally expected CO and O_2 levels on several occasions. But, as these poisons are brought under control in the upstream units, KAAP catalyst fully recovers its activity demonstrating both resiliency and stability; key features for an industrial ammonia synthesis catalyst.

HIGH INERT HELIUM

Shortly after the catalyst recovery from CO poisoning, the loop had to be purged on a regular basis. Temperature rise across the KAAP varied widely and at times was lower than expected. It was suspected that there was either a cyclic poisoning of the catalyst again or some inert material was entering the loop. After an extensive investigation and laboratory analysis of the various process and feed streams, it was discovered that helium was present in the natural gas feed to the methanol plant and was building up in the ammonia plant's synthesis loop. Helium essentially reduced the effective partial pressure of the reactants and hence lowered the ammonia conversion. The original design did not call for a continuous loop purge as the make-up gas was very low in inerts (helium was not expected in the natural gas) which were all removed in the liquid ammonia. However, later analyses showed that there were times when the helium in the synthesis loop reached almost 20% vol, which definitely required a gas purge.

With the addition of the new front-end in 1994, there was a continuous gas purge for the methane, which automatically removed the helium as well. Because the membrane-based hydrogen recovery unit that was added during the front-end expansion does not effectively separate hydrogen from helium, a secondary purge has been added which effectively controls excess inert build-up in the synthesis loop. Helium analysis was added to the mass spectrometer and is now continuously measured for more effective plant control and stability.

H/N RATIO

The optimum hydrogen to nitrogen ratio for the KAAP catalyst is one of the fundamental differences between the magnetite and KAAP catalysts. Magnetite catalyst prefers an H/N ratio of about 2.8 to 2.9, but the optimum for the KAAP catalyst is lower. The PAI ammonia synloop has separate H2 and N2 feeds so it is quite convenient to vary the H/N ratio. In the early days of KAAP operation at PAI, the control system was such that a close control of the H/N ratio was difficult and accurate analysis of H and N was not available. This led to more than expected variations in the ammonia conversion across the KAAP reactor. As the importance of H/N ratio became more and more relevant to the operators, a closer control of the H/N ratio to the loop was initiated. Analysis of the KAAP streams was added to the mass spectrometer. With these improvements, plant operation has become smoother and the ammonia conversion more consistent.

GAS HOURLY SPACE VELOCITY (GHSV)

The KAAP system by design and due to site specific circumstances operates through a wide GHSV. The original plant was designed to use purge gas as feed from the adjacent methanol plant. Therefore, any variation in the methanol plant purge rate or disturbances in the methanol plant would directly impact the available feed and hence the GHSV through the KAAP reactor. The PAI complex is subject to natural gas curtailments during the winter months. A major change came when the new front-end was installed and the ammonia plant was upgraded by 40%, from the original nameplate capacity of 544 MTPD to 772 MTPD. Through all of these various operating modes, the KAAP converter performance has been excellent. The PAI KAAP Reactor has been operated at rates as high as 860 MTPD.

FULL P/T CYCLES

During the past four years of operation, the KAAP system has gone through several full and partial shutdowns and restarts. These shutdowns were caused by planned yearly turnarounds in the methanol plant and trips due to power failures. These shutdowns and restarts have proven the mechanical integrity of the new radial flow ammonia converter and the physical stability of the KAAP catalyst through a wide range of thermal cycling. The PAI KAAP Reactor System has proved to be easy to operate continuously and easy to start-up and shutdown as well.

CATALYST ACTIVITY

Kellogg monitors and evaluates the KAAP performance from operating data provided by PAI on a regular basis. Production rates and catalyst bed temperature differentials are plotted as received to give an indication of catalyst activity and activity trends. The data presented in Figure 4 covers the third year of KAAP operation, including the transition to the higher ammonia production. The actual temperature rises across the two KAAP beds have been very consistent and as expected, decreased slightly when the plant capacity was increased to around 772 MTPD. Today, the KAAP catalyst continues to perform excellent, with no evidence of any catalyst deactivation or loss of physical integrity.

PAI KAAP INSPECTION IN FEBRUARY 1996

Since the startup of the original PAI plant in 1986, there was a small migration of magnetite catalyst from the magnetite converter. This situation has been corrected in newer horizontal converter designs. The PAI plant continued to operate this way because the migration was too small to interfere with the plant's normal operation. When the KAAP reactor retrofit was conceived, it was decided to install a filter between the magnetite converter and the KAAP converter as a precautionary measure, until the magnetite converter could undergo the minor repairs needed. After KAAP came on line in 1992, the catalyst leakage from the magnetite converter progressively increased. The filter subsequently failed several times allowing magnetite catalyst to enter the KAAP reactor. In December of 1995, the pressure drop in the KAAP converter increased to unacceptably high levels and the KAAP system was shut down. The inspection and magnetite catalyst removal took place in early February 1996.

Inspection of the KAAP converter revealed that magnetite catalyst had plugged the catalyst bed inlet screens and some fine magnetite had entered the first catalyst bed and was mixed with the KAAP catalyst, causing the high pressure drop. The reactor and its internals were found to be in excellent condition.

The first bed of KAAP catalyst was removed, screened of magnetite fines and reloaded by Reactor Services of Edmonton. During the entire operation, the catalyst inside and outside the reactor was kept under nitrogen blanket, without passivation. While the catalyst was outside in 55 gallon drums, the magnetite catalyst was successfully screened out by standard methods.

This inspection of the KAAP converter gave an opportunity to confirm many aspects of the new converter design as well as the KAAP catalyst itself after more than three years in operation.

The KAAP reactor findings were:

- the internal heat exchanger was in perfect condition
- all metal surfaces were clean
- no evidence of corrosion
- no evidence of nitriding
- catalyst retaining screens in perfect condition
- no unusual changes in internal tolerances
- proprietary catalyst bed inlet design confirmed
- catalyst bed sealing design confirmed

The KAAP catalyst findings were:

- expected catalyst bed level confirmed
- no physical deterioration
- physical properties within original specification
- chemical properties within original specification

The KAAP reactor was restarted on 1 March 1996, and within 24 hours it was back on line operating normally.

TURNAROUND PLANS

Maintenance of the magnetite converter is planned for the next turnaround which coincides with having to replace the 10-year old magnetite catalyst, which has lost much of its activity. The converter fix itself is a minor maintenance activity, involving repairing some screens around the catalyst support grid and sealing some of the thermowell penetrations through the basket partition plates. The PAI converter is the last one of the original horizontal converters to be repaired. All later converters had design modifications to the internals and have experienced no problems.

COMPARATIVE DATA AT 544 AND 780 MTPD

As mentioned above, the KAAP converter has been operated over a wide range of conditions. A major step change in operation took place when the plant capacity was increased by 40% from 544 MTPD to around 772 MTPD. Table 1 shows comparative operating data at two considerably different production rates.

TABLE 1 - COMPARISON OF PAI KAAP OPERATION

Plant Capacity	MTPD	544	780
Days-from-Start-up		471	1174
Loop Pressure	psia	1890	1958
Bed #1 Delta T Bed #2 Delta T Total Delta T	Deg. C Deg. C Deg. C	41 38 79	34 28 62
Design Delta T	Deg. C	77	61
Converter Pressure Drop	psi	6.4	14.5
NH_3 Conversion	Delta %	5.9	4.6

The Pacific Ammonia KAAP Reactor System continues to operate as expected. The KAAP catalyst has proven to be robust in its performance. With nearly four years in service at Pacific Ammonia, there is no evidence of any deactivation of the KAAP catalyst. The KAAP reactor is very reliable. With KAAP, the Pacific Ammonia plant has realized significant benefits, including increased capacity, exceeding 820 MTPD of ammonia.

KAAP GRASSROOTS APPLICATIONS

The Kellogg Advanced Ammonia Process (KAAP) is primarily aimed at the large-scale grassroots ammonia plant market. Incorporation of the new KAAP ammonia synthesis catalyst into a grassroots ammonia plant allows for several unique advantages to be exploited. The benefits of the high activity ammonia synthesis catalyst allows for the manufacture of ammonia at milder conditions than with traditional iron-based plants, resulting in excellent capital and operating cost economics. The KAAP Grassroots flowsheet takes maximum advantage of the high activity properties of the new catalyst. In addition to the KAAP catalyst, the KAAP plant incorporates current cost and energy savings features found in the Kellogg reduced energy ammonia plant. The basic sequence of process operations is also similar, retaining the same degree of reliability and operability as the conventional Kellogg technology. Employing KAAP technology will not require operators to relearn the process since the basic sequence is the same as that used in a conventional plant.

The KAAP ammonia process described here is based on conventional natural gas steam reforming and catalytic low pressure ammonia synthesis. Figure 5 shows key processing steps for the KAAP Grassroots synthesis loop. The KAAP grassroots plant achieves high ammonia conversion (18-22%) at a low synthesis loop design pressure (700-1300 psia(a)/(49.2-91.4 kg/cm^2(a)).

Since the use of the KAAP catalyst primarily impacts the synthesis loop, KAAP-based plants can be designed with a variety of front-end options (and feedstocks). Kellogg can provide KAAP plants with a conventional front-end (primary and secondary reforming), with a Kellogg Reforming Exchanger System (KRES) front-end, with a partial oxidation front-end, and KAAP synthesis loop designs for ammonia plants based on off-gas. KAAP technology can be used for any desired ammonia capacity level.

KAAP GRASSROOTS: TECHNICAL FEATURES

The design of the KAAP Grassroots ammonia plant is a result of an extensive engineering effort. The design effort was structured to ensure that the KAAP technical features confirmed during the development phase were incorporated in such a manner as to produce maximum economic and technical advantage in the KAAP plant. The KAAP design was influenced heavily by Kellogg's extensive experience in providing technology to over 160 ammonia plants worldwide. It is important that the KAAP design retains all of the proven features of Kellogg's conventional reduced energy technology, while utilizing the KAAP catalyst to make the plant more efficient and less costly.

The front-end of the natural-gas fed KAAP Grassroots plant design, described here is based on conventional reforming. The natural gas feed is first desulfurized and then partially reformed in a primary reformer followed by a secondary reformer. The KAAP front-end operates with about 8% excess air (to accommodate the desired H/N ratio in the synloop). After reforming, the gas is purified in the conventional manner: high and low temperature shift, CO_2 removal and methanation. The KAAP plant, like the conventional plant provides all the downstream CO_2 requirements (and ammonia) for an urea plant. Final purification is accomplished by molecular sieve dryers and the gas is compressed in a single-case centrifugal compressor for synthesis. The bulk of the changes in a KAAP plant are centered in the ammonia synthesis loop, where the KAAP reactor replaces the Kellogg horizontal converter and allows for a higher conversion of ammonia at low pressures. Ammonia product is recovered by employing conventional technology, utilizing Kellogg's « unitized chiller » with ammonia as the refrigerant. A purge gas recovery unit provides for hydrogen recovery and also for nitrogen recovery required for operating a substoichiometric ammonia synloop. The KAAP plant retains all of the environmental and safety features of Kellogg's conventional technology. The resultant KAAP Grassroots plant will allow its operator to be the low cost producer in any competitive market.

The KAAP Grassroots ammonia plant contains the following technical features:

- Single Case Synthesis Gas Compressor
- Radial Flow, Intercooled Converter Design
- Low Pressure Synthesis Loop
- High Activity Ammonia Synthesis Catalyst (KAAP)

Table 2 gives a comparison of the key design parameters of a KAAP Grassroots plant and a conventional reduced energy ammonia plant.

TABLE 2
COMPARISON OF DESIGN PARAMETERS: CONVENTIONAL AND KAAP

DESIGN BASIS	CONVENTIONAL	KAAP
Front End Pressure	37 kg/cm^2	41 kg/cm^2
Synloop Pressure	141 kg/cm^2	91 kg/cm^2
Synloop H/N Ratio	3.0	2.3
Synthesis Gas Compressor	Two Stage Centrifugal	Single Stage Centrifugal
Ammonia Converter	Axial/ Two Bed	Radial/Four Bed
Ammonia Catalyst	Magnetite	Magnetite + KAAP
Ammonia Conversion	15 %	21 %

Table 3 gives the comparative overall plant energy and compression power savings for a conventional plant and the KAAP design. The high ammonia concentration per pass achieved with the KAAP design increases the ammonia dew point, and shifts more ammonia product condensation to cooling water, away from the energy intensive refrigeration circuit. The high ammonia concentration, which results in lower recycle flow, coupled with the lower synthesis loop operating pressure results in significant synthesis gas compression power savings, as well as capital and maintenance cost savings with the single case machine.

TABLE 3
COMPARATIVE ENERGY AND POWER: CONVENTIONAL AND KAAP

	CONVENTIONAL	KAAP
Air Compressor	100 %	107 %
Synthesis Gas Compressor	100 %	59 %
Refrigeration Compressor	100 %	94 %
Total Feed + Fuel	100 %	95 %

KAAP GRASSROOTS: REACTOR DESIGN

The KAAP grassroots radial flow reactor incorporates the same design features as the PAI KAAP reactor. The KAAP Grassroots reactor is a single, vertically-oriented, 4-bed, Intercooled, radial-flow vessel. The lower KAAP reactor operating pressures and temperatures permit the use of a hot wall design and also mild steel construction. The first bed utilizes a charge of conventional magnetite catalyst to take advantage of high ammonia reaction rates at low ammonia concentrations. The downstream bed are loaded with KAAP catalyst. At low operating pressures, where equilibrium constraints are greater, the KAAP catalyst's excellent low temperature performance allows for high ammonia conversions. Maximum heat integration and efficiency is achieved via a series of intercoolers and external steam generators. Figure 6 gives the KAAP Grassroots Reactor and Heat Exchanger Network. The KAAP Reactor is designed for ease of start-up, catalyst loading and unloading, catalyst activation and passivation, operation and overall control.

KAAP GRASSROOTS: ECONOMIC BENEFITS

The technical advantages of the KAAP ammonia plant design translate into significant, tangible benefits for the KAAP plant. The benefits of KAAP technology relative to current reduced energy technology can be briefly summarized as follows:

- the synloop energy consumption is reduced by 40 percent.
- the synloop capital cost is reduced by about 20 percent.
- the overall plant capital cost is reduced by about 10 percent.
- the overall plant energy consumption is reduced by about 0.25 Gcal(LHV)/MT.

END NOTE

The continued successful commercial experience of KAAP at the Pacific Ammonia paves the way for new grassroots facilities which will position ammonia operators to be *the low cost producer* in a highly competitive industry.

PAI KAAP/KRES EXPANSION PROJECT BLOCK FLOW DIAGRAM

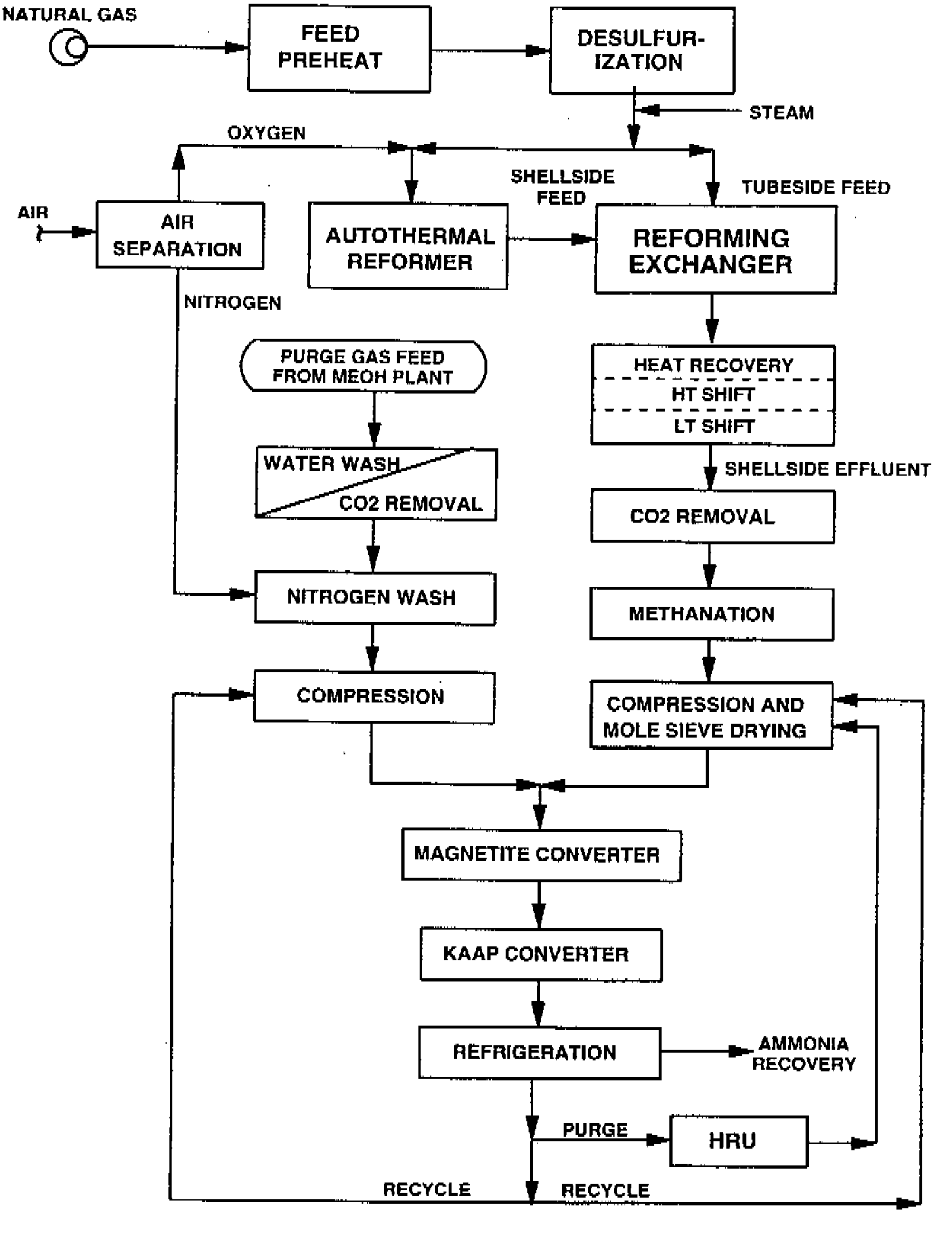
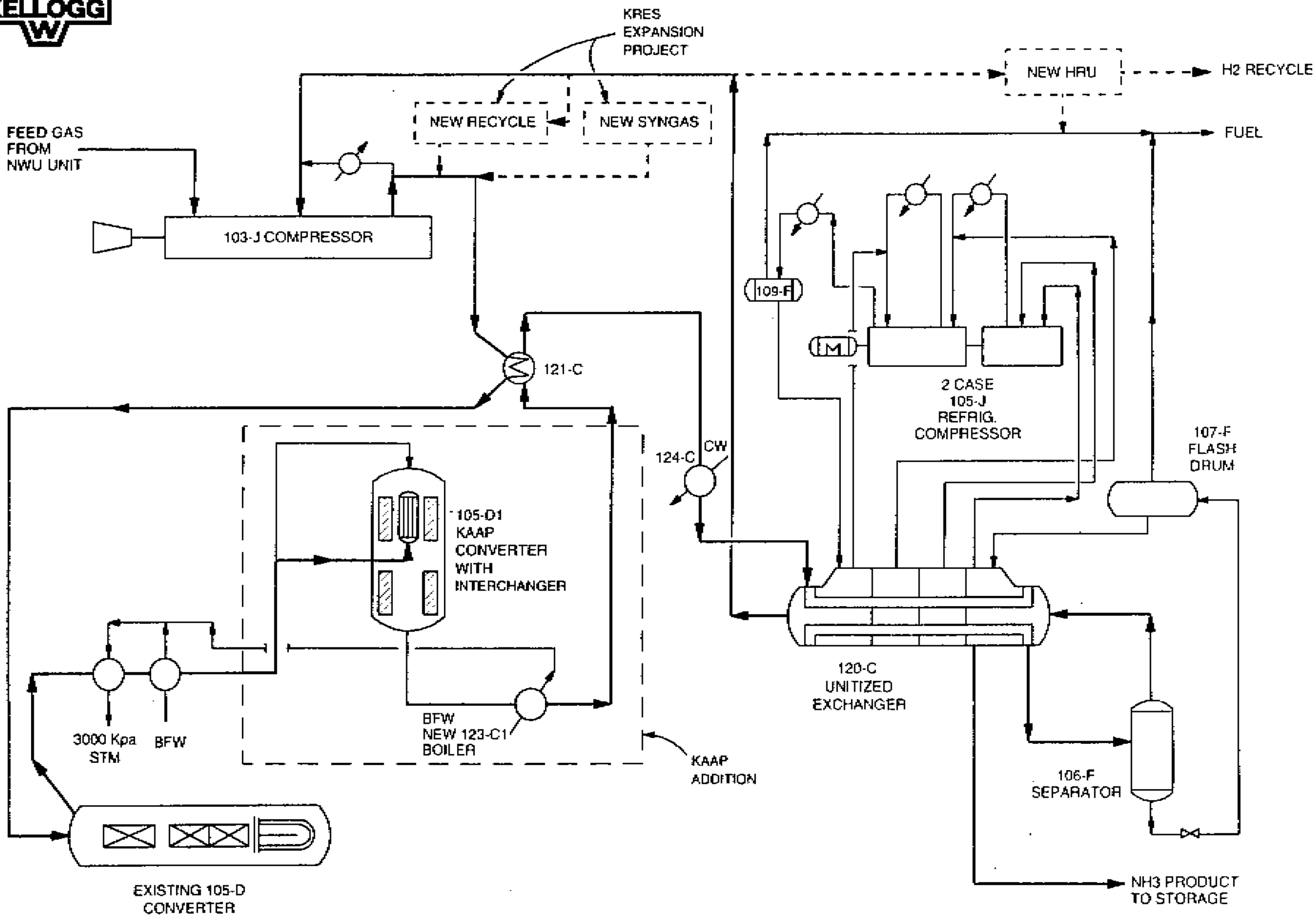


Figure 1



PAI KAAP RETROFIT

Figure 2

PAI KAAP REACTOR DESIGN (105-D1)

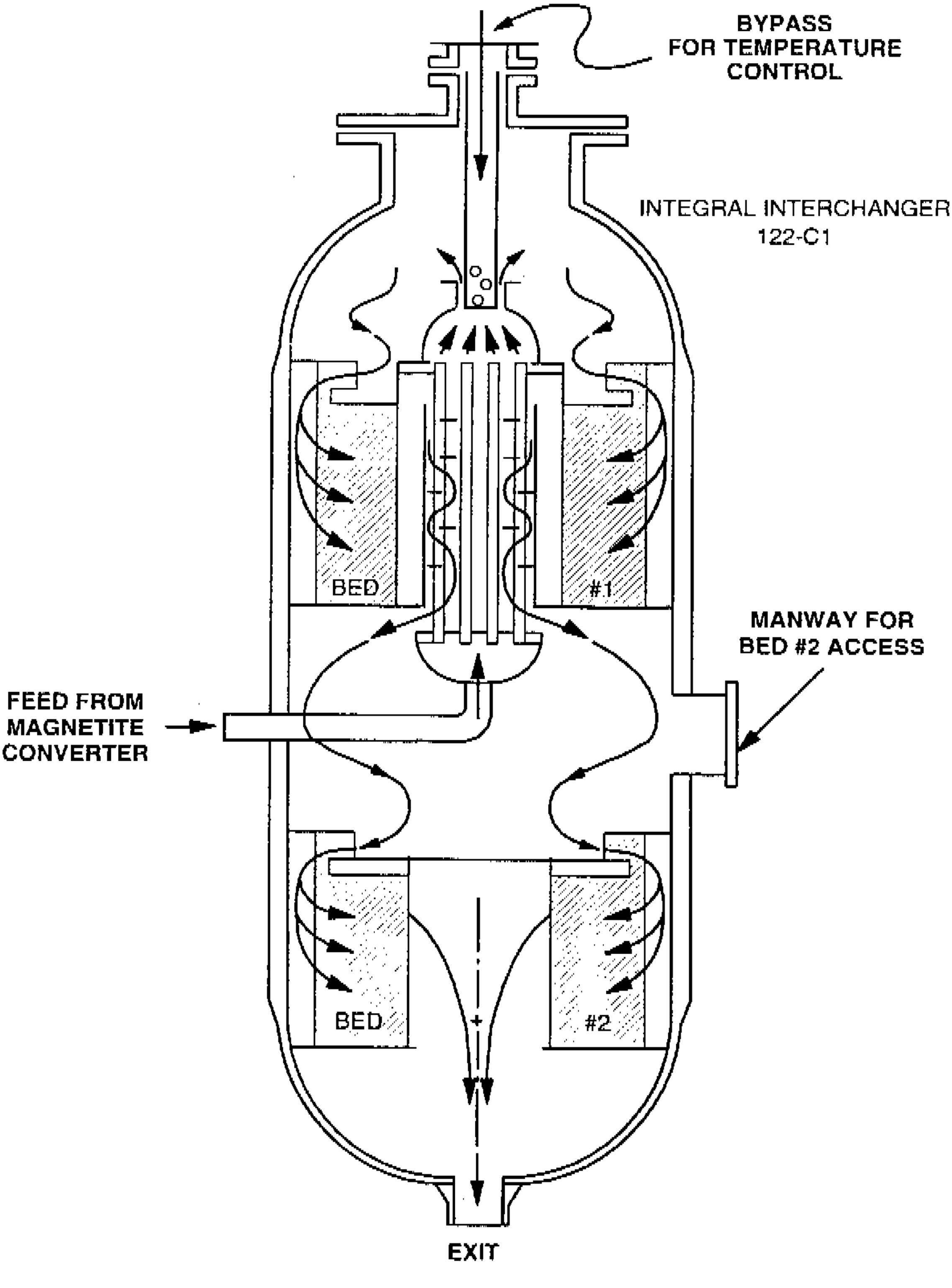


Figure 3

PAI KAAP Reactor System

KAAP Temperature Profiles

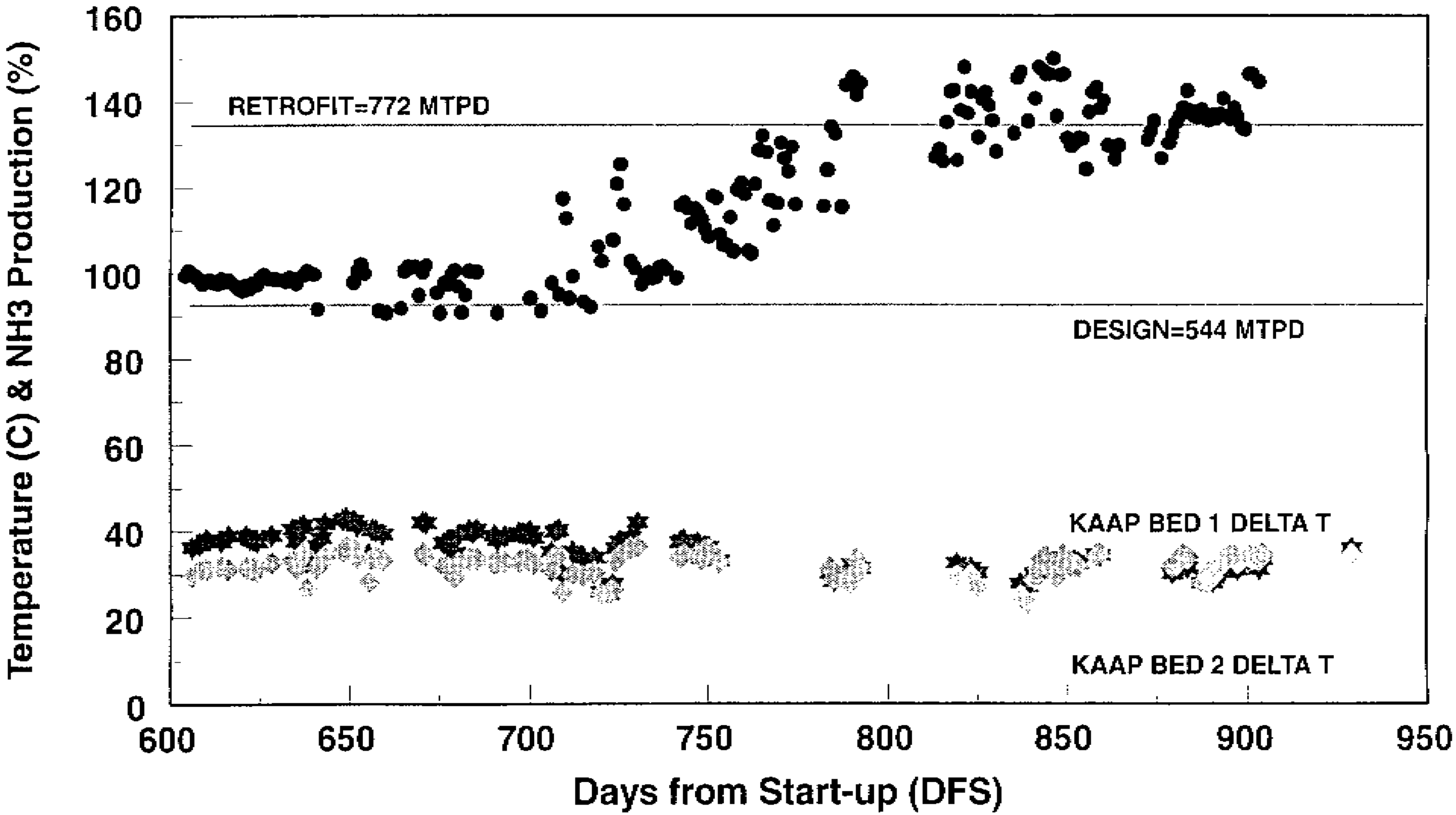


Figure 4

KAAP GRASSROOTS SYNTHESIS LOOP

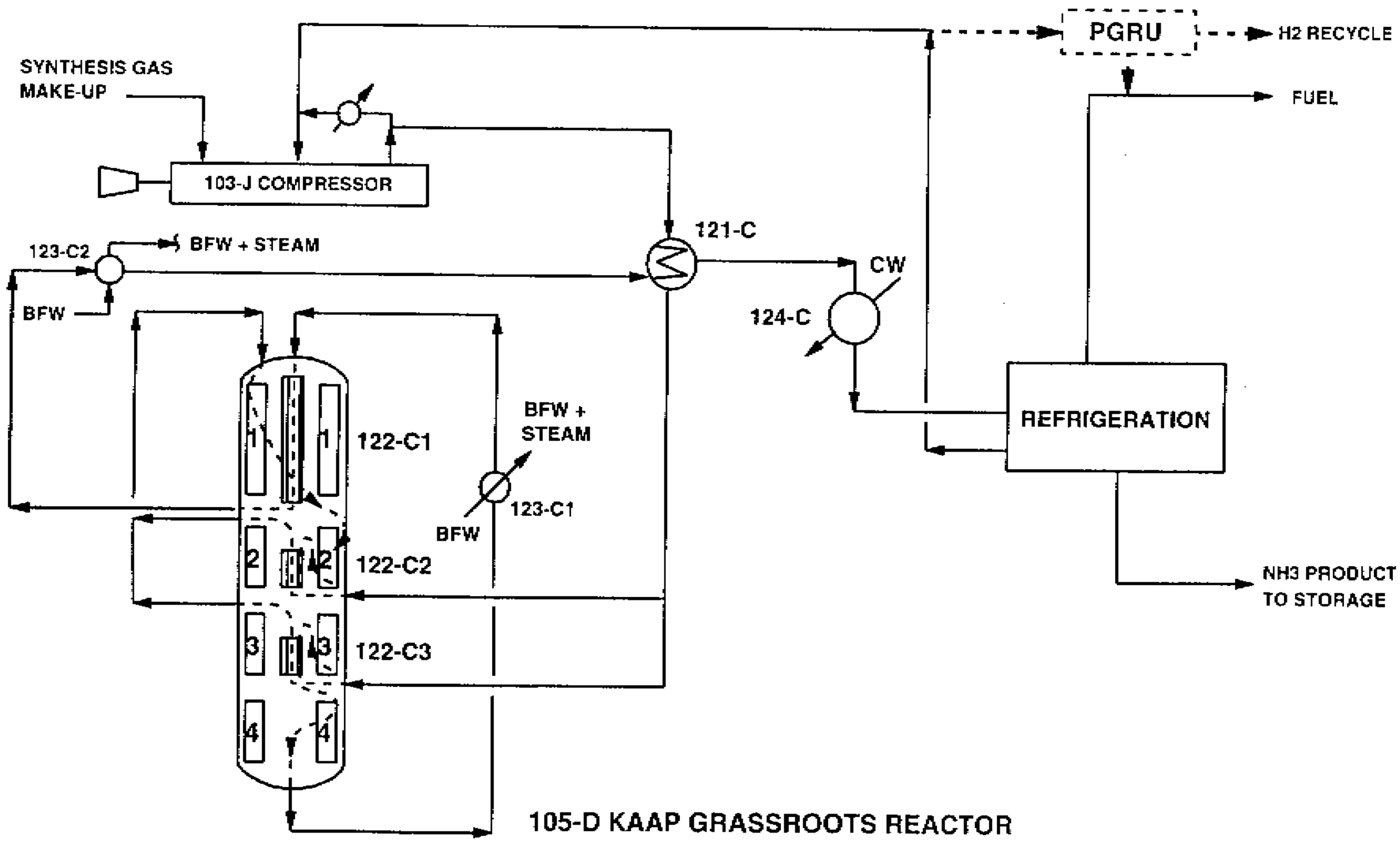


Figure 5

KELLOGG

105-D KAAP GRASSROOTS REACTOR

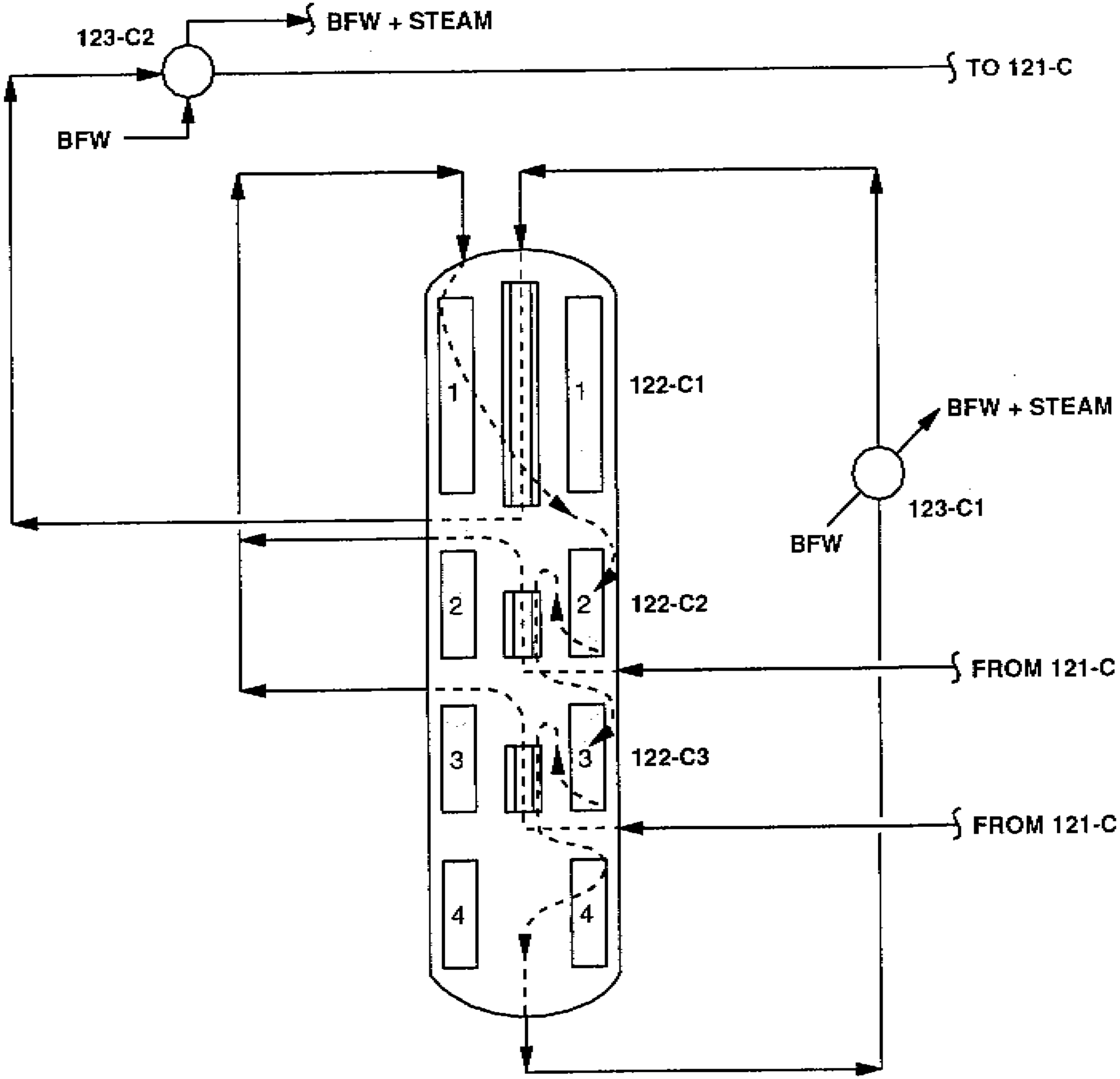


Figure 6