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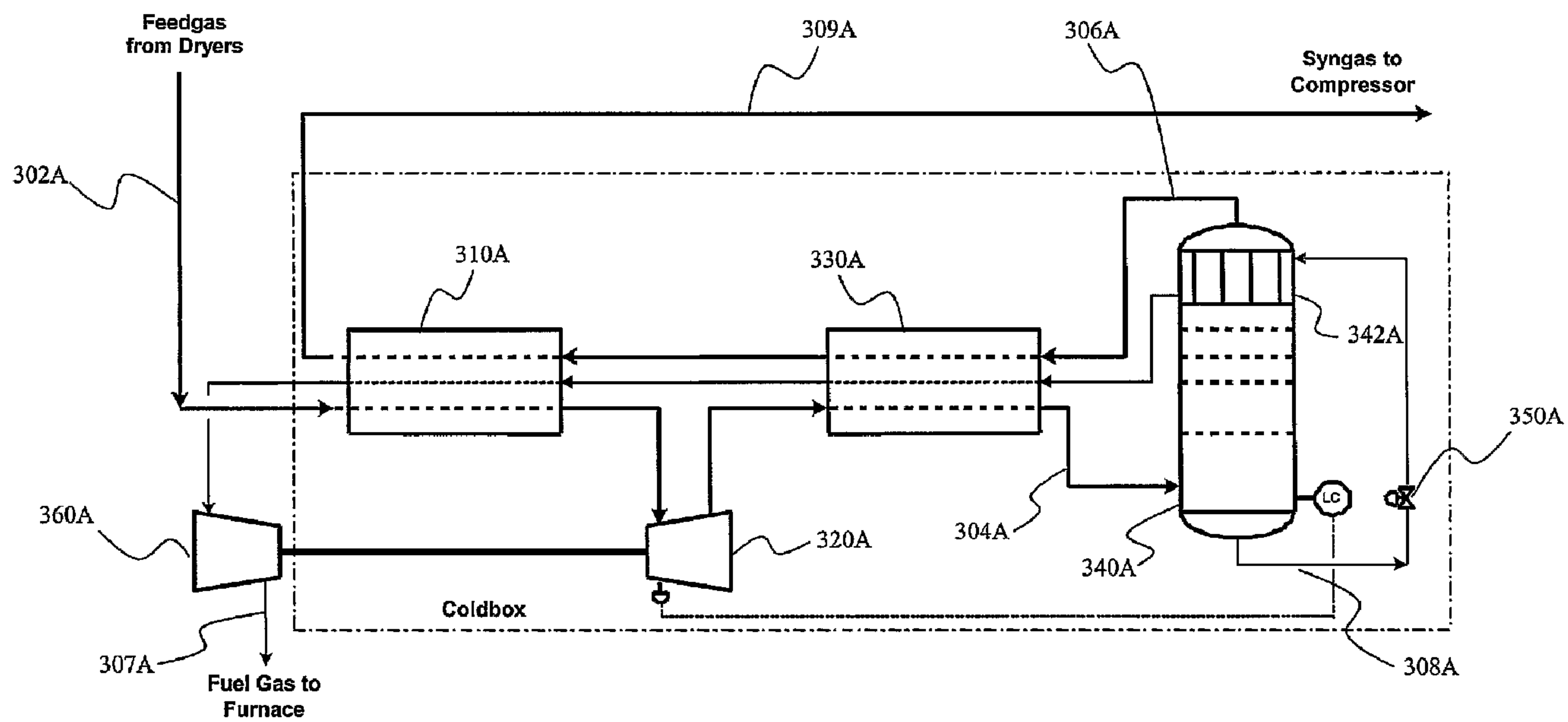
(54) Title: IMPROVED AMMONIA PLANT



(57) Abrégé/Abstract:
A synthesis plant (309A) includes a compression device (360A) that increases a pressure differential between the bottom product pressure of a cryogenic separator (340A) and the delivery pressure of the bottom product to a downstream plant component. Such increased pressure differential is employed to increase cooling in the separator (340A) to thereby significantly reduce the volume of excess air. In most preferred aspects, at least part of the energy required for the compression device is provided by expansion (320A) of the separator feed.

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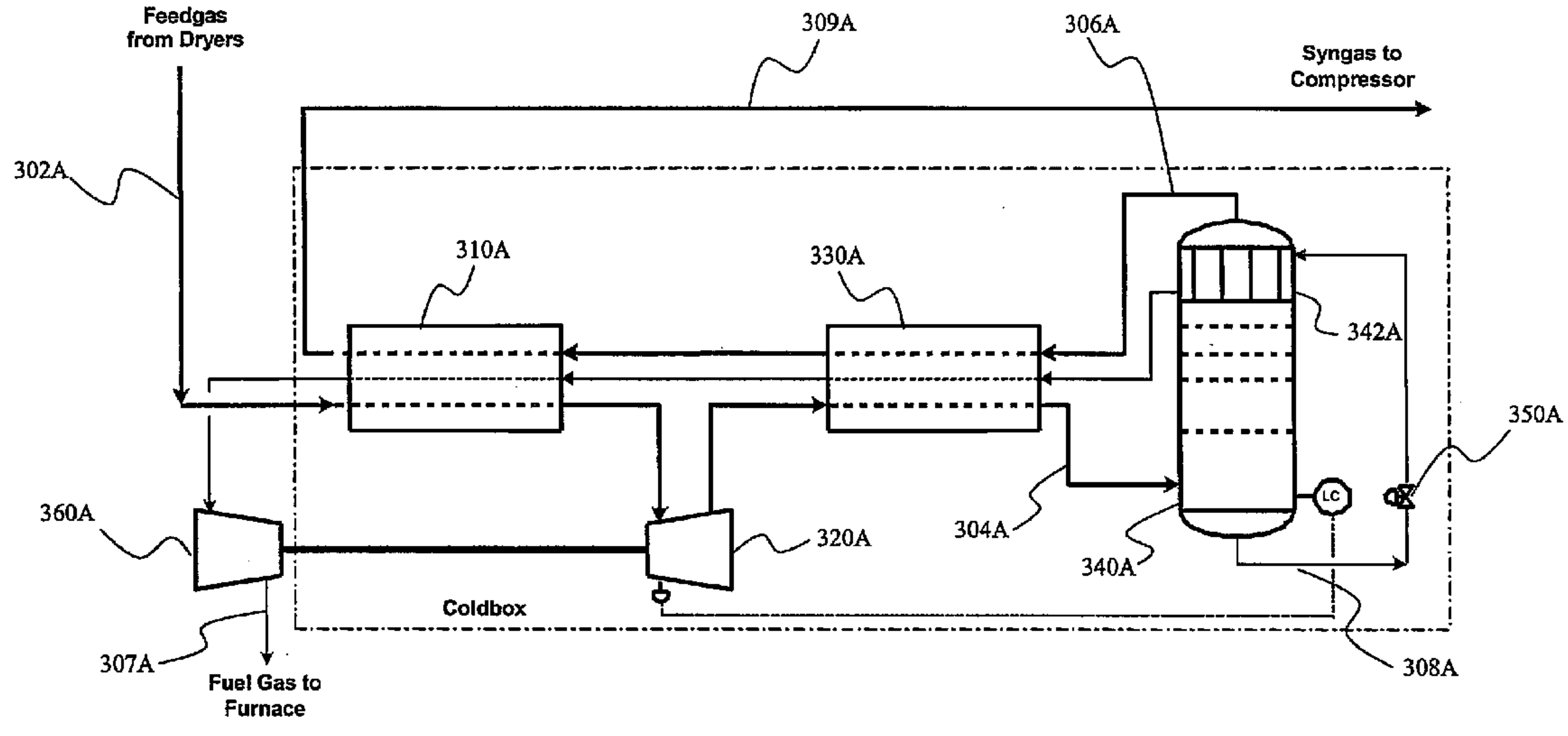

(57) Abstract: A synthesis plant (309A) includes a compression device (360A) that increases a pressure differential between the bottom product pressure of a cryogenic separator (340A) and the delivery pressure of the bottom product to a downstream plant component. Such increased pressure differential is employed to increase cooling in the separator (340A) to thereby significantly reduce the volume of excess air. In most preferred aspects, at least part of the energy required for the compression device is provided by expansion (320A) of the separator feed.

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IMPROVED AMMONIA PLANT

Field of The Invention

The field of the invention is configurations and methods for ammonia production.

Background of The Invention

In most conventional ammonia plants, natural gas is processed in primary and secondary reformers to generate hydrogen, and the reformed gas stream is then subjected to a shift conversion for additional hydrogen production after excess heat has been recovered from the reformed gas stream. In a still further step, acid gases (here: carbon dioxide) are removed and residual carbon monoxide (CO) and carbon dioxide (CO_2) are converted into methane in a downstream methanator. The resulting raw synthesis gas stream is then passed into the synthesis loop for production of ammonia, wherein the nitrogen is typically provided from process air that is fed into the secondary reformer.

Typically, an ammonia plant will use a stoichiometric amount of process air in the secondary reformer to maintain a hydrogen to nitrogen molar ratio of 3 to 1 in the methanator effluent gas (raw synthesis gas), which is typically the make-up gas to the ammonia synthesis loop. Where desirable, production capacity can be increased by introducing excess air and then by removing excess nitrogen from the syngas stream by combination of gas expansion, autorefrigeration, and cryogenic separation as for example described in U.S. Pat. No. 3,442,613 to *Grotz*. While *Grotz's* configuration is relatively effective in some ammonia production plants, retrofitting of existing plants is problematic since the expansion step requires considerable increase in front-end pressure in a ammonia synthesis plant and thereby typically necessitates retrofits/rebuilds to accommodate for the increased pressure.

To circumvent at least some of the problems associated with retrofitting existing ammonia synthesis production plants, *Bhakta* describes in U.S. Pat. No. 5,935,544 a configuration in which a purifier process has been applied to a low methane content syngas with moderate N_2 excess, wherein an external refrigeration step produces a syngas with sufficiently low inert content to significantly increase synthesis capacity or decrease in synthesis loop pressure. Although *Bhakta's* configuration overcomes in many cases the need for retrofitting existing plants, *Bhakta's* configuration is typically limited to relatively narrow process parameters in order to provide satisfactory improvements in synthesis capacity.

In yet other known plant configurations (see *e.g.*, our commonly owned International patent application with publication number WO 03/002459), an ammonia plant includes a separation system upstream of a synthesis loop that removes excess nitrogen and other gaseous compounds from a feed gas having a ratio of hydrogen to nitrogen of less than 3:1 to thereby produce a syngas with a ratio of hydrogen to nitrogen at about 3:1. In particularly preferred systems, a coldbox with a refrigerant other than air, or pressure swing adsorption unit operates as the separation system. While such configurations provide numerous advantages over previously known ammonia plants, demands for excess air are still relatively high.

Therefore, despite numerous known configurations and processes for improvements of ammonia synthesis, all or almost all of them suffer from one or more disadvantages. Thus, there is still a need to provide improved methods and configurations for ammonia synthesis.

Summary of the Invention

The present invention is generally directed towards configurations and methods of an ammonia synthesis plant in which separator refrigeration is increased by increasing a pressure differential in the separator bottom product.

In one aspect of the inventive subject matter, an ammonia plant includes a cryogenic separator that is configured to receive a raw syngas and to produce a bottom product and a processed syngas overhead product. An expansion device is further coupled to the cryogenic separator and is configured to provide refrigeration cold to the cryogenic separator by expanding the bottom product from a first pressure to a second pressure. Contemplated plants still further include a compression device that is fluidly coupled to the separator such that the compression device increases a pressure differential between the first and second pressure that is usable to increase the refrigeration cold.

Most preferably, a raw syngas expander is coupled to the cryogenic separator, wherein the raw syngas expander is configured to provide expanded raw syngas to the cryogenic separator, and wherein the compression device is coupled to the raw syngas expander to thereby provide at least part of a compression energy. Where the expansion device is located upstream of the compression device, it is generally preferred that the expansion device is configured to expand the bottom product to a pressure between atmospheric pressure and 30 psig (*e.g.*, JT valve). On the other hand, where the expansion device is located downstream of the compression device, it is generally preferred that the compression device is a pump that increases the first pressure up to 50 psig.

Thus, the inventors also contemplate a method of operating an ammonia plant in which in one step raw syngas is separated in a cryogenic separator into a bottom product and a processed syngas overhead product. In another step, refrigeration cold is provided to the cryogenic separator by expanding the bottom product from a first pressure to a second pressure, and in yet another step, the bottom product is compressed or pumped to increase a pressure differential between the first and second pressure to thereby increase generation of the refrigeration cold.

Viewed from another perspective, the inventors contemplate a method of operating an ammonia plant in which in one step raw syngas is expanded in an expander to produce work and refrigeration for cryogenic separation of the raw syngas into a bottom product and a processed syngas overhead product. Most preferably, the work is used to increase a pressure differential between a pressure of the bottom product of a cryogenic separator and a delivery pressure of the bottom product to a plant component downstream of the cryogenic separator.

Various objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the invention.

Brief Description of The Drawing

Figure 1 is a prior art schematic of a known configuration for an ammonia plant.

Figure 2 is a graph illustrating pressure gradients of contemplated plants as compared to previously known plant configurations.

Figure 3A is an exemplary configuration of one ammonia plant in which the bottom product is over-expanded and recompressed to fuel header pressure.

Figure 3B an exemplary configuration of one ammonia plant in which the bottom product is pumped to an increased pressure and expanded to fuel header pressure.

Detailed Description

The inventors have discovered that the amount of excess air in ammonia plants can be substantially reduced by increasing refrigeration in the coldbox rectifier. In most preferred configurations, the refrigeration is increased by increasing a pressure gradient in the rectifier bottom product, which is expanded to thereby generate refrigeration cold. Thus, contemplated configurations will advantageously reduce excess air rate (e.g., 37% versus 50% for the standard Braun process), which will also result in a lower hydraulic load in the front end of the plant and/or a lower CO_2 removal system duty.

For example, in one aspect of the inventive subject matter, the bottom product is over-expanded (*i.e.*, expanded to a pressure below a delivery pressure to a downstream device) and then re-compressed using energy provided by raw syngas expansion. Alternatively, bottom product may also be pumped to a desired pressure using energy provided by raw syngas expansion, and the so pressurized bottom product is then expanded (or over-expanded and recompressed) to provide refrigeration. In preferred configurations, excess air and/or nitrogen can be introduced to the front-end of the syngas production process to improve capacity in contemplated configurations, while maintaining the stoichiometric ratio of hydrogen to nitrogen at about 3:1. The term "a molar ratio of hydrogen to nitrogen of about 3" as used herein refers to molar ratios of between 2.95 to 3.05, and more preferably between 2.97 to 3.03, and most preferably between 2.99 to 3.01. Moreover, it should be appreciated that contemplated configurations may be operated using relatively wide process parameters while improving productivity and/or reducing energy requirements.

An exemplary configuration of a known ammonia synthesis plants is depicted in **Prior Art Figure 1**. Here, ammonia production in plant 100 is improved using an air separation unit. In such configurations, oxygen-rich gas 106 (*i.e.*, comprising at least 25 mol%, more typically at least 75 mol%, and most typically at least 90 mol% oxygen) may be provided to the secondary reformer 120, and a nitrogen rich gas 108 (*i.e.*, comprising at least 80 mol%, more typically at least 90 mol%, and most typically at least 95 mol% nitrogen) may be introduced to the reformed and/or shift converted gas at a position upstream of the methanator 160. Alternatively, the air separation unit may be omitted where desired or addition of an air separation unit would not be economically practicable. With respect to various process configurations and operating considerations of such plants, the same considerations apply as set forth in our International patent application having publication number WO 03/002459.

The inventors have now found out that the efficiency of the above and other ammonia plants can even further be improved by expanding the separator (rectifier) bottoms liquid to a pressure that is substantially lower than currently practiced and/or from a pressure that is substantially higher than currently practiced. It should be appreciated that use of such increased pressure differential alleviates the temperature pinch in the overhead condenser and the feed/effluent exchangers in the coldbox upstream of the rectifier. Therefore, and depending on the degree of rectifier bottoms liquid expansion, operation of the stoichiometric correction unit can be achieved with an excess air rate of less than 50%, more typically less than 40%, even more typically less than 30%, and most typically with an excess air rate of between about 20% to 30% (in some cases even less than 20%).

In most of the preferred configurations according to the inventive subject matter, the pressure differential used for refrigeration will be at least 10-20 psi, more typically at least 20-30 psi, and most typically between 25-50 psi across the expander. For example, the bottom product may now be expanded to atmospheric pressure (or slightly above) and is subsequently recompressed using power provided by the raw syngas expander. Such expansion typically will provide a pressure differential of about 15-25 psi, and more typically about 30 psi. The term "about" as used herein in conjunction with a numeral refers to a range of that numeral starting from 10% below the absolute of the numeral to 10% above the absolute of the numeral, inclusive. Similarly, a pump may be provided that increases the bottom product pressure from the rectifier pressure to an increased pressure that is between 20-40 psi higher, and more typically between 30-50 psi (or even higher).

In contrast, heretofore known coldbox configurations were limited in their bottoms liquid expansion to an elevated pressure, typically corresponding to the fuel header pressure, which lead to a loss in refrigeration as compared to the configurations and methods according to the inventive subject matter. Moreover, most known coldbox configurations employ the energy from the expander for recompression of the syngas, which contributes only to a relatively small amount in the energy savings. **Figure 2** schematically illustrates the increase in pressure differential using contemplated configurations and methods. Here, with reference to a conventional ammonia plant, the pressure differential Δ1 between the separator bottom product pressure and a downstream device receiving the bottom product (typically the fuel header) has a first value. In configurations in which the bottoms product is over-expanded to a pressure at or near atmospheric pressure, pressure differential Δ2 between the separator bottom product pressure and the expander has a second value that is substantially greater than the first value. Energy expended to recompress over-expanded bottom product to the downstream device receiving the bottom product (shown in hatched line CC2) is preferably provided by the raw syngas expander. Similarly, in configurations in which the bottoms product is first pressurized (e.g., with a pump) to an increased pressure and then expanded, pressure differential Δ3 between the pump and the expander has a third value that is substantially greater than the first value. Energy expended to pressurize the bottom product (shown in hatched line CC3) is preferably provided by the raw syngas expander.

One exemplary configuration with over-expansion and recompression is depicted in **Figure 3A**, which illustrates a detail view of a coldbox configuration (schematically shown in hatched lines). Here, feed gas 302A from feed gas dryers (not shown) is cooled in a first heat exchanger 310A, expanded in an expander 320A, and further cooled in a second heat exchanger 330A. The so expanded and cooled feed 304A is then separated in rectifier 340A into a vapor portion 306A and a liquid portion 308A. The liquid portion 308A is expanded in JT valve 350A to or near atmospheric pressure to provide refrigeration in the overhead condenser 342A. After providing refrigeration to the overhead condenser, the expanded product is then routed to the second and first heat exchangers 330A and 310A, respectively, before recompression in compressor 360A that is coupled to the expander. The recompressed gas 307A is then used as fuel in a furnace (not shown) or other downstream device. Similarly, the vapor phase (i.e., the syngas) 306A from the rectifier 340A is routed to the second and first heat exchangers 330A and 310A, respectively, to provide refrigeration. Heated syngas 309A typically has a hydrogen to nitrogen ratio of 3:1 and is then compressed by a syngas compressor (not shown).

In another configuration, as schematically depicted in **Figure 3B**, the bottom product is first pumped to a desired pressure above rectifier pressure and then expanded to the pressure of a downstream device receiving the bottom product. Here, feed gas 302B from feed gas dryers (not shown) is cooled in a first heat exchanger 310B, expanded in expander 320B, and further cooled in a second heat exchanger 330B. The so expanded and cooled feed 304B is then separated in rectifier 340B into a vapor portion 306B and a liquid portion 308B.

The liquid portion 308B is pressurized in pump 360B to a pressure above rectifier pressure (*e.g.*, 30-50 psi above rectifier pressure) to form pressurized bottom product 308'B, and then expanded in JT valve 350B to provide refrigeration in the overhead condenser 342B. After providing refrigeration to the overhead condenser, the expanded product is then routed to the second and first heat exchangers 330B and 310B, respectively, before entering a downstream device (*e.g.*, furnace) as stream 307B. Similarly, the vapor phase (i.e., the syngas) 306B from rectifier 340B is routed to the second and first heat exchangers 330B and 310B, respectively, to provide refrigeration. Heated syngas 309B typically has a hydrogen to nitrogen ratio of 3:1, and is then compressed by a syngas compressor (not shown).

It should be appreciated that the over-expansion of the rectifier bottoms liquid will result in a pressure that is typically between a pressure below the fuel header pressure and atmospheric pressure (and in some cases even below atmospheric pressure. Such expansion of the rectifier bottoms will generally not provide low pressure waste gas (e.g., fuel gas). Thus, it is preferred that the expanded gas exiting the coldbox exchangers will typically be recompressed to a desired pressure (e.g., about 15 psig for fuel gas), where recompression is required. In such cases, it is generally preferred that recompression is coupled with the process expander in the coldbox. Therefore, it should be recognized that no additional power for recompression is required. Moreover, in most cases cooling water will not be required as there are no intercoolers or aftercoolers included. Additionally, or alternatively, it should be appreciated that the work provided by the expander may also be employed for a pump that pressurizes the rectifier bottom liquid. In such configurations, cooling for the pressurized liquid may be provided using part of the refrigeration content of the expanded gas. The pressurized liquid may then be expanded to fuel gas header pressure or below as discussed above to provide an even higher refrigeration content. It should be appreciated that contemplated configurations may be installed de novo, or as an upgrade to an existing plant.

With respect to suitable pressure differentials, and especially those that are employed to provide refrigeration to the separator, it should be noted that all pressure differentials are deemed appropriate. Thus, contemplated pressure differentials include those between 1-100 psi (or even higher), more typically between 1-50 psi, and most typically between 10-50 psi. Therefore, contemplated compression devices for bottom products of the rectifier will include pumps that can increase the pressure of the bottom product in an amount of at least 10 psi, more typically at least 50 psi, and most typically at least 100 psi. Such devices may employ any energy available in the ammonia plant. However, it is especially preferred that the pump will be operationally coupled to the raw syngas expander. For example, suitable operational coupling includes mechanical coupling and electric coupling (e.g., expander drives generator that provides electric power to pump).

Similarly, the compression device may also be a compressor that recompresses expanded bottom product, wherein the compressor is operationally coupled to the raw syngas expander. Where the compression device is a compressor that recompresses previously expanded bottom product, it is generally contemplated that the compressor increases the previously expanded bottom from atmospheric pressure or a pressure above atmospheric pressure to a pressure that is suitable for a downstream device that receives the recompressed bottom product. For example, where the downstream device is a fuel gas header of a combustor, the compressor may increase the pressure up to between about 5-30 psig. With respect to contemplated expansion devices, it should be appreciated that all expansion devices are deemed suitable for use herein. However, it is typically preferred that the expansion device is a Joule-Thompson (JT) valve to provide refrigeration to the separator condenser. Alternative, the expansion device may also be used to generate power or to provide motive or compressive force to a fluid in the plant.

Thus, specific embodiments and applications of ammonia plant configurations and methods have been disclosed. It should be apparent, however, to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the spirit of the appended claims. Moreover, in interpreting both the specification and the claims, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms "comprises" and "comprising" should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Furthermore, where a definition or use of a term in a reference, which is incorporated by reference herein is inconsistent or contrary to the definition of that term provided herein, the definition of that term provided herein applies and the definition of that term in the reference does not apply.

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CLAIMS

What is claimed is:

1. An ammonia plant comprising:
a cryogenic separator that is configured to receive a raw syngas and to produce a bottom product and a processed syngas overhead product;
an expansion device that is coupled to the cryogenic separator and that is configured to receive and expand the bottom product from a first pressure to a second pressure to thereby provide refrigeration cold to the cryogenic separator; and
a compression device that receives the expanded bottom product and that is fluidly coupled to the separator such that the compression device allows for an increase in a pressure differential between the first and second pressure that is usable to thereby increase the refrigeration cold.

2. The ammonia plant of claim 1 further comprising a raw syngas expander coupled to the cryogenic separator, wherein the raw syngas expander is configured to provide expanded raw syngas to the cryogenic separator.

3. The ammonia plant of claim 2 wherein the compression device is coupled to the raw syngas expander to thereby provide at least part of a compression energy.

4. The ammonia plant of claim 3 wherein the expansion device is located upstream of the compression device.

5. The ammonia plant of claim 4 wherein the expansion device is configured to expand the bottom product to a pressure between atmospheric pressure and 30 psig.

6. The ammonia plant of claim 3 wherein the expansion device comprises a JT valve and wherein the compression device comprises a compressor.

7. The ammonia plant of claim 3 wherein the expansion device is located downstream of the compression device.

8. The ammonia plant of claim 7 wherein the compression device comprises a pump that increases the first pressure by an amount of 30 to 50 psi.

9. A method of operating an ammonia plant, comprising:
separating raw syngas in a cryogenic separator into a bottom product and a processed syngas overhead product;
expanding the bottom product from a first pressure to a second pressure to thereby provide refrigeration cold to the cryogenic; and
compressing the expanded bottom product to thereby allow for an increase in a pressure differential between the first and second pressure to thereby increase generation of the refrigeration cold.

10. The method of claim 9 further comprising a step of expanding the raw syngas in a raw syngas expander.

11. The method of claim 10 wherein the raw syngas expander is operationally coupled to a compression device that compresses the bottom product.

12. The method of claim 9 wherein the bottom product is expanded to a pressure between atmospheric pressure and 30 psig, and wherein the expanded bottom product is compressed to increase the pressure differential.

13. The method of claim 12 wherein the re-compressed bottom product has a pressure suitable for feeding to a reformer furnace.

14. The method of claim 9 wherein the bottom product is pumped to the first pressure and then expanded to the second pressure, wherein the first pressure is higher than an operating pressure of the cryogenic separator.

15. A method of operating an ammonia plant, comprising:
expanding raw syngas in an expander to produce work and refrigeration for cryogenic separation of the raw syngas into a bottom product and a processed syngas overhead product; and
using the work to drive a compression device that compresses the bottom product to thereby allow for an increase in a pressure differential between a pressure of the bottom product of a cryogenic separator and a delivery pressure of the bottom product to a plant component downstream of the cryogenic separator.

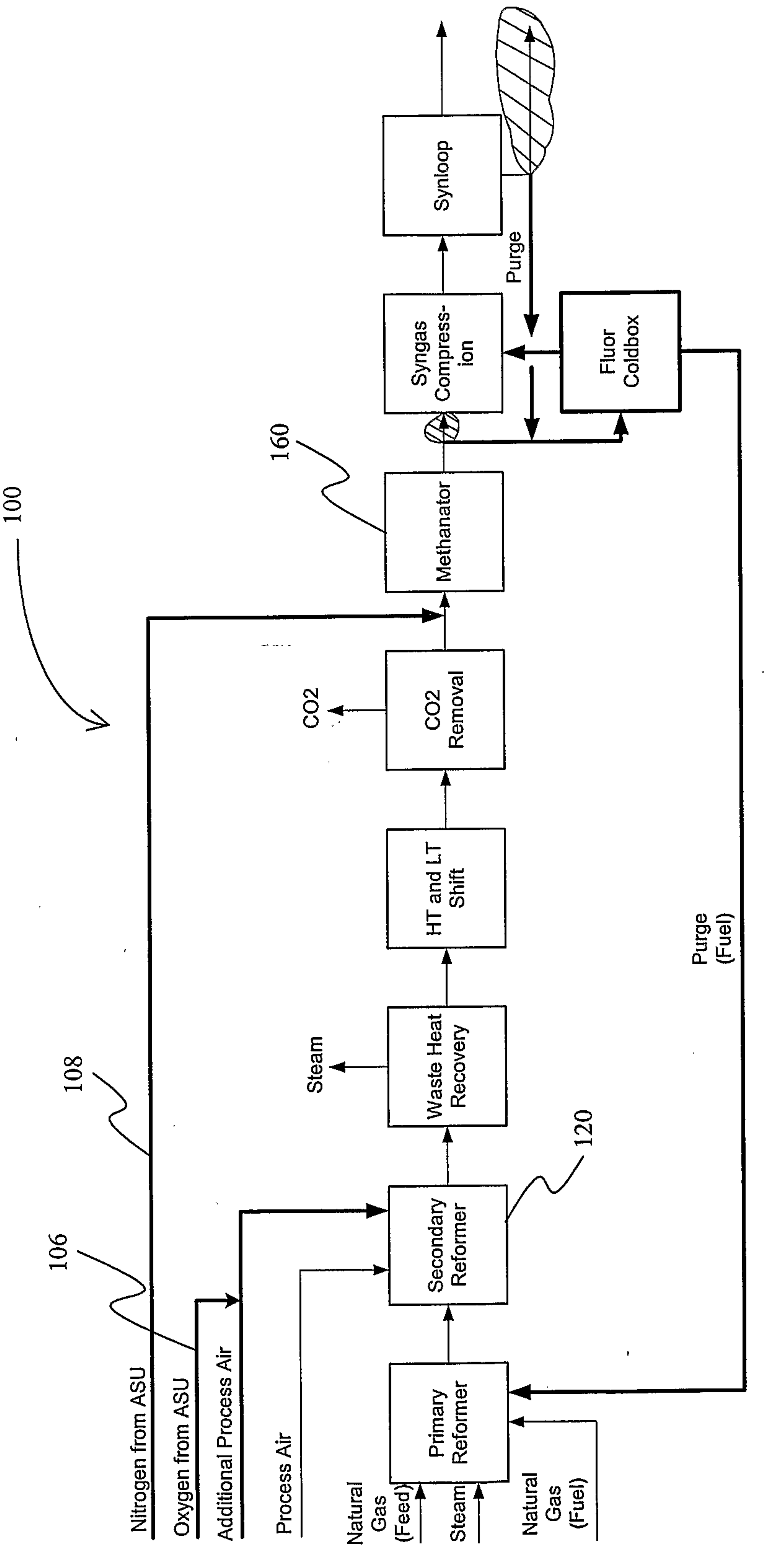
16. The method of claim 15 wherein the step of using the work comprises compressing the bottom product using a pump that increases the pressure, wherein the pump is located upstream of an expansion device that expands the pumped bottom product to the delivery pressure.

17. The method of claim 16 wherein the pump increases the pressure by an amount of 30 to 50 psi.

18. The method of claim 15 wherein the step of using the work comprises compressing the bottom product using a compressor that increases the pressure, wherein the compressor is located downstream of an expansion device and compresses expanded bottom product to the delivery pressure.

19. The method of claim 18 wherein the expansion device reduces the pressure of the bottom product to a pressure between atmospheric pressure and 30 psig.

20. The method of claim 19 wherein the expanded bottom product further provides refrigeration in at least one heat exchanger.



Prior Art Figure 1

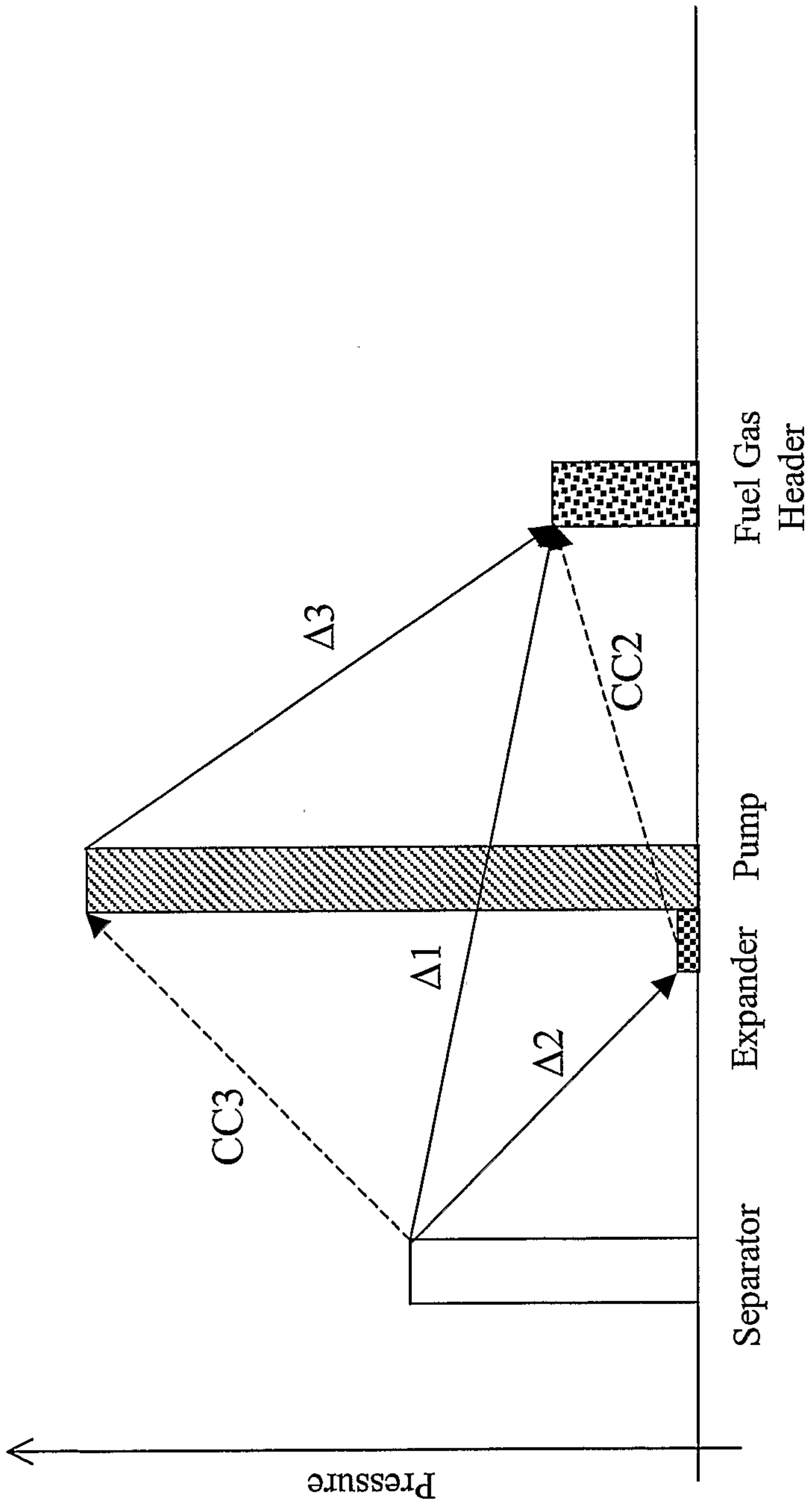

Pressure
Separator
Expander
Pump
Fuel Gas Header
Δ1
Δ2
Δ3
CC2
CC3

Figure 2

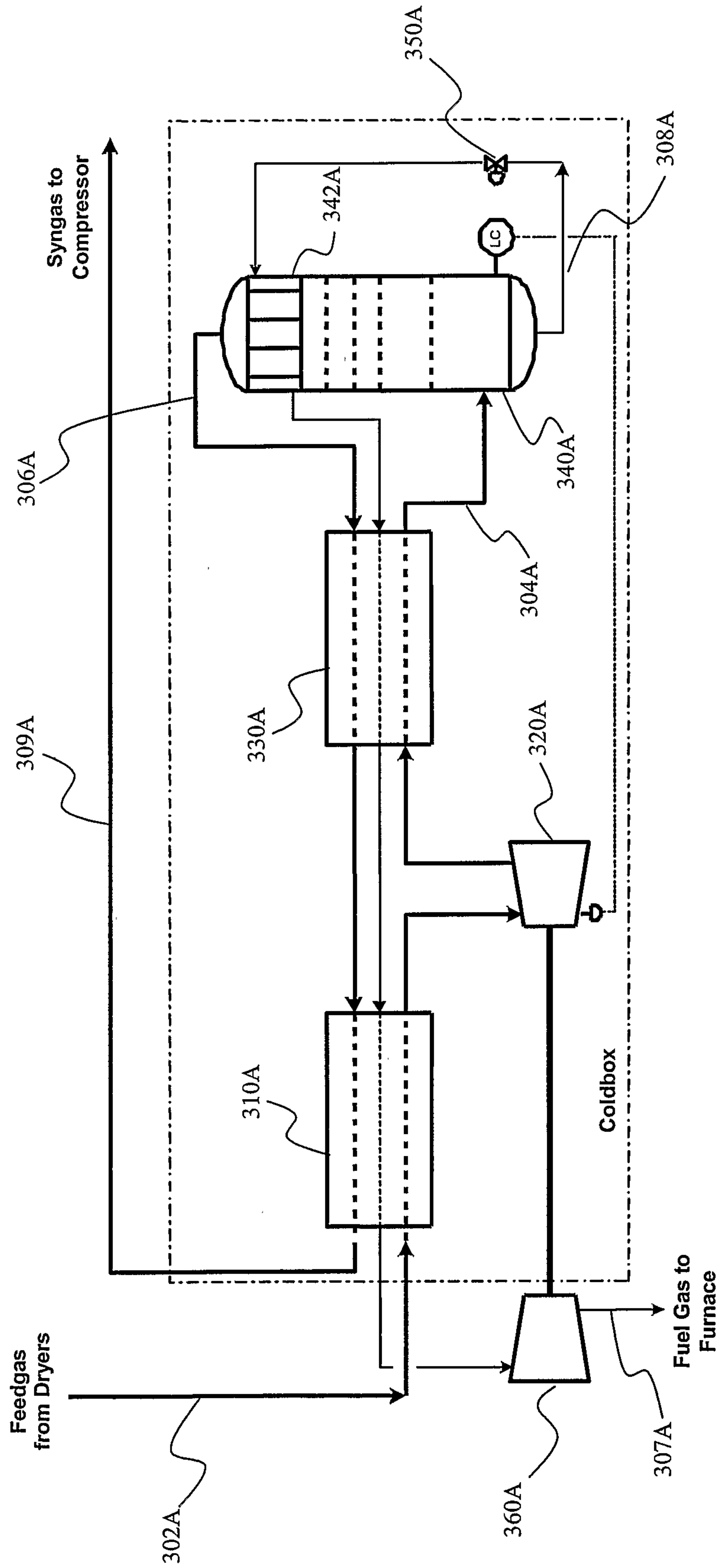
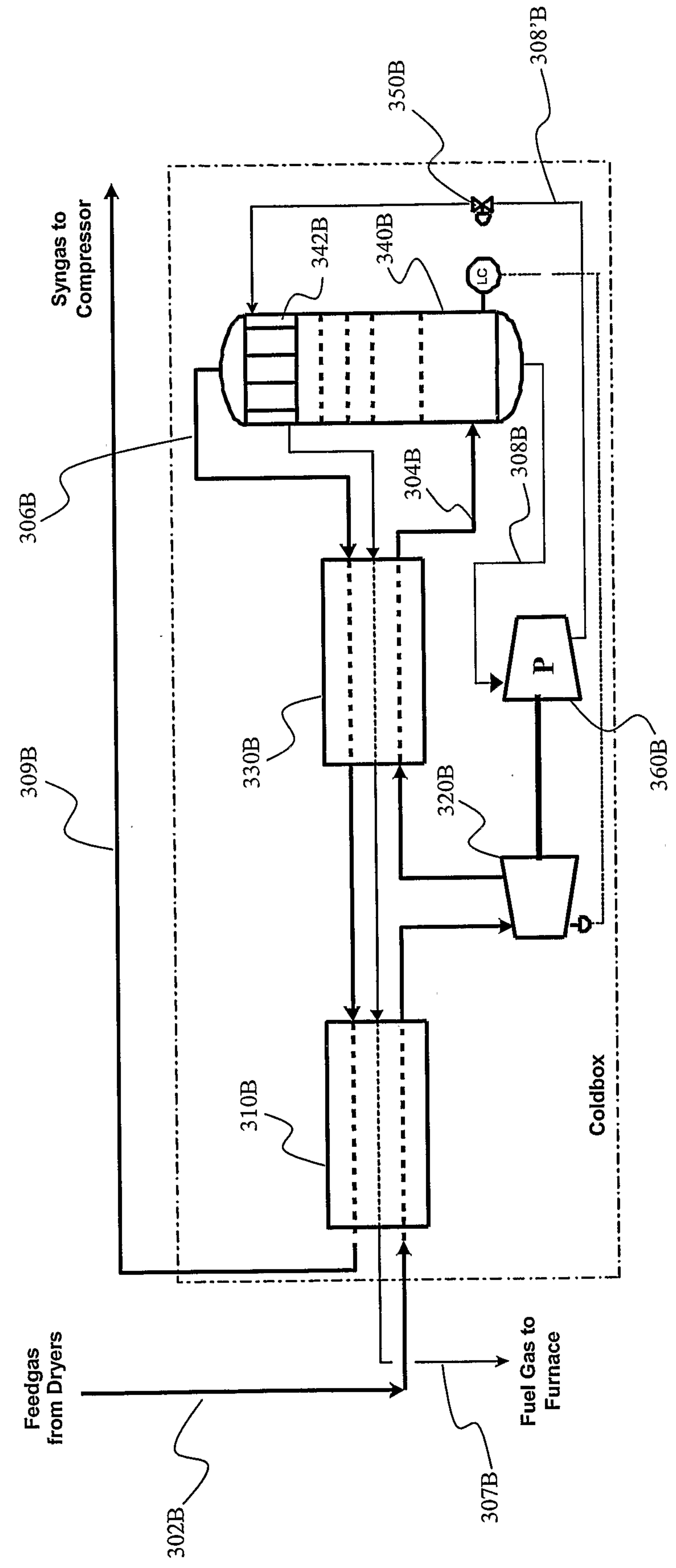

350A
308A
342A
Syngas to Compressor
LC
306A
340A
304A
330A
320A
309A
310A
Coldbox
Fuel Gas to Furnace
Feedgas from Dryers
302A
360A
307A

Figure 3A



Syngas to Compressor
Feedgas from Dryers
Fuel Gas to Furnace
Coldbox
LC
P
302B
304B
306B
307B
308B
308'B
309B
310B
320B
330B
340B
342B
350B
360B

Figure 3B


Feedgas
from Dryers
309A
306A
Syngas to
Compressor
302A
310A
330A
342A
350A
304A
360A
320A
340A
Coldbox
307A
308A
Fuel Gas to
Furnace
LC