

# Impact of Mari Gas and RLNG Mixture on Pre-Existing Ammonia Plant

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**ABSTRACT:** *The decline in the pressures of natural gas wells is forcing industries to either find more sustainable alternatives or temporarily make up for the shortfall. One such Pakistani gas field is the Mari Gas Field reservoir, from which the natural gas is extracted and used to produce ammonia which is the precursor of urea production. To temporarily cope with the declining pressures, this study proposes that a mixture of exported RLNG (30%) and Mari gas (70%) be used as feed. Material and Energy balances and the reactor designs were carried out and compared with the existing feed. Results showed that the proposed blend of RLNG and Mari gas could be used for ammonia production. However, alterations in the form of increased tube lengths, reactor volumes and catalyst loading will be required in the main equipment of plants. Nevertheless, these modifications result in 20784-20791a +20.65% increase in hydrogen production, +4.53% increase in ammonia production and +4.54% increase in urea production. Thus the proposed scheme can be adopted to manage the shortfall of Mari gas.*

**KEYWORDS:** *Mari Gas (Natural Gas); LNG (Liquefied Natural Gas); Primary Reformer; Secondary Reformer; High-Temperature Shift; Low-Temperature Shift; Methanator; Ammonia Reactor.*

## INTRODUCTION

By 2050, the world population is expected to exceed 9.4 billion. Moreover, the global gross domestic product (GDP) has been forecast to double by 2040. This exponential growth in world population, industrialisation and urbanisation will result in an expected increase in energy consumption to  $10^{21}$  joules by 2070, which

has already depleted the existing oil and gas reservoirs significantly during the last century. This increased demand warrants a higher supply of fuels and energy storage chemicals in the future [1-4].

The depletion of fossil fuels has caused the pressures of many oil and gas fields to fall, making it difficult

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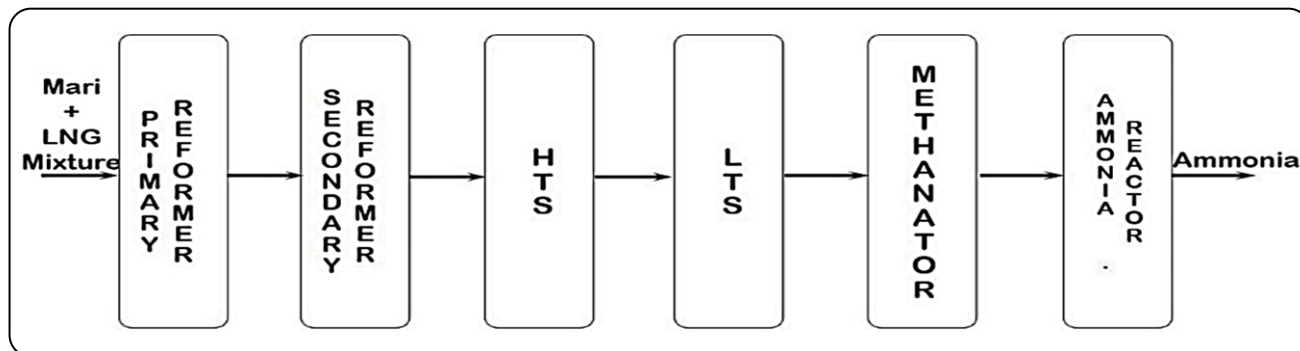


Fig. 1: Block flow diagram of ammonia process

to sustain the current energy demands of the world. Moreover, these fossil fuels are the precursors of various chemicals essential for the sustenance of our current lifestyle, as fossil fuels currently have a share of 80% of the energy mixture [4].

Ammonia ( $\text{NH}_3$ ) is one of the most commonly used and produced chemicals globally, with reported worldwide production of over 0.14 billion tonnes [5]. It is produced by natural gas and is extensively used to produce fertilisers, pesticides, textiles, dyes and plastics. It is also used in water treatment and refrigeration [6]. It has been reported that 80% of the ammonia produced worldwide is used for the production of fertilisers; thus, a 1.1% per annum increase in agricultural demands will result in increased requirements for ammonia [7, 8].

Ammonia also has the potential to serve as an important energy carrier since it may curb the emission of greenhouse gases if produced using renewable sources, and its hydrogen content is high, i.e., 17.8 wt%. It was first introduced as an energy vector in 1982 in which the heat rejected from the nuclear power plants was used to power ammonia production [9]. It may be stored as a cryogenic liquid at ambient pressure or a low-pressure liquid at ambient temperature. Countries like the USA already have an ammonia transmission infrastructure for ammonia [10]. Minor modification is needed to recover the stored energy in ammonia by using it as synthetic fuel in engines and turbines without significant modifications [11]. Renewables have been used lately in ammonia production [12-16].

Mari gas is the natural gas extracted from Mari, Sindh, Pakistan, utilised in the production of ammonia which is the raw material for urea production [17]. However, due to high consumption rates in Pakistan, the non-renewable Mari gas reserves are depleting. Thus the fertilizer

industries are forced to look for alternates of Mari gas for ammonia production. Meanwhile, the ‘load shedding’ of Mari gas to the production plants continues, which means that the supply-demand gap is met by planned intermittent outages of gas supply [18]. Alternatives such as Coal Gasification, Biomass Gasification are available to deal with the shortfall of process gas. However, the available alternative is to import regasified LNG (RLNG) and use a mixture of Mari gas and RLNG as the process gas to produce ammonia and urea.

To the best of the authors’ knowledge, no study has been reported that has revamped the ammonia production plant from natural gas using RLNG. The only study which has revamped the ammonia plant from RLNG has performed the switchover from Naphtha, and mixed feed is not utilized [19]. This paper investigates the option of revamping the ammonia production plant to counter the diminishing natural gas supply. The revamp replaces the natural gas feed from a 70-30 mixture of natural gas and RLNG in an Aspen HYSYS® simulation environment. The base case of 100% natural gas is also simulated for comparison. The effect of feed changes on the utilities, flows and equipment is also monitored.

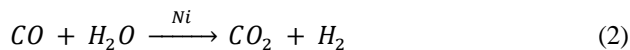
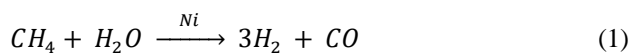
## THEORETICAL SECTION

### Process

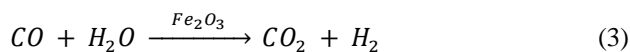
The block diagram of the process is shown in Fig. 1. The reactions of this process have been reported in Ref. [20]. Ammonia preparation plants extract  $\text{H}_2$  from a hydrocarbon in the form of natural gas. As with all ammonia preparation plants,  $\text{N}_2$  is distilled from atmospheric air.

The natural gas is kept at a pressure between 3.7-4.4 MPa, as a pressure of approx. 3.9 MPa is required for the process. It is then preheated and passed through a de-sulphurised, where the sulphur in the natural gas is

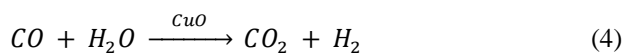
removed. The sulphur-free feed is then introduced in the Primary reformer along with the steam, where methane is reformed as follows:



This highly endothermic reaction uses metallic Nickel as the catalyst in the primary reformer. Then the processed gas from the primary reformer enters a secondary reformer. In the convection zone, compressed, processed air from the atmosphere is heated. In the upper space of the secondary reformer, an air-gas reaction occurs. High gas temperatures are incurred at the bottom and front of the catalyst bed due to air combustion. 950°C is the approximate exit temperature, whereas the reaction, in contact with the catalyst, will occur at approx. 1100–1200°C. The gases exiting the secondary reformer are extremely hot and tend to have a temperature of more than 1000°C. The heat from these gases is then utilised in the production of high-pressure steam, which tends to be of approximately 3.3 MPa pressure. This high-pressure steam is then used to run a high-pressure turbine. Hot gases from the secondary reformer are then cooled down to a temperature of 336 °C after passing them through a waste heat reboiler. The reformed gas from the secondary reformer contains about 11.9% carbon monoxide (CO). This CO is oxidised into CO<sub>2</sub> by reaction with steam, using Iron Oxide as the catalyst already present in the gas.



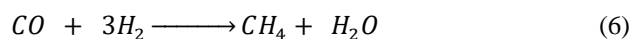
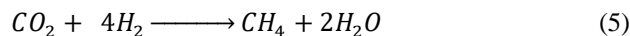
The 430°C gas is cooled to a temperature of 203°C by passing it through the waste heat reboiler. The cooled gas is then fed to Low-Temperature Shift (LTS) Reactor, where it again reacts with steam and CuO is used as the catalyst. After passing through LTS, CO's concentration is lessened to approx. 0.18%.



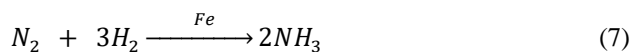
The gas now contains 18.5% CO<sub>2</sub> and 0.18% CO. CO<sub>2</sub> is absorbed by the Benfield Solution, i.e. the Potassium Carbonate Solution. Packed bed absorbers containing Pall Rings absorb CO<sub>2</sub>. Gas injected from the bottom is sprayed with the Benfield Solution from the top. The solution flows down and is called Rich CO<sub>2</sub> solution.

The released gas consists of 0.1% CO<sub>2</sub>, whereas the rich CO<sub>2</sub> solution is passed on to the stripping tower

for regeneration. The CO and CO<sub>2</sub> in the gas are then converted into Methane in the Methanator. The process is an inverse of a reforming process and is an exothermic hydrogenation reaction:



The synthesised gas, after being compressed to a pressure of approx. 24.5 MPa is passed to an axial radial flow converter at a temperature of about 380-520°C for the Haber Bosch process. The gas is passed over Iron (catalyst) [21], and about 33% of the gas is converted into ammonia. The reaction effluent is cooled ammonia, which is liquefied and separated. The unreacted gas is recycled.



### Methodology

This section presents the assumptions, equations and modelling approaches used to conduct this study. The scope of the calculations and design are also included.

### Material balance

Material balance is done to determine the impact of the proposed feed on the plant. The manual calculations were done using a Microsoft Excel® sheet. Material balance was applied to the main units, i.e. reactors, separation columns and the Benfield section. To apply the material balance to the reactors following steps were followed [22]:

1. The material balance was applied on a per-hour basis.
2. A steady-state process was assumed. (Accumulation=0).
3. For the number of substances, kg mol units were used.
4. The conversions were used to find the moles of the reactant of each reaction.

### Energy balance

Energy balance was applied to the ammonia plant using the proposed feed of the LNG-Mari gas mixture. Energy balance on furnace, reactor, compressors and multiple heat exchangers was applied as they are the main units affected by the change in feed. The main equation used in this balance was the law of energy conservation. Values of the required parameters, such as specific heats, were taken from Perry's chemical engineering or Aspen HYSYS® database.

The following assumptions were made for the energy balance of the plant [21]:

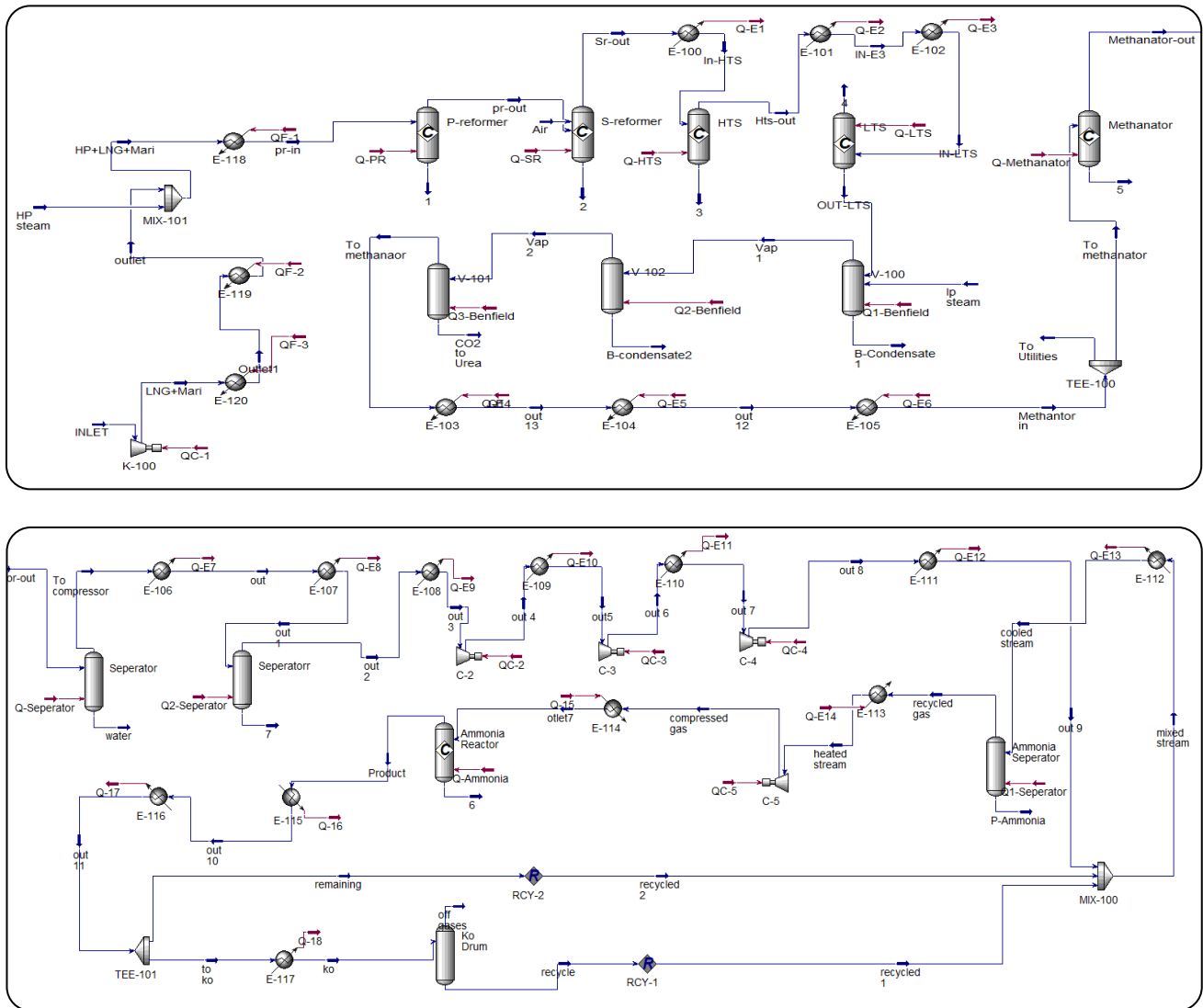


Fig. 2: ASPEN flowsheet for processes with 70% Mari gas and 30% LNG used as feed

1. The process is at a steady state.
2. For the energy balance of a component of a plant involving a reaction, equation  $\Delta H, (W) = \Delta H_P - \Delta H_R + \Delta H_{rxn}$  is used.
3. The molar specific heats ( $C_p$ ) of a mixed stream containing two or more chemical species were assumed to be equivalent to the weighted average of specific heats.
4. The power of the compressor was determined by calculating the work done by the compressor and then dividing it by isentropic efficiency.

**ASPEN simulation**

Two Aspen HYSYS® simulations of the ammonia plant with the existing feed (Mari) and proposed feed (Mari-RLNG) were made. It should be noted that other

simulation software such as Aspen Plus® or Aveva Pro-II® may also be used for simulating these simulations, but Aspen HYSYS® was selected for this study. The fluid package used for this process was Peng-Robinson since it is reasonably accurate near the critical point and applicable to all fluid properties calculations in natural gas processes. Pressure and Temperature conditions are taken from the industry using 100% Mari Gas. The ratio of the mixture was roughly based on the shortfall of the Mari gas. Conversion reactors are being used with the known conversion of all the reactions. The kinetics of reformers and shift reactors are based on the Aspen HYSYS® tutorial [23]. Fig. 2 shows the simulation sheet for the ammonia process using the Mari-RLNG mixture as feed.

**Table 1: Composition of mari gas and mari-RLNG mixture**

| Feeds<br>Components | Existing: Mari Gas (100%) |               | Proposed: Mari Gas (70%) and RLNG (30%) |               |
|---------------------|---------------------------|---------------|---|---------------|
|                     | Moles                     | Mole Fraction | Moles                                   | Mole Fraction |
| Nitrogen            | 337.00                    | 0.170         | 235.85                                  | 0.119         |
| Carbon dioxide      | 149.73                    | 0.075         | 104.52                                  | 0.053         |
| Methane             | 1494.50                   | 0.753         | 1604.68                                 | 0.809         |
| Ethane              | 3.75                      | 0.002         | 29.62                                   | 0.015         |
| Propane             | 0.00                      | 0.000         | 6.50                                    | 0.003         |
| Butane              | 0.00                      | 0.000         | 2.47                                    | 0.001         |
| Total Moles         | 1984.00                   | 1.000         | 1984.00                                 | 1.000         |

**Table 2: Material balance for reformers**

| Components      | Primary Reformer |          | Secondary Reformer |        |          |
|-----------------|------------------|----------|--------------------|--------|----------|
|                 | Mass In          | Mass Out | Mass In            |        | Mass Out |
| Nitrogen        | 1.835            | 1.836    | 1.835              | 9.570  | 11.405   |
| Carbon dioxide  | 1.278            | 9.144    | 9.141              | 0.006  | 9.159    |
| Methane         | 7.151            | 2.002    | 2.002              | 0.000  | 0.163    |
| Ethane          | 0.247            | 0.000    | 0.000              | 0.000  | 0.000    |
| Propane         | 0.080            | 0.000    | 0.000              | 0.000  | 0.000    |
| Butane          | 0.040            | 0.000    | 0.000              | 0.000  | 0.000    |
| Water           | 28.899           | 19.455   | 19.456             | 0.039  | 20.735   |
| Hydrogen        | 0.000            | 2.420    | 2.422              | 0.000  | 2.745    |
| Carbon monoxide | 0.000            | 4.673    | 4.675              | 0.000  | 7.877    |
| Oxygen          | 0.000            | 0.000    | 0.000              | 2.940  | 0.000    |
| Argon           | 0.000            | 0.000    | 0.000              | 0.165  | 0.004    |
| Total [kg/s]    | 39.530           | 39.530   | 39.530             | 12.720 | 52.251   |

## RESULTS AND DISCUSSION

This section presents the observations, inferences and possible explanations for the results. The material, energy balances, and equipment design specifications for the process with the proposed feed were obtained from the Aspen HYSYS® simulation.

### *The mixture of RLNG and Mari gas*

When the mixture of exported RLNG and Mari gas is used, there will be changes in the feed gas composition, as shown in Table 1.

Table 1 shows the compositions of existing and proposed feeds. It can be observed that the number of alkanes has increased in the proposed feed, which is expected to increase the duty and specifications required for the processing of the current feed. The comparison of some reactor specifications, as well as the amount of ammonia produced, are discussed.

### *Material balance using 70% Mari gas and 30% RLNG used as feed*

Material balance for major equipment is shown in Table 2 to Table 4.

It can be observed from Table 2 that the primary reformer is converting 72% of the methane and 33% of water into hydrogen and oxides of carbon. The presence of a small amount of propane and butane in the feed is a drawback, which was not present in the previous feed. They can cause choking in the tubes of the primary reformer as their reforming is favorable at low temperatures. However, the gas mainly consisted of methane, which reforms at very high temperatures. So, a little coking of higher hydrocarbons like propane and butane is possible at this high temperature and cannot be prevented. Nevertheless, the product stream of the primary reformer is free of other alkanes, as shown in Table 2. The secondary reformer then converts 91.85% of the methane and 100% of oxygen (from the air) into hydrogen and oxides

**Table 3: Material balance for HTS and LTS**

| Components        | High-temperature Shift |        | Low-temperature Shift |        |
|-------------------|------------------------|--------|-----------------------|--------|
|                   | In                     | Out    | In                    | Out    |
| Nitrogen          | 11.405                 | 11.405 | 11.405                | 11.405 |
| Carbon dioxide    | 9.159                  | 18.689 | 18.689                | 21.308 |
| Methane           | 0.163                  | 0.163  | 0.163                 | 0.163  |
| Water             | 20.735                 | 16.834 | 16.834                | 15.762 |
| Hydrogen          | 2.745                  | 3.182  | 3.182                 | 3.302  |
| Carbon monoxide   | 7.877                  | 1.812  | 1.812                 | 0.145  |
| Argon             | 0.165                  | 0.165  | 0.165                 | 0.165  |
| Total mass [kg/s] | 52.251                 | 52.251 | 52.251                | 52.251 |

**Table 4: Material balance for methanator and ammonia reactor**

| Components        | Methanator |        | Ammonia Reactor |         |
|-------------------|------------|--------|-----------------|---------|
|                   | In         | Out    | In              | Out     |
| Nitrogen          | 11.281     | 11.281 | 36.791          | 25.937  |
| Carbon dioxide    | 0.097      | 0      | 0               | 0       |
| Methane           | 0.162      | 0.279  | 13.815          | 13.815  |
| Water             | 0          | 0.172  | 0               | 0       |
| Hydrogen          | 3.270      | 3.221  | 54.347          | 52.004  |
| Carbon monoxide   | 0.143      | 0      | 0               | 0       |
| Ammonia           | 0          | 0      | 15.480          | 28.676  |
| Argon             | 0.163      | 0.163  | 7.207           | 7.207   |
| Total mass [kg/s] | 15.116     | 15.116 | 127.640         | 127.639 |

of carbon, as shown in Table 2.

The material balance for the High-Temperature Shift (HTS) reactor is presented in Table 3. It can be observed that 77% carbon monoxide and 19% water have been converted into hydrogen and carbon dioxide in the reactor. shows that the low-temperature shift reactor converts 92 % of the carbon monoxide and 6.3% of water into hydrogen and carbon dioxide. As in the previous equipment, Methane, Nitrogen, or Argon are not involved in any of these reactions.

The material balance for the methanator and ammonia reactor is shown in Table 5. Table 4. A complete conversion of carbon oxides into methane and water is observed in the methanator.

#### **Energy balance using 70% Mari gas and 30% RLNG used as feed**

In reactors, the concentration of reactant converting into products increases, which further increases the reactor

duties. In addition, the duties of heat exchangers and compressors are also increased due to an increase in the mass flow rates of individual components, as shown in Table 5.

#### **Impact of mixture of RLNG and Mari gas on equipment**

The change in specification of reactors by using RLNG and Mari Gas mixture is discussed in this section since the compositions of both feeds were different from each other, as mentioned in Table 1. Reactors undergo significant modification when the proposed feed is being used. So, the change in the specification of reactors is given below.

#### **Reformers**

By comparing the design calculation, we can see the impact of feed on primary reformer specifications. Duty is calculated from energy balance; as the duty is increased, the catalyst weight and the reactor volume are also increased for the reforming reaction, as shown in Table 6. Moreover, the number of tubes of the primary reformer is also increased.

**Table 5: Energy balance for mari gas and RLNG used as feed by ASPEN HYSYS**

|               |           |           |             |              |             |
|---------------|-----------|-----------|-------------|--------------|-------------|
| Name          | Q-PR      | Q-SR      | Q-E1        | Q-HTS        | Q-E2        |
| Heat Flow [W] | 9.94E+07  | 8.56E+06  | 7.14E+07    | -1.29E+06    | 1.19E+07    |
| Name          | Q-E3      | Q-LTS     | Q1-Benfield | Q2-Benfield  | Q3-Benfield |
| Heat Flow [W] | 1.46E+07  | -7.19E+05 | -5.50E+07   | -1.15E+07    | -2.48E+07   |
| Name          | Q1        | Q-E5      | Q-E6        | Q-Methanator | Q-Sep       |
| Heat Flow [W] | 6.00E+06  | 6.00E+06  | 6.08E+06    | -4.75E+05    | 2.325       |
| Name          | Q-E7      | Q-E8      | Q2-Sep      | Q-E9         | QC-2        |
| Heat Flow [W] | 1.27E+07  | 4.25E+06  | -4.72E+06   | -4.17E+06    | 6.11E+06    |
| Name          | Q-E10     | QC-3      | Q-E11       | QC-4         | Q-E12       |
| Heat Flow [W] | 3.86E+06  | 3.58E+06  | 4.25E+06    | 7.72E+06     | 7.75E+06    |
| Name          | Q-E13     | Q1-Sep    | Q-E14       | QC-5         | Q-15        |
| Heat Flow [W] | 3.67E+07  | 0         | 4.03E+07    | 5.11E+06     | 1.14E+08    |
| Name          | Q-Ammonia | Q-16      | Q-17        | Q-18         | Q-E4        |
| Heat Flow [W] | -2.60E+06 | 2.73E+05  | 1.74E+08    | 2.58E+05     | 1.49E+07    |

**Table 6: Specification of primary and secondary reformers**

| Specifications                       | Primary reformer |          | Secondary reformer |          |
|--------------------------------------|------------------|----------|--------------------|----------|
|                                      | Existing         | Proposed | Existing           | Proposed |
| Internal Dia of the tube (m)         | 0.113            | 0.113    | 3                  | 3        |
| Length of tube (m)                   | 11               | 11       | 6.19               | 6.87     |
| Volume of Catalyst (m <sup>3</sup> ) | 27.6             | 31.8     | 28.4               | 30.43    |
| Volume of reactor (m <sup>3</sup> )  | 31.8             | 36.6     | 43.76              | 48.684   |
| Voidage                              | 0.131            | 0.131    | 0.25               | 0.25     |
| Weight of Catalyst (kg)              | 26,543           | 30,846   | 29,580             | 32,568   |

**Table 7: Specification of high- and Low-temperature shift reactors**

| Specifications                       | High-Temperature Shift (370-429 °C) |          | Low-Temperature Shift (203-217 °C) |          |
|--------------------------------------|-------------------------------------|----------|------------------------------------|----------|
|                                      | Existing                            | Proposed | Existing                           | Proposed |
| Internal Dia of the tube (m)         | 4.3                                 | 4.3      | 4.3                                | 4.3      |
| Length of tube (m)                   | 5.8                                 | 6.09     | 7                                  | 7.64     |
| Volume of Catalyst (m <sup>3</sup> ) | 61                                  | 64.4     | 82                                 | 86.12    |
| Volume of reactor (m <sup>3</sup> )  | 84                                  | 87.22    | 102.5                              | 111      |
| Voidage                              | 0.04                                | 0.04     | 0.036                              | 0.036    |
| Weight of Catalyst (kg)              | 64,050                              | 66,829   | 86,920                             | 91,288   |

Due to the change in feed, the outlet of the primary reformer is changed, which is the inlet of the secondary reformer. As a result, more methane is converted into hydrogen for the reforming reaction. Therefore, the volumes of the reactor and catalyst have also been increased to get the desirable conversion.

#### Shift reactors

The amount of carbon monoxide to convert into carbon dioxide is increased for the proposed feed compared

to the previous feed. Therefore, the amount of catalyst also increased to undergo the reaction at the given conversions. In this way, the volume of reactors has also increased, as shown in Table 7.

#### Methanator and ammonia reactor

Compared to the previous feed, the amounts of carbon dioxide and carbon monoxide that need to be removed from the methanator are increased. Moreover, the amount of hydrogen and nitrogen is also increased, as presented in Table 8

**Table 8: Specification of methanator and ammonia reactors**

| Specifications                       | Methanator |          | Low-Temperature Shift |          |
|--------------------------------------|------------|----------|-----------------------|----------|
|                                      | Existing   | Proposed | Existing              | Proposed |
| Internal Dia of tube (m)             | 3.5        | 3.5      | 3.5                   | 3.5      |
| Length of tube (m)                   | 8.1        | 8.54     | 5.9                   | 6.29     |
| Volume of Catalyst (m <sup>3</sup> ) | 62         | 65.71    | 23.8                  | 25.2     |
| Volume of reactor (m <sup>3</sup> )  | 78         | 82.12    | 57.24                 | 60.54    |
| Voidage                              | 0.04       | 0.04     | 0.5                   | 0.5      |
| Weight of Catalyst (kg)              | 58,900     | 62,426   | 30,225                | 31,536   |

**Table 9: Utility requirements**

| uty (W)                          | 100% Mari Gas         | 70% mari gas and 30% RLNG | Change  |
|----------------------------------|-----------------------|---------------------------|---------|
| E-100 (After Secondary Reformer) | 6.83x10 <sup>7</sup>  | 7.14 x10 <sup>7</sup>     | +4.47%  |
| E- 102 (After LTS)               | 1.00 x10 <sup>7</sup> | 1.46 x10 <sup>7</sup>     | +45.55% |
| E- 106 (After Methanator)        | 1.10 x10 <sup>7</sup> | 1.27 x10 <sup>7</sup>     | +14.86% |

**Table 10: Product composition**

| Components  | 100% Mari Gas | 70% Mari Gas and 30% RLNG | Change   |
|-------------|---------------|---------------------------|----------|
|             | Moles         | Moles                     |          |
| Nitrogen    | 6.03          | 1.17                      | -80.60%  |
| Methane     | 17.18         | 13.57                     | -21.01%  |
| Water       | 0             | 0                         | -        |
| Hydrogen    | 14.77         | 41.93                     | +183.89% |
| Ammonia     | 2567          | 2712                      | +5.65%   |
| Argon       | 2.99          | 4.27                      | +42.81%  |
| Total Moles | 2607.97       | 2774.44                   | 6.38%    |

Thus, the catalyst weight in these reactors has also increased to achieve the required conversions in a specific time. In this way, the volumes of catalysts have increased.

#### Utility requirements

By using the proposed feed, utility requirements are increased, such as heat duties, steam requirement, and the power requirement of compressors, the flow rates of cooling water and Boiler Feed Water (BFW) are also increased because the mass flow rate in total feed is increased. Table 9 compares the duties of some heat exchangers for Mari Gas and Mari gas mixture used as feed.

#### Impact on product and other streams

As shown in Table 10 the amount of ammonia produced from Mari gas and RLNG mixture is more than the previous feed. Methane is the primary source of hydrogen. The increased amount of methane in the changed feed results in increased hydrogen and ammonia production

compared to 100% Mari gas feed. It was shown that more ammonia is being produced as compared to 100% Mari Gas because of the higher content of methane in the proposed feed.

Table 11 compares the major streams like hydrogen, ammonia, and urea for both feed streams. The change in feed has increased the throughput of all important streams. This is because of the increased amount of methane in the proposed feed.

#### CONCLUSIONS

Ammonia is one of the most important chemicals for industrial growth and a sustainable future. However, the precursor of ammonia, i.e., natural gas, is depleting. This study proposes a temporary solution to maintain the throughput by mixing regasified LNG (RLNG) with natural gas and using it as feed for ammonia production. Aspen HYSYS simulation for the existing and proposed feeds was developed.



Table 11: Major streams

| Feed (Process Gas)                | 100% Mari Gas | 70% Mari Gas and 30% RLNG | Change  |
|-----------------------------------|---------------|---------------------------|---------|
| H <sub>2</sub> produced(kgmol/s)  | 0.996         | 1.201                     | +20.65% |
| NH <sub>3</sub> produced(kgmol/s) | 0.724         | 0.757                     | +4.53%  |
| Urea produced (kgmol/s)           | 0.355         | 0.371                     | +4.54%  |

Results show that change in the feed will require modification in the equipment and utility section. The modified feed contains more alkanes than the existing feed; thus, the exchanger duties and reactor volumes are increased. Moreover, a small amount of choking is also possible in the primary reformer only due to the presence of propane and butane. All the streams have higher throughput, thus requiring plant modifications. However, the advantage of this modification is an increase in the throughput of important by-products along with ammonia, i.e. +20.65% hydrogen production and +4.53% ammonia and urea production. Moreover, the proposed feed will also result in a 30% relief in Mari Gas requirement, thus extending the life of Mari gas field. This case study is directly applicable to the Mari Gas Field and can be extended to other gas fields using the steps followed in this study.

Although this study provides the initial feasibility for the Mari-RLNG feed, more work may be done to explore its feasibility further and find the optimum solution for the problem presented in this study. For example, a detailed techno-economic analysis [24, 25] or life cycle analysis [26] may be carried out to find out the internal rate of return (IRR) and payback period of the proposed study. The optimum feed flow rate and Mari-RLNG ratio may be investigated to minimise the equipment changes or maximise profits [27, 28]. Sensitivity analysis of different parameters and components may be carried out to develop correlations that estimate the optimum RLNG-Natural gas ratio for any natural gas under consideration.

### Nomenclature

Abbreviations:

|                 |                        |
|-----------------|------------------------|
| BFW             | Boiler Feed Water      |
| GDP             | Gross Domestic Product |
| HTS             | High-Temperature Shift |
| LNG             | Liquefied Natural Gas  |
| LTS             | Low-Temperature Shift  |
| RLNG            | Regasified LNG         |
| Symbols:        |                        |
| CH <sub>4</sub> | Methane                |
| CO              | Carbon Monoxide        |

|                                |                                 |
|--------------------------------|---------------------------------|
| CO <sub>2</sub>                | Carbon Dioxide                  |
| C <sub>p</sub>                 | Molar specific heat             |
| CuO                            | Copper (II) Oxide               |
| Fe                             | Iron                            |
| Fe <sub>2</sub> O <sub>3</sub> | Iron (III) Oxide                |
| H <sub>2</sub>                 | Hydrogen                        |
| H <sub>2</sub> O               | Water                           |
| N <sub>2</sub>                 | Nitrogen                        |
| NH <sub>3</sub>                | Ammonia                         |
| Ni                             | Nickel                          |
| P                              | Power of the compressor         |
| Q                              | Heat Transferred                |
| T                              | Temperature                     |
| x <sub>i</sub>                 | Mole fraction of component i    |
| W <sub>s</sub>                 | Shaft Work                      |
| W <sub>fl</sub>                | Flow Work                       |
| ΔE <sub>k</sub>                | Kinetic Energy                  |
| ΔE <sub>p</sub>                | Potential Energy                |
| ΔH <sub>p</sub>                | Enthalpy of the product stream  |
| ΔH <sub>R</sub>                | Enthalpy of the reactant stream |
| ΔH <sub>r</sub>                | Heat Duty of the Reactor        |
| ΔH <sub>rxn</sub>              | Heat of reaction                |
| ΔH <sub>T</sub>                | Enthalpy of each stream         |
| ΔU                             | Internal Energy                 |

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### REFERENCES

- [1] "The Facts About Ammonia (Technical Information)," New York State Department of Health, Accessed on: 21st May (2021).
- [2] "World Population Prospects: Key Findings and Advance Tables. the 2017 Revision," United Nations, Accessed on: (2018).
- [3] "BP Energy Outlook: 2018 Edition," 2018, Accessed on: 01 March (2019).
- [4] Shell R.D., "Shell Energy Transition Report," in The Hague, (2018).
- [5] "Nitrogen—Statistics and information", United States Geological Survey 2020.

- [6] "Population Estimates and Projections", World Bank, Accessed on: 21 May (2021).
- [7] Appl M., "Ammonia: Principles & Industrial Practice", John Wiley & Sons Inc. (1999).
- [8] Alexandratos N., Bruinsma J., "World Agriculture Towards 2030/2050: The 2012 Revision" (2012).
- [9] Green Jr L., An Ammonia Energy Vector for the Hydrogen Economy, *International Journal of Hydrogen Energy*, **7(4)**: 355-359 (1982).
- [10] Morgan E.R., Manwell J.F., McGowan J.G., Sustainable Ammonia Production from US Offshore Wind Farms: A Techno-Economic Review, *ACS Sustainable Chemistry Engineering*, **5(11)**: 9554-9567 (2017).
- [11] Morgan E., Manwell J., McGowan J., Wind-Powered Ammonia Fuel Production for Remote Islands: A Case Study, *Renewable Energy* **72**: 51-61 (2014).
- [12] Wang G., Mitsos A., Marquardt W., Conceptual Design of Ammonia-Based Energy Storage System: System Design and Time-Invariant Performance, *AIChE Journal*, **63(5)**:1620-1637 (2017).
- [13] Gençer E., Al-Musleh E., Mallapragada D.S., Agrawal R., Uninterrupted Renewable Power through Chemical Storage Cycles, *Current Opinion in Chemical Engineering*, **5**: 29-36 (2014).
- [14] Lan R., Irvine J.T., Tao S., Ammonia and Related Chemicals as Potential Indirect Hydrogen Storage Materials, *International Journal of Hydrogen Energy*, **37(2)**:1482-1494 (2012).
- [15] Miura D., Tezuka T., A Comparative Study of Ammonia Energy Systems as a Future Energy Carrier, with Particular Reference to Vehicle Use in Japan, *Energy*, **68**: 428-436 (2014).
- [16] Preuster P., Alekseev A., Wasserscheid P., Hydrogen Storage Technologies for Future Energy Systems, *Annual Review of Chemical Biomolecular Engineering*, **8**: 445-471 (2017).
- [17] Mumtaz Y., Ur Rehman A., Junaid Shaikh M., "Simulation Model for Optimization of Gas Production System Through Integration of Sub-Surface and Surface Facilities", in *Abu Dhabi International Petroleum Exhibition & Conference*, Society of Petroleum Engineers (2018).
- [18] Kazmi H., Mehmood F., Tao Z., Riaz Z., Driesen J., Electricity Load-Shedding in Pakistan: Unintended Consequences, Opportunities and Policy Recommendations, *Energy Policy*, **128**: 411-417 (2019).
- [19] Sunny A., Soloman P., "Revamping of Ammonia Plant with R-LNG and Simulation of Syngas Production Using Aspen HYSYS". *Proceedings of International Conference on Gas, Oil and Petroleum Engineering* (2016).
- [20] "Operating Manual for 1200 MTPD Ammonia Plant (PROJ-PM-008)", M.W. Kellogg Ltd. (2005).
- [21] Oudi A.H., Irankhah A., Screening of Important Factors Affecting the Process of Ammonia Synthesis by Plackett-Burman Method and Process Optimization with RSM. *Iranian Journal of Chemical Engineering (IJCCE)*, **19(2)**: 3-20 (2022).
- [22] Felder R. M., Rousseau R.W., Bullard L.G., "Elementary Principles of Chemical Processes." John Wiley & Sons, Inc. (2020).
- [23] "Tutorials and Applications: HYSYS 3.0," Hyprotech Ltd. (2002).
- [24] Hoseinzadeh S., Ghasemi M.H., Heyns S., Application of Hybrid Systems in Solution of Low Power Generation at Hot Seasons for Micro Hydro Systems, *Renewable Energy*, **160**: 323-332 (2020).
- [25] Tjahjono T., Ehyaei M.A., Ahmadi A., Hoseinzadeh S., Memon S., Thermo-Economic Analysis on Integrated CO<sub>2</sub>, Organic Rankine Cycles, and NaClO Plant Using Liquefied Natural Gas, *Energies*, **14(10)**: 2849 (2021).
- [26] Hoseinzadeh S. Heyns P. S., Thermo-Structural Fatigue and Lifetime Analysis of a Heat Exchanger as a Feedwater Heater in Power Plant, *Journal of Engineering Failure Analysis*, **113**:104548 (2020).
- [27] Sohani A., et al., Techno-Energy-Enviro-Economic Multi-Objective Optimization to Determine the Best Operating Conditions for Preparing Toluene in an Industrial Setup, *Journal of Cleaner Production*, **313**: 127887 (2021).
- [28] Mahmoudan A., Samadof P., Hosseinzadeh S., Garcia D.A., A Multigeneration Cascade System Using Ground-Source Energy with Cold Recovery: 3E Analyses and Multi-Objective Optimization, *Energy*, **233**: 121185 (2021).