Design project
Design proposal

Group 6

Jiajie SUN (20125123)
Yu'ang GUO (20126326)
Yukun WANG (20126873)
Huanyu CHEN (20126514)
Jiaxu LYU (20126937)
Lisha WEI (20126940)
Zhiyu CHAI (20126306)

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1. Introduction

With the growing methacrylic acid monomer market, the current demand is increasing by 6-8% every year. Lucite currently produces methacrylate monomers in its UK factories and around the world. To ensure that the needs of northern Europe can be met in the future, Lucite invests in the factory to produce the feedstock of methacrylic acid. The goal of the company is to consolidate and focus on acrylate production at the Kassel plant, which was founded in the 1920s and is now owned and operated by Lucite. As part of this investment, which is proposed to replace the existing aging HCN (hydrogen cyanide) and AMS (ammonium sulfate) plants on-site with a new plant and related storage facilities to supply hydrogen cyanide as raw material for the production of methacrylic acid. The proposal provides a fixed price lump sum for this design, supply, installation, and commissioning of the new HCN plants and AMS replacement plants. Worksite located at Cassel Works, New Road, Billingham, TS23 1LE. The proposed design for the HCN production utilizes the Andrussow process. It is the most extensive method is to mix preheated ammonia, oxygen, and methane at appropriate temperature and pressure and in the presence of an appropriate metal-based catalyst and react to produce a mixed gas of hydrogen cyanide and water vapor. The proposed hydrogen cyanide plant and AMS replacement plant is a cost-effective plant that can meet the objectives of all customers without compromising the safety of people and the environment in and around the plant. The plan will explain how to meet the customer's objectives and how the plant is safe, environmentally friendly, and cost-effective.

2. Plant duty

The plant can produce 764 to 6673 kg/h of hydrogen cyanide. The purity is up to 99.5 % with the remaining 0.5% of water. Meanwhile, 7776 to 67943 kg/h of steam and 297 to 2441 kg/h of AMS crystal are obtained as a by-product. The purity of AMS crystal is up to 99.8% with the remaining 0.2% of water. Steam and AMS crystal can be sold to increase the profit of the plant. The specific data for project products and by-products have been shown in the below table.

Table 1. Data for the product and by-product

Product and by-product	Maximum Prodction (kg/h)	Minimum Production (kg/h)	Purification (%)	Pressure (Barg)	Temperature (ºC)
Hydrogen cyanide	6673	764	99.5	0.95	5
Steam	67943	7776	100	20	210
AMS Crystal	2441	297	99.8	1	60

Moreover, Natural gas, Air, Ammonia, Process water, Coolant (LM4), and Sulfuric acid are used. To get high purification of Methane as raw material for the HCN production, purification of natural gas is proposed. More information will be included in the process description. The specific data will show in the below table as utilities used.

Table 2. Utilities used

Utilities used	Maximum usage (kg/h)	Minimum usage (kg/h)	Mass fraction (%)	Pressure (Bar)	Temperature (°C)
Natural gas	6161	705	100	52	25
Ammonia	5034	567	100	20	25
Air	153439	17562	100	1	25
Sulfuric acid	2190	251	98	1	25
Process water	84049	9620	100	1	5
Coolant (LM4)	278102	31831	35	1.5	25
Cooling water	356443	40798	100	1	25
Hydrogen peroxide	161	18	32	1.2	25

3. Process description

3.1 Pre-treatment of Natural gas

The raw material of the natural gas with a pressure of 52 bar and a temperature of 25 degrees. The Andrussow process with high requirement for the purity of methane, therefore, the natural gas should be processed to increase the purity of methane. Flowing processes are used,
The first step is the natural gas with a temperature of 25 ℃ and pressure of 52barg can exchange heat with the treated methane after heat exchange (HE-001).
In the second step, after the heat exchanger HE-001, the natural gas temperature drops to -42 degrees and the pressure is 52 bar.
The third step is natural gas with a temperature of -42 degrees and a pressure of 52 bar entering the turbine and promotes the turbine to work and generate electricity. The natural gas pressure is reduced to 1.5 bar and the temperature is reduced to -146 degrees. Natural gas becomes a gas-liquid mixture.
The principle of this stage is flowing the equation.

$$PV = NRT$$

P is the pressure,

V is the volume
N is the molar
R is the constant
T is the temperature

When the pressure decreased, the temperature also decreased. To separate gas-liquid mixed natural gas, the flash column is used.
The fourth step, gas-liquid separation is carried out in FC-001. The top product is high purity of methane, and the top product temperature is -146 degrees. After heat exchange between high-purity methane at -146 degrees and imported high-pressure and normal temperature of natural gas, and then, the temperature rises to -47 degrees.
Fifth step, the high purity of methane is transported to HE-002 for heat exchange with the coolant, and the temperature rises to zero. In addition, the bottom product temperature of FC-001 is -146 degrees and the pressure is 1.5 bar.
Finally, the bottom product is transported to HE-003B for heat exchange with the coolant. After the heat exchange, the temperature of the bottom product changes to 0 degrees with pressure is 1.5 bar. The detailed component of the products of FC-001 has been included in the following table.

Table 3. FC-001 product

Component	**Top Maximum Product (kg/h)**	**Top Minimum Product (kg/h)**	**Mass fraction (%)**	**Bottom Maximum Product (kg/h)**	**Bottom Minimum Product (kg/h)**	**Mass fraction (%)**
Methane	5045.119	577.453	92.095	162.722	18.625	23.828
Ethane	28.393	3.250	0.518	291.028	33.310	42.616
Propane	0.143	0.016	0.003	91.992	10.529	13.471
Butane	0	0	0	59.695	6.833	8.741
Carbon dioxide	43.244	4.950	0.789	77.000	8.813	11.275
Nitrogen	361.250	41.348	6.594	0.476	0.054	0.070
Temperature (^oC)	-146		None	-146		None
Pressure (Bar)	1.5		None	1.5		None

3.2 Pre-treatment of Ammonia

Liquid ammonia with a pressure of 20 bar and a temperature of 25 degrees is provided for the production of hydrogen cyanide. This reaction requires gaseous ammonium. Therefore, to get ammonia, the following steps are used.
The first step is to reduce the pressure of liquid ammonia at high pressure and normal temperature through the expansion valve. In the process of reducing the strong pressure to 2.5 bar, the temperature will also be gradually reduced to - 25 degrees.
The second step is to pass 2.5 bar and - 25 ℃ ammonia into BL-001
heat exchange with the coolant until the ammonia pressure drops to 1 bar and the temperature increases to 0 degrees.

3.3 Pre-treatment of Process water

The process water is treated for steam generation. Free ions and dissolved oxygen in the process water will lead to corrosion of the water system, waste heat boiler, and pipeline when they are used to produce steam or other processes, which will affect the production of steam and cause damage to equipment or pipeline. The following steps are used for water treatment,
In the first step, fast sand filter (included in the WT-001) is used to filter particles.
The second step is ion exchange (included in the WT-001). The filtered water is transported to the ion exchanger to remove the free ions. The material used for ion exchange is resin, which can adsorb cations or anions and release hydrogen ions or hydroxyl ions. In addition, hydrogen chloride solution and sodium hydroxide solution are used to provide hydrogen ions and hydroxyl ions, respectively. After treatment, part of the water will be stored in T-001 and used for sulfuric acid dilution and absorption of Hydrogen cyanide. Some of the water is transported to ED-001.
In the third step, in ED-001, 5 bar and 152 degrees of steam are utilized to remove dissolved oxygen from water. Dissolved oxygen is released into the atmosphere with water vapor. The water will be used in the steam generation after the deaeration process. This process of the process water treatment is capable of dealing with a large amount of water, the data on water production has been included in the below table,

Table 4. The data of treated water

Treated water	**Maximum production (kg/h)**	**Minimum production (kg/h)**	**Temperature, ºC**	**Pressure, bar**
After WT-001	76484.8	8754.3	5	0
After ED-001	85416.1	9776.5	99.5	0

3.4 Main Synthesis process

HCN is synthesized via the Andrussow process. The raw materials, methane, ammonia, and air are premixed in the initial section of the reactor R-001 which is narrower, as shown in the figure below. In the narrower section, a flow distorting device is added to enhance mixing, in the trapezoidal section, a flow distributor is added to distribute the flow more evenly, in the wider cylindrical section, another flow distributor is added on the left side to further evenly spread the flow across the cross-section. The catalyst is a 1.2 mm thick gauze consisting of 48 layers of platinum nets. The platinum nets consist of platinum wires with a diameter of 0.0025cm spaced at 0.03cm as prescribed by the paper: Modeling catalytic gauze reactors: HCN Synthesis (N. Waletzko, L. D. Schmidt,1988)
The synthesis process is exothermic at circa 1100 C° and self-sustaining. The reactor is to be integrated with the waste heat boiler, meaning no additional pipeline between them is required. The output is a mixture of H_2, HCN, N_2, residual NH_3, etc.

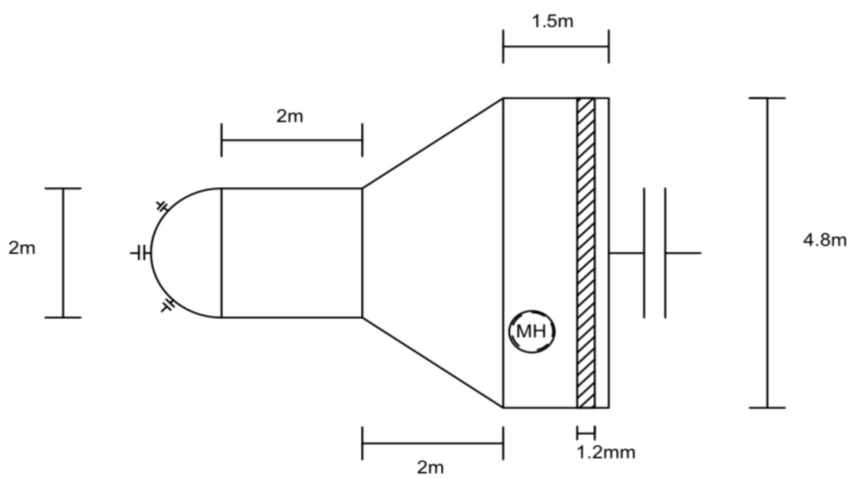

Figure 1. The reactor R-001, the inlet is on the left, the outlet is on the right, the outlet is to be integrated with the main boiler

3.5 AMS solution treatment

One of the by-products is the AMS solution, to get a high concentration of AMS crystal, the AMS solution was processed. Thus, AMS can be sold.
Ammonium sulfate is generated in an ammonia absorption tower (A-001) with a small amount of sulfuric acid and hydrogen cyanide. To obtain ammonium sulfate crystallization, the following steps are used.
The first step is to add a small amount of ammonia to MT-002 to remove the excess sulfuric acid from the ammonium sulfate solution. The principle of the first step is based on the following reactions:

In the second step, the ammonium sulfate solution is transported to EV-001. The ammonium sulfate crystallizes under the conditions of a pressure of 0.8 bar and a temperature of 80 degrees. Steam is used to provide the heat (HE-008) to heat the ammonium sulfate solution to 80 degrees to make the ammonium sulfate solution supersaturated. The steam containing hydrogen cyanide is discharged to ensure that the pressure reaches 0.8 bar. The wastewater containing hydrogen cyanide will be transported to MT-003 for treatment and meet the discharge standard.
The third step is to exchange heat with the air through the heat exchanger (HE-009), reduce the temperature of ammonium sulfate slurry to 50 degrees, and then transport it to the centrifuge (CT-001) for separation of ammonium sulfate slurry. After separation, the saturated ammonium sulfate solution is recycled to EV-001.
The fourth step is to transport the separated ammonium sulfate solid to D-001 for drying. After the air is heated in the HE-009, hot air and cold air are introduced into D-001 in the ratio of 2:1 to remove excess water in ammonium sulfate crystallization and improve the purity of ammonium sulfate crystallization.
Finally, the ammonium sulfate crystal with a purity of 99.8% was obtained.

3.6 Tail gas treatment

To meet the clients' requirements and the environmental consideration, the tail gas will be treated.
Firstly, waste gases come from the A-002 and that will be transported to the F-001 to reburn, the component of the waste gases from the A-002 is shown below table,

Table 5. Waste gases from the A-002

Component	Maximum production (kg/h)	Minimum production (kg/h)
Methane	0.047	0.005
Carbon dioxide	93.147	10.661
Nitrogen	51726.515	5920.505
Oxygen	70.904	8.116
Hydrogen cyanide	8.692	0.995
Carbon monoxide	2074.008	237.386
Hydrogen	17.732	2.030
Nitric Oxide	32.475	3.717
Pressure, bar	1	1
Temperature, ^{o}C	38	38

The waste gases contain the flammable gas of hydrogen, methane, and carbon monoxide. Furthermore, Nitric oxide is a toxic and corrosive material. To treat the waste gases, which will be introduced to the furnace (F-001).

Second, in the F-001, the waste gases have been oxidized. The principle of this stage,

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

The methane reacts with oxygen, after that carbon dioxide and water are produced.

$$2CO + O_2 \xrightarrow{\Delta} 2CO_2$$

The carbon dioxide is produced, and the concentration of carbon monoxide decreases.

$$H_2 + O_2 \rightarrow H_2O$$

Hydrogen reacts with oxygen, and then, the water is produced.

$$NO + O_2 \xrightarrow{\Delta} NO_2$$

The nitric oxide will react with oxygen, and then, the nitric dioxide will be produced.

The component of waste gases from the F-001 is shown,

Table 6. Waste gases

Component	**Maximum production (kg/h)**	**Minimum production (kg/h)**
Carbon dioxide	4973.498	569.256
Nitrogen	11446.776	1310.173
Vapor	1216.580	139.247
Nitric dioxide	49.794	5.699
Pressure, bar	0.8	0.8
Temperature, ^oC	153	153

The hazardous materials have been treated. The treated waste gases with high temperature, are transported to the chimney (CN-001), and then, waste gases will be released into the atmosphere.

3.7 Wastewater treatment

Streams 158 and 141 containing hydrogen cyanide wastewaters are transported to mt-003 for treatment. Hydrogen cyanide considered is toxic and flammable (a detailed risk assessment of materials used has been included in HAZID), thus, hydrogen peroxide is used to oxidize hydrogen cyanide in wastewater. The principle of this step is:
Firstly, hydrogen cyanide will react with hydrogen peroxide, and then, the cyanic acid and water will be produced as follows,

$$HCN + H_2O_2 \rightarrow HOCN + H_2O$$

Second, the cyanic acid will react with water, and then, the ammonia and carbon dioxide will be produced as follows,

$$HOCN + H_2O \rightarrow NH_3 + CO_2$$

Therefore, the total chemical reaction is as follows,

$$HCN + H_2O_2 \rightarrow NH_3 + CO_2$$

After the MT-003, the treated wastewater will be transported to the wastewater treatment plant for further treatment.

4. Health and Safety Analysis

Health and safety analysis is the most important assessment for the project establishment. And, the health and safety of employees, contractors, the factory, and the public must be considered, and risk assessment must be completed in the design project.

Inherent safety has been practiced ensuring that safety is the most important aspect. The factory adopts inherent safety principles such as minimization, substitution, and prevention, to ensure the safety of the factory. For example, hydrogen cyanide will be generated in the plant's production process. To avoid leakage, the pressure of hydrogen cyanide gas is negative pressure during transportation. And hydrogen cyanide is contained in wastewater. Hydrogen peroxide will also be used to oxidize hydrogen cyanide to reduce the concentration of hydrogen cyanide and meet the discharge standard. More information on hazard assessment will be presented in Hazard Operability (HAZOP) and Hazard Identification (HAZID).
The HAZID and HAZOP studies for the project of hydrogen cyanide and AMS plant replacement have been carried out. HAZID and HAZOP workbooks are used to identify the potential hazards associated with the project and determine the consequences that link to the potential hazards. Moreover, the mitigation methods that relied on the consequences have been proposed.

The health and safety analysis includes the basic process control system (BPCS), safety instrumented system (SIS), alarm system, and the system of emergency shut down.

5. Environmental analysis

The environmental analysis of the plant has been completed to assess whether the project is suitable and environmental-friendly. The selected site locates in an industrial zoning which has been used for chemical industries since 1917. The ground foundation under the site is soft, which means that pre-treatment for the ground is needed before construction. The climate here is typical temperate marine climate. Thus, there will be high percentage of rainy day and relatively low temperature difference, which is not conductive to pollution diffusion. There is no flooding risk in the site, but the potential flooding area is quite close to the site. Both exhaust gas and wastewater are well treated in the designed project, producing very low environmental burden (Atmospheric acidification burden per unit value added 0.000013 te/£, Global warming burden per unit value added 0.002588 te/£, Photochemical ozone burden per unit value added 0.00000052 te/£, Ecotoxicity to aquatic life per unit value added 0.0000028 te/£, Eutrophication per unit value added 0.0000038 te/£). All emissions fulfil the regulatory emission standard (Environmental Permitting (England & Wales) Regulations 2016).

6. Economic analysis

The economic analysis of the plant has been determined to ensure that the project is cost-effective. When HCN is sold at £550 per ton, the cumulative cash flow of the project is always negative for the effective operating life of the project (24 years), whereas when HCN is sold at £630 per ton, the IRR value of the project is 8.2%, which means this is an acceptable minimum price. When the price of HCN is raised to £850 per ton, the whole plant can break even in 5.6 years and the IRR reaches 26.93%, which means it is a good project.

Table 8. Economic summary for full production

Economic Indicator	**Cost (£)**
Fixed Capital Cost	42.4 million
Working Capital Cost	7.5 million
Total Capital Investment	49.8 million
Total Operating Cost	41.6 million/year
Total Revenue	60.5 million/year
Profit (Full production)	18.9 million/year
Payback Period	5.6 years
Net Present Value (NPV)	167 million
IRR	26.93 %

In the process of economic analysis, sensitivity analysis is also considered. With the operation of the plant, the process level will decline and due to the international economic fluctuations, the price of products, raw materials, and utility will vary to varying degrees. So, after combining these conditions, the payback period for the entire factory is 7.5 years.