Urea Production from Air and Natural Gas

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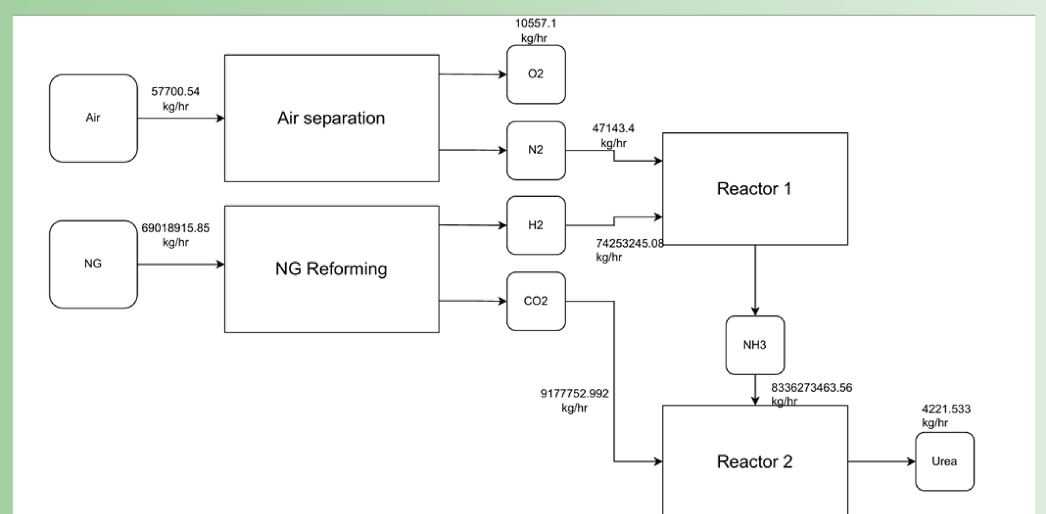
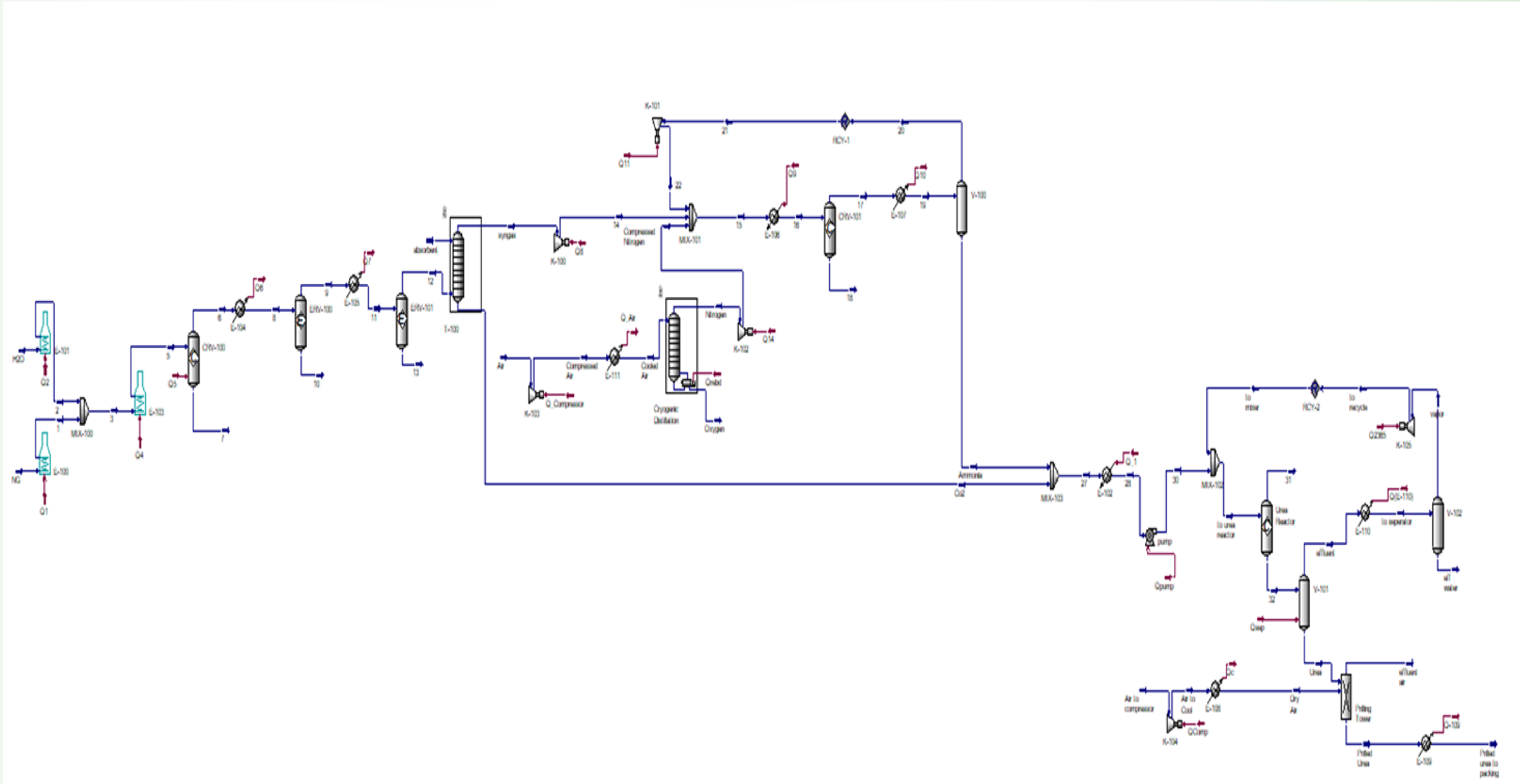
Abstract:

Urea plays a crucial industrial role across various sectors. In agriculture, it serves as a primary component of fertilizers, providing essential nitrogen for plant growth. Additionally, urea is utilized in skincare products as a moisturizing agent due to its water-retaining properties, which help keep skin hydrated. Its significance spans agriculture, biology, and skincare, underscoring its multifaceted importance. Conversely, carbon dioxide (CO_2) is a major contributor to environmental damage, primarily through its role in climate change. Excessive CO_2 emissions, largely from burning fossil fuels, trap heat in the Earth's atmosphere, leading to global warming and its associated impacts. Our project aims to mitigate this by consuming CO_2 instead of releasing it into the environment, adapting the dry reforming process to produce hydrogen. Urea production is described in four steps: air separation to isolate nitrogen and oxygen, natural gas reforming to produce hydrogen and CO_2, ammonia production via the reaction of hydrogen with nitrogen, and finally, urea production through the reaction of ammonia with CO_2. These methodologies are reviewed and detailed in the report, with a material balance completed using a common method to produce 4167 metric kg/h. The project includes detailed design and sizing, accompanied by an economic evaluation. The estimated net present value (NPV) at the end of the project's life is 1613.368 million dollars, indicating a substantial positive return. The discounted rate of return on investment (ROI) is calculated at 51.089%, and the discounted payback period is 1.957 years, following a 2-year construction phase. In terms of equipment costs, the highest investment is allocated to the ammonia synthesis reactor, which represents a significant portion of the total capital expenditure due to its critical role in the urea production process and the need for high-pressure, high-temperature operations. This comprehensive approach ensures the production of urea is efficient and economically viable. The purified urea is then fed into a prilling tower with dry air to achieve the desired amount of prilled urea. In conclusion, this project not only demonstrates a profitable venture with a strong ROI and quick payback period but also contributes to environmental sustainability by utilizing CO_2 in the production process. The successful implementation of this urea production facility could serve as a model for integrating industrial productivity with eco-friendly practices, potentially paving the way for similar projects that aim to reduce greenhouse gas emissions while meeting global fertilizer demands.

Process Description

Urea is an important industrial chemical with applications in fertilizers, animal feed, and various chemical processes. The production of urea primarily involves the synthesis of ammonia from natural gas and nitrogen from air, followed by the reaction of ammonia and carbon dioxide to form urea. For the natural gas process water stream and natural gas are mixed and heated then fed to a conversion reactor then cooled and fed to two stage equilibrium reactors to increase the conversion then separated in an absorber the top product is the syngas compressed then fed into mixer. For the air separation process air is compressed and cooled to liquified the air and then fed into a separator the oxygen is produced from the bottom of the tower as by product and the nitrogen is produced from the top of the tower then compressed and fed to the mixer that contains the syngas the mixed stream is heated then fed to a conversion reactor the top product of the reactor contains ammonia and hydrogen are cooled and fed to a vessel to separate the hydrogen which is recycled and fed back into the mixer to increase the conversion of ammonia production. The ammonia produced is mixed with carbon dioxide that produced from natural gas then heated and fed into a conversion reactor to produce the desired product which is the urea with 100 ton/day as shown .





EQUIPMENT DESIGN:

Summary of Urea Reactor design:

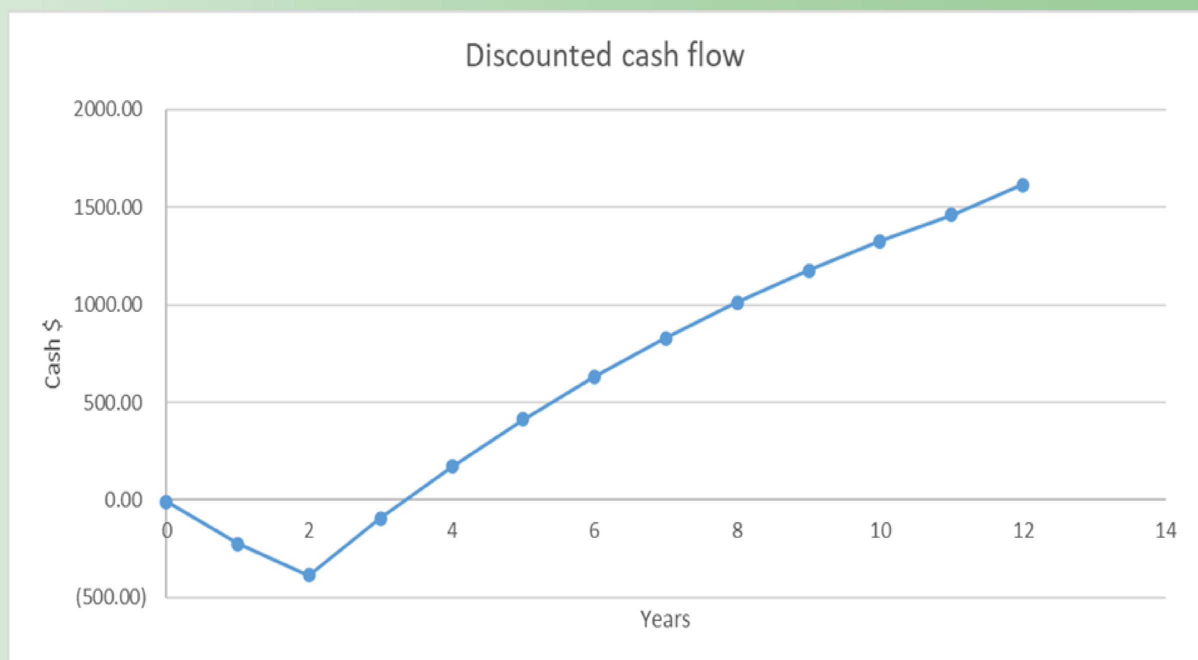
Parameter	Value
Unit	Urea Reactor
Diameter	3.14 m
Height	10.206 m
Material of construction	carbon steel
Head and closure	tori-spherical
Thermal insulation type	a mixture of asbestos and diatomaceous earth
Thermal insulation thickness	1.25 inch
Heating and cooling system	Jacket

Summary of Cooler (E-104) design:

Name		E-104	
Q (W)	580110326.19	No. tubes	5995
Shell Passes	1	Tube arrangement	square
Tube Passes	1	Tube pitch (mm)	20
Type	fixed tubesheet	Bundle diameter (m)	1.65
TEMA	AEL	Shell diameter (m)	1.68
A_{HT} (m^2)	2205.62	Baffle spacing (m)	0.67
Tube Dimensions		Baffle cut	25
d_o (mm)	16	ΔP_{shell} (Pa)	217.17
t (mm)	2	ΔP_{tube} (Pa)	$4.12 * 10^5$
d_i (mm)	12	t shell (mm)	31
L (m)	7.32	Support	saddle

Capital Cost:

Equipment Type	Cost in 2024 (million $)
Urea Reactor	2.8
Cooler (E-104)	1.765
Prilling Tower	0.143
Compressors	203.277
Reactors	66.734
Fired Heaters	39.27
Pumps	9.76
Total	232.8



Conclusion:

The urea production project from air and natural gas is a comprehensive industrial endeavor aimed at producing 100 tons of urea per day while addressing environmental concerns. The process is divided into four main steps: air separation, natural gas reforming, ammonia production, and urea synthesis.

In the air separation phase, air is compressed, cooled, and liquefied before being fed into a separator. Nitrogen is extracted from the top of the tower, while oxygen is produced as a by-product from the bottom. The isolated nitrogen is then compressed and directed to a mixer.

Natural gas reforming involves combining water and natural gas streams, which are heated and fed into a conversion reactor. The resulting mixture is cooled and processed through two-stage equilibrium reactors to enhance conversion. An absorber is used for separation, with the top product (syngas) being compressed and fed into the mixer containing the previously separated nitrogen.

Ammonia production occurs when the mixed stream of syngas and nitrogen is heated and introduced into a conversion reactor. The reactor's top product, containing ammonia and hydrogen, is cooled and separated. Hydrogen is recycled back into the mixer to improve ammonia production efficiency.

In the final step, the produced ammonia is combined with carbon dioxide derived from the natural gas process. This mixture is heated and fed into a conversion reactor to produce the desired urea product at a rate of 100 tons per day.

The project incorporates detailed design and sizing of key equipment, including:

Urea Reactor: A plug flow reactor with a volume of 1625.55 m^3, diameter of 8.84 m, and height of 26.52 m. It operates under high pressure and temperature conditions to maximize yield and efficiency.

Cooler (E-104): A shell and tube heat exchanger with a heat transfer area of 2205.62 m^2, 5995 tubes, and a shell diameter of 1.68 m.

Prilling Tower: Used for transforming molten urea into solid, spherical particles called prills. It has a diameter of 1.6 m and a height of 8 m.

The project emphasizes environmental considerations by consuming carbon dioxide instead of releasing it into the environment. This approach adapts the dry reforming process to produce hydrogen, contributing to the mitigation of climate change impacts.

An economic evaluation of the project has been conducted using CAPCOST software. The key financial metrics are:

Estimated net present value (NPV) at the end of the project's life: 1613.368 million dollars

Discounted rate of return on investment (ROI): 51.089%

Discounted payback period: 1.957 years (following a 2-year construction phase)

These figures indicate a substantial positive return and suggest that the project is financially viable.