Upgrading ammonia plants

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Ammonia has been widely used in fertilizers and industrial applications. In addition to its critical role in supporting global food production through nitrogen-based fertilizers, ammonia also serves as a key feedstock in the chemical industry, where it is utilised in the synthesis of plastics, explosives, and various cleaning agents.

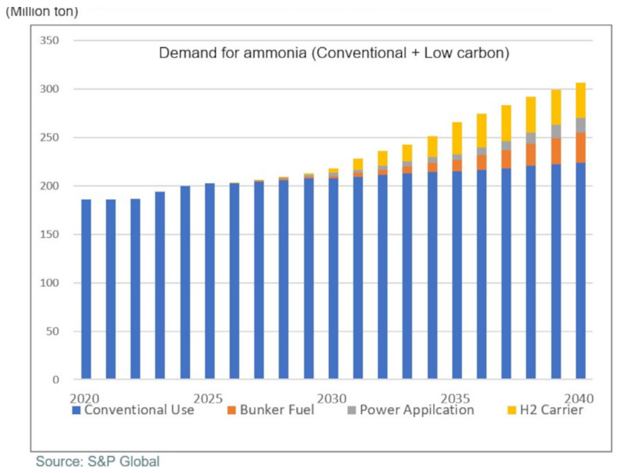


Figure 1. Prediction of demand for ammonia.

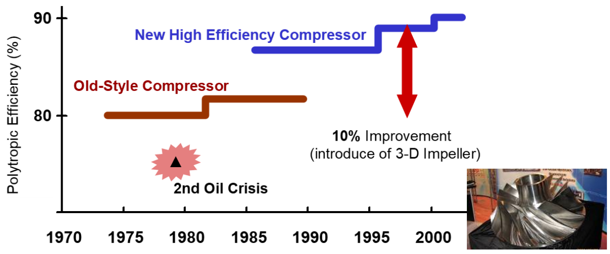


Figure 2. Evolution of compressor efficiency.

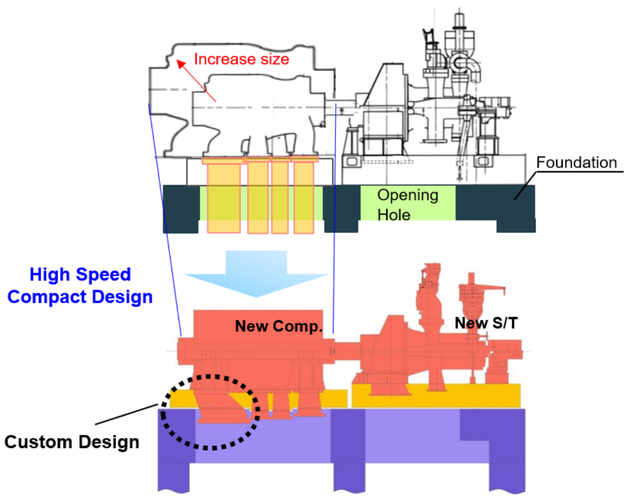


Figure 3. Minimum modification required for the capacity expansion project.

In recent years, as the push towards carbon neutrality has accelerated, there has been growing interest in reducing carbon emissions in conventional ammonia plants (Figure 1), particularly in applications such as bunker fuel, power generation, and hydrogen carriers.

Extensive experience has been accumulated in the design and manufacture of synthesis gas (syngas) compressors and associated steam turbine drivers used in fertilizer plants with capacities of up to approximately 3700 tpd. This expertise has also been applied in the modernisation of syngas compressors and steam turbines that have been in operation for several decades. Based on this background, the present study examines a case of syngas compressor train modernisation focused on reducing the overall carbon footprint.

In ammonia plants, some older facilities face constraints on their production capabilities due to the use of outdated low efficiency compressors. Those older machines may be equipped with outdated two-dimensional impellers, which are less efficient compared to modern compressors. By replacing these with recent three-dimensional impellers, compressor efficiency will be improved (Figure 2).

Replacement with more modern compressor technology not only expands the plant capacity, but also can help customers to improve their operational expenditure (OPEX) via increased efficiency.

Updating older plants brings substantial environmental benefits. By using more efficient compressors, energy consumption decreases, leading to a reduction in greenhouse gas emissions. This allows companies to achieve sustainable operations and fulfill their social responsibilities.

When upgrading an existing plant, it is generally advisable to minimise the scope of modifications in order to reduce overall investment costs. It is possible to optimise or limit the required modifications based on the existing plant conditions or specific project requirements.

For instance, during a capacity expansion project, applying a conventional design approach may result in the need for a larger compressor, which could require modifications to the existing concrete foundation. However, since such revamp or replacement work typically must be completed during a limited turnaround period – and evaluating the condition of older foundations can be challenging – it is often beneficial to consider design approaches that minimise these changes.

By employing compact, high-speed, and customised design solutions, a new compressor can be arranged to fit within the existing foundation. This approach reduces the overall modification scope, supports more efficient project execution, and enables improved operational performance within the existing plant layout, as illustrated in Figure 3.

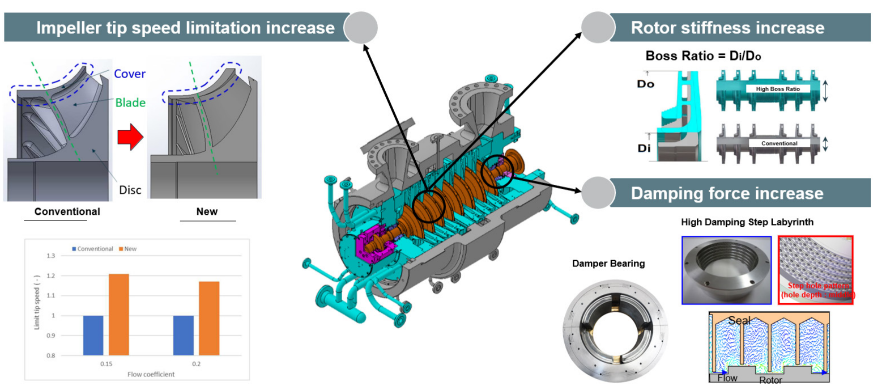


Figure 4. High-speed compact design.

The key aspects of high-speed compact design is introduced focusing on compressor impeller design and rotor dynamics (Figure 4).

High speed impellers

Recent advancements in impeller technology have focused on optimising the thickness of the cover and blades. By adjusting these dimensions, the centrifugal stress of the impeller could have been reduced and its tip speed allows an approximate 20% increase compared to traditional designs. This increase in speed not only enhances the compressor's efficiency via a higher flow coefficient impeller but also contributes to its compactness, as higher speeds can achieve the desired pressure ratios with the smaller diameter.

High boss ratio impellers

The boss ratio, defined as the ratio of the inner diameter to the outer diameter of the impeller, is a crucial parameter in determining the mechanical stability and dynamic behaviour of the rotor. Implementing a high boss ratio further contributes to the compact design of centrifugal compressors. A higher boss ratio increases the rigidity of the rotor and this advantage enables the compressor to operate at higher speeds in terms of rotor dynamics.

Damping force increase

To further improve mechanical performance at the higher speed compressor operation, the application of high-damping seal patterns and bearings is essential. These components enhance the damping characteristics of the rotor, mitigating vibrations and improving overall stability during operation.

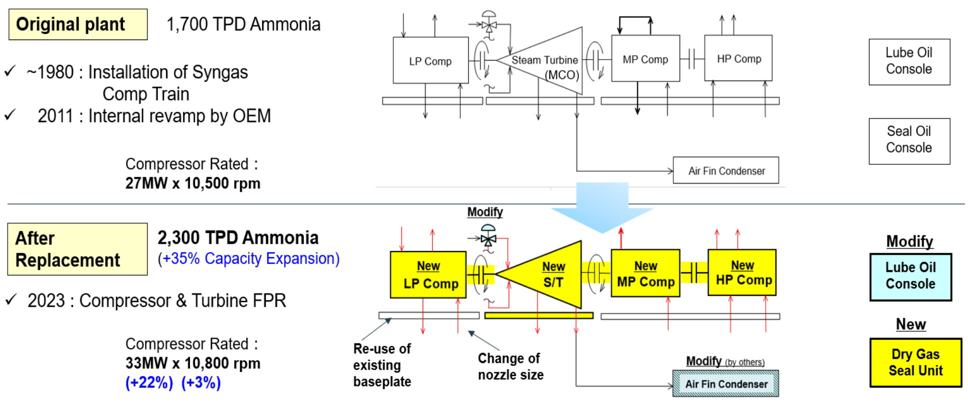
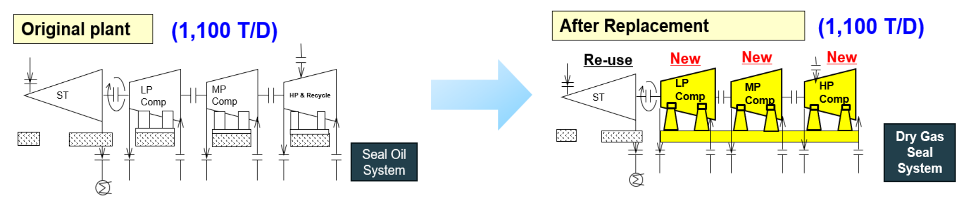


Figure 5. Footprint replacement summary for case study 1.



	Original Train	After Replacement
Ship Date	1968	2015
Plant Capacity	1,100 TPD	1,100 TPD
Compressor Power	22,108 HP	19,599 HP (Approx. - 11%)
Steam Consumption	150 klb/hr	135 klb/hr (-15 klb/hr)

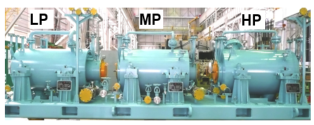


Figure 6. Footprint replacement summary for case study 2.

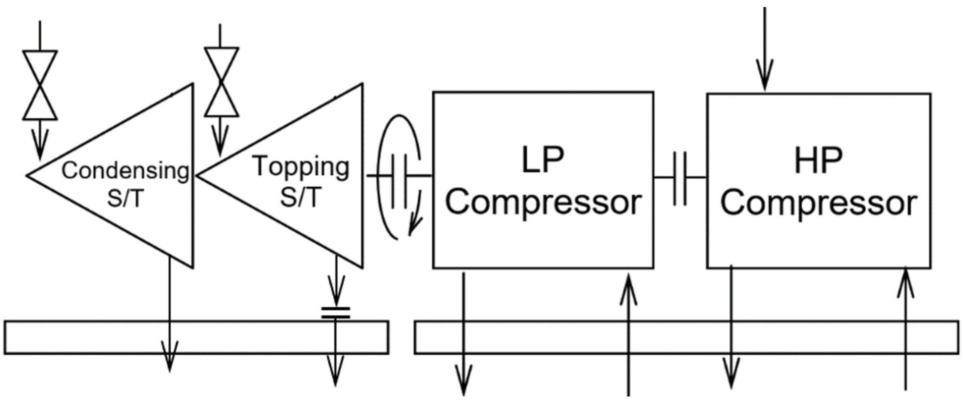


Figure 7. Historical two tandem turbine.

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Case study 1: capacity expansion and efficiency improvement

This case study presents the experience related to the capacity expansion of an old ammonia plant established in the 1980s. The project aimed to significantly enhance plant capacity by upgrading the original facilities. The original capacity of the plant was 1700 tpd of ammonia, with an internal revamp carried out by the original equipment manufacturer (OEM) in 2011. The plant configuration consisted of three case compressors and one steam turbine.

In 2023, plant upgrading was carried out and the primary objective of the project was to expand the plant capacity. Since the plant's capacity was expanded +35% from its original capacity, all of the compressor and steam turbine needed to be replaced with new ones to handle the large capacity. Due to this large capacity, compressor nozzle sizes were increased, and therefore process piping was also changed from its original positioning. However, the new nozzles fit into existing opening holes without any modifications of the existing foundation. Additionally, the compressor's baseplates could be re-used. These were achieved by a high-speed, compact, and unique custom design.

The advantages of this footprint replacement case study include not only the upgraded plant capacity, but improved efficiency. Even though capacity increase was +35%, an approximate 13% efficiency improvement was achieved by new compressors and steam turbine, and thus power usage increased only +22%. Therefore, footprint replacement with the latest technology is extremely beneficial for plant owners (Figure 5).

Case Study 2: plant renewal and efficiency improvement

This section presents a case study of plant renewal and efficiency improvement for an original old ammonia syngas compressor train in the US. The original compressor trains were installed in 1968 on this historical plant that has operated for over 40 years. Since the plant owner's requirement was not capacity expansion, but plant renewal with efficiency improvement, three compressors were replaced with new ones and seal systems were updated from a conventional seal oil system to a dry gas seal system. This upgrading was carried out in terms of minimum modification in 2011.

The highlight of this case study is efficiency improvement via the replacement of compressors. By replacing old compressors with new compressors, compressor power was improved from 22 108 HP to 19 599 HP: approximately an 11% improvement.

According to this power reduction, steam consumption of the original steam turbine was also reduced with -15 klb/hr. Assuming US$7 per 1000 lbs as steam cost, a total of US$840 000/yr could be saved.

This OPEX improvement indicates that the payback period for initial investment cost can be recovered in the short-term, and footprint replacement is one of the best approaches with minimum investment (Figure 6).

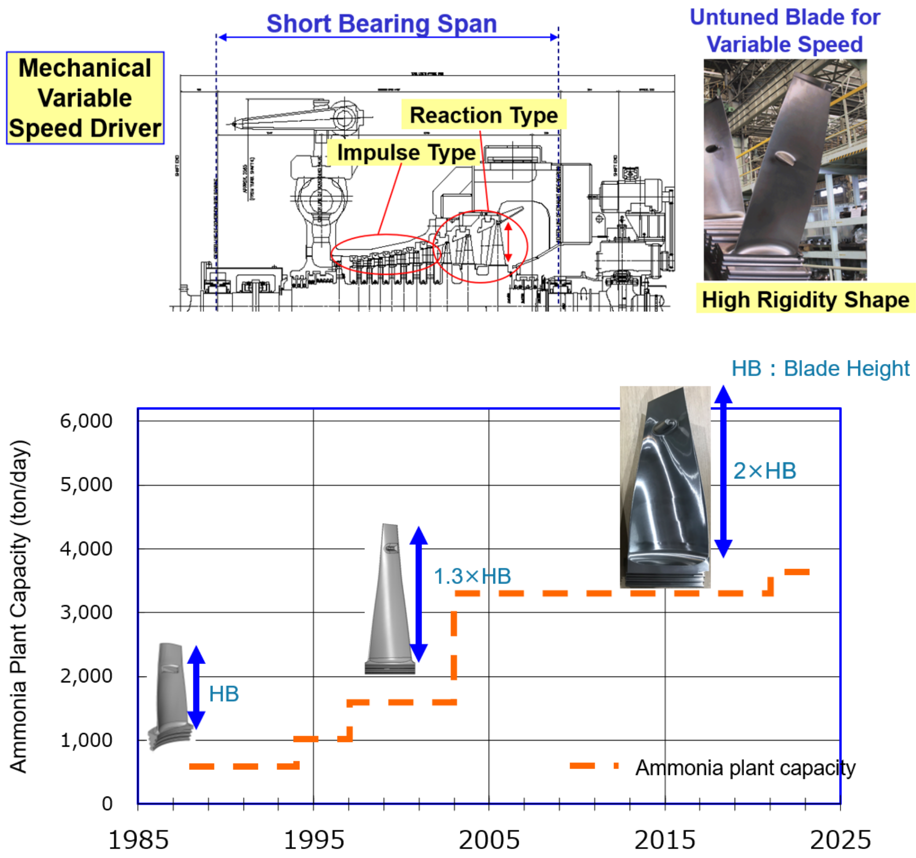

Figure 8. Improved steam turbine design.

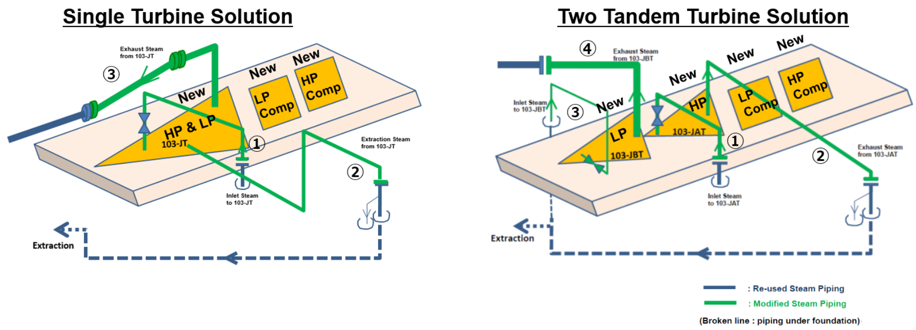

Figure 9. Single turbine and two tandem turbine solution.

Modernisation of syngas steam turbine

In older ammonia plants, a two-tandem turbine design was necessary because suitable steam turbines capable of handling the required combination of speed and power were not yet available (Figure 7). The higher speed (> 10 000 RPM) is ideal for the smaller frame size centrifugal compressors in syngas service, and the higher power is required as a result of large pressure ratio. Mechanical design and rotor stability were the main bottleneck of a single turbine. Splitting the service into two turbines allowed for less challenging rotodynamic designs that could operate at faster speeds.

On the other hand, steam turbine technology has improved over time and could have a single turbine solution for syngas compressor service in an ammonia plant. As shown in the improved steam turbine design in Figure 8, features such as a shorter bearing span and more rigid blades enhance rotor dynamics and enable higher-speed operation. Over the years, continuous advancements in last-stage blade design have also increased power output and provided a variety of blade options to suit different ammonia plant capacities.

Table 1. Comparison of advantage between single turbine and two tandem turbine

		Turbine one casing	Turbine two casings
Experience of replacement		More (for normal turbine replacement)	None or less (for two casing turbines replacement)
Site installation	Equipment and baseplate	New turbine with new baseplate	New turbines with new common baseplate
	Piping modification (main steam piping)	Required	Required
	Piping modification (auxiliary piping)	Less	More
	Instrument and wiring modification	Less	More
	Auxiliary equipment modification	Less	More
	Foundation	No modification basis (needs to check extraction piping space)	No modification basis (needs to check foundation size)
	Installation period	Fair	Fair
Operation and maintenance	Operability and controllability	Good (simple)	Not good (complicated) (two governors)
	Maintainability	Good (simple)	Not good (complicated) (two turbine casings to maintain)
Performance		Better	Worse
CAPEX		Fair	Higher
OPEX		Fair	Higher

Case Study 3: modernisation of a steam turbine

This case study introduced footprint replacement of a steam turbine for syngas compressor service in an ammonia plant. The original steam turbine, a historical two tandem type, was originally built in the 1960s such as shown in Figure 7. The project was initiated in response to the customer's demand for plant renewal with +25% increase in production capacity. To address these requirements, the solution identified was footprint replacement.

For the footprint replacement of the steam turbine, two potential configurations were studied: a single turbine and a two-tandem turbine arrangement (matching the original turbine type). While the compressor sizes remained the same in both cases, the main differences lie in the steam turbine design, as shown in Figure 9. Since the project focused on footprint replacement, minimising modifications to the existing plant infrastructure was a key priority.

Due to the large power increase, steam turbine size and steam piping were larger than the original. The size and positions needed to be changed. As for original turbine (two tandem turbine), four steam piping changes were required. On the other hand, a single turbine requires only three steam piping changes. Single turbine piping changes is a less extensive, more simple solution in terms of piping change work at site during plant turnaround period.

Regarding the equipment and baseplate, both turbine configurations require a new baseplate; however, the baseplate for the two-tandem turbine is larger than that for the single turbine. Sometimes the larger dimension may impact the original foundation space. On the other hand, in the case of a single turbine, downside or side extraction piping would be necessary due to the space limitation.

From an operational and maintenance perspective, a single turbine offers substantial benefits. Its simpler design means that only one governor is required for operation, resulting in reduced complexity. Additionally, maintenance procedures are streamlined for a single turbine compared to a two tandem turbine.

In terms of capital expenditure (CAPEX), a single turbine has a cost advantage due to fewer parts, leading to lower overall costs for steam turbines and spare parts. Performance-wise, this configuration also positively impacts OPEX. Even when both turbine types are aerodynamically identical in terms of stage number and design, a single turbine demonstrates higher overall efficiency and reduced steam consumption due to several factors, including:

- Reduce bearing losses (two sets vs four sets).
- Decrease steam leakages across shaft ends.
- Lower piping pressure drops between turbines.

As summarised in Table 1, a single turbine solution offers numerous advantages, making it a superior choice for a capacity expansion project.

Conclusion

In conclusion, there has been a recent trend toward increasing the productivity and reducing the carbon footprint of current plants. This study can serve as a reference for anyone associated with these plants. In addition, this can support new plant stakeholders regarding potential opportunities involved in design of a new plant. WF

Notes

OPEX improvement = 15.0 klb/h x US$7 klb x 8000 hpy.