Application study of fluid pressure energy recycling of decarbonisation process by C4H6O3 in ammonia synthesis systems by hydraulic turbochargers

Yunguang Ji1, Yangyang Xu1, Hongtao Li1, Michael Oklejas2 and Shuqi Xue1,*

1 College of Mechanical Engineering, Hebei University of Science and Technology, Shijiazhuang, China
2 Oklejas Turbo Solutions LLC, Ann Arbor, MI, USA

*Corresponding author e-mail: xueshuqi@hebust.edu.cn

Abstract. A new type of hydraulic turbocharger energy recovery system was designed and applied in the decarbonisation process by propylene carbonate of a 100k tons ammonia synthesis system firstly in China. Compared with existing energy recovery devices, hydraulic turbocharger energy recovery system runs more smoothly, has lower failure rate, longer service life and greater comprehensive benefits due to its unique structure, simpler adjustment process and better adaptability to fluid fluctuation.

1. Introduction
Ammonia synthesis is a high energy-consuming industry, and about 20 GJ is required as producing 1t gaseous ammonia in the state 0.1MPa and 298 K. The decarbonisation process in ammonia synthesis system is a non-spontaneous process and its energy consumption accounts for about 10% [1] of that of the whole system. In the decarbonization process, the Propylene carbonate rich liquid needs to pass through the pressure reducing valve into the regeneration tower when it is discharged from the absorption tower. If the pressure energy dissipated by the pressure reducing valve can be recovered and used, a large amount of energy cost can be saved. Therefore, it is of great social and economic value to recycle the pressure energy in the process of ammonia synthesis, which is also in line with the future development of the ammonia synthesis industry in China.

1.1. Conventional decarbonisation process by C4H6O3 in ammonia synthesis systems
Propylene carbonate (C4H6O3) decarburization process, i.e. PC process, is a common and most-used wet decarburization method in many small ammonia synthesis systems due to its stable property, easy regeneration, high purification degree and low price [2, 3]. Table 1 shows general operating conditions of PC process.

In PC process C4H6O3 solvent absorbs and eliminates the acid gas produced under high pressure and will be regenerated under low pressure and then increased to a high pressure to form a circulating. The higher the pressure in the absorption tower is, the more conducive to the removal of acid gas, so a large amount of pressure energy is accumulated at the bottom of the absorption tower.
Table 1. General operating conditions of PC process.

| Operating pressure (MPa) | Operating temperature (°C) | CO₂ in raw gas (%) | CO₂ in purified gas (%) |
|--------------------------|----------------------------|--------------------|-------------------------|
| 1.4~2.0                  | 25~38                      | 20~30              | 0.2~1.0                 |

The conventional PC decarbonisation process as shown in figure 1, has the following shortcomings: high flow rate required with large flow fluctuations; waste of pressure energy as the rich liquid passing through the valve; and demanding high sealing performance. Solving the above problems can greatly reduce the cost of investment, saving energy.

![Figure 1](image)

**Figure 1.** Principle of PC decarbonization process in ammonia synthesis

1.2. Existing pressure energy recycling turbines system

Figure 2 illustrates the existing pressure energy recycling system using a hydraulic turbine [4].

![Figure 2](image)

**Figure 2.** The existing pressure energy recycling system by turbine

When rotating speed of hydraulic turbine impeller is higher than that of motor, clutch is engaged and then the system showed in figure 2 starts working, however, the clutch is prone to be disengaged and easily damaged in the cases of high system pressure and flow fluctuations; mechanical seal needs maintenance and replacement scheduled/non-scheduled; Installation, failure diagnosis and maintenance of the pump-motor-clutch-turbine-unit is time-consuming and difficult. All of above result in low comprehensive efficiency, high investment and low safety of the system.
2. Structure and pressure energy recycling system by hydraulic turbocharger

2.1. Structure of hydraulic turbocharger
As a new type of pressure energy recycling device, hydraulic turbocharger [5], originated from turbo-pump and automobile turbocharger, has obvious structural and efficiency advantages than currently most used “pump as turbine(PAT)” in pressure energy recycling systems.

As shown in figure 3 the hydraulic turbocharger has the following advantages: it has less rotating parts and fully assembled in the sealed shell, and then no extended shaft; no dynamic sealing parts; mean operating time between failures is up to 20,000 hours, etc.

Figure 3. Schematic diagram of hydraulic turbocharger

Different from PAT, the specially designed radial blades of turbo impeller has higher energy recovery efficiency by way of hydraulic theoretical calculation, CFD numerical simulation, and then optimization of key dimensional parameters.

The hydraulic turbocharger has auxiliary flow rate and pressure control functions. The main nozzle in the entrance side helps to collect pressure energy of rich liquid and there is an auxiliary nozzle in turbo casing connected to a valve which may control 10%~15% of flow rate, so the liquid level and pressure of absorption tower can be adjusted, and then the device is more adapted to variations of flow rate and pressure.

2.2. Pressure energy recycling process of hydraulic turbocharger
Hydraulic turbocharger has been applied in reverse osmosis (RO) sea water desalination process [5], which transfers the pressure energy of rich liquid directly into the low pressure liquid through the shaft connecting the turbo impeller and the pump impeller, as shown in figure 4, then only a lower pressure for the booster pump is needed and energy consumption is decreased; in addition, sealing requirements is lowered and service life is prolonged of the equipment.
3. Application case of pressure energy recycling by hydraulic turbocharger

The hydraulic turbocharger was installed and then operated in the PC process of ammonia synthesis system in Hebei Jinghua Chemical Equipment Co., Ltd in March, 2016. The maximum flow rate of C4H6O3 is 1000 m³/h, and the operating pressure inside absorption tower is 1.8MPa, then 0.4MPa needs to be reduced to before rich liquid flowing into the flash tank, hence in this case the pressure energy wasted can be recycled by hydraulic turbocharger.

3.1. Process design

As shown in figure 5, The outlet of the absorption tower connects a DN600 pipeline and then divided to 3 subsequent ones A, B, C; A (DN450) connects the turbine section of the turbocharger after a series of pipeline valves; B (DN125) is a bypass pipeline; C (DN600) goes to the flash tank combining the flow from the pump section of the turbocharger. Flow fluctuation will be reduced and output power of hydraulic turbocharger is stabilized via flow regulation of bypass pipeline turbine.

![Figure 5. Principles and main configuration of hydraulic turbocharger energy recycling process](image)

During operation, 85% of the high pressure rich liquid of the absorber tower flow through the turbine section of turbocharger to recycle the pressure energy which is transferred to mechanical energy of the pump impeller. The liquid level is adjusted by 2 valves, which are the throttle valve(capable of 10%~15% flow rate)located at the inlet of the turbine section of the turbocharger, and the bypass valve(20% flow rate) parallel to the turbocharger. If liquid level of the absorption tower
decreases, liquid level controller will send signal to close the throttle valve to reduce flow into turbine side, then the liquid level rises.

3.2. Performance evaluation methods

3.2.1. Design parameters of hydraulic turbocharger. Table 2 shows the main operating parameters of hydraulic turbocharger used in Hebei Chemical Equipment Co., Ltd.

| Parameter          | value |
|--------------------|-------|
| \( Q \) : Process flow rate/m^3·h^-1 | 1000  |
| \( Q_t \) : Flow rate of turbo/m^3·h^-1 | 850   |
| \( P_{t,in} \) : Inlet pressure of turbo/MPa | 1.8   |
| \( P_{t,out} \) : Outlet pressure of turbo/MPa | 0.4   |
| \( Q_p \) : Flow rate of pump/m^3·h^-1 | 1000  |
| \( P_{p,in} \) : Inlet pressure of pump/MPa | 1.6   |
| \( P_{p,out} \) : Outlet pressure of pump/MPa | 2.3   |
| \( \eta \) : Comprehensive energy recycling efficiency /% | 67.2  |

3.2.2. Comprehensive energy recycling efficiency. The energy conversion efficiency of the hydraulic turbocharger is one of key factors to judge if the device meets its design requirements:

\[
\eta = \frac{Q_p \times (P_{p,out} - P_{p,in})}{Q_t \times (P_{t,in} - P_{t,out})} = 67.2\% \quad (1)
\]

3.2.3. Economic feasibility evaluation. Economic feasibility evaluation of the selected hydraulic turbocharger in the application case was carried out. It is suggested that the equipment investment should be recycled for 3 years as the reference standard.

\[
K = (M_1 \times B_{HP} \times 26280) / M_2 \geq 1 \quad (2)
\]

In equation 2, \( K \) is the economic coefficient; \( B_{HP} \) is the output power, kW; \( M_1 \) is electricity cost, RMB Yuan/kW; \( M_2 \) is the one-time investment of the hydraulic turbocharger and is estimated maintenance cost in 3 years, RMB Yuan.

3.3. Application Performance

A MD900-50×5 lean liquid circulating pump and a GSF-F-52016 lubrication pump were utilized in the pressure energy recycling system. Form March 2016 the system started operating after installation and commissioning (figure 6), and liquid level in absorption tower is maintained at 61%~65%. The comprehensive pressure energy recycling efficiency obtained is more than 65%, as shown in figure 7. The 2 sets of independently operated synthetic ammonia system in Hebei Chemical Equipment Co., Ltd saved electricity \( 763.54 \times 10^4 \) kWh, or about equivalent cost of RMB Yuan 5,344,700.

4. Conclusion

Hydraulic turbocharger energy recovery system was designed and applied in the decarburization process by propylene carbonate of a 100k tons ammonia synthesis system firstly in China. Low flow rate, high fluid with flow fluctuation of ammonia synthesis system makes hydraulic turbocharger a
good choice for fluid pressure energy recycling. Field operation shows that the energy recycling system has strong adaptability, and high comprehensive recycling efficiency.

**Figure 6.** Field operation picture of hydraulic turbocharger

**Figure 7.** Operating parameters of hydraulic turbocharger
1 - Outlet pressure of pump
2 - Inlet pressure of turbine
3 - Inlet pressure of pump
4 - Outlet pressure of turbine
5 - Energy recycling efficiency.

Application of hydraulic turbocharger in the PC process of ammonia synthesis system to recycle the fluid pressure energy may greatly reduce energy consumption, equipment failure rate, and investment recovery period.

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