

2014

Asian Nitrogen + Syngas

Improved efficiency and lifetime reliability with new hydraulic energy recovery design for CO₂ removal in ammonia plants

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The CO₂ removal process in ammonia production is a significant contributor to overall plant energy consumption. The bulk of the energy is used for regeneration of the rich solution, but an appreciable part is electric energy for pumping of the semi-lean solvent. Historically, hydraulic power recovery turbines, in the form of reverse running pumps, have been utilized as an energy recovery device in this application. This paper presents a new turbocharger-based solution. The use of a liquid phase turbocharger offers simplified design, compact footprint, rapid install and increased plant uptime with high efficiency across a wide range of operating conditions.

The IsoBoost™ energy recovery system is an integrated, skid-mounted unit that uses a proprietary liquid phase turbocharger, essential piping, valves, instruments and a control system to recover up to 80% of the hydraulic energy in the rich solvent and transfer it directly to the semi-lean solvent. The fluid-to-fluid energy recovery in the turbocharger eliminates the need for a direct shaft connection to the process pump, as well as subsequent long train of gear, clutch, couplings, intermediate bearings and mechanical seals. With the turbocharger, the speed of the rotating assembly is self-regulating, ensuring optimum efficiency and eradicating problems of vibration, misalignment and mechanical instability. Availability of the system is up to 99% with minimal maintenance required. The system can help new and existing plants drive

uptime, increasing productivity and profitability. A complete description of the system will be presented along with performance data.

INTRODUCTION

The first turbocharger-based energy recovery solutions are now available for ammonia plants. These solutions were designed specifically for CO₂ removal processes and provide process control, increased reliability, improved efficiency and more plant uptime. The liquid phase turbocharger at the core of the system uses letdown energy to pressurize the semi-lean solvent to the required absorber pressure, without external shafts, shaft seals, bearing oil lubrication systems or other components associated with common failure modes of high-pressure equipment. The liquid-phase turbocharger design, process control methodology, performance metrics and benefits and plant configuration are described.

OVERVIEW OF CO₂ REMOVAL WITHOUT AN ENERGY RECOVERY SYSTEM

Solvent-based processes to remove CO₂ in the syngas purification step of ammonia production have been used for many years. A conventional configuration shown in Figure 1 includes lean and semi-lean circulation pumps, which are used to pressurize the lean and semi-lean solvent above the absorber pressure to start the stripping process. A pressure letdown valve, used as the absorber level control valve, reduces pressure in the solvent stream prior to entering the HP flash vessel. In this process, energy is dissipated and lost through the action of the level control valve. Given the pump efficiencies, the actual energy used in pressurization is significantly greater than the hydraulic energy dissipated in the level control valve.

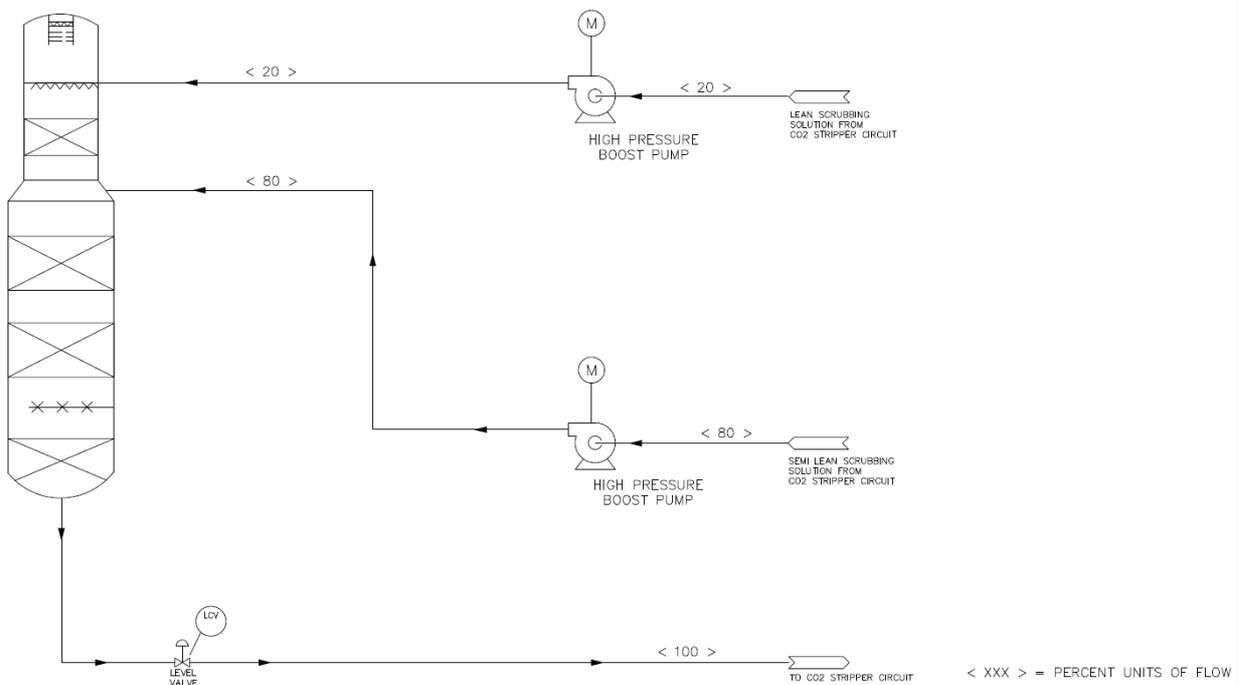


Figure 1. Simplified Conventional Configuration of a CO₂ Removal System with Recovery Turbine

IsoBoost technology provides maximum energy recovery efficiency and provides the same flexibility and process control as conventional configurations without energy recovery systems.

The IsoBoost system and its proprietary liquid phase turbocharger (the GP Turbo) reduces the energy consumed by recovering and recycling a significant portion of the energy dissipated in the level control valve to pressurize the semi-lean, solvent stream to absorber inlet pressure. A process flow diagram for the application of the IsoBoost system in CO₂ removal is provided in Figure 2.

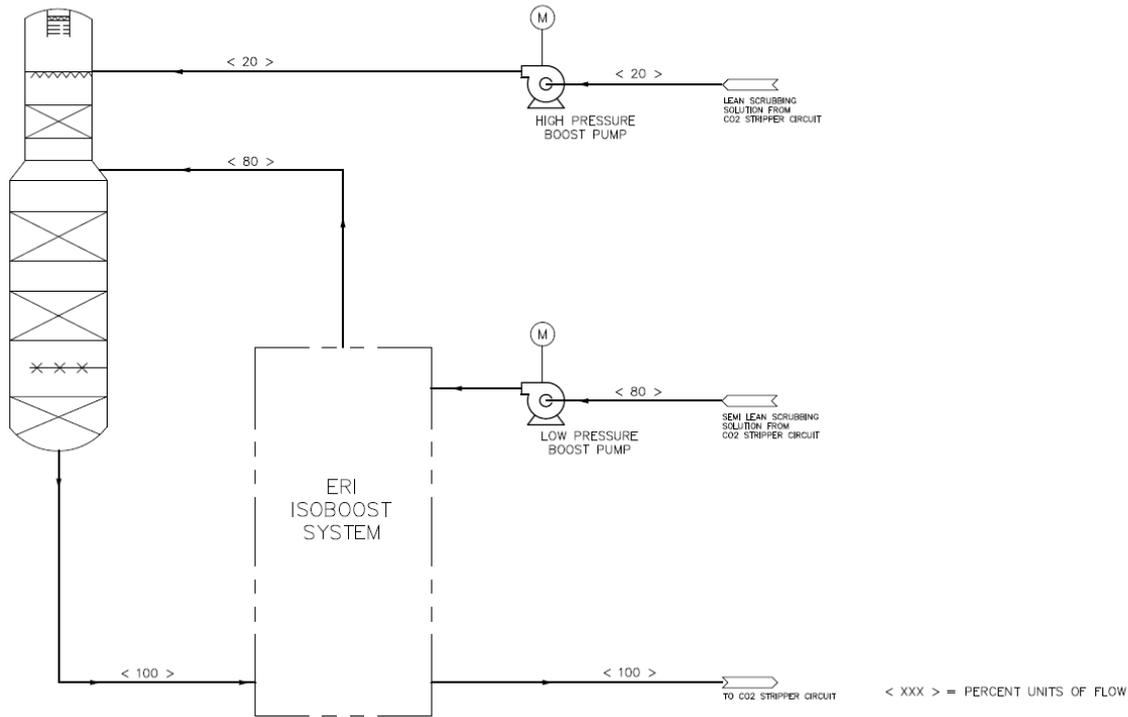


Figure 2. Application of the GP Turbo in CO₂ Removal

Rich solvent from the absorber is directed to the turbine inlet side of the IsoBoost GP Turbo. Rich solvent exiting the turbine is at low pressure and is directed to the flash tank. At the same time, semi-lean solvent from the stripper circuit is directed through a solvent circulation pump to the pump inlet side of the GP Turbo. The solvent circulation pump shown in the conventional flow sheet in Figure 1 is replaced by a low head pump, approximately one-sixth the size, which reduces the operational footprint. Semi-lean solvent partially pressurized by the low pressure boost pump enters the pump side of the turbocharger, where the hydraulic energy absorbed by the turbine side is used to further increase the pressure of the semi-lean solvent to that of the absorber.

Different from a reverse running pump, the IsoBoost system is not coupled to the semi-lean solvent pump. This is an important difference as the mechanical coupling of a reverse running pump to the semi-lean solvent pump limits operation and turndown of the process in legacy hydraulic recovery solutions. The IsoBoost recovers energy independently from the main pump operating point. All components within the indicated IsoBoost system shown in Figure 3 are skid-mounted along with an electronics and control module to form a completely integrated system for application in any size plant.

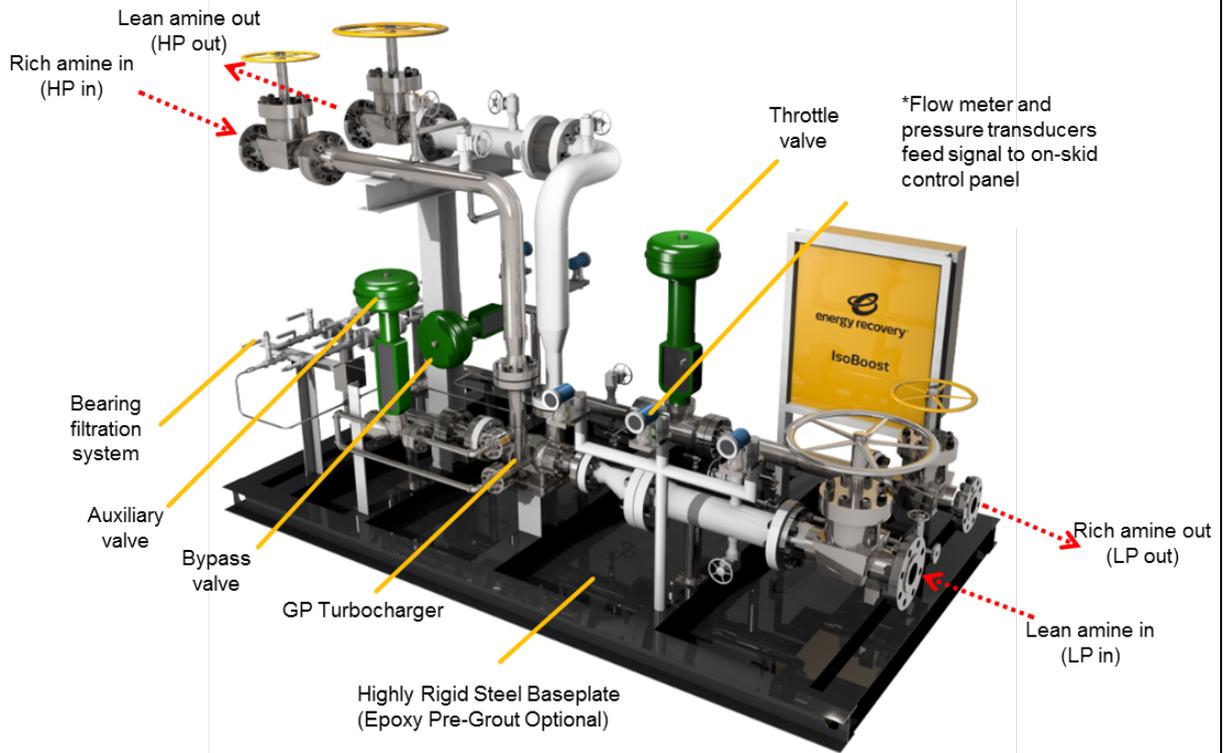


Figure 3. IsoBoost Integrated Skid-mounted System with Components

DESIGN OF A LIQUID PHASE TURBOCHARGER

To understand the performance of IsoBoost, it is essential to describe the core component of this integrated skid-mounted system, the GP Turbo.

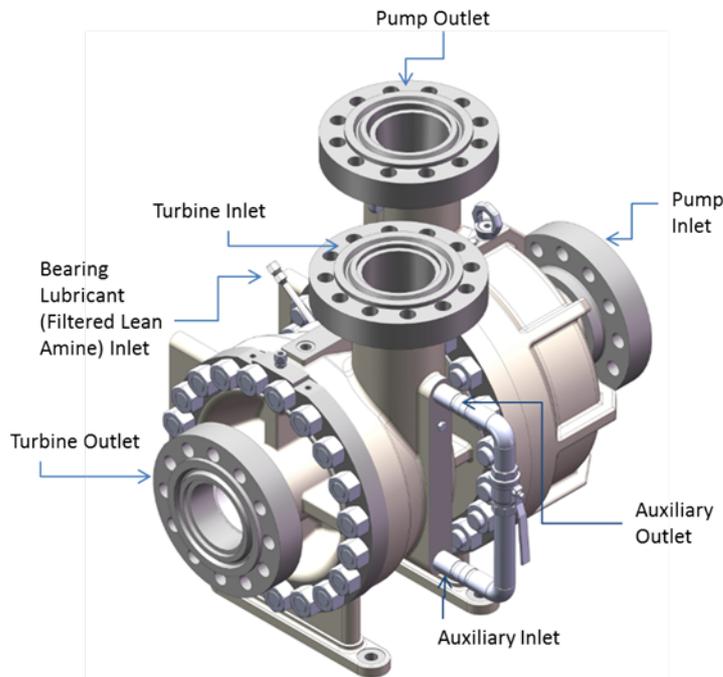


Figure 4. GP Turbo with Fluid Connections Identified

The turbocharger (GP Turbo) consists of a high-speed turbine powering a centrifugal pump and sharing a common shaft and casing with the pump. In addition to the fluid connections, the turbocharger integrates a secondary nozzle (auxiliary nozzle) and product lubricating line for internal bearings.

In a typical CO₂ removal application, rich solvent exiting the absorber flows through the turbine, thereby pumping semi-lean solvent into the absorber and reducing the energy consumption of the semi-lean solvent circulation pump by up to 80%. A cross-sectional view in Figure 5 identifies the key internal components.

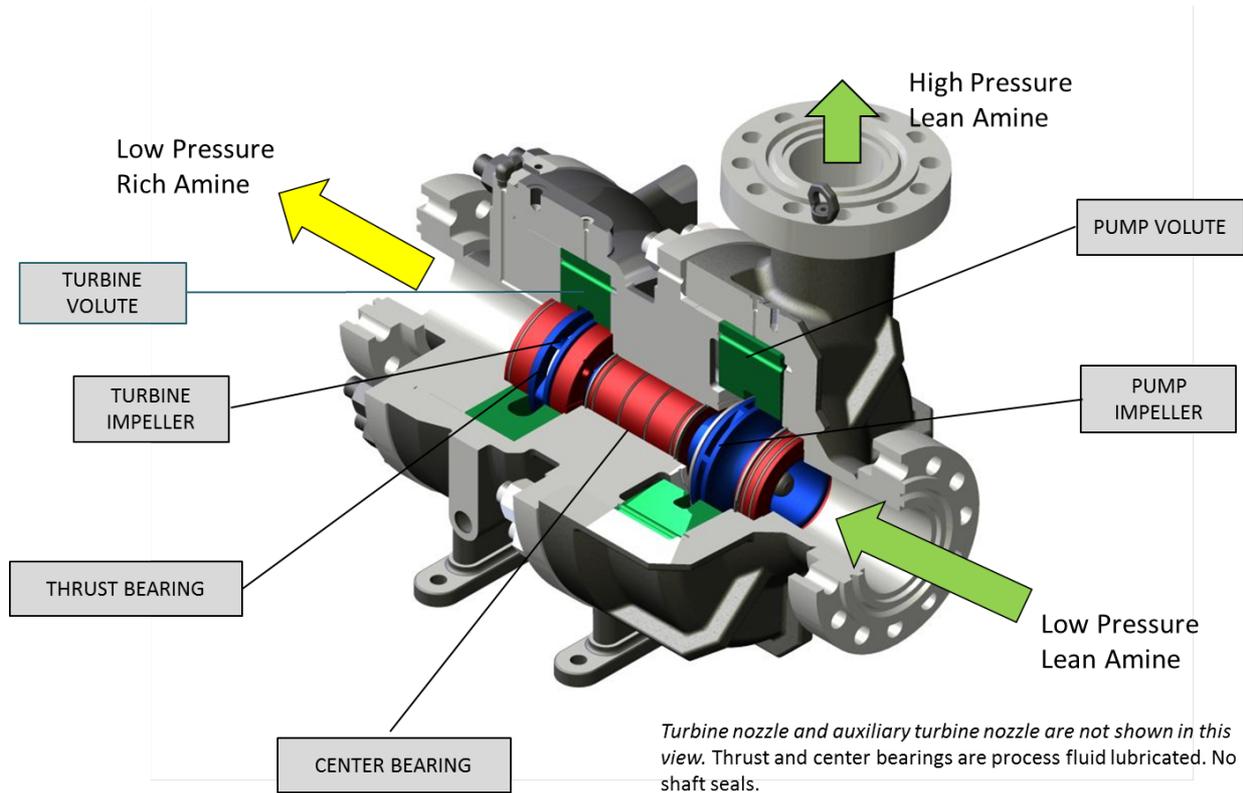


Figure 5. Cross-sectional View of the GP Turbo

The turbine side has an auxiliary line that diverts a portion of the turbine inlet flow to the side of the turbine runner. This auxiliary nozzle in the turbine side provides a variable geometry of the turbine, allowing for a wide operational range. By adjusting a simple valve on this line, it is possible to alter the effective flow coefficient of the turbocharger during operation. This allows the turbocharger to handle the entire operating range of a typical solvent absorber efficiently, without wasting energy by throttling the rich solvent flow or bypassing it around the turbocharger. Throttle and bypass valves are only used to handle large deviations from normal operating conditions, as will be described in a subsequent section.

The rotating assembly consists of a turbine runner and pump impeller connected by a common shaft. This assembly is supported by bearings lubricated by the process fluid. A small portion of high pressure semi-lean solvent (typically less than one percent of the flow) is taken from the pump outlet, filtered, and supplied to the bearings. Process lubricated bearings eliminate the need for external bearing lubrication support systems. The process lubricated bearings have an extremely long operational life and require no

scheduled maintenance except for periodic replacement of the filter cartridges, which is completed during operation without incurring any downtime or disturbing the process in any way.

Thrust loads are absorbed by a hydrostatic thrust bearing, which runs against a hardened insert in the turbine runner. A hydrodynamic touchdown bearing is also provided to limit axial movement of the rotating assembly. The rotating assembly is supported radially by a hydrodynamic center bearing, which also acts as a seal between semi-lean solvent on the pump side and rich solvent on the turbine side to ensure fluid integrity.

The Energy Recovery GP Turbo is a liquid phase turbocharger engineered for flexibility and easy reconfiguration if application requirements change dramatically over the lifetime of a plant. The turbine runner and pump impeller can be easily changed. The geometry of the entire hydraulic flow path through the casing can be changed as well through the use of Energy Recovery patented insertable volutes and nozzles. The turbocharger can also be adapted easily and inexpensively to a different hydraulic operating regime in case of a revamp with very large changes in operating conditions. No compromise needs to be made between the cost of new equipment and the expense of running existing equipment far from its design point.

RELIABILITY AND AVAILABILITY

While the execution of energy transfer from rich to semi-lean can be done using conventional rotating equipment, there are inefficiencies and maintenance issues that can arise. In a typical configuration, a long train of a recovery turbine, or reverse running pump, is coupled via a shaft and clutch to a high pressure pump and electric motor. The high pressure pump is typically fixed-speed. The connection of the recovery turbine to this pump then constrains the speed of the turbine. When off-design flow conditions occur, the turbine is unable to adjust to operate at the speed dictated by the flow. The speed mismatch can cause vortices and flow separation inside the turbine. This turbulent flow results in serious problems including vibration and impeller damage caused by flashing in the turbine due to the long residence time. To prevent this, flow must be bypassed or the recovery turbine disengaged from the pump, resulting in significant energy wasted and requiring extra attention from operators.

In CO₂ removal with a turbocharger, the energy transfer happens in a single, compact device. The rich solvent spins the turbine, which then spins the pump, pulling in semi-lean solvent and pumping it into the absorber. The rotating assembly speed is unconstrained and self-regulating. No overspeed protection is needed. The custom turbine and pump are directly coupled inside a single casing. There is no shaft exiting the casing, which means no shaft seals, no possibility of seal leak and no seal support systems. The single thrust bearing in the turbocharger is process lubricated by a small amount of filtered semi-lean solvent from the pump discharge. The hydrodynamic radial bearings are also lubricated by this process fluid. No oil lubrication or cooling systems are needed. The simple design and low part count of the turbocharger results in a very high availability and reliability of the device.

The process integration of this highly reliable device can improve overall plant uptime by virtue of removing a high-pressure pump from the process. The process is simplified, with less high-pressure equipment required than before the install. As process reliability is a function of the components involved, the removal of a high-pressure pump from the standard operating regime improves overall reliability.

PROCESS CONTROL METHODOLOGY

The IsoBoost turbocharger-based solution offers full process control and ability to operate at best efficiency across a range of conditions.

In addition to the multiple nozzle design in the GP Turbo, the IsoBoost provides two additional valves: (1) a throttle valve and (2) a bypass valve to enable a wide flow rate range of operation. The three valves, auxiliary, bypass and throttle are operated via a control system to achieve absorber level control in response to a level control signal provided by the plant supervisory control and data acquisition (SCADA) system.

Process control of the absorber is achieved through controlling the flow of semi-lean solvent into the absorber and simultaneously controlling the level of the rich solvent in the bottom of the absorber. Flow rate control of the solvent entering the absorber is achieved with a conventional flow control valve. An optional variable frequency drive with the reduced sized high pressure pump can provide additional energy savings by reducing throttle effect and pressure drop through the flow control valve. Absorber level control is achieved through the controlled operation of the auxiliary, bypass and throttle valves. A level control signal is received from the plant and is split into three ranges to actuate the three valves.

In normal operation, the bypass valve is fully closed, the throttle valve is fully open and the auxiliary valve performs the control function by adjusting the flow exiting the absorber in response to the level control signal. Efficiency remains constant across the turndown range. If the level control signal demands a flow response that is lower than the lowest flow that is achievable in the normal mode of operation, wherein the auxiliary valve is fully closed, the throttle valve will begin to take over control by closing to the desired level. If the level control signal demands a flow response that is higher than the highest flow that is achievable in the normal mode of operation, wherein the auxiliary valve is fully open, the bypass valve will begin to take over control by opening and bypassing additional flow to the flash tank. In actual operation, the control system is set up to overlap the control regions of the three valves, thus ensuring a smooth system response.

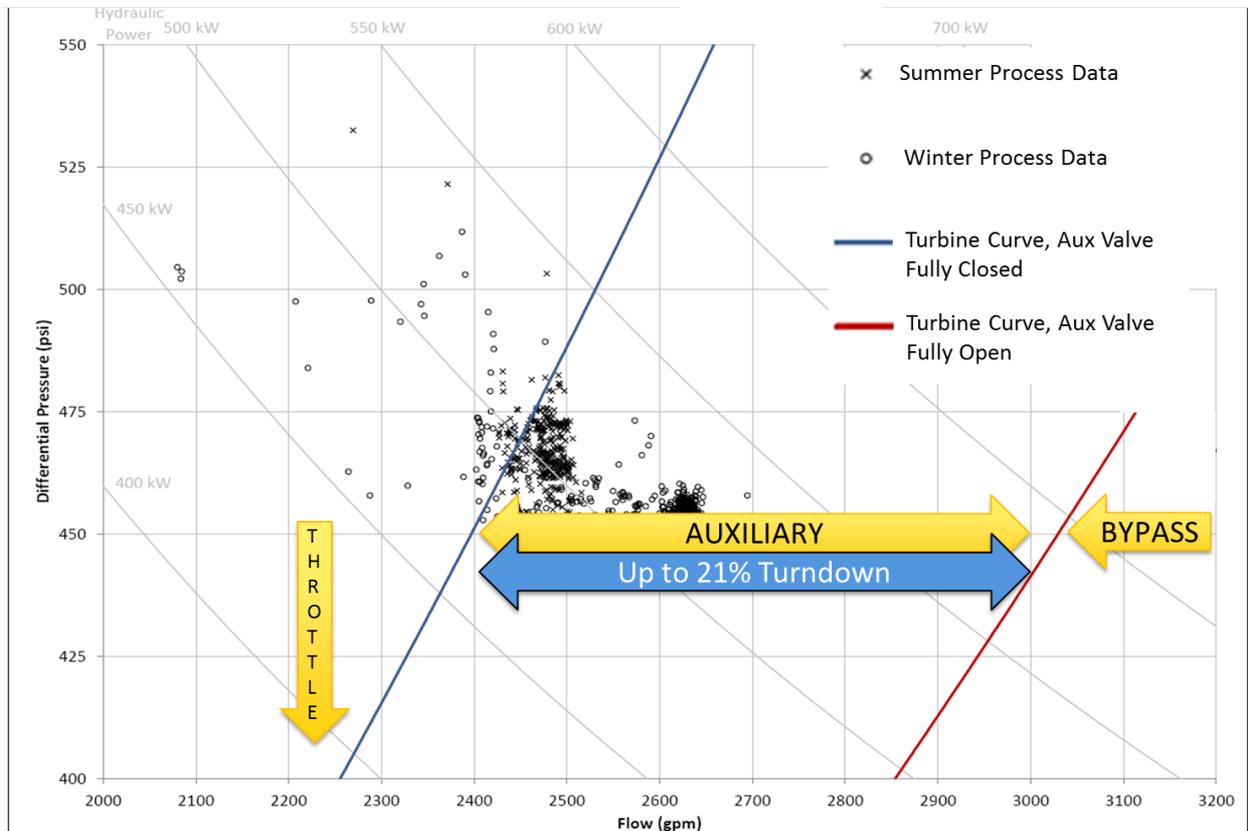


Figure 6. Level Control Action with Three Valves

Figure 7 below depicts the three valves' control action in response to the level control signal. The proportions of level control signal assigned to each valve and the amount of overlap is implemented using

the Energy Recovery control system. The IsoBoost creates operating characteristics similar to the level control valve (LCV) that the system replaces.

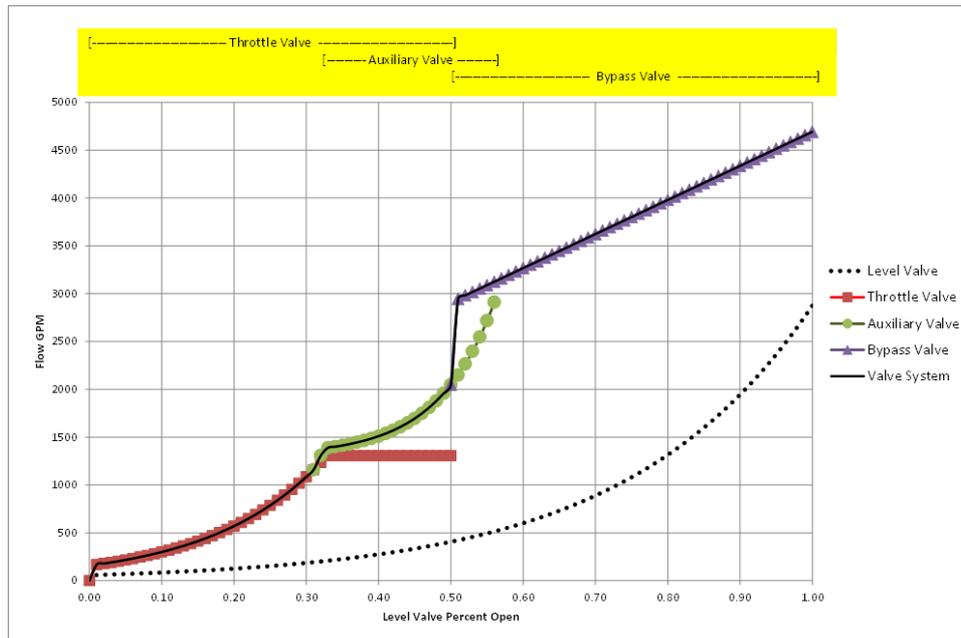


Figure 7. Control Valve Action

STARTUP CONDITIONS

Plant startup represents a special condition that is not a part of routine operation, but is critical nonetheless. In the application of the conventional flow sheet of Figure 1, independent control is maintained for the absorber level control valve and the solvent circulation pump and control valve delivering solvent fluid to the top of the absorber. During the startup of the plant, absorber tray holdup will increase significantly as the gas flow is increased. In order to accommodate this increase in absorber holdup, the absorber level control valve is closed down while maintaining flow to the top of the absorber, thus enabling the required absorber holdup increase. In the case of applying the GP Turbo to CO₂ removal, a simple alternative startup is required. Figure 8 is a schematic of a startup operation. In this startup operation, the throttle valve and the bypass valve are fully closed, and a portion of the semi-lean solvent flow is used to drive the turbine side of the GP Turbo, thus enabling the pump side to develop full absorber pressure at the pump discharge.

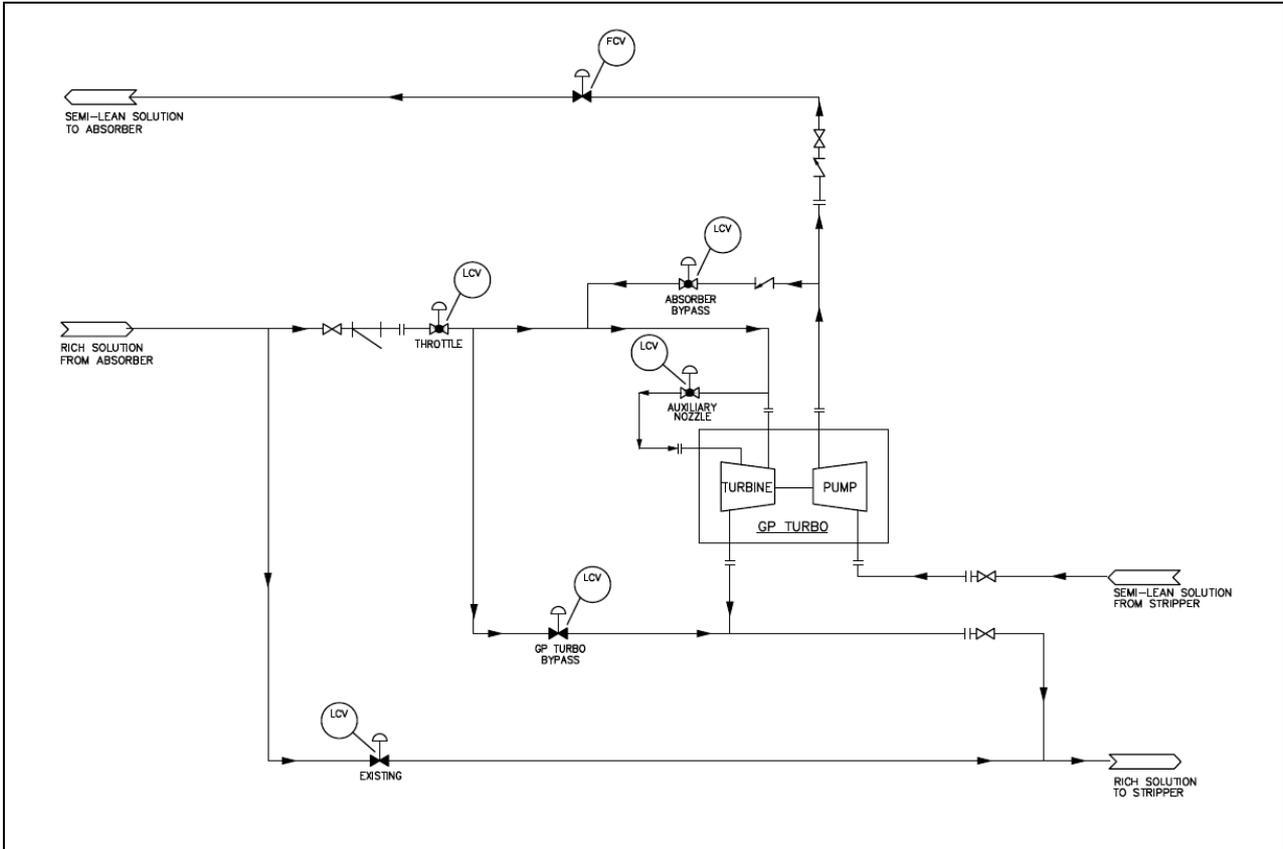


Figure 8. Start-up Operation with GP Turbo

The operation of the startup valve enables the achievement of full absorber pressure at the pump exit of the GP Turbo, even though there is no flow from the bottom of the absorber to drive the turbine side of the GP Turbo.

HYDRAULIC TRANSFER EFFICIENCY

The GP Turbo has a high operational efficiency in a wide range of operating conditions. Because the turbocharger transfers hydraulic energy directly, the efficiency metric is calculated differently than with a typical recovery turbine. An energy recovery turbine is usually rated as having a certain efficiency based on the conversion of hydraulic power into mechanical shaft power. This shaft output is then mechanically transmitted to the feed pump, which then converts that power back into hydraulic power in the solvent stream. The efficiency of that feed pump is not included in the efficiency calculation. A better measure of efficiency is the ratio of the hydraulic energy returned to the semi-lean solvent to the amount of hydraulic energy available in the rich solvent.

This ratio, the hydraulic transfer efficiency, or n_{te} , is defined as:

$$n_{te} = H_{out} / H_{in} [1]$$

H_{out} = Hydraulic energy transferred to the semi-lean solvent
 H_{in} = Hydraulic energy available from the rich solvent

In the case of a recovery turbine or reverse running pump, n_{te} is calculated by:

$$n_{te} = (n_{ert}) (n_{md}) (n_p) [2]$$

n_{ert} = recovery turbine efficiency
 n_{md} = mechanical power transmission efficiency between recovery turbine and semi-lean pump

n_p = semi-lean pump efficiency

Assume a CO₂ removal system uses a multistage semi-lean pump rated at 74% efficiency at the operating point. The system also employs a multistage reverse running pump as a recovery turbine that displays an efficiency of 80% at the operating point. The two units are coupled by a double extended shaft motor. The data is summarized as:

n_{ert} = 80% or 0.80

n_{md} = 100% or 1.00 (no loss)

n_p = 80% or 0.80

Substituting the above values into equation [2] yields an energy transfer efficiency, n_{te} , of 0.59 or 59%. That is, 59% of the hydraulic energy in the rich solvent is converted into hydraulic energy in the semi-lean solvent. The rest of the energy is lost.

On the other hand, the energy transfer efficiency of a turbocharger is independent of the semi-lean pump efficiency. Thus, the hydraulic transfer efficiency equation can be used to define the turbocharger efficiency—up to 80% for the Energy Recovery IsoBoost system.

ENERGY SAVINGS AND BENEFITS

The energy savings obtained by the proper implementation of liquid phase turbocharger technology may be estimated using:

$$\text{Power Savings (kW)} = \frac{Q \times \Delta P \times \varepsilon_t \times \rho_f}{\varepsilon_p \times \varepsilon_m \times 2299}$$

Where:

Q = Solvent fluid flow, gpm

ΔP = Differential pressure between the absorber and flash tank pressures, psi

ε_t = Overall turbocharger hydraulic efficiency

ρ_f = Solvent fluid specific gravity at operating temperature

ε_p = Solvent circulation pump efficiency

ε_m = Solvent circulation pump motor electric efficiency

2299 = Conversion factor

From operating experience, we may assign certain typical values for some of the variables above.

ρ_f = 1.05

ε_p = 0.8

ε_m = 0.95

Using these values, Table 1 shows some exemplary annualized energy savings.

Table 1 Energy Savings for Four Examples of Different Operating Conditions				
	Plant A	Plant B	Plant C	Plant D
Capacity (MTPD)	1000	1500	2000	2500
Absorber Pressure, psi	440	550	440	550
HP Flash Pressure, psi	110	110	110	110
Solvent Flow Rate, gpm	5300	8000	10700	13000
Power Savings, kW	841	1692	1698	2750
Annualized Energy Savings, MW-Hr.	6,998	14,083	14,127	22,885
Annualized Cost Savings ¹ , \$	699,752	1,408,306	1,412,707	2,288,498

1. \$0.10/kWh electricity cost

As expected, the energy and cost savings are significant for larger plants with larger solvent flows. Based on these energy savings alone, equipment related return-on-investment (ROI) periods are estimated to be 2-3 years for larger plants and 4-5 years for smaller plants. The actual ROI is, of course, highly specific to individual plant conditions.

DIFFERENT CONFIGURATIONS

IsoBoost technology does not limit different process configurations provided by different plants and licensors.

There are two main configurations that can be designed with the IsoBoost system:

Option A: 2 x 100% semi-lean solvent pump flow design (1+1)

Option B: 3 x 50% semi-lean solvent pump flow design (2+1)

Option A replaces a high-pressure pump with an IsoBoost and a low-head pump with optional variable frequency drive to produce the additional boost. The standby circulation pump remains available.

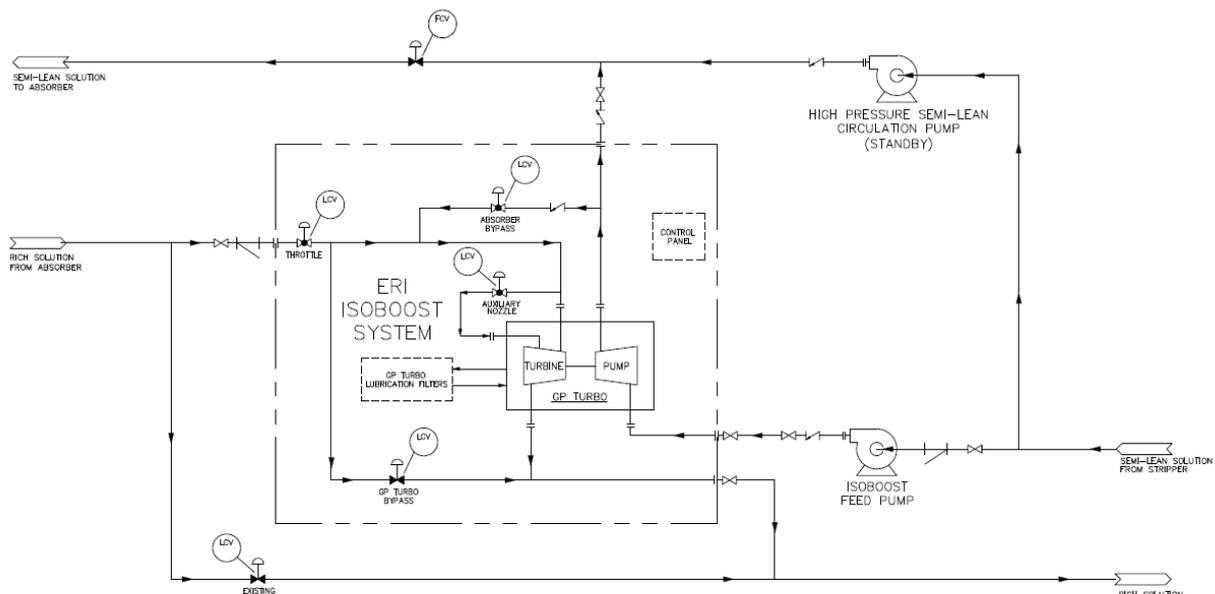


Figure 10: Option A, 2 x 100% semi-lean solvent pump flow design (1+1)

A significant amount of plants are designed with a 3x50% design configuration in the semi-lean solvent pumps, providing one of these pumps as standby. The same principle can be applied to the IsoBoost technology, where IsoBoost will replace one of the semi-lean solvent pumps.

Although Option A is better in terms of energy efficiency, the Option B configuration provides a lower CAPEX and can also be implemented in retrofits of existing semi-lean solvent pumps.

The main advantage of Option B, apart from initial investment, is that IsoBoost will use the necessary rich solvent flow to provide full pressure to the 50% of the semi-lean solvent pump with no need of booster pump. Necessary flow from rich solvent side will be controlled by the bypass valve that has been described in the section on control philosophy.

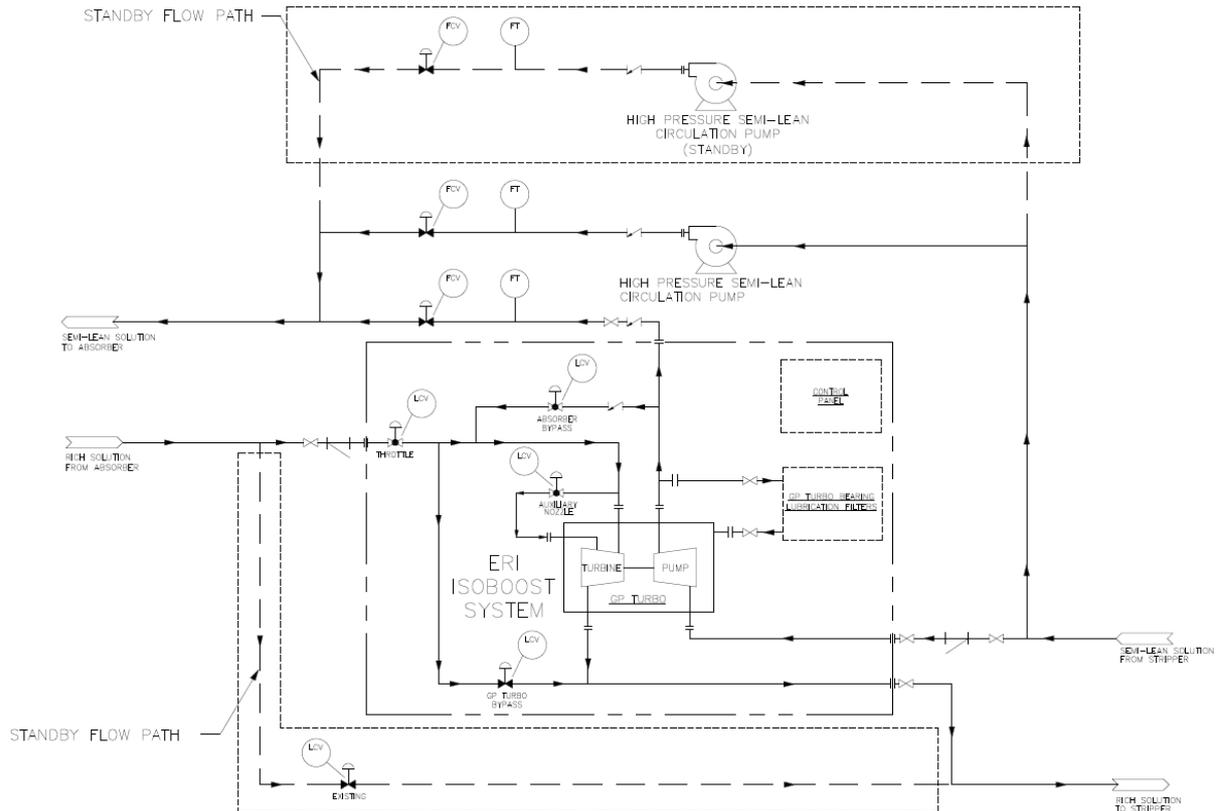


Figure 11: Option B, 3 X 50% semi-lean solvent pump flow design (2+1)

This configuration could be extrapolated for revamping an installation to increase capacity. Rich solvent flow will be used to power the additional amount of semi-lean solvent that needs the revamp, with the significant advantage that the existing semi-lean solvent pumps do not need to be overhauled.

CONCLUSION

The liquid phase turbocharger-based IsoBoost solution is unlike any energy recovery device used previously in ammonia plants. The turbocharger simplifies the pressurization of the lean solvent while recycling energy and incorporating process control. Including this solution in revamps or greenfield ammonia projects will lead to a more efficient, productive, and reliable plant with increased uptime.

ABOUT ENERGY RECOVERY

Energy Recovery (NASDAQ: ERII) develops award-winning innovations that make industrial processes more productive, more profitable and environmentally cleaner. Our solutions tap into pressure energy from

fluid flows to drive uptime throughout industrial processes. By recycling otherwise lost pressure energy, we are able to make systems more efficient and reduce overall maintenance costs, with solutions customized to adapt to all conditions. Working in oil & gas, chemical and water industries, more than 15,000 solutions worldwide save clients over \$1.4 Billion (USD). Headquartered in the San Francisco Bay Area, Energy Recovery has offices in Madrid, Shanghai, and Dubai. Learn more at www.energyrecovery.com