ENERGY RECOVERY FOR GAS PROCESSING

Recovery of the hydraulic energy in liquid-based gas processes has always held promise for improving the economics of plant operation. However, no energy recovery turbine (ERT) has combined the simplicity, low cost,and reliability of the PEI TurboCharger^{TM}.

Pump Engineering, Inc. has developed a revolutionary energy recovery device that will be equally appreciated by the OEM and the end user; the Hydraulic TurboCharger^{TM} or TURBO^{TM}.

With three U.S. patents and other patent applications pending in the U.S. and other countries, the TURBO^{TM} represents advanced technology in energy recovery.

PROVEN AROUND THE WORLD

Hundreds of TURBOs^{TM} are operating around the world in services similar to gas processing. Locations include the United States, Middle East, Caribbean, Canary Islands, and East Asia.

EXTENSIVE SELECTION

Pump Engineering offers a complete line of TURBOs^{TM} suitable for flows from 20 to 4,000 gpm per unit.

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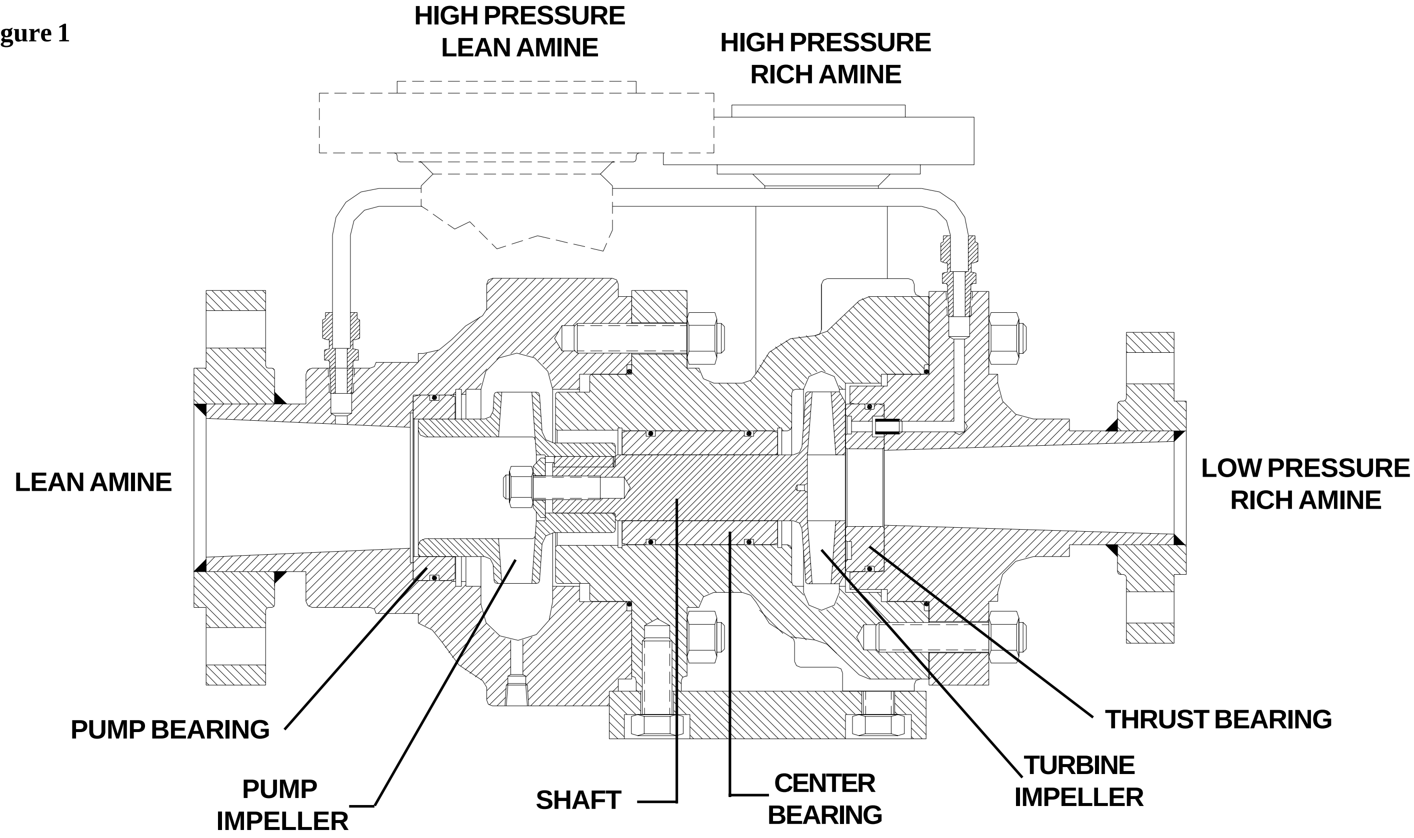
DEFINITION OF TERMS

PSI	Pounds per Square Inch
PSIG	Pounds per Square Inch Gauge
GPM	Gallons per Minute
HP	Horsepower
kW	Kilowatt
ERT	Energy Recovery Turbine

Designed specifically for hydraulic energy recovery, the TURBO™ addresses the major issues facing the gas processing designer and user including design simplicity, efficiency, reliability, maintainability, ease of field repair, and versatility.

Figure 1



Design

The TURBO™ is an integral turbine-driven centrifugal pump. The unit is driven by the high pressure fluid passing through the turbine section. The turbine is a single stage radial inflow type (similar to a reverse running pump). The pump is a single stage centrifugal type with its impeller mounted on the turbine shaft.

Two styles of TURBOs™ are offered. The smaller units use a one piece center body that houses both the turbine and pump sections. Larger units (see Figure 1) use a separate pump casing to permit interchangeability of casing sizes for greater hydraulic range.

Efficiency

Since the unit is not mechanically driven by a motor, the rotor freely seeks a running speed that maximizes efficiency. With just one moving part, no seals to generate drag, and virtually 100% volumetric efficiency, the TURBO™ is inherently efficient. In fact, its efficiency has set new standards for centrifugal fluid machinery.

Safety

The Turbo's rotor is entirely contained within the casings, hence there are no shaft penetrations of the pressure boundary and no shaft mechanical seals. The Turbo is "zero emissions" and inherently safe. This is expecially important when handling gas-processing fluids that can release hydrogen sufide or other dangerous gases into the environment.

Maintainability

The TURBO™ is designed to be overhauled in one to four hours, depending on size, using only hand tools.

Reliability

Elimination of shaft seals and separate lube systems (the TURBO™ is lubricated by the pumpage), as well as single stage design means that there are very few parts to fail. Use of high grade materials such as second generation duplex stainless steel, titanium, and ceramics add to reliability.

This manual describes several ways the TURBO™ can be used in gas processing plants to obtain energy savings, reduced capital costs, and increased plant reliability.

Applications presented in this manual should be considered as guidelines. Always confirm the feasibility of a condition change with the equipment suppliers involved.

FEATURES

Casings

Volutes are machined in both the pump and turbine casings of each Turbo. The nozzle connecitons are ANSI 600# class flanges. For models HPT-150 and above the pump casing is radially split for easy assembly/disassembly inspection and attached to the turbine casing by heavy hex nuts. The maximum operating pressure is 1500 psi.

Rotor

The turbine and pump impellers are closed, radial flow design for optimum hydraulic performance and efficiency. The pump side impeller is keyed to the shaft and mounted with a shrink fit against a shoulder. The turbine impeller is cast integral with the shaft. The complete rotor aassembly is dynamically balanced to ISO G 4 precision. All shaft surfaces that are in contact with journal or thrust bearings have a plasma sprayed ceramic coating of chrome oxide.

Bearings

The turbo utilizes two journal bearings for radial rotor positioning and one hydrostatic thrust bearing to carry unbalanced axial thrust. All bearings are made of aluminum oxide and are lubricated by the pump liquid. For gas processing, product lubricated bearings offer the following benefits:

- No grease or oil inventory
- Elimination of periodic maintenance
- No oil or shaft seals
- No possibility of operation without lubrication

Immunity to Ambient Conditions

The TURBO™ does not have shaft penetrations or external bearings. Thus, the TURBO™ can operate in the hottest desert environments, extreme dust, water sprays, etc. (the TURBO™ can operate even fully submerged in water). In short, the TURBO™ can handle virtually any external environment.

Flexible Installation

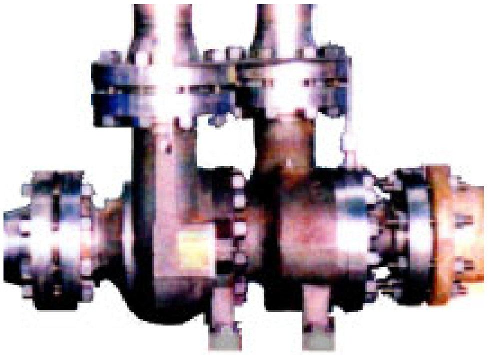
The TURBO™ may:

- be mounted in any orientation
- be located anywhere in the system including next to the absorber to reduce fluid piping costs
- discharge fluid against a backpressure.

HPT-50

Flow Control

The Turbo can be equipped with an optional auxiliary turbine nozzle and control valve that allows amine flow and pressure to be adjusted to maintain proper liquid level in the contactor. All of the amine passes through the TURBO™ for maximum energy recovery efficiency. For more information on flow control see page 7.



HPT-1200

Low Noise

Since the TURBO™ is entirely self-contained and uses journal bearings, its noise level is lower than other flow machines of comparable capacity and pressure differential. On lower pressure applications, often the only way to verify that the Turbo is operating is to observe the pressure guages for the Turbo boost pressure. Since the Turbo dramatically lowers the size and power of the high pressure pump, the overall noise level associated with this pump and its driver is also significantly reduced.

Compact Size and Light Weight

A unit able to handle 100 gpm (22 m3/hr) of amine can be held in one hand. The light weight combined with the flexibility described above insures the lowest cost and most convenient installation possible.

Customized Design and Manufacturing

Every TURBO™ is designed and manufactured to meet the customer's specific hydraulic conditions. A set of proprietary computer programs developed by PEI calculates the required dimensions of the hydraulic passages and automatically generates the CNC (Computer Numerical Control) programs to control the machine tools in the production process.

Advantages of custom machining includes:

- a perfect hydraulic match every time
- smooth hydraulic passages for added efficiency
- minimized lead times as PEI need keep only a few types of castings in inventory to cover a broad hydraulic range.

Figure 2 illustrates a simple liquid absorbent system. For the purpose of description, the term “amine” is used to designate any liquid absorbent. The principles described hold equally true for any absorbent.

High pressure amine passes through the contactor where it absorbs carbon dioxide and hydrogen sulfide from the gas. The amine, now called “rich amine” passes through a pressure reduction (throttling) valve. The depressurized amine is admitted to a stripper where the contaminants are removed from the amine. The “lean” amine is then pumped back into the contactor thus completing the process.

The required flows and pressure differentials are often high enough to make pumping energy a major cost factor. Most of that pumping energy, however, is lost in the pressure reduction valve. A large savings is obtainable if the hydraulic energy normally lost in the reduction valve can be recovered and “recycled” in the process.

Figure 3 shows the TURBO™ acting as a pressure booster in the lean amine stream. The rich amine passes through the turbine section where it gives up its hydraulic energy. The feed pump boosts the amine pressure to typically about 35-50% of the contactor pressure. The amine then passes through the pump section of the TURBO™ where it receives the final pressure boost.

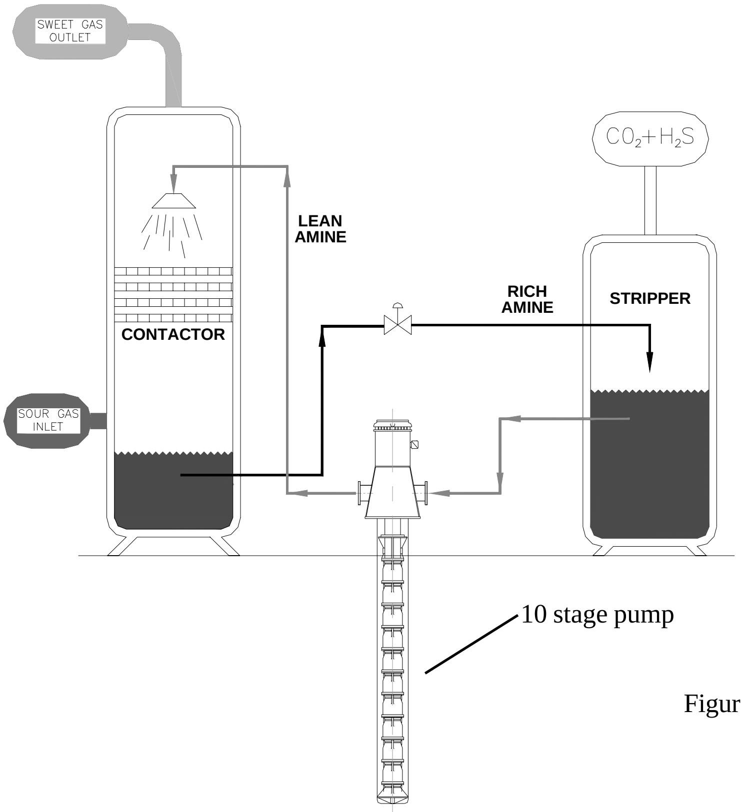


Figure 2

The TURBO™ is entirely engergized by the high pressure rich amine. The pressure reduction valve has been eliminated, and the size of the high pressure feed pump has been reduced. As will be shown later, the TURBO™ provides a significant reduction in pumping equipment costs. The savings may exceed the cost of the TURBO™ thus making the TURBO™ a zero or even negative-cost component.

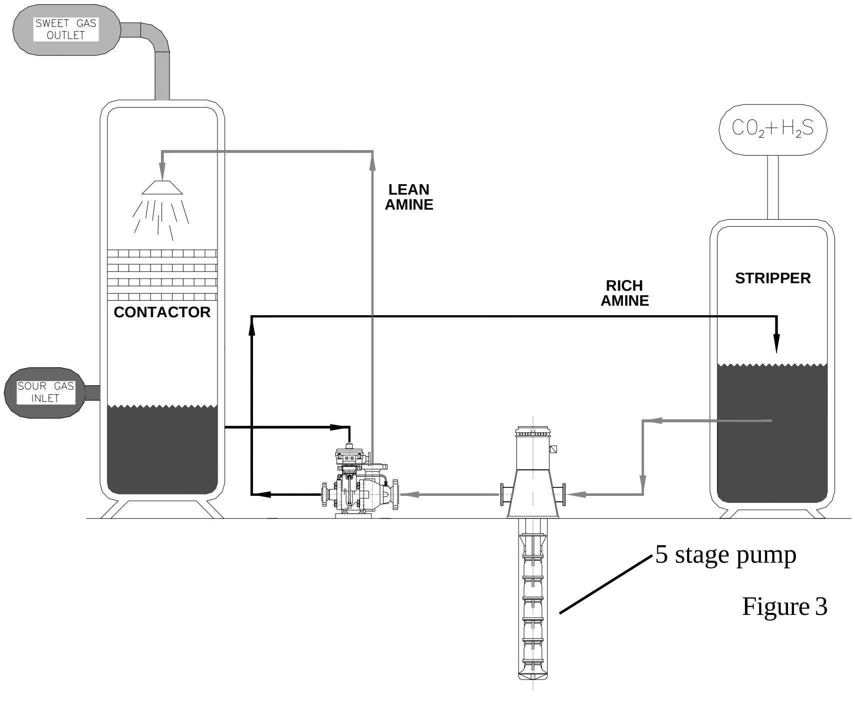


Figure 3

Performance Calculations

An energy recovery turbine is usually rated as having a certain efficiency based on the conversion of hydraulic power into mechanical shaft power. However, the liquid absorbent gas purification process relies on a varying absorbent pressure. Therefore, the most appropriate use of the recovered energy is to repressurize the amine. Thus, the ERT shaft output is mechanically transmitted to the feed pump which then converts that power back into hydraulic power in the amine stream.

A better measure of ERT efficiency is the ratio of the hydraulic energy returned to the lean amine to the amount of hydraulic energy available in the rich amine. This ratio, the **hydraulic transfer efficiency**, or **n**te, is defined as:

nte = **H**out / **H**in [1]

where **H**out = Hydraulic energy transferred to the lean amine

Hin = Hydraulic energy available from the rich amine

In the case of a reverse running pump ERT, **n**te is calculated by:

nte =(**n**ert) (**n**md) (**n**p) [2]

Where **n**ert = ERT efficiency

nmd = mechanical power transmission efficiency between ERT and feed pump

np = feed pump efficiency.

Assume an amine system uses a multistage feed pump rated at 74% efficiency at the operating point. The system also employs a multistage reverse running pump as an ERT that displays an efficiency of 70% at the operating point. The two units are coupled by a double extednded shaft motor. The data is summarized as:

nert = 70% or 0.70
nmd = 100% or 1.00 (no loss)
np = 74% or 0.74

Substituting the above values into equation [1] yields an energy transfer efficiency, **n**te, of 0.52 or 52%. That is, 52% of the hydraulic energy in the rich amine is converted into hydraulic energy in the lean amine. The rest of the energy is lost as heat.

Unlike conventional ERT's, the energy transfer efficiency of the TURBO™ is independent of the feed pump efficiency. Thus, Figure 2 can be used to find the approximate hydraulic energy transfer efficiency for the TURBO™.

Knowing **n**te makes calculation of the TURBO™ pressure boost, Δ**P**tc, very simple:

ΔPtc = (**n**te) (**R**r) (**P**ri - **P**ro) [3]

where **R**r = rich flow / lean flow

Pri = Rich amine pressure entering TURBO™

Pro = Rich amine pressure leaving TURBO™

The amine pressure drop, Δ**P**r, is defined as:

Δ**P**r = **P**ri - **P**ro [4]

Note that **R**r is typically equal to 1.0 thus equation [3] simplifies to:

Δ**P**tc = (**n**te) (**P**ri - **P**ro) [5]

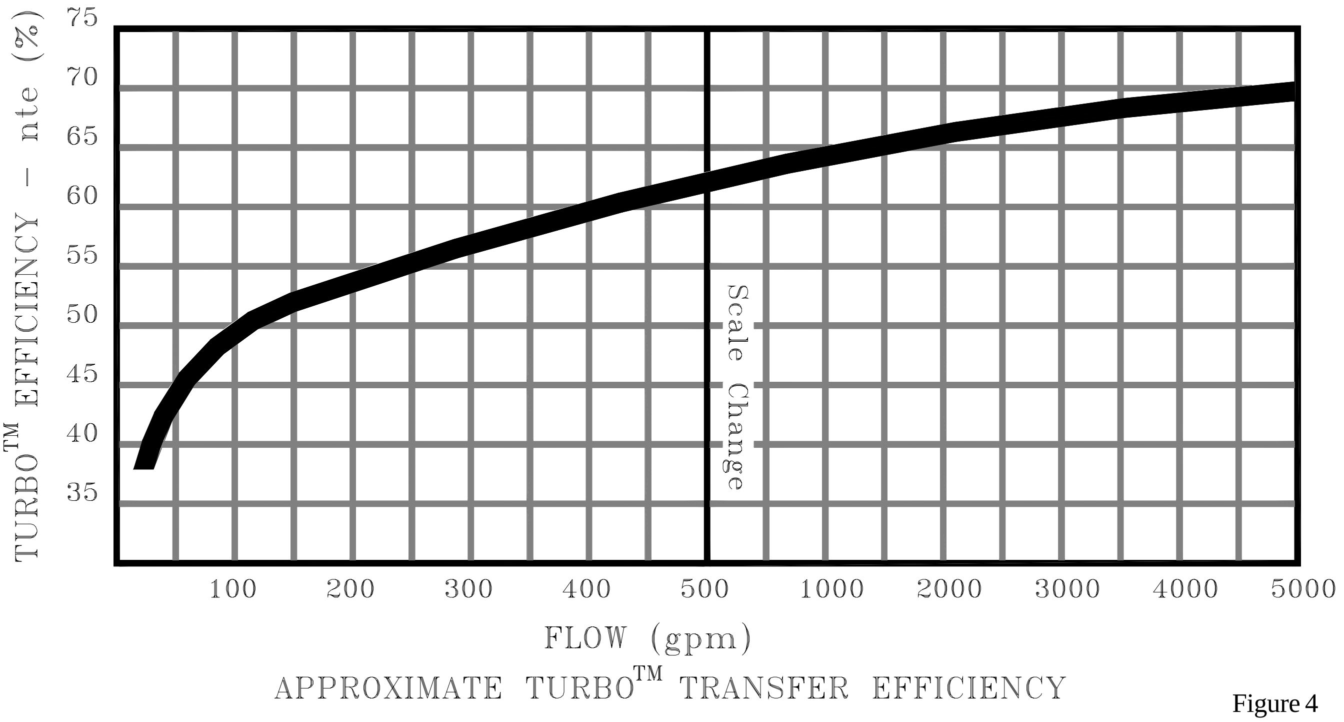


Figure 4

Calculating Amine Pressure Boost

The following example illustrates how to calculate the pressure boost generated by the TURBO™. In this example, the flow and pressures are as follows:

Q = 350 gpm (amine flow)
Pri = 980 psig (rich amine pressure to TURBO™)
Pro = 60 psig (flash tank pressure)
Plo = 995 psig (contactor pressure)

For 350 gpm of feed flow, **n**te is read from Figure 2 as 58%.

Substituting the above data into equation [5] yields:

Δ**P**tc = (.58) (980-60)
=534 psi

The feed pump discharge pressure **P**li equals the contactor pressure, Plo minus the Turbo™ boost ΔPtc or

Pli = (995-534) = 461 psi

Assumming the inlet pressure to the pump is 20 psig then the pump differential pressure is only 441 psig.

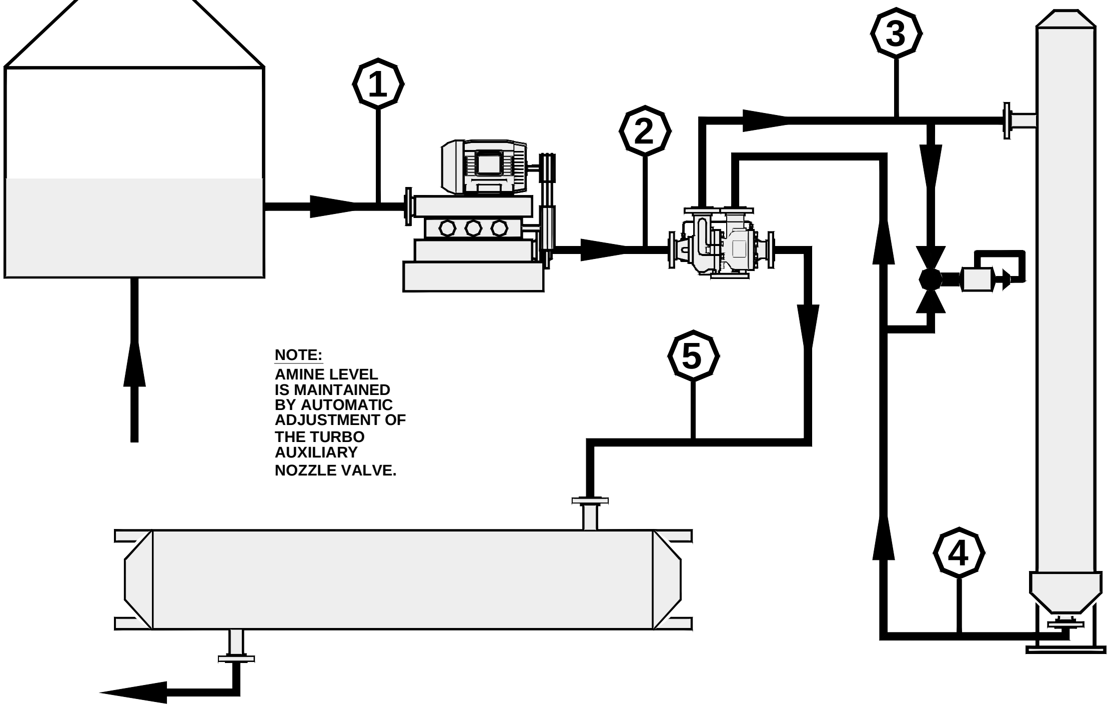
A more accurate analysis would account for pipe and fitting pressure losses as well as changes in elevation. Also, the specific TURBO™ model would be selected to permit a more precise determination of the efficiency.

As will be shown later, the large reduction on the required pump differential pressure has a very positive and substantial impact on the cost and type of pump and motor selection.

Figure 5

HYDRAULIC TURBOCHARGER HPT 450 FOR NATURAL GAS PROCESSING ENERGY RECOVERY

163kW SAVED
$131,062 PER YEAR COST REDUCTION *



LOCATION	FLOW(gpm)	PRESSURE(psig)	COMMENTS
		20	LEAN AMINE LEAVING STRIPPER
		461	LEAN AMINE PARTIALLY PRESSURIZED BY MOTOR DRIVEN FEED PUMP
		995	ADDITIONAL PRESSURE INCREASE PROVIDED BY TURBO ™
		980	RICH AMINE EXITING CONTACTOR AT HIGH PRESSURE
		60	RICH AMINE READY FOR STRIPPING

YEAR OPERATION

CENTRIFUGAL AND POSITIVE DISPLACEMENT FEED PUMPS

Since the TURBO™ is a self-contained unit, it can be used in conjunction with any type of feed pump such as:

- vertical turbine
- horizontal split case
- power (reciprocating)

However, the characteristics of the feed pump can influence the TURBO™ installation.

Reciprocating Power Feed Pumps

Positive displacement (PD) pumps deliver essentially a constant flow rate regardless of discharge pressure (assuming a constant-speed driver).

When used with a Power Pump, the TURBO™ simply reduces the Power Pump discharge by an amount that equals the TURBO™ boost pressure of the lean amine stream.

The implications are many, including improved service life of:

- plunger packing
- valves and seats
- crosshead and crank bearings.

Also, the power end will run cooler due to reduced frame loading. Likewise, the motor will run cooler and increased bearing life can be expected.

Note that the Power Pump can be sized to develop the full pressure so that if the TURBO™ were not in service, the plant can be operated normally.

The TURBO™ can also improve the performance of gas-charged pulsation dampeners. The reduced feed pump discharge pressure permits a reduction in the dampener charge pressure which makes the dampener “softer” thus better able to attenuate pressure pulsations in the fluid stream.

Centrifugal Feed Pumps

These pumps deliver a flow rate equal to the capacity at which the system resistance curve crosses the head-capacity curve of the pump.

Use of the TURBO™ can have a dramatic effect on pump selection. The very large pressure boost reduces pump discharge pressure such that:

- many fewer pump stages are needed
- much smaller motor and switchgear
- extended shaft seal life can be expected

In fact, the feed pump pressure is reduced to such an extent that a single stage feed pump is often sufficient. The greatly reduced capital and maintenance costs can offset the cost of the TURBO™ several times over.

CONTACTOR PRESSURE CONTROL

Every HPT is equipped with a flow control valve called the Auxiliary Nozzle Valve. Thus, the contactor pressure valve normally used in amine plants is replaced by the HPT. Flow and pressure adjustment can meet typical gas processing requirements. Contact PEI if the contactor pressure can vary more than 25% at a constant flow. Note that the entire rich amine flow passes through the turbine impeller regardless of the valve setting, thus ensuring maximum energy recovery.

A conventional reverse running pump requires two (2) pressure control valves. One valve adds flow resistance to the rich amine stream when the contactor pressure requirement exceeds the system resistance of the turbine (i.e. the operating point is above the hydraulic curve in the following figure.)

The other valve is used to bypass rich amine when the desired contactor pressure is below the curve. In either case, the energy recovery of the ERT is reduced. The broad operating envelope of the Turbo™ discounts these problems using one auxiliary nozzle valve.

MEDIUM-CAPACITY SYSTEM

This example compares a feed pump - TURBOTM package with a feed pump - reverse running pump package. TEFC 3600 RPM (60 Hz) motors are assumed. Data are based on manufacturer's published performance data, published prices and estimates. Electricity cost is assumbed to be $.10/kw-hr.

TURBO^{TM}

Total equipment costs = $97,555
Electrical power consumption = 134 kW

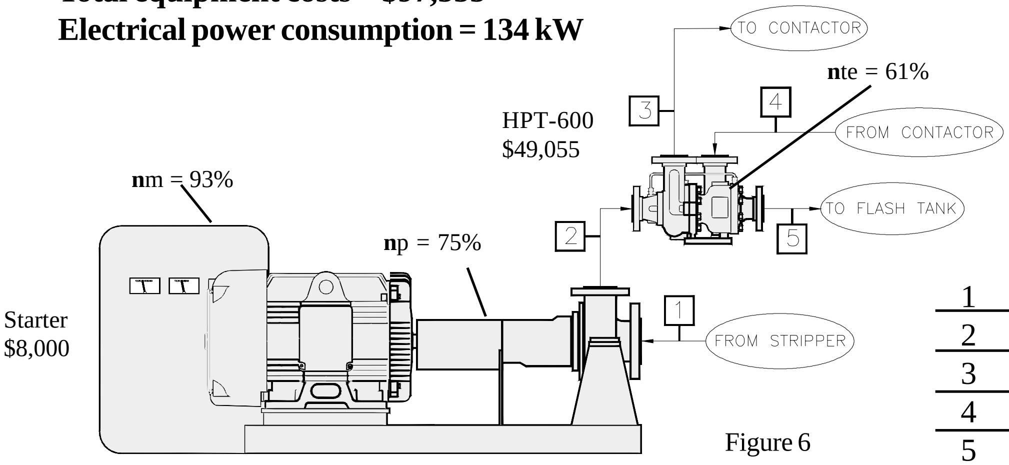


Figure 6

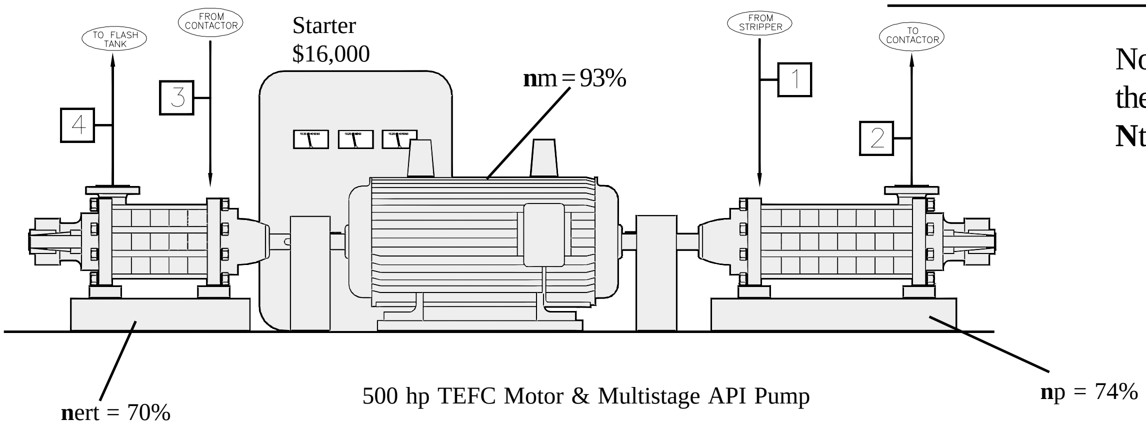
200 hp TEFC Motor & Pump Engineering's HPG Pump

	Flow (gpm)	**Pressure** (psi)
1	600	30
2	600	388
3	600	870
4	600	850
5	600	60

Energy Recovery Turbine

Total equipment costs = $151,000
Electrical power consumption = 164 kW

	Flow (gpm)	**Pressure** (psi)
1	600	30
2	600	870
3	600	850
4	600	60



500 hp TEFC Motor & Multistage API Pump

Note: For this example, the overall efficiency is **N**te= (0.074)(0.70) = 0.52

Figure 7

TURBO^{TM} Benefits

- The TURBOTM saves $68,000 in capital costs AND $33,300 per year in energy costs over the ERT
- The feed pump used with the TURBOTM is less expensive to install and overhaul
- The smaller starting electrical load will permit reduction in transformer and generator capacity
- Other cost savings include reduced foundation size

SMALL AMINE SYSTEM

The TURBO™ makes energy recovery cost effective even on small systems. This example calculates cost savings for a small system using a positive displacement feed pump.

Reciprocating Feed Pump with TURBO™

Total Equipment Costs = $33,684
Power Consumption = 23 kW
Energy Savings =
21.5 kW x \$0.10 $_{\text{kW-Hr}}$ x 8000 Hr/$_{\text{year}}$ = \$17,200

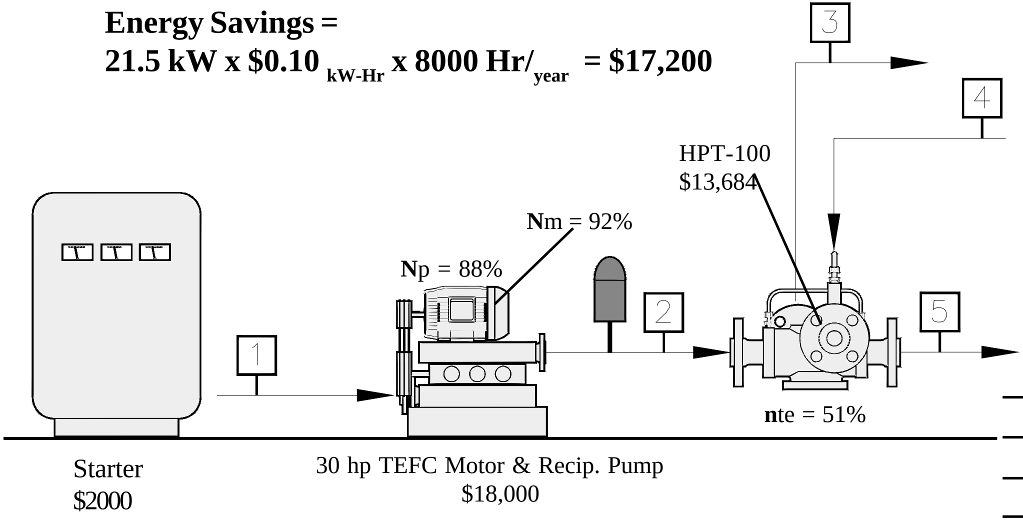


Figure 8

	Flow (gpm)	**Pressure** (psi)
1	90	30
2	90	524
3	90	950
4	90	930
5	90	60

Reciprocating Feed Pump - No Energy Recovery

Total Equipment Costs = $23,000
Power Consumption = 44.5 kW

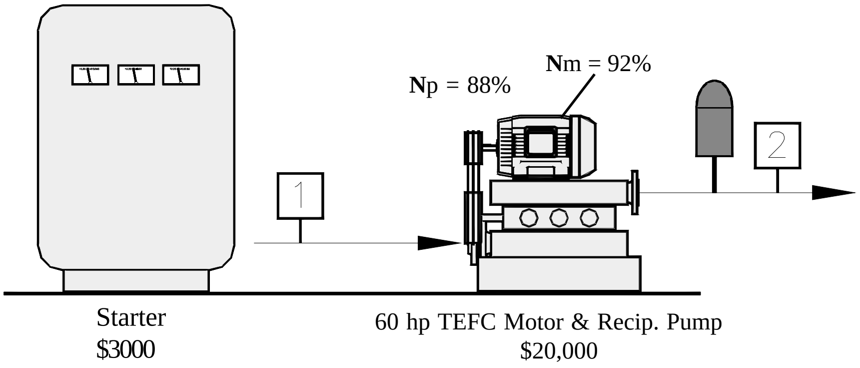


Figure 9

	Flow (gpm)	**Pressure** (psi)
1	90	30
2	90	950

TURBO™ Benefits

- $17,200 Saved in electricity. ($0.10 kW-hr electricity cost) Payback: 9.5 months
- Lower pump maintenance costs and higher reliability due to reduced pump discharge pressure.

CAPACITY INCREASE BY HIGHER FEED FLOW

In this design option, the objective is to increase the production in an existing plant using the original centrifugal pump and motor. A TURBO™ will be placed in series with the existing feed pump. The two untis will display a much greater hydraulic range than the feed pump alone. The increased hydraulic range permits greater amine flow thus allowing the addition of new contactor and stripper capacity for greater gas throughput.

In this example, the plant owner wishes to increase the capacity of the high pressure amine pumping system. The plant uses a 7 stage centrifugal feed pump. The NPSHR curve shows that the pump capacity can be increased from the present 500 gpm to 800 gpm without the NPSHA falling below the NPSHR.

Next, the TURBO™ boost is calculated near the 800 gpm rate. The combined feed pump - TURBO™ pressure is far higher than needed. At this point a decision needs to be made; should the TURBO™ be derated to produce less boost or should the pump be destaged thus saving pumping power.

Assume the owner wishes to save energy as well as increase capacity. A combined destaged pump - TURBO™ curve is then drawn based on removing three (3) stages (see Figure 10).

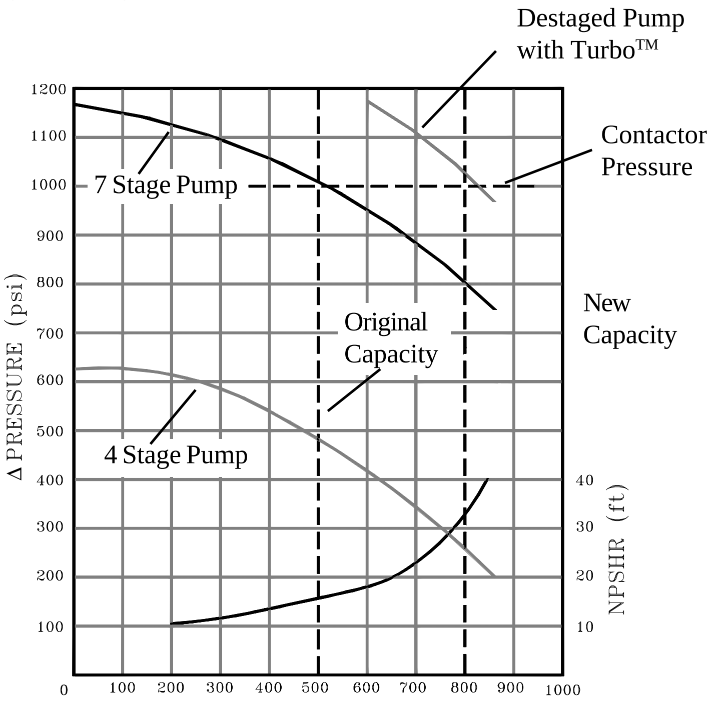


Figure 10

Areas to be Evaluated

Several areas need evaluation before using this approach.

- Contactor and stripper capacity need to be evaluated.
- The NPSHR of the feed pump must be satisfied
- Feed piping and headers must handle a higher flow
- Feed pump motor rating must not be exceeded
- Feed pump suitable for higher capacity

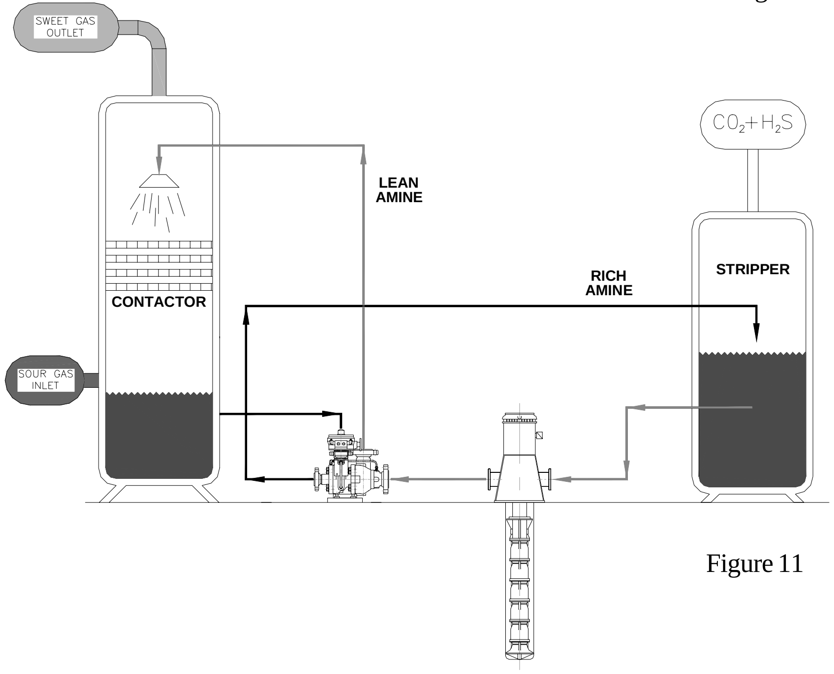


Figure 11

- Pumping capacity increased 60% using the existing feed pumps and motors
- Energy consumption per gallon of amine pumped reduced by 60%
- Minimized disruption to the existing plant

INSTALLATION

Characteristics of the TURBO™ that affect installation are described below:

Compact Size and Low Weight

The compact size permits installation in very confined spaces. A unit able to handle 100 gpm (23 m^3/hr) can be carried in one hand. A unit rated for 1,800 gpm weighs 520 lbs.

Flexible Installation

- mountable in any orientation
- supportable by the supply piping (HTC-25 thru HTC-100 only)
- locatable anywhere in the system

ANSI raised face flanges are standard.

The TURBO™ does not require shaft alignments or heavy foundations. Installation usually requires only simple pipe work, only the larger sizes require a modest foundation.

Low Noise and Smooth Flow

An operating TURBO™ is usually inaudible over the noise of the feed pump. The TURBO™ can reduce overall machinery noise by virtue of the reduced size of the feed pump and motor.

The TURBO™ does not generate pressure or flow pulsation in the fluid streams.

Pressurized Discharge

The TURBO™ can discharge the rich amine against any level of backpressure. There is never a need for a booster pump.

Other Factors

- Material selection should be based on specific experience. Standard material for the TURBO™ is alloy 2205 steel (a second generation duplex stainless steel).
- A pressure gage should be installed near the feed inlet to the TURBO™. Another pressure gage should be installed near the feed outlet of the TURBO™. These gages permit measurement of the amine pressure boost to verify normal operation.

Two-phase flow

There will be a release of gas as the amine is depressurized within the TURBO™. The TURBO™ is designed to handle levels of entrained gases typical in liquid absorbent systems.

Requirements

- Discharge pressure pulsation dampeners should always be used with reciprocating feed pumps. The dampener should be set for proper operation at the discharge pressure of the feed pump. Also, the dampener should be located between the feed pump discharge and the inlet to the TURBO™.
- Perform all pipe flushing <u>before</u> installing the TURBO™. Debris such as welding slag or mill scale can cause premature failure of the bearings.

See the PEI <u>Installation and Maintenance Manual</u> for further information and recommendations.

Flow Control and Energy Recovery in an Amine Gas Processing Plant Utilizing Positive Displacement Pumps

Many amine systems use positive displacement pumps (PD pumps) for the high-pressure charge service. Because of the constant flow output of theis type of pump flow control can be achieved in two ways, variable speed drives (VFD) or recirculation of flow through a high-pressure throttle valve back to the pump suction. VFDs have high capital cost and introduce additonal mantenance requirements and alsthough they save energy at the pump, they donot recover any energy that is consumed by the pump motor. Flow recirculation requires a relatively costly throttle valve and has the highest energy consumption.

The Turbo offers an elegant solution to PD pump flow control requirements. As seen in Figure 5 the total PD pump lean amine flow enters the pump side of the Turbo where it is boosted to contactor pressure. To control contactor level, a portion of the flow is diverted through a bypass valve directly to the rich amine flow from the contactor. The merged flow then enters the Turbo, therby providing energy recovery to 100% of the high-pressure pump output.

Flow Control and Energy Recovery in an Amine Gas Processing Plant Utilizing Centrifugal Pumps

When using centrifugal pumps as the high-pressure charge pump, recirculation of pump flow back to suction is not necessary as with PD pump driven systems. However, to control contactor level, the pump discharge is throttled to vary the capacity of the system. The amount of downturn can be significant, which results in energy losses by the pump running off design in a lower efficeincy range and by pressure lost through the throttle valve.

The use of the Turbo with centrifugal pump driven gas processing plants provides the optimum sulution to flow control and energy recovery. Like with the PD system the total flow at the pump duty point (which should be a t or near the pump's Best Efficiency Point) enters the pump section of the turbo where the flow is boosted to contactor pressure. Lean amine flow not required by the current operating conditions of the contactor is diverted throught the bypass valve as seen in Figure X to be merged with the rich amine flow coming from the contactor. The merged flow enters the turbine section of the Turbo, therby providing energy recovery for 100% of the high pressure pump flow.

STARTING AND OPERATION

Response Time

A question occasionally asked about the TURBO™ is its response time to changes in flows and pressures, especially during startup of the system.

Figure 12 shows the measured pressure during startup of a triplex reciprocating power pump equipped with a model HTC-150 TURBO™. Note that the TURBO™ feed discharge pressure lags the inlet pressure by only about 0.1 seconds. This responsiveness insures easy control of the system.

For complete starting and operation data refer to the PEI Installation and Operation Manual.

System Startup

Since the feed pump is downsized to take advantage of the TURBO™ boost, it can not generate enough pressure to establish flow through a fully pressurized contactor.

Since the TURBO™ comes up to speed quickly, simply precharging the contactor with a small amount of amine before pressurization will provide enough high pressure liquid to develop full TURBO™ boost.

If the above is not possible, then a bypass line with a valve connecting the TURBO™ lean amine outlet to the rich amine inlet can be used to briefly direct high pressure amine to TURBO™ turbine inlet (see figure 5). After a few seconds the valve can be closed as the valve to the contactor is opened.

MAINTENANCE

The Turbo's bearings are full fluid film lubricated and will have a long operating life, however rates of wear will depend on the cleanliness of the liquid. If it becomes necessary to replace the bearings, an overhaul is a very simple and quick procedure. A turbo overhaul consists of removing the TURBO™ from the piping, removing the end cap and pump casing, removing the pump impeller and then replacing the rotor and sleeve bearings. An overhaul can be done in one to four hours depending on the size of the TURBO™.

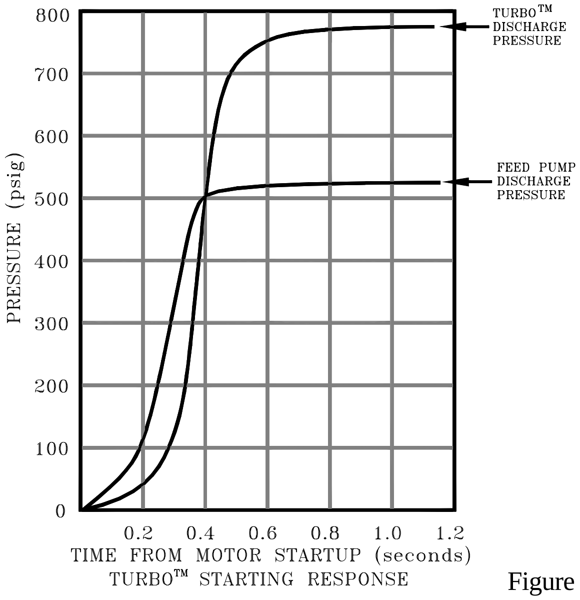


Figure 12

The radial bearing is a sleeve type and thrust bearing is a hydrostatic type. The bearings are mounted in O-rings with a "slip fit" with the casing. Removing the old bearings and installing new bearings is a simple manual procedure.

No Lubrication

Pumpage-lubricated bearings eliminate a range of problems such as contaminated oil, improper maintenance of oil level, oil seal failure, bearing cooling failure, etc.

No Shaft Seals

Shaft penetrations to the atmosphere, with the attendant shaft seals, don't exist with the TURBO™. Shaft seals require periodic maintenance and can catastrophically fail resulting in emergency shutdowns.