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SERVICE REGION
Middle East

ERI PRODUCT DIVISION
Oil & Gas

Waste-to-Energy in Amine Gas Sweetening:

An Innovative Approach to Recovering Hydraulic Energy from Natural Gas Processing Acid Gas Removal Units

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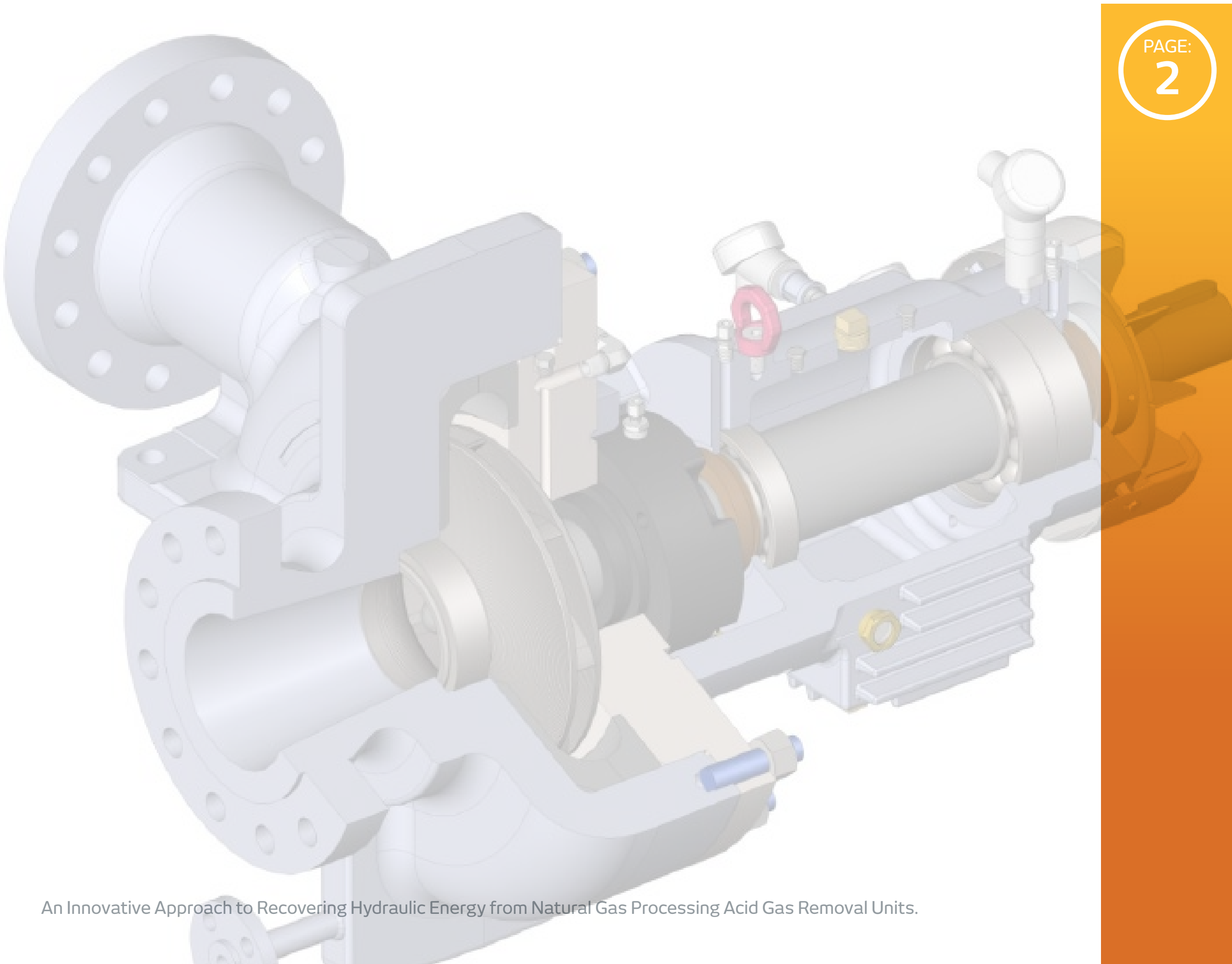
EXECUTIVE SUMMARY

Pressure is a common byproduct of many oil and gas related operations, and though it has the ability to reliably drive a wide range of processes, it's largely been disregarded as a potential source of energy. This, however, is quickly changing as producers look for new and efficient ways to cut carbon emissions and overcome the challenges associated with increasing operating costs. Energy Recovery's innovative IsoGen™ system has proven to be effective to reduce carbon footprint while creating electricity and increasing operational efficiency.

Amine gas sweetening is an energy intensive process commonly used to remove hydrogen sulfide and carbon dioxide from natural gas streams. The process involves an amine gas contactor that typically operates at pressure up to 1200 psi (83 bar), and an amine regenerator that operates at near atmospheric pressure. Energy is first consumed in pumping lean amine from the regenerator up to contactor pressure, and later dissipated in depressurizing the rich amine exiting the contactor at the level control valve (LCV). The IsoGen is a skid-mounted system with a hydraulic turbogenerator and state-of-the-art ancillary equipment. The size of the IsoGen unit discussed in this paper is per client specifications and flow range. For this particular reference, the IsoGen System can recover as much as 80% of the energy wasted but the IsoGen's efficiency can go well beyond 80% in other applications. This paper provides an example of a hydraulic turbogenerator system retrofit for an amine gas treatment plant in Saudi Arabia with an electrical power output at the rated operating point of 637 hp (475 kW).



INTRODUCTION

Natural gas is an abundant, reliable, and clean-burning source of energy that is typically processed to remove impurities before use. This process, known as amine gas treating, gas sweetening, or acid gas removal, consumes a significant portion of the electrical energy associated with delivering gas from the wellhead to the distribution pipeline. Much of this pressure energy has historically been wasted, the value of which as a potential energy source has been largely ignored.

It is now possible, however, to capture the energy found in high pressure process flows in the oil and gas value chain. Energy Recovery's IsoGen™ system converts this pressure energy into electrical energy, creating opportunities for productivity gains and improved profitability. The IsoGen can be understood as a "waste-to-energy" system, analogous to hydroelectric power. With up to 85% efficiency, the IsoGen skids can be installed in parallel for maximum flexibility. This paper focuses on the core technology in the IsoGen™ system: The hydraulic turbogenerator. It explains the technology and provides witness performance test data and results for an IsoGen™ system designed for a large gas plant in Saudi Arabia.

The IsoGen is a waste-to-energy system much like hydroelectric power.

The IsoGen will reduce this Saudi plant's carbon footprint annually by 2,750 metric tons of CO_2.

At the customer gas plant in Saudi Arabia, an amine circulation flow of 2500 gpm and a contactor to flash tank differential pressure of 475 psi result in an annual hydraulic energy dissipation of 4.5 gigawatt-hours in the existing level control valve. The IsoGen™ turbogenerator to be installed in the stated facility can capture up to 80% of this wasted energy, resulting in an annual electricity savings of $US 362,000, assuming an energy cost of 0.10 USD per kilowatt-hour and a significant reduction in carbon footprint of 3,620,000 kWh x (1.52 lb CO2 / kWh*), or 2,750 tons of CO2 per year. This reduction in carbon dioxide output translates to almost 6,500 barrels of oil consumed or 3 million pounds of coal burned per year – underscoring the IsoGen's positive environmental impact. Another added benefit of the system is expanded processing capability without having to increase plant electrical feed size.

CONVENTIONAL CONFIGURATION IN AMINE GAS PROCESSING

A typical gas processing facility operates the contactor (absorber) at pressures of up to 1200 psi and the regenerator circuit at pressures as low as 50 psi. The process is typically configured (shown in Figure 1 below) so that a high pressure amine circulation pump pressurizes the lean amine above the contactor pressure to start the absorption process, while a pressure letdown valve, used as the contactor LCV, reduces pressure in the exiting amine fluid stream prior to entering the regenerator (stripper). Energy is dissipated and lost through the letdown action of the contactor LCV.

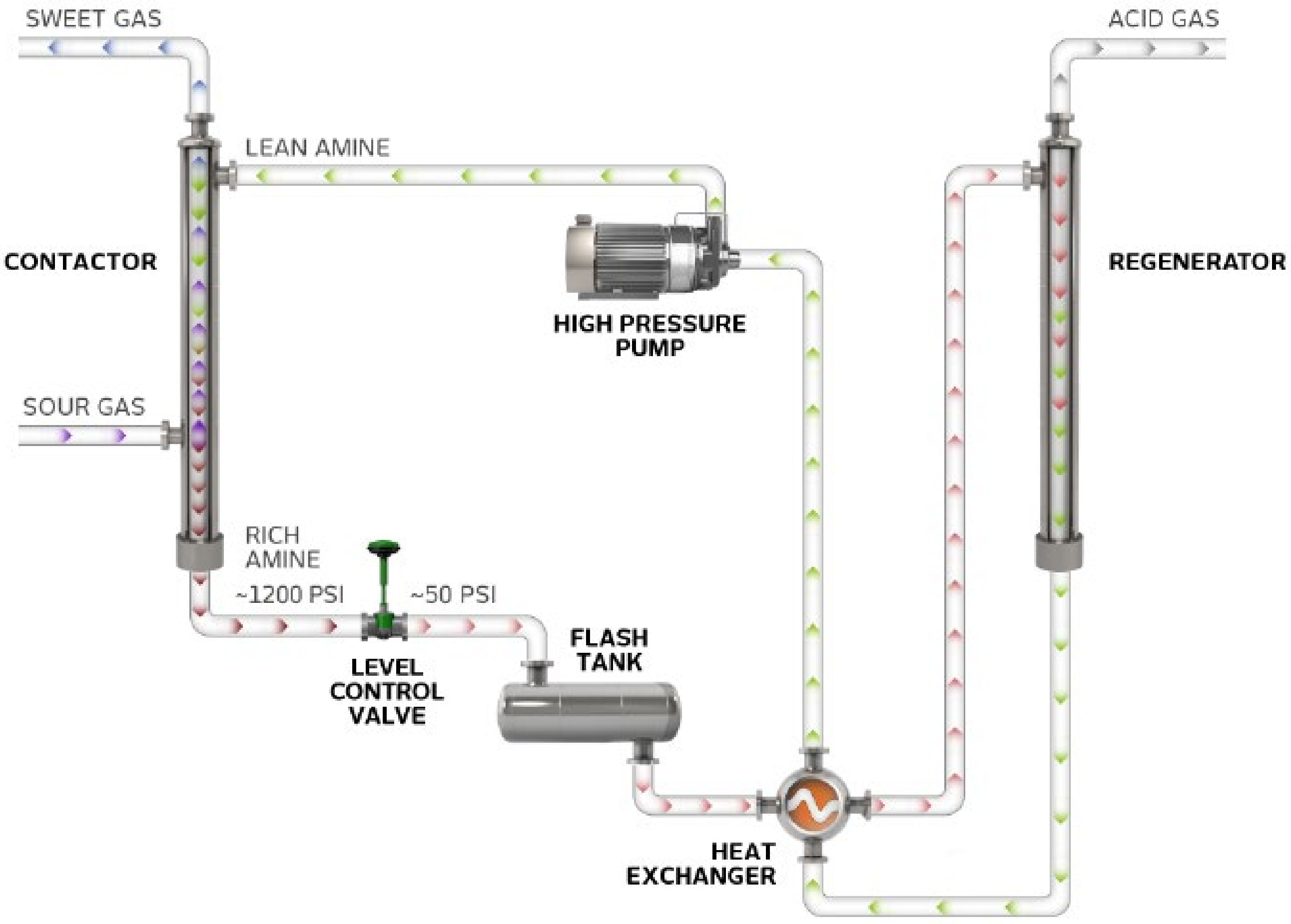


Figure 1 – Conventional configuration of an amine gas treating circuit

HYDRAULIC TURBOGENERATOR APPLICATION IN AMINE GAS PROCESSING

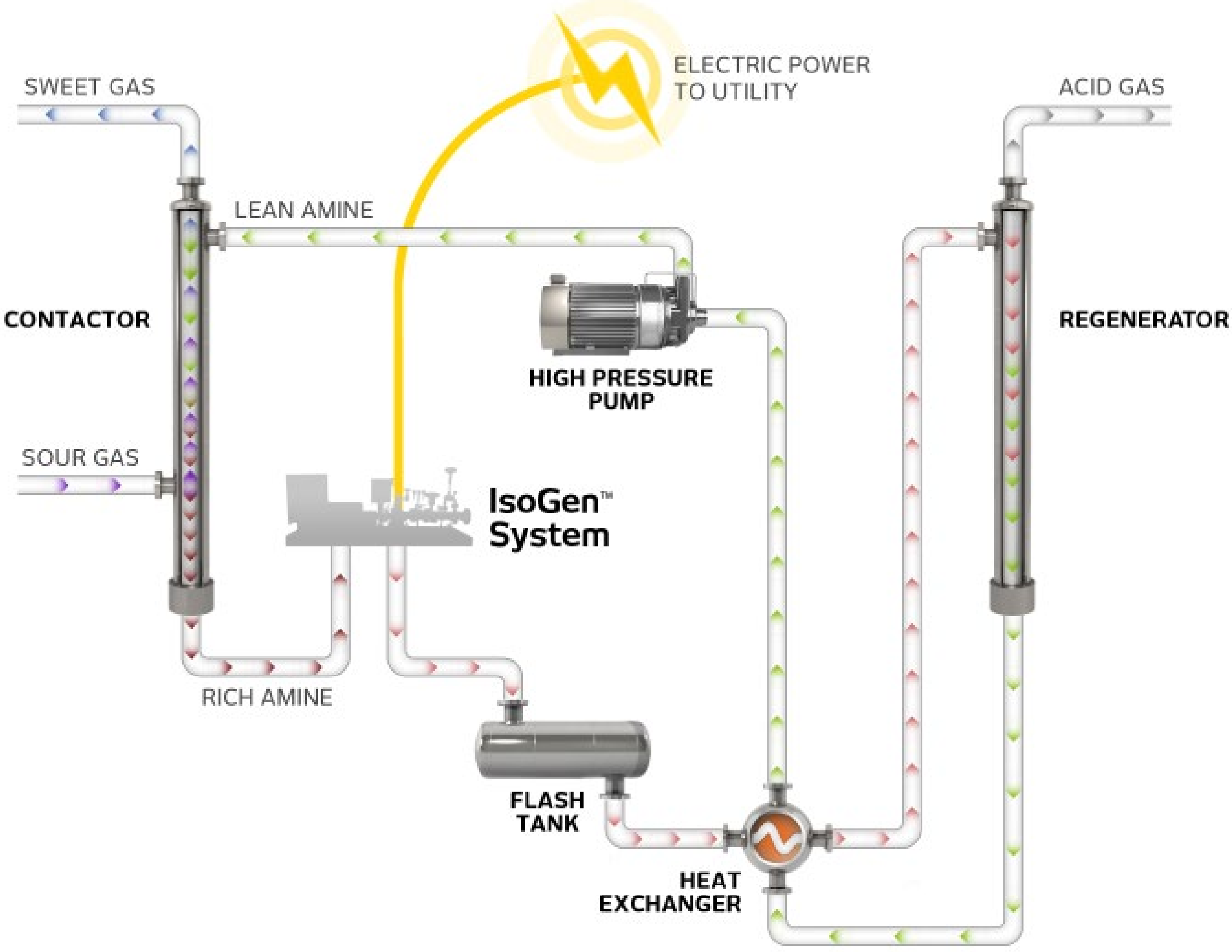


Figure 2 – IsoGen™ system configuration of an amine gas treating process

The IsoGen System, Figure 3 and schematically in Figure 4, is a standalone solution that coverts hydraulic energy to electrical energy. It is designed to replace existing throttle, backpressure, and LCVs in pipeline and process flow applications. Energy that is usually wasted within these valves is efficiently converted to usable electricity that can be used to reduce a plant's overall electricity consumption or, in some cases, be returned to the electrical grid. A wide range of flows and pressure drops can be accommodated at peak efficiency by a single unit using IsoGen's unique auxiliary nozzle technology and variable speed induction generator.

Hydraulic Turobgenerator Application in Amine Gas Processing (cont.)

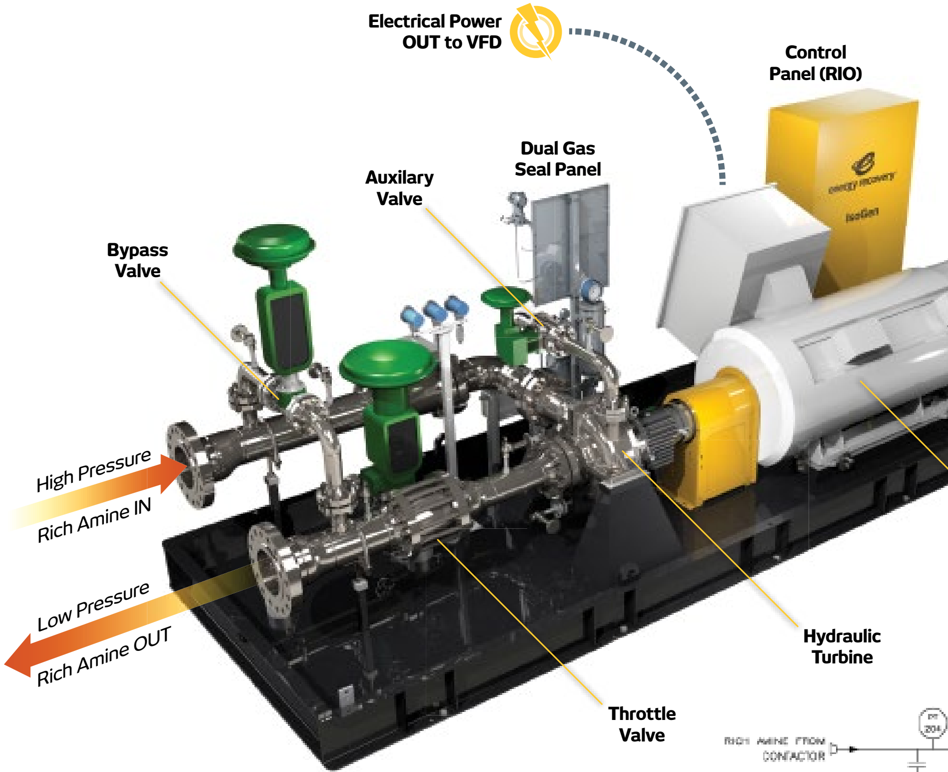


Figure 3 – The Waste-to-Energy IsoGen™ System

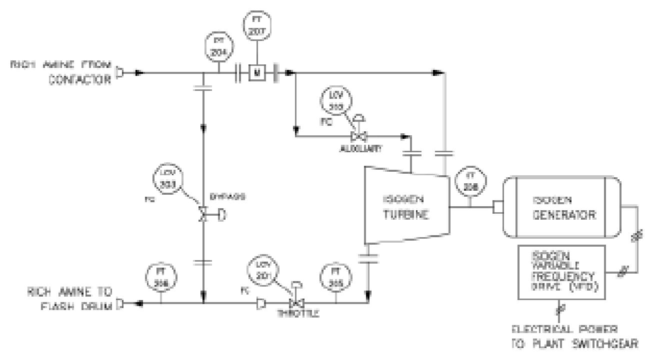


Figure 4 – Simplified Piping and Instrumentation Diagram (P&ID) of the IsoGen™ System

At the core of the IsoGen System is a single-stage turbine that drives a medium voltage variable speed induction generator.

At the core of the IsoGen System is a single-stage turbine that drives a medium voltage variable speed induction generator. The generator's output is conditioned to match grid voltage and frequency at near unity power-factor using a regenerative variable frequency drive (VFD). Turbine runner hydraulics are custom designed and fabricated to meet each customer's unique process conditions. Insertable nozzle and volute geometries allow the turbine hydraulics to be easily retrofitted if flow or pressure drop requirements change by a significant amount. Because of the turbine casing's back pullout configuration, turbine hydraulics can be replaced in a matter of hours without disturbing the process piping connections. This flexibility is key to allow for plant capacity changes. The IsoGen turbine has external oil-mist lubricated anti-friction bearings that make the device highly resistant to debris suspended in the process flow. A rigid bearing housing, low shaft flexibility index (L3/D4), closed cycle oil-mist lubrication, and magnetic face seal bearing isolators ensure premium reliability in even the most severe operating environments. A state-of-the-art Plan 74 dual gas shaft seal allows the unit to be deployed with almost any process liquid and virtually eliminates fugitive emissions.

Diagnostic Overview of Hydraulic Turbogenerator Application

Both turbine and generator are designed to be API compliant and are rated for use in hazardous environments. Pressure drops and flows that lie outside of the turbine's already large operating envelope are accommodated using a parallel bypass valve as well as a series throttle valve. The generator and valves are controlled by a programmable logic controller (PLC) using Energy Recovery's proprietary control algorithms. The PLC code is customized by application to seamlessly integrate with existing plant controls. High operational reliability and safety are ensured through continuous monitoring, analysis, and logging of numerous process and machine parameters. A screenshot of the PLC human machine interface (HMI) can be seen in Figure 5.

Both turbine and generator are designed to be API compliant and are rated for use in hazardous and extreme environments.

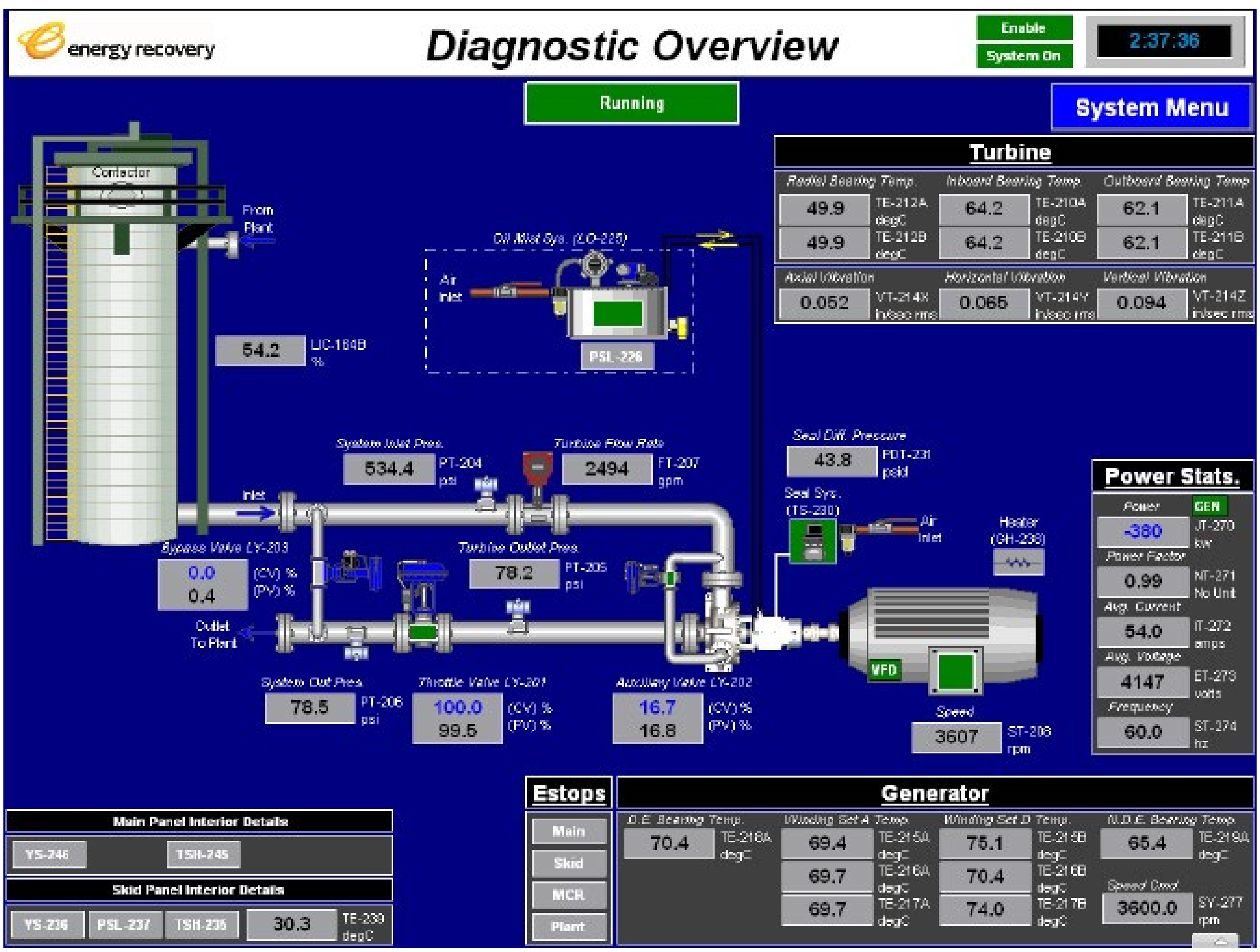


Figure 5. Screen shot of the IsoGen™ system HMI at the "Normal Operating Point"

PROCESS CONTROL METHODOLOGY

Process control of the contactor is achieved through controlling the flow of lean amine into the top of the contactor and simultaneously controlling the level of the rich amine in the bottom of the contactor. The flow rate of the amine entering the contactor is controlled by a throttle valve located downstream of the high pressure amine circulation pump. Energy Recovery recommends using VFD to control the high pressure amine circulation pump, which saves energy by eliminating throttling losses.

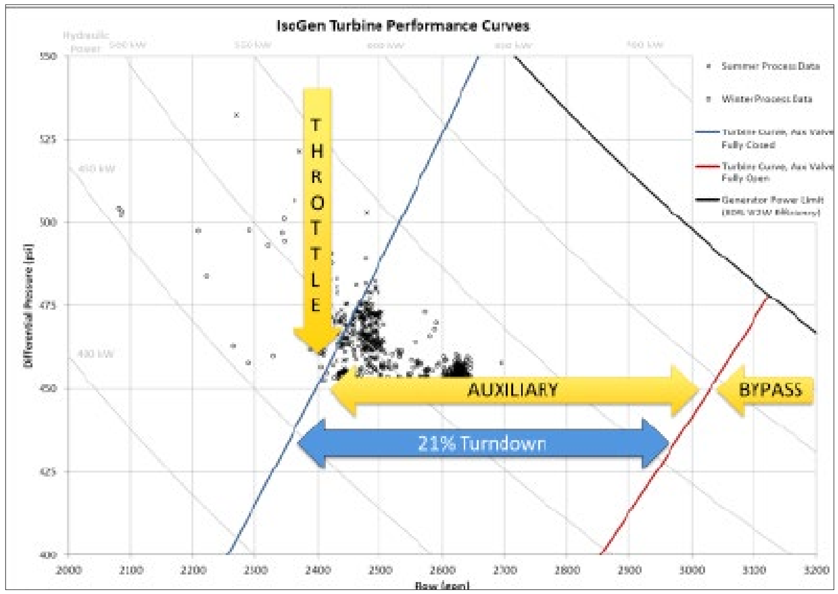


Chart 1 – IsoGen™ valve control strategy

The IsoGen System is designed to seamlessly integrate into a plant's existing architecture by replacing the existing LCV and using the valve's existing control signal. Contactor level control is achieved through Energy Recovery's control system, which coordinates the operation of the auxiliary, bypass, and throttle valves on the IsoGen System. The level control signal is received from the plant and split into three ranges to activate the three system 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 contactor in response to the level control signal. The turbine in this application achieved a flow turndown of approximately 21% using only the auxiliary valve, while maintaining near peak efficiency. If the level control signal demands a flow response that is lower than the lowest flow achievable in normal operation, (auxiliary valve almost fully closed) the throttle valve begins 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 achievable in normal operation, (auxiliary valve almost fully open) the bypass valve enters the control scheme by opening and bypassing additional flow to the flash tank. Chart 1 graphically represents this behavior.

The IsoGen System operates at near maximum efficiency across a 21% turndown range.

The IsoGen System is designed to seamlessly integrate into a plant's existing architecture by replacing the existing LCV and using the valve's existing control signal.

PROCESS CONTROL METHODOLOGY (CONT.)

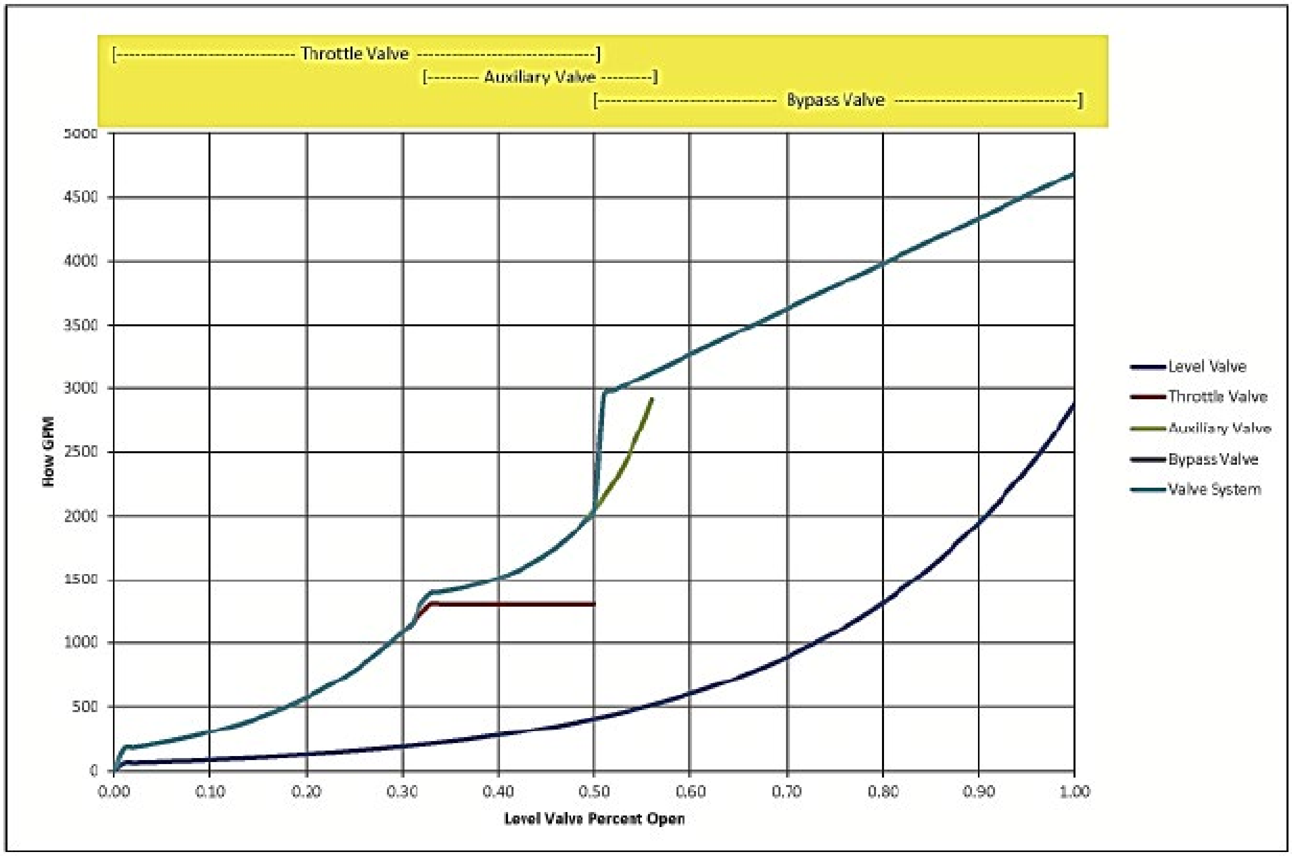


Chart 2 – Example of the LCV percent open command vs. the IsoGen™ system valve response

Chart 2 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 Energy Recovery's proprietary control algorithms.

- The throttle valve operates from 0 to 100 percent open with a level control signal of 0 to 50 percent.
- The auxiliary valve operates from 0 to 100 percent open with a level control signal of 31 to 56 percent. This valve begins to open before the throttle valve is completely open.
- The bypass valve operates from 0 to 100 percent open with a level control signal of 50 to 100 percent. This valve begins to open before the auxiliary valve is fully open.

If desired, the control algorithm can be adjusted to create operating characteristics similar to the LCV the system replaces, simplifying installation. The PID controller on the plant end does not need to be adjusted or re-tuned when an LCV is replaced with an IsoGen™ system.

TESTING, VALIDATION AND DEPLOYMENT

The IsoGen System described in this paper will be installed at a large gas plant in Saudi Arabia in 2014. Test criteria defining success and acceptable performance were extracted from industry standards, including API 610 and API 682, among others. An operating window was established based on gas plant data representative of winter and summer process conditions.

Performance Measurement

A "normal operating point" was defined at the averaged center of the representative process data, as well as a "rated operating point" at the upper bounds of flow and differential pressure. Eight additional test points were defined to encompass the supplied process conditions and represent a test of the system's operating window. A tabular representation of the test points is presented in Table 2.

The test success criteria and measured results can be summarized as follows:

Criteria	Performance Requirement	Witness Test Measured Value
Normal Operating Point		
Corrected** hydraulic to electrical efficiency	Greater than 70%	77.3%
Power factor	Greater than 0.90	0.99
Bearing housing vibration	Less than 0.18 inch/s RMS	0.05, 0.07, 0.09 (X, Y, Z in/s)
Turbine bearing temperature	Less than 93°C	68.5°C, 66.6°C 51.0°C (Inboard, outboard, radial)*
Rated Operating Point		
Corrected** hydraulic to electrical efficiency	Greater than 70%	75.7%
Power factor	Greater than 0.90	0.99
Bearing housing vibration	Less than 0.18 inch/s RMS	0.06, 0.08, 0.10 (X, Y, Z in/s)
Turbine bearing temperature	Less than 93°C	68.7°C, 66.7°C 50.7°C (Inboard, outboard, radial)*
All Other Operating Points		
Power Factor	Greater than 0.90	0.99 – 1.00
Bearing housing vibration	Less than 0.18 inch/s RMS	0.08, 0.10, 0.13 (X, Y, Z in/s Maximum recorded value over all points)
Turbine bearing temperature	Less than 93°C	68.3°C, 66.5°C 51.1°C (Inboard, outboard, radial. Maximum recorded value over all points)

Table 1 – Test points

* – Inboard bearing is the thrust bearing closest to the turbine runner
– Outboard bearing is the thrust bearing closest to the coupling

** Viscosity correction per American National Standards Institute
– Hydraulic Institute 1.6, Section 1.6.5.8.9, x=0.1 is used per Energy Recovery standard.

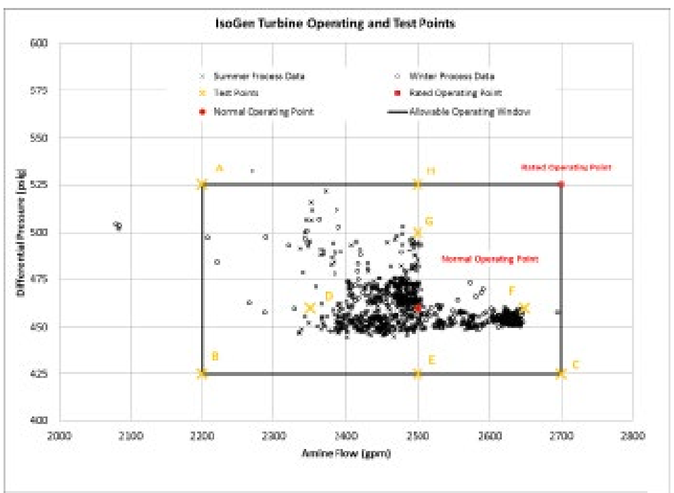
TESTING, VALIDATION AND DEPLOYMENT (CONT.)

Test Loop Description

The IsoGen System was tested at Energy Recovery's test facility in San Leandro, California, USA using a closed test loop comprised of a pump, heat exchanger, expansion tank and instrumentation. The test fluid was potable water at a maximum temperature of 110˚F (43˚C).

A dedicated test loop control system maintains the test fluid temperature as well as the inlet and outlet pressures supplied to the IsoGen System. The test loop flow is controlled by the IsoGen System operating the turbine and control valves.

Process fluid values (flow, pressures, temperature) are continuously recorded by the test loop control system. Additionally, the IsoGen System itself continuously records all values from the onboard instrumentation: power generated, power factor, process flows and pressures, bearing housing vibration (3 axis), turbine and generator bearing temperatures, generator shaft position, generator winding temperatures, and valve positions.



Test Point	Flow (gpm)	dP (psi)
Normal Operating	2500	460
Rated Operating	2700	525
A	2200	525
B	2200	425
C	2700	425
D	2350	460
E	2500	425
F	2650	460
G	2500	500
H	2500	525

Table 2 – IsoGen System Test Points

Test Conditions

Test Points were selected upon review of customer-supplied historical contactor pressure, flash tank pressure, and amine flow. This data is summarized in Table 2. The IsoGen™ system is capable of adjusting to and accommodating variations in these parameters that may be caused on-site by piping losses, hydrostatic head, or other conditions.

TESTING, VALIDATION
AND DEPLOYMENT (CONT.)

Energy Recovery, Inc.
CERTIFIED IsoGen PERFORMANCE TEST RECORD

energy recovery™

Proposal Information		Project Information	
Proposal No.		Project Name	Seagull
Order No.		Plant Location	Saudi Arabia
Part No.		Customer	
Serial No.		Test Date	5/29/2013

Operating Data Point	Eqn	Normal	Rated	A	B	C	D	E	F	G	H
Rich Amine Flow (gpm)		2500	2700	2200	2200	2700	2050	2500	2650	2500	2500
Contactor Discharge Pressure (psi)		540	605	605	505	505	540	505	540	580	605
Flash Tank Inlet Pressure (psi)		80	80	80	80	80	80	80	80	80	80
Differential Pressure (psi)		460	525	525	425	425	460	425	460	500	525
Testing Processing Flow Data											
Testing Starting Time (h:m:s)		13:58:00	13:38:00	14:20:00	14:16:00	13:42:00	14:12:00	14:02:00	13:46:00	13:54:00	13:50:00
Testing End Time (h:m:s)		13:59:00	13:39:00	14:21:00	14:17:00	13:43:00	14:13:00	14:03:00	13:47:00	13:55:00	13:51:00
Process Flow (gpm)		2485.5	2691.7	2204.4	2198.1	2697.6	2348.5	2508.0	2639.5	2501.4	2504.7
Turbine Inlet Pressure (psi)		535.2	604.3	601.4	500.6	500.4	534.1	503.1	538.8	577.2	601.2
Turbine Outlet Pressure (psi)		78.0	86.7	212.1	113.6	78.6	91.4	78.1	78.6	80.2	112.3
Skid Outlet Pressure (psi)		78.8	77.3	67.1	74.3	78.1	77.6	77.3	77.7	75.5	74.0
Generator Data											
Generator Speed (rpm)		3604.0	3604.6	3317.8	3308.2	3395.1	3539.9	3454.0	3584.7	3604.1	3604.3
VFD Output Power (kW)		-387.8	-475.2	-288.0	-285.3	-387.6	-352.6	-363.5	-416.0	-415.6	-416.8
VFD Power Factor		0.99	0.99	0.99	0.99	1.00	0.99	0.99	0.99	0.99	0.99
Vibration Data											
BH Vibration X (in/s)		0.049	0.057	0.052	0.036	0.075	0.045	0.066	0.055	0.047	0.049
BH Vibration Y (in/s)		0.071	0.083	0.096	0.077	0.099	0.079	0.096	0.080	0.079	0.079
BH Vibration Z (in/s)		0.093	0.104	0.113	0.090	0.126	0.089	0.096	0.109	0.093	0.087
Piping Info											
Turbine Inlet Pressure Gauge Pipe Size (in)		8	8	8	8	8	8	8	8	8	8
Turbine Outlet Pressure Gauge Pipe Size (in)		6	6	6	6	6	6	6	6	6	6
Skid Outlet Pressure Gauge Pipe Size (in)		8	8	8	8	8	8	8	8	8	8
Temperature Data											
T BH Inboard Bearing (°C)		68.5	68.7	64.4	66.7	68.1	67.7	68.3	67.0	68.1	67.0
T BH Outboard Bearing (°C)		66.6	66.7	63.6	65.2	66.3	66.0	66.5	66.1	66.3	66.1
T Radial Bearing (°C)		51.0	50.7	50.5	50.8	50.3	50.0	50.8	50.5	51.1	50.0
T Winding Phase X Set A (°C)		72.8	73.2	71.0	71.8	73.0	72.1	72.6	72.8	72.5	72.8
T Winding Phase X Set D (°C)		78.4	78.8	76.7	77.3	78.5	77.8	78.2	78.4	78.5	78.4
T Winding Phase Y Set A (°C)		73.0	73.3	71.3	71.9	73.2	72.4	72.8	73.0	73.1	73.0
T Winding Phase Y Set D (°C)		73.5	73.8	71.0	72.5	73.6	72.0	73.3	73.5	73.6	73.5
T Winding Phase Z Set A (°C)		73.1	73.5	71.4	72.0	73.3	72.5	72.9	73.1	73.2	73.1
T Winding Phase Z Set D (°C)		77.1	77.5	75.4	76.0	77.3	76.5	77.0	77.1	77.2	77.1
T Gen Drive End Bearing (°C)		72.0	71.8	72.1	72.1	71.9	71.9	72.1	71.7	71.9	71.9
T Gen Non-Drive End Bearing (°C)		67.2	66.9	67.0	67.0	66.8	66.9	67.2	66.7	67.1	66.9
Water Temperture (°C)		40.0	40.4	40.7	40.0	40.0	40.0	40.0	40.0	39.9	40.1
Ambient Temperature (°C)		27.1	26.7	27.1	27.2	26.7	27.1	27.6	26.7	27.1	26.8
Valve Operating Data											
Plant Signal (%)		54.2	53.6	19.8	28.1	60.4	35.9	56.2	56.8	37.5	30.2
Throttle Valve opening (%)		99.5	79.6	40.1	56.4	99.5	72.1	99.5	99.6	75.2	60.3
Aux Valve Opening (%)		16.7	14.6	0.1	0.1	41.6	0.1	25.1	27.2	0.1	0.1
Byass Valve Opening (%)		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Calculated Data											
Turbine Inlet Dynamic Head (ft)	1-1	4.8	5.2	4.2	4.2	5.2	4.5	4.8	5.1	4.8	4.8
Turbine Outlet Dynamic Head (ft)	1-1	9	9	8	8	9	8	9	9	9	9
Skid Outlet Dynamic Head (ft)	1-1	4.8	5.2	4.2	4.2	5.2	4.5	4.8	5.1	4.8	4.8
Turbine Differential Total Pressure (psi)	1-2,1-4	454.7	515.9	387.8	385.6	420.0	441.2	423.4	458.3	488.4	487.3
Throttle Valve Differential Total Pressure (psi)	1-3,1-4	1.7	11.2	146.1	40.7	2.3	15.3	2.4	2.6	12.9	38.8
Skid Differential Total Pressure (psi)	1-2,1-4	456.3	527.1	534.2	426.4	422.3	456.5	425.7	460.9	501.3	527.2
Input Hydraulic Power (kW)	1-5	493.2	616.9	512.1	407.5	495.4	466.2	464.3	528.9	545.3	574.1
Skid Test Hydraulic to Wire Efficiency (%)	1-6	78.6%	77.0%	56.2%	70.0%	78.1%	75.6%	78.3%	78.7%	76.2%	72.6%
Viscosity Correction on Performance											
Kinetic Viscosity of Field Process Fluid (cSt)		1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79
Kinetic Viscosity of Test Process Fluid (cSt)		0.661	0.651	0.655	0.661	0.651	0.661	0.661	0.651	0.667	0.661
Assumed VFD and Generator Efficiency (%)		92%	92%	92%	92%	92%	92%	92%	92%	92%	92%
Throttling Valve Loss Percentage (%)	1-7	0.4%	2.1%	27.4%	9.6%	0.5%	3.4%	0.6%	0.6%	3.0%	7.6%
Calculated Turbine Efficiency (%)	1-8	85.8%	85.6%	84.2%	84.1%	85.5%	85.1%	85.6%	86.0%	85.4%	85.4%
Corrected Turbine Efficiency (%)	1-9	84.3%	84.0%	82.5%	82.5%	84.0%	83.5%	84.1%	84.5%	83.9%	83.8%
Corrected Hydraulic to Wire Efficiency (%)	1-10	77.3%	75.7%	55.1%	68.6%	76.9%	74.2%	76.9%	77.3%	74.9%	71.3%

Table 1 – Certified Performance Test Record *See Appendix 1 for explanation of calculations used.

TESTING, VALIDATION, AND DEPLOYMENT (CONT.)

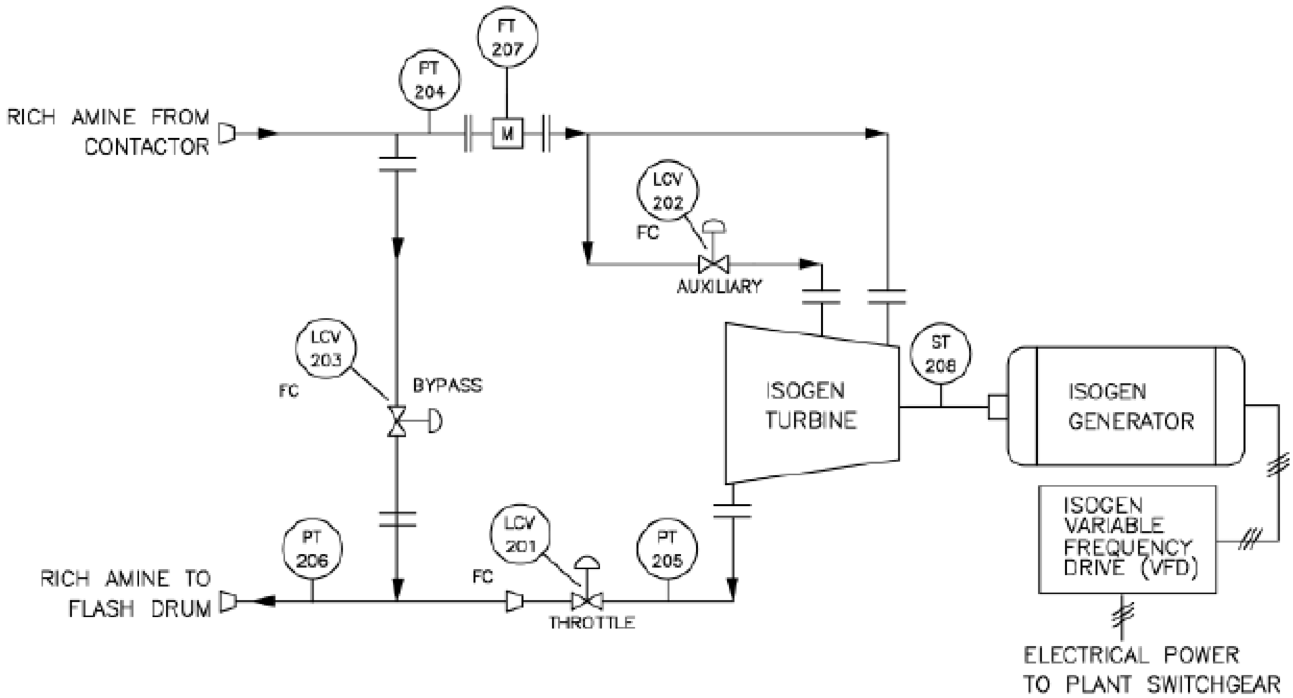


Figure 6 – Simplified Piping and Instrumentation Diagram (P&ID) of the IsoGen™ System

Calculation Procedure For Performance Testing

After the system achieved steady state, values for the following measured parameters were averaged over a one-minute period and are displayed in Figure 6 below.

Turbine Flow gpm (FT-207)
- Turbine Inlet Pressure psi (PT-204)
- Turbine Outlet Pressure psi (PT-205)
- Skid Outlet Pressure psi (PT-206)
- Export Power kW (JT-270)

The averaged data points, which were normalized for applicable specific gravity and actual process fluid viscosity, were used to calculate turbine performance. All pressure data was corrected for the expected process fluid specific gravity.

1. Velocity head was calculated for the inlet and outlet conditions based on the flow rate and pipe diameter. Velocity head was added to the static gauge readings to obtain the total differential pressure.

2. All data was recorded on a certified-performance test record, shown in Table 3.

CONCLUSION

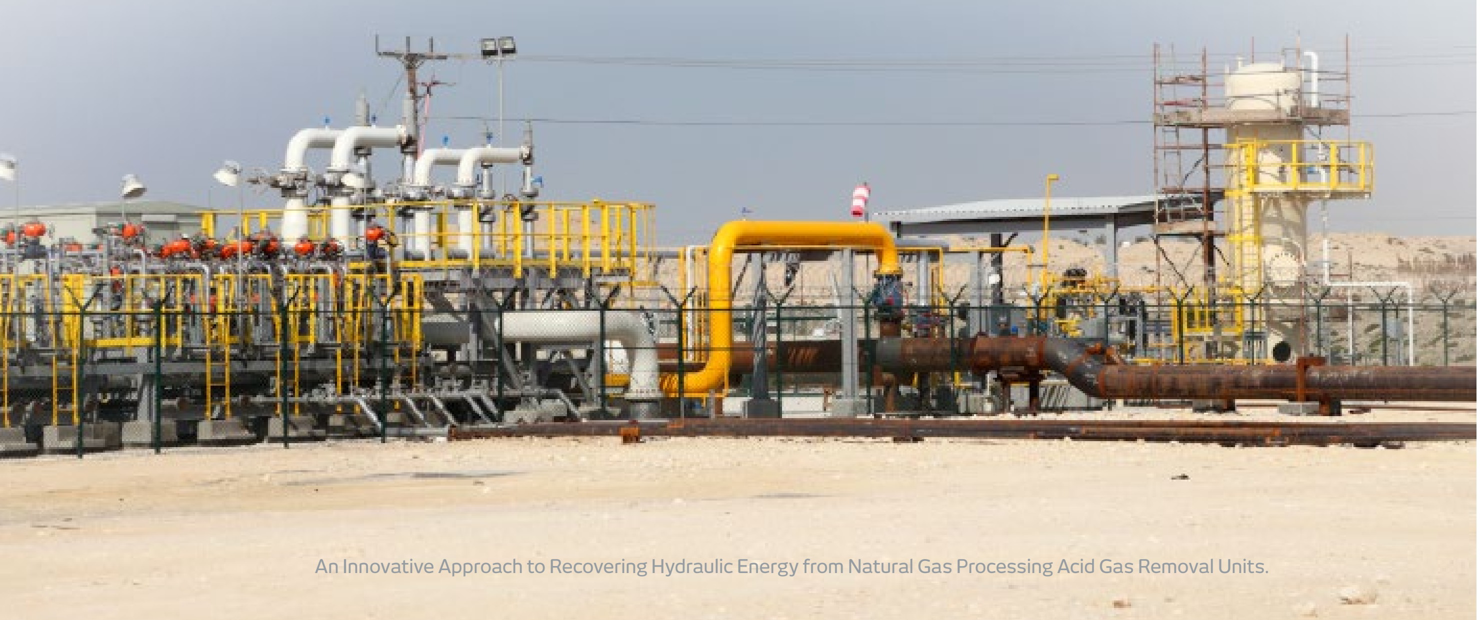
In today's oil and gas economy, energy wasted is money lost. In the natural gas sweetening process, a great deal of energy is dissipated during the depressurization of rich amine, and there is significant opportunity for savings. In the US and Canada alone, there are over 300 gas processing plants with medium to large flow rate capacities (300 – 2400 gpm), representing the potential for hundreds of millions of dollars in savings every year.

Energy Recovery has a proven track record of success. The installation in the Kingdom of Saudi Arabia showcases where this technology will help transform what was once considered wasted energy into a reliable source of power.

As the demand for clean energy throughout the world continues to grow, the need for disruptive technologies to help natural gas producers overcome the effects of rising operational costs and adhere to more stringent regulations will become increasingly prominent. Energy Recovery's flexible IsoGen™ skid-mounted system provides natural gas producers with a way to recover otherwise lost pressure energy by replacing the contactor LCV with a liquid phase turbogenerator within their amine treating cycle. The IsoGen can be adapted to almost any flow rate, with the option of installing multiple systems in parallel, and installation has minimal impact on plant operations. With Energy Recovery solutions, plant owners and operators have a cost-effective way to achieve substantial energy savings within new plant designs, as well as retrofitting existing plants.

About Energy Recovery

Energy Recovery Inc. (NASDAQ: ERII) technology harvests power from high-pressure fluid flows and pressure cycles. Through collaboration with industry, Energy Recovery helps make industrial processes within water, oil & gas, and other industries more profitable and environmentally sustainable. With over 15,000 energy recovery devices installed worldwide, Energy Recovery sets the standard for engineering excellence, cost savings, and technical services to clients across the globe. Year after year, the company's clean technologies save clients over $1.4 Billion (USD) in energy costs. Headquartered in the San Francisco Bay Area, Energy Recovery has offices in Madrid, Shanghai, and Dubai. **www.energyrecovery.com**



Conclusion

APPENDICIES

Appendix 1: Explanation of Calculations used in Table 3

BASIC CALCULATIONS			
Dynamic Head:	H_v	$= (Q/A \times 0.00223 \times 144)^2/g$	(1-1)
Total Pressure:	P_t	$= P+\rho\times(H_v+Z)/144$	(1-2)
Differential Static Pressure:	dP	$= P_{in} - P_{out}$	(1-3)
Differential Total Pressure with pipe correction:	dP_t	$= P_{t,in} - P_{t,out}$	(1-4)*
Water Power (kW):	Pw	$= Q \times dP_t \times .0005831 \times .7457$	(1-5)
Skid Test Hydraulic to Wire Efficiency:	η_s	$=Pe / Pw \times 100\%$	(1-6)
Valve Power Loss Percentage:	η_{loss}	$=dPt,v / dPt,s$	(1-7)
Turbine Efficiency at Test Fluid Viscosity:	η_t	$= \eta_s/ \eta_e/ (1- \eta_{loss})$	(1-8)**
Performance Test Correction for Viscosity Variations:	η_{ot}	$= 1 - (1 - \eta_t) \times ()^x$	(1-9)***
Turbine Efficiency at Operating Fluid Viscosity	η_{os}	$= (1- \eta_{loss}) \times \eta_{ot} \times \eta_e$	(1-10)

Notes:

* no elevation correction applied since all pressure transmitters are on the same level
** η is an average value 92% based on previous measurement
*** Correction per ANSI-HI 1.6, Section1.6.5.8.9, x=0.1 is used per Energy Recovery standard.

APPENDICIES

Appendix 2: Nomenclature

SYMBOL	TERM	UNIT
Q	Process Flow	gpm
P	Static Pressure (Gauge Pressure)	psig
P_t	Total Pressure	psig
Dp	Differential Static Pressure	psi
Dp_t	Differential Total Pressure	psi
P_w	Hydraulic Power	hp
Pe	Output Electric Power	hp
H_t	Total Head	ft
H_g	Static(Gauge) Head	ft
H_v	Dynamic Head	ft
Z	Elevation Head	ft
A	Pipe Area (at ID)	in^2
ρ	Fluid Density	lb/ft^3
γ_1	Specific Gravity of Test Liquid	Decimal Value
γ_2	Specific Gravity of Operating Liquid	Decimal Value
η_e	Electronic Efficiency including generator and VFD	Decimal Value
η_{loss}	Valve loss Percentage	Decimal Value
η_{ot}	Turbine Efficiency at Operating Fluid Viscosity	Decimal Value
η_t	Turbine Efficiency at Test Fluid Viscosity	Decimal Value
η_s	Skid Efficiency at Operating Fluid Viscosity	Decimal Value
η_{os}	Skid Efficiency at Test Fluid Viscosity	Decimal Value
x	Computation Exponent	Dimensionless
g	Standard Gravity	ft/s^2

Appendix 3: Subscripts

SYMBOL	TERM
in	Inlet (Suction) Area
out	Outlet (Discharge) Area
v	Valve
s	Skid

Middle East
SERVICE REGION

Oil & Gas
ERI PRODUCT DIVISION

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More Information
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