SRI/USEPA-GHG-QAP-20
September 2003

Environmental Technology Verification Report

Engineered Concepts, LLC Quantum Leap Dehydrator

Prepared by:

Greenhouse Gas Technology Center
Southern Research Institute

Under a Cooperative Agreement With
U.S. Environmental Protection Agency

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV

U.S. Environmental Protection Agency

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ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Emissions Control of Criteria Pollutants, Hazardous Pollutants, and Greenhouse Gases**
APPLICATION:	**Natural Gas Dehydration**
TECHNOLOGY NAME:	**Quantum Leap Dehydrator**
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative or improved environmental technologies through performance verification and information dissemination. The ETV program goal is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this by providing high-quality, peer-reviewed performance data to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups composed of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates technology performance by developing test plans that are responsive to stakeholders' needs, conducting field or laboratory tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols. This ensures that the resulting data are of known quality and that the results are defensible.

Southern Research Institute operates the Greenhouse Gas Technology Center (GHG Center), one of six ETV Centers, in cooperation with EPA's National Risk Management Research Laboratory. The GHG Center has recently evaluated the performance of the Quantum Leap Dehydrator (QLD), manufactured by

Engineered Concepts, LLC, of Farmington, NM. This Verification Statement provides a QLD verification test summary.

TECHNOLOGY DESCRIPTION

Background

Natural gas often contains excess water vapor at the wellhead which must be removed to avoid pipeline corrosion and solid hydrate formation. Glycol dehydration is the most widely used natural gas dehumidification process. Triethylene glycol (TEG) typically absorbs water from natural gas in a contactor vessel. The TEG absorbs water from the natural gas, but also absorbs methane (CH_4), volatile organic compounds (VOCs), and hazardous air pollutants (HAPs). Gas-assisted or electric pumps circulate the TEG through a distillation column for regeneration and back to the contactor vessel. Distillation removes the absorbed water and HAPs from the TEG to the still column vent as vapor. Conventional dehydrator still columns often emit this vapor directly to the atmosphere. Natural gas dehydration is the third largest CH_4 emission source in the natural gas production industry. Glycol dehydrators also cause over 80 percent of the industry's annual HAP and VOC emissions.

QLD Technology

Information supplied by Engineered Concepts, LLC provided the basis for this discussion. GHG Center personnel verified the function and operation of major system components during the test campaign.

The QLD is an integrated system which collects the water and hydrocarbons present in the glycol reboiler vent stream and separates condensable and non-condensable fluids. The two primary condensable products are: (1) wastewater, which can be disposed of with treatment and (2) hydrocarbon condensate, which is a saleable product. The reboiler burner combusts the uncondensable vapors as the system's primarily fuel. The QLD uses condensation and combustion to reduce both HAP and CH_4 emissions.

The QLD uses a series of heat exchangers, condensers, separators, and electric pumps to recover and use distillation column vapors. First, a liquid removal vacuum separator condenses and collects still column vent water and HAPs vapors under vacuum. The separator partitions the vapor stream into three products: (1) wastewater, (2) condensate, and (3) uncondensed hydrocarbon vapors. The separator discharges the wastewater and condensates into product holding tanks through pneumatically-operated level controllers. Negative gage pressure, created by glycol flow through an eductor (which provides additional scrubbing), transfers hydrocarbon vapors to the emissions separator.

The emissions separator further separates liquid products from uncondensable hydrocarbon vapors and glycol. It transfers liquid products back to the vacuum separator while the reboiler burner combusts the hydrocarbon vapors. The burner operates continuously and throttles the heat output in response to still column heat demand. Burner performance is the primary indicator of whether the QLD can combust the widely varying amounts and quality of fuel gas recovered by the system. The burner system can also accept makeup natural gas if the still column demands additional heat.

An electric pump circulates approximately four gallons per minute (gpm) of TEG through the natural gas contactor vessel. A separate pump circulates about 72 gpm within the QLD condensation/separation system. Electric pumps, in contrast to the widely used gas-assisted pumps, further reduce CH_4 emissions and losses.

Primary QLD air emission sources include: (1) the reboiler burner exhaust, (2) HAPs dissolved in the recovered wastewater, and (3) pressure-relief vents (PRVs). The QLD fabricator and field installers certified the equipment as leak-free, so this verification did not quantify fugitive emissions.

VERIFICATION DESCRIPTION

The GHG Center executed the QLD performance verification test at the Kerr-McGee Gathering Station in Brighton, CO. The test campaign proceeded under requirements set forth in the Test and Quality Assurance Plan – Engineered Concepts, LLC Quantum Leap Dehydration (SRI/USEPA-GHG-QAP-20), June, 2002 (Test Plan). The system was designed to dehydrate approximately 28 million standard cubic feet per day (mmscfd) of natural gas.

Testing commenced in April 2003, approximately one month after completion of system start-up activities. Tests consisted of a seven-day operational performance monitoring period followed by one day of environmental performance testing. The system operated normally during testing, and the GHG Center evaluated the verification parameters listed below:

Operational Performance

Sales Gas Moisture Content: The field site requires that dry natural gas exiting the QLD process contain less than seven lb water/mmscf. An inline moisture analyzer continuously monitored and recorded sales gas moisture readings at one-minute intervals.

Sales Gas Production Rate: The QLD must allow uninterrupted natural gas dehydration and maintain a continuous natural gas flow. An inline integral orifice meter continuously monitored the natural gas flow rate. Data were logged in one-minute intervals.

Glycol Circulation Rate: Facilities affected by the 40 CFR Part 63 standard (Subpart HH) regulations must continuously monitor TEG circulation rates. An ultrasonic meter, installed on the regenerated lean glycol line, recorded one-minute average circulation rates.

Makeup Natural Gas Flow Rate: A separate meter continuously monitored reboiler burner makeup natural gas. The one-minute average readings characterized any additional fuel required by the QLD.

Environmental Performance

Reboiler Stack Emission Rates: Emissions tests determined concentration in parts per million volume, dry (ppmvd) and emission rates in pound per hour (lb/h) for the following air pollutants: nitrogen oxide (NO_X), carbon monoxide (CO), VOCs, HAPs (benzene, toluene, ethylbenzene, xylene, and hexane), and greenhouse gases (CO_2 and CH_4). Three test runs were conducted, each lasting approximately 90 minutes. All testing conformed to U.S. EPA Title 40 CFR 60 Appendix A Reference Method procedures.

HAP Destruction Efficiency: Dehydration facilities subject to MACT must reduce HAP emissions by 95 percent. The tests verified HAP destruction efficiency as a measure of emissions reduced by the QLD. HAP destruction efficiency is the HAPs entering the system (absorbed in rich and lean glycol streams) minus the HAPs emitted from the system (discharged and vented to atmosphere from stack, PRVs, and wastewater) divided by the HAPs entering the system. HAPs dissolved in the condensate product stream are not an emission source because the site uses this product as feedstock for other processes. The regulation defines this as “controlled” or “sequestered” emissions.

Wastewater and Condensate Production Rate: HAP destruction efficiency determination required volumetric measurement of wastewater and condensate production rates.

Independent GHG Center QA personnel conducted a technical systems audit during testing to ensure that field activities complied with the Test Plan. The Center’s QA Manager implemented a data quality audit of at least ten percent of the data to ensure that data reduction and reporting accurately represented actual results. The field team leader conducted performance evaluation audits to ensure that the measurement system produced reliable data. In addition to these quality assurance audits, EPA QA personnel conducted a quality assurance review of the Verification Report and a quality systems audit of the GHG Center's Quality Management Plan.

PERFORMANCE VERIFICATION

Operational Performance

One-minute readings provided daily average flow rates and moisture content over the seven-day performance evaluation period. The 75th percentile interval of these readings defined normal operating conditions.

- The QLD natural gas dehydration process met the test site's 7.00 lb/mmscf moisture content requirement. Daily average values ranged between 0.89 and 1.28 lb/mmscf.

- The QLD enabled continuous sales gas flow, with daily average flow rates ranging between 26.8 and 29.3 mmscfd.

- Daily average glycol circulation rates through the absorption and regeneration process ranged between 3.00 and 3.77 gpm.

- The verification test demonstrated that the QLD required little to no makeup natural gas. The normal range of the makeup natural gas flow rate was 0.00 to 1.76 scfh, which is well below the 166 scfh design capacity. The volume and fuel quality of the uncondensed hydrocarbon vapors was generally sufficient to maintain optimum burner control.

Environmental Performance

- Average NO_X concentration for the three test runs was 65.1 ppmvd during normal operations. This equates to a mass emission rate of 0.0817 lb/h.

- Emissions of CO and VOCs were low during all three test runs, averaging 0.6 ppmvd (0.0005 lb/h) and 0.6 ppmvd (0.0003 lb/h), respectively.

- Stack emissions of all HAP constituents were below the sensitivity of the sampling system. The detection limit was 0.1 ppmvd, which meets the specifications of the Title 40 CFR 60 Appendix A reference methods. The hourly average stack HAP emission rate is verified to be less than 0.0016 lb/h.

- Methane concentrations were not detected during any of the test periods The detection limit was 0.1 ppmvd, which meets the specifications of the Title 40 CFR 60 Appendix A reference methods. CO_2 concentrations averaged about 9.3 percent of the stack gas volume, equating to a mass emission rate of 111 lb/h.

- PRVs did not operate at any time during the entire test campaign, nor are releases anticipated during normal operations. Therefore, no expected emissions were assigned to PRV operation.

REBOILER STACK EMISSIONS

	NO_X		CO		VOC	
	ppmvd	lb/h	ppmvd	lb/h	ppmvd	lb/h
Run 1	67.8	0.0873	0.3	0.0003	0.4	0.0002
Run 2	66.0	0.0817	1.0	0.0007	0.8	0.0004
Run 3	61.6	0.0761	0.6	0.0004	0.5	0.0002
Avg.	**65.1**	**0.0817**	**0.6**	**0.0005**	**0.6**	**0.0003**
	HAP		CH_4		CO_2	
	ppmvd	lb/h	ppmvd	lb/h	ppmvd	lb/h
Run 1	<0.6	<0.0016	<0.1	<0.00004	9.5	117
Run 2	<0.6	<0.0016	<0.1	<0.00004	9.2	109
Run 3	<0.6	<0.0015	<0.1	<0.00004	9.1	108
Avg.	**<0.6**	**<0.0016**	**<0.1**	**<0.00004**	**9.3**	**111**

- HAPs entering the QLD were 9.09 lb/h. Maximum HAPs leaving the system in the reboiler exhaust and wastewater were 0.0016 and 0.0220 lb/h, respectively. The HAP destruction efficiency is greater than 99.74 ± 0.01 percent.

- Wastewater production rate was approximately 0.106 gallons per minute or 6.36 gallons per hour.

- Saleable condensate product recovery rate was approximately 0.048 gallons per minute or 2.88 gallons per hour.

Signed by: Hugh W. McKinnon, 9-2003

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Signed by: Stephen D. Piccot, 9-2003

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Notice: GHG Center verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. The EPA and Southern Research Institute make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate at the levels verified. The end user is solely responsible for complying with any and all applicable Federal, State, and Local requirements. Mention of commercial product names does not imply endorsement or recommendation.

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Greenhouse Gas Technology Center

A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization

Environmental Technology Verification Report

Engineered Concepts, LLC
Quantum Leap Dehydrator

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☒ indicates comments are integrated into Verification Report

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LIST OF ABBREVIATIONS AND ACRONYMS

acfh	actual cubic feet per hour
ARL	atmospheric rich/lean method
bcfy	billion cubic feet per year
BTEX	benzene, toluene, ethylbenzene, xylenes
CAR	corrective action report
dscfh	dry standard cubic feet per hour
dscfm	dry standard cubic feet per minute
ECL	Engineered Concepts, LLC
EPA	Environmental Protection Agency
EPA-ORD	Environmental Protection Agency–Office of Research and Development
ETV	Environmental Technology Verification
fps	feet per second
ft	feet (foot)
gal	gallon(s)
gal/in.	gallons per inch
GC	gas chromatograph
GC/FID	gas chromatograph with flame ionization detector
gpm	gallons per minute
GRI	Gas Research Institute (became the Gas Technology Institute)
GTI	Gas Technology Institute
HAP	hazardous air pollutant
hp	horsepower
in.	inches
lb	pound
lb/h	pounds per hour
lb/mmscf	pounds per million cubic feet
LDL	lower detection limit
m	meters
mm	millimeters
MACT	maximum achievable control technology
MDL	method detection limit
mBtu	thousand British thermal units
mBtu/h	thousand British thermal units per hour
ml	milliliter
mg	milligram
mmscfd	million standard cubic feet per day
mmscfh	million standard cubic feet per hour
mscf	thousand standard cubic feet
mscfd	thousand standard cubic feet per day
MW	molecular weight
ng	nanogram
NIST	National Institute of Standards and Technology
ppm	parts per million
pmvd	parts per million by volume, dry
psia	pounds per square inch, absolute
psig	pounds per square inch, gage
PRV	pressure-relief vent (or valve)
QA	quality assurance
QA/QC	quality assurance / quality control

LIST OF ABBREVIATIONS AND ACRONYMS, CONTINUED

QLD	Quantum Leap Dehydrator
QMP	Quality Management Plan
scfgal	standard cubic feet per gallon
scfh	standard cubic feet per hour
SRI	Southern Research Institute
TEG	triethylene glycol
VOC	volatile organic compound
w.g.	water glass or water head pressure
^{o}F	degrees Fahrenheit
ìg	microgram
ìg/ml	micrograms per milliliter
ìl	microliter

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1.0 INTRODUCTION

1.1. BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) is charged with facilitating the deployment of improved and innovative environmental technologies. EPA-ORD operates the Environmental Technology Verification program (ETV) to achieve this end. ETV's mission is to further environmental protection by accelerating these technologies acceptance and use.

To realize its mission, ETV independently verifies technology performance and disseminates the results to a wide variety of public, industry, regulatory, and private stakeholders. Congress funds ETV in response to the belief that there are many viable environmental technologies that are not being used for the lack of credible third-party performance data. With performance data developed under ETV, technology buyers, financiers, and permitters will be better equipped to make informed decisions regarding environmental technology purchase and use.

EPA's partner organization, Southern Research Institute (SRI) operates the Greenhouse Gas Technology Center (GHG Center) which is one of six ETV organizations. The GHG Center verifies the performance of promising greenhouse gas mitigation and monitoring technologies by developing verification protocols, conducting field tests, collecting and interpreting field and other data, obtaining independent peer review input, and reporting findings. Externally reviewed "Test and Quality Assurance Plans" (test plans) and well-established quality assurance (QA) protocols regulate the GHG Center's verification activities.

Volunteer stakeholder groups guide the GHG Center. These stakeholders advise on specific technologies most appropriate for testing, help distribute results, and review test plans and "Environmental Technology Verification Reports" (reports). National and international environmental policy, technology, and regulatory experts participate in the GHG Center's Executive Stakeholder Group. The group includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested parties. Industry-specific stakeholders also peer-review key GHG Center publications and guide verification test strategies in those areas related to their expertise.

The GHG Center's Oil and Gas Stakeholder Group has identified a need for independent third-party methane (CH_4) and carbon dioxide (CO_2) emission reduction technology verification. Natural gas dehydration is a significant source of these two greenhouse gases and other pollutants. This report documents the performance of a new dehydration technology that reduces greenhouse gases, hazardous air pollutant (HAP), and volatile organic compound (VOC) emissions.

Approximately 252,000 natural gas production wells currently operate in the U.S. The natural gas often contains excess water vapor which can cause corrosion and form solid gas hydrates inside pipelines. The natural gas production and transportation sectors consequently invest considerable resources to remove water from natural gas.

Glycol dehydration is the process where dry triethylene glycol (TEG) absorbs water vapor by directly contacting the sales gas. It is the most widely used natural gas dehumidification process. TEG primarily absorbs water, but it also absorbs CH_4, VOCs, and HAPs from the gas. Dehydrators re-dry the TEG (usually in at least one reboiler per dehydrator), often emitting both the absorbed water and air pollutants directly to the atmosphere.

EPA estimates that the more than 38,000 active glycol dehydrators in the U.S. collectively emit about 18.6 billion cubic feet per year (bcfy) of CH_4 [1]. Natural gas glycol dehydration is the third largest CH_4 emission source within the production sector, creating 17 percent of this sector's total greenhouse gas emissions [2]. Glycol dehydrators are also responsible for 85 and 81 percent of the production sector's HAP and VOC emissions, respectively [3,4]. The EPA promulgated final maximum achievable control technology (MACT) standards on June 17, 1999, which require that glycol dehydrator owners or operators reduce HAP emissions by 95 percent [5].

The MACT standard requires affected facilities install control devices to recover or destroy pollutants in the dehydration vent stream. Engineered Concepts, LLC (ECL), located in Farmington, NM, has developed a patented gas dehydration technology known as the Quantum Leap Dehydrator (QLD) to meet this goal. The QLD is an integrated system which collects all the water and hydrocarbons present in the glycol reboiler vent stream. It condenses and collects most hydrocarbons into a salable product; water is collected for disposal; and the uncondensed hydrocarbon balance is routed to the reboiler burner for combustion. The end result of the QLD process is the reduction of both HAP and CH_4 emissions.

ECL requested that the GHG Center perform an independent QLD performance verification at a natural gas gathering station operated by Kerr-McGee Gathering, LLC. This report presents the results obtained during the recently concluded performance verification test. The *Test and Quality Assurance Plan—Engineered Concepts, LLC Quantum Leap Dehydrator* [6] provided the verification test design, measurement and quality assurance/quality control (QA/QC) procedures. It is available for download from the GHG Center's web site (www.sri-rtp.com) or the ETV Program web site (www.epa.gov/etv). ECL, SRI, selected stakeholders, and EPA-ORD have reviewed the test plan and report as evidenced by the signature pages at the front of both documents. They satisfy the pertinent GHG Center Quality Management Plan (QMP) requirements.

The following paragraphs describe the QLD technology and the as-built system at the Kerr-McGee site. The remaining subsections define the verification parameters and briefly describe the test methods used to quantify these parameters. Section 2.0 presents the verification test results and Section 3.0 assesses data quality. Circumstances required departures from the Test Plan in some cases and Corrective Action Reports (CARs) were prepared to describe such modifications. The appropriate sections below discuss any deviations. Section 4.0 was submitted by ECL and presents additional QLD system information, its performance at the test site, and other facts the manufacturer deems significant to the reader. The GHG Center has not independently verified information contained in Section 4.0.

1.2. QLD TECHNOLOGY DESCRIPTION

Comparison between conventional natural gas dehydrators and the QLD is an effective way to understand the latter's operating principles. Figure 1-1 shows the schematic of a generic dehydrator. The wet natural gas enters a two-phase separator which divides liquid hydrocarbons from the gas stream. Pipelines route the liquid products to a condensate storage tank for sale and the wet gas to an absorber. Lean TEG (which contains little water) directly contacts the wet gas and absorbs the water vapor. Dry natural gas exits the absorber column as pipeline-quality gas, ready for sale.

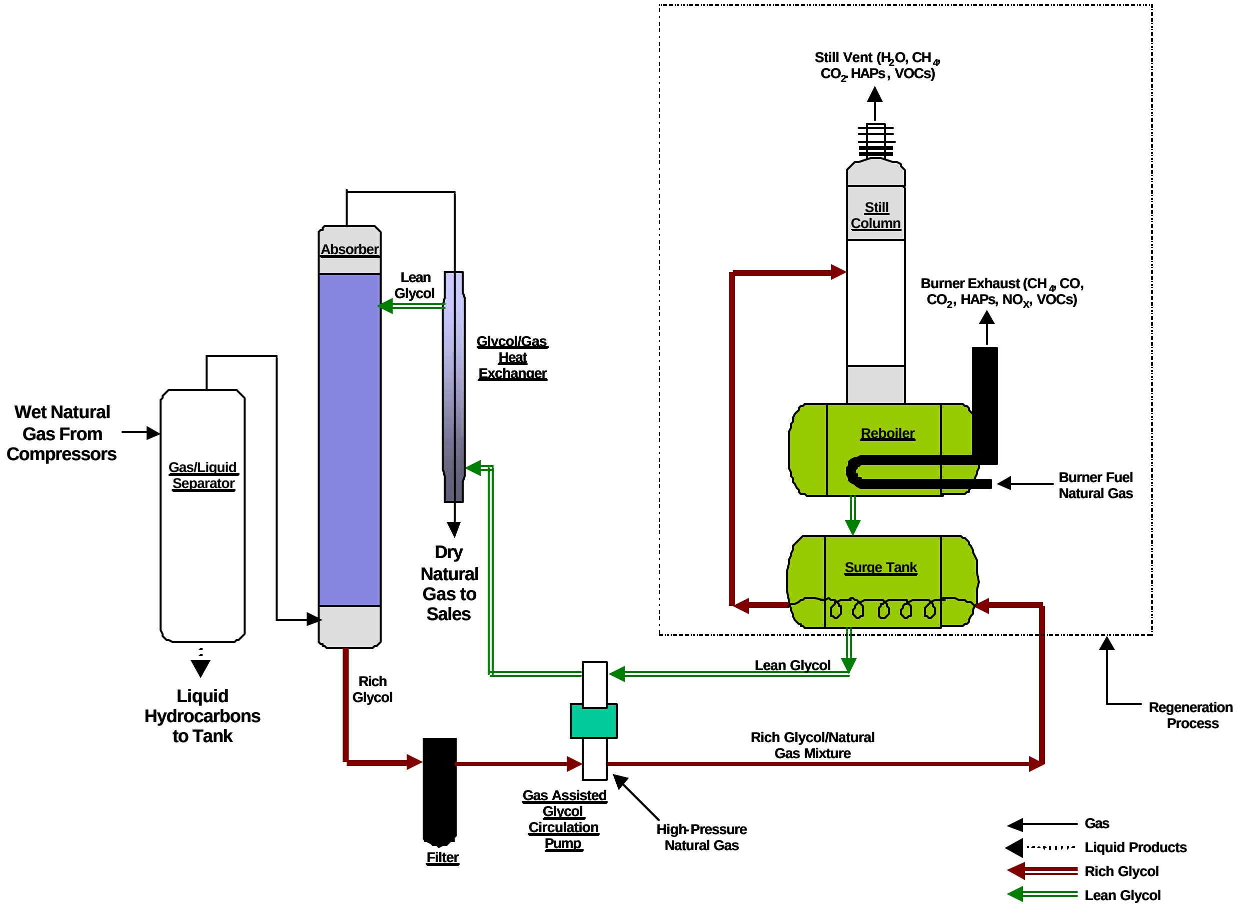

Figure 1-1. Generic Natural Gas Dehydration Process

The rich (wet) glycol exiting the absorber contains the constituents which the TEG easily absorbs or dissolves. These are mainly water, CH_4, VOCs, and HAPs. The primary HAPs, as defined in the MACT regulations [5], include benzene, ethylbenzene, toluene, and xylene (collectively referred to as BTEX) and n-hexane. These five pollutants are estimated to represent about 99 percent of HAP emissions from glycol dehydrator vents. A regeneration reboiler removes the absorbed constituents, resulting in a lean glycol mixture that is suitable for reuse in the absorber.

The regeneration process is the primary emission source. It consists of a glycol circulation pump, a reboiler still, and a variety of heat exchangers (Figure 1-1). The circulation pump moves the glycol throughout the system. Conventional dehydrators may employ either of two different types of circulation pumps: electric-powered and gas-assisted. Gas-assisted pumps are the most common type because many dehydration facilities are located in remote sites where electricity is not readily available. Gas-assisted pumps use energy from externally supplied high-pressure natural gas to pressurize the glycol. Since CH_4 is the primary constituent in natural gas, CH_4 emissions are substantially higher when the glycol/natural gas mixture passes through the reboiler. Conventional dehydrators may include a reduced-pressure flash tank (not shown) prior to the reboiler. A flash tank allows dissolved methane to escape and be re-routed to other processes. This prevents its being emitted from the still column.

The reboiler strips the absorbed water (and HAPs) out of the glycol and into the still column. The regenerated lean glycol exits the reboiler and enters a surge tank. The pump then conveys it to a glycol/gas heat exchanger and back to the absorber. This heat exchanger reduces the lean glycol temperature prior to the lean glycol entering the absorber tower. This reduces hydrocarbon condensation within the absorber [7].

The still column vent conveys the stripped water vapor, CH_4, HAPs, CO_2 and VOCs away from the process. Most conventional dehydrators emit this overhead gas/vapor stream directly to the atmosphere. The still vent stream contains water vapor (90 percent), trace CO_2, HAPs, CH_4, VOCs, and other components absorbed from the natural gas.

Two common still vent emission control methods are combustion and condensation. Combustion devices typically include flares and thermal oxidizers. The Kerr-McGee test site initially controlled still vent emissions with enclosed flares, but the site was unable to continuously operate them because the vapor stream's heat content varied widely.

Condensers include water knockout systems and other separation systems that produce condensate product for sale. These devices vent non-condensable gases to the atmosphere or burn them in a flare, thermal oxidizers, or the reboiler. An additional emissions control measure used at some sites is to separate lighter hydrocarbons (such as CH_4) from the rich glycol in flash tank separators prior to the still column.

The QLD also employs both condensation and combustion to control still vent emissions. Its implementation of controlled condensation and partial vacuum-phase separation produces: 1) a saleable product, 2) wastewater that does not require significant cleaning, and 3) very little air pollution. The most significant result is that the reboiler burns uncondensed hydrocarbons, significantly reducing fuel input requirements and emissions. Figure 1-2 depicts the primary design features. Process modifications to this system, as compared to the majority of conventional dehydrators, are:

- Replacement of gas-assisted pump with electric pump (reduces CH_4 losses and emissions);
- Recovery and use of still vent emissions (eliminates direct release of CH_4, HAPs, and VOCs); and
- Reboiler burner re-design (reduces natural gas fuel input and emissions).

Major QLD components are:

- Glycol Circulation Pump An electric pump circulates the glycol through the absorber at about 4 gallons per minute (gpm). This feature is intended to save a significant amount of high-pressure natural gas over a gas-assisted pump. The Gas Technology Institute (formerly the Gas Research Institute) estimates that pump gas losses account for as much as three standard cubic feet natural gas per gallon (scfgal) of glycol circulated. Over 20 thousand standard cubic feet per day (mscfd) natural gas or $14,600 per year (based on a gas price of $2.00 per mscf) would be saved by switching to an electric pump at the host site. Note that this analysis is conservative because recent natural gas prices have risen to $5.45/Mcf and more in some areas. An additional benefit is that CH_4 and BTEX, normally present in increased quantities when a gas-assisted pump is used, will not be vented from the still column.

- Effluent Condenser The effluent condenser is a fin-and-tube heat exchanger that reduces the vapor stream temperature from the still vent to about 120 degrees Fahrenheit (^{o}F) to enable product separation. It uses the rich glycol, circulated from the emissions separator, as the coolant media. The cooled overhead vapor stream is brought into the liquid removal vacuum separator.

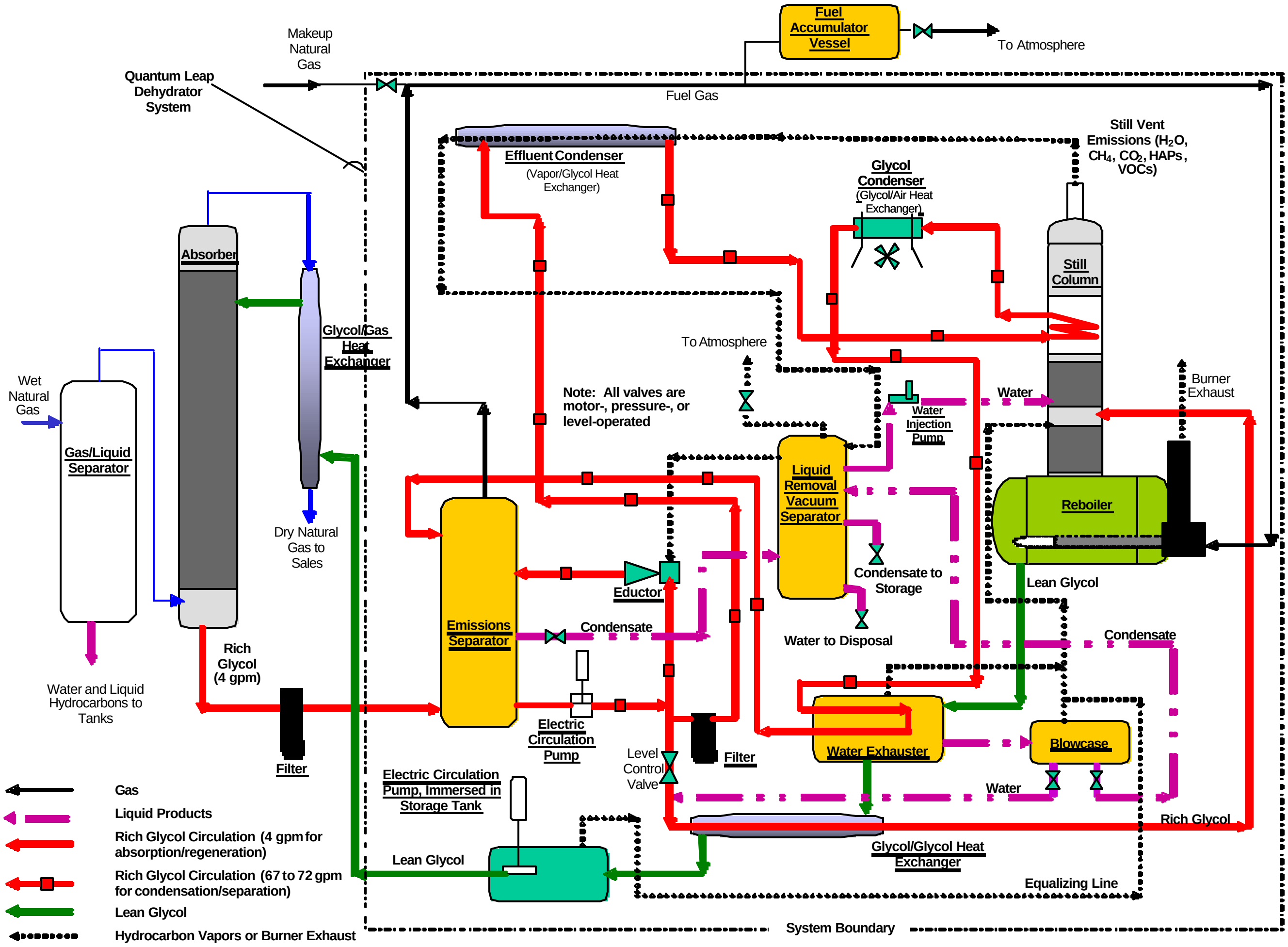

Figure 1-2. QLD Natural Gas Dehydration Technology

- Liquid Removal Vacuum Separator (vacuum separator) Internal baffles and weirs in this vessel condense and partition the vapor stream from the still vent into three phases: (1) wastewater, (2) condensate, and (3) uncondensed hydrocarbon vapors. The condensed hydrocarbons and wastewater collect in the appropriate chamber and are periodically discharged into storage tanks for sale and disposal. An eductor system creates a partial vacuum to remove uncondensable hydrocarbons and the remaining water vapor to the emissions separator.

- Glycol Condenser A forced-draft, air-cooled heat exchanger cools the rich glycol exiting the still column reflux coil and the overhead condenser. Ambient air reduces the glycol temperature to between 150 and 110 °F. A pipeline conveys condensed liquids, rich glycol, and noncondensable gas to the emissions separator.

- Emissions Separator The emissions separator operates in three phases to separate rich glycol, liquid hydrocarbons, and gaseous hydrocarbon streams.

Control valves and piping split the rich glycol exiting the emissions separator. The first stream, about 4 gpm, originates from the bottom of the separator. This is precisely equal to the amount of lean glycol pumped into the absorber. A 72-gpm pump pressurizes the second rich glycol stream for use as a working fluid throughout the QLD. The effluent condenser uses about 10 gpm for still vent-stream cooling. The remainder provides cool glycol to other heat exchangers, compresses the recovered uncondensed hydrocarbons for use at the burner, and powers the eductor system which, in turn, creates the required partial vacuum at the vacuum separator.

Separate piping conveys condensed hydrocarbons to the vacuum separator which collects them as described above. The uncondensed hydrocarbons exit the emissions separator at about 20 pounds per square inch, gage (psig), and serve as fuel gas for the reboiler burner.

- Water Exhauster The water exhauster removes any remaining water and condensable hydrocarbons from the lean glycol. Section 4.0 discusses some of its benefits.

- Still Column The still column collects the entrained gases, water, and hydrocarbon vapors from the rich glycol as it flows through the reboiler. The resulting hot lean glycol exits the still column and reboiler through a glycol/glycol heat exchanger.

- Reboiler The QLD incorporates a re-designed conventional U-shaped firetube reboiler. The QLD burner is unlike many commercial burners, in that it contains air injectors which allow effective combustion with wide ranges in operating pressure and water vapor content. The burner operates continuously and throttles the heat output in response to reboiler heat demand, in contrast with many conventional burners which cycle off and on to meet changing demand. The burner can accept up to 30 percent of capacity, or 166 standard cubic feet per hour (scfh) of supplemental natural gas if needed.

ECL and the test facility installed certain modifications after the initial shakedown period because of site-specific natural gas conditions. Consequently, the as-tested unit differed from the original design. The following subsection includes a brief discussion.

Air emission sources include the reboiler burner exhaust, vacuum separator and fuel accumulator vessel PRVs, HAPs dissolved in the recovered wastewater, and fugitive emissions (which were subsequently found to be negligible). The QLD uses recovered hydrocarbon vapors as its primary fuel source, so VOC and HAP emissions may be present in the burner exhaust. There may also be NO_x, CO, CO_2, and unburned CH_4 emissions. The wastewater stream could contain dissolved HAPs which could be emitted to the atmosphere through evaporation. Wastewater condensation occurs under partial vacuum so there should be no HAP and CH_4 flash-loss emissions.

1.3. TEST FACILITY DESCRIPTION AND QLD MODIFICATIONS

The Kerr-McGee Gathering Facility, located 14 miles northwest of Brighton, CO, processes about 26 million standard cubic feet per day (mmscfd) of natural gas through the QLD. Kerr-McGee installed the QLD technology after excess moisture content in the still vent caused persistent problems with thermal oxidizers. Figures 1-3 and 1-4 show the as-built system at the site.

Figure 1-3. QLD at Kerr-McGee Gathering Station

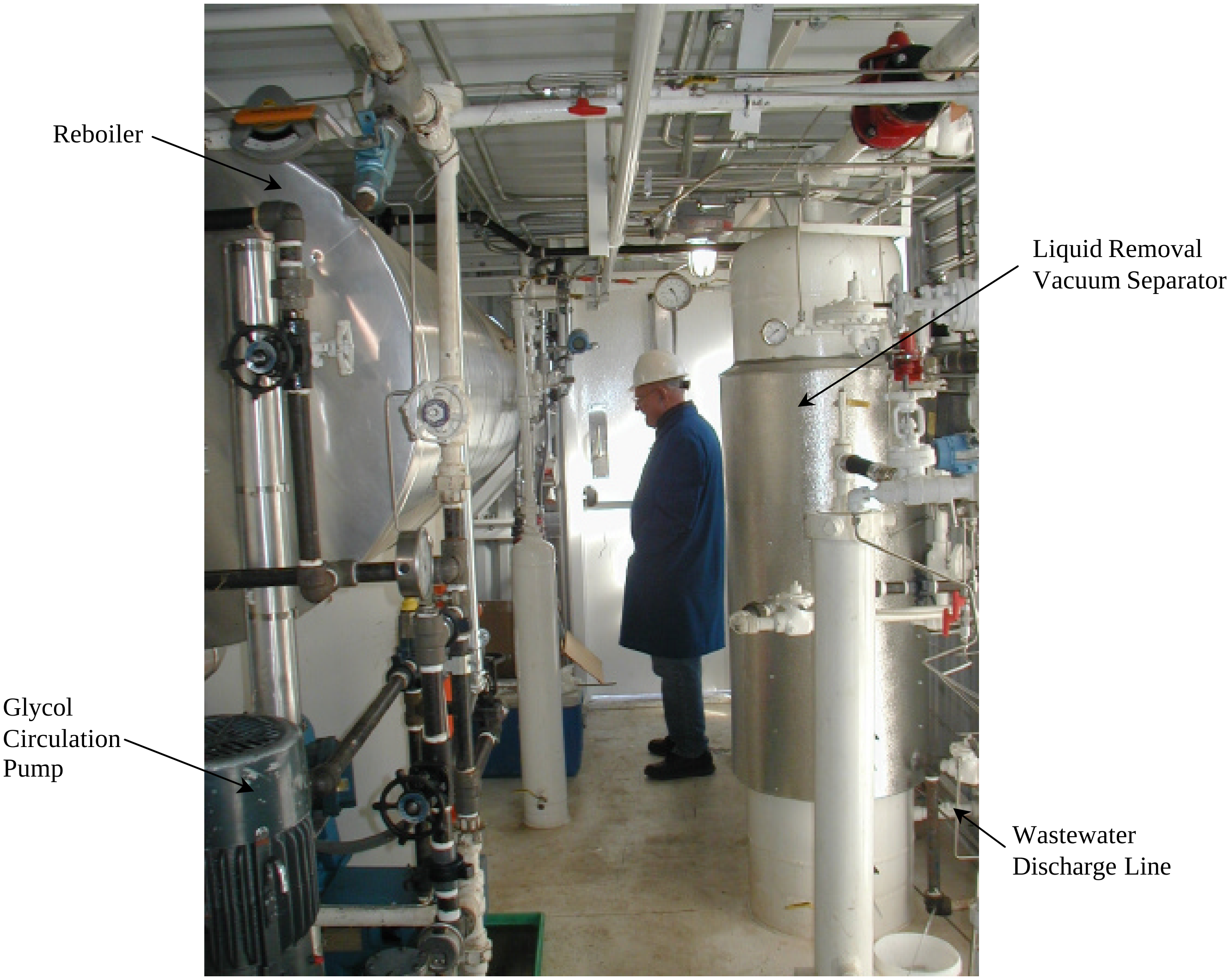

Figure 1-4. QLD Interior

In-ground storage tanks collect and store the wastewater from the QLD and other processes at atmospheric pressure. Fixed-roof tanks receive the condensate. Contractors periodically transfer the stored wastewater and condensate into tank trucks for transport and disposal or sale.

Table 1-1 summarizes the test site's key design and operating parameters. These parameters formed the basis for the test plan's verification strategy.

Table 1-1. Test Site Design and Operating Conditions

1. Natural gas production rate	26 mmscfd (at 14.7 psia, 60 °F)
2. Sales gas moisture content	< 7 lb water / mmscf natural gas
3. Circulation rates for electric pumps	
• Glycol for absorption and regeneration	5 gpm, 5-hp motor
• Glycol for condensation and eductor power	72 gpm, 5-hp motor
4. Glycol/Glycol Heat Exchanger	
• Duty	325 mBtu
• Shell operating conditions (lean glycol)	atmospheric pressure @ 400 °F
• Tube operating conditions (rich glycol)	30 psig @ 300 °F
5. Reboiler Still	
• Duty	600 mBtu/h
• Operating Conditions	0 to 2 in. water column (vacuum)
6. Reboiler Burner	
• Total heat input required	1.2 mmBtu/h
• Fuel gas from the emissions separator	~ 233 to 388 scfh (70 to 80% volume), specific gravity = ~0.75, LHV = ~1410 Btu/ft^3
• Makeup natural gas	~ 0 to 166 scfh (0 to 30% volume), specific gravity = ~0.65, LHV = ~950 Btu/ft^3
• Stack dimensions	10-in. diameter, 20-ft high
7. Glycol Condenser - Glycol/Air Heat Exchanger	
• Duty	225 mBtu/h
• Rich glycol operating conditions	30 psig @ 150 °F
8. Emissions Separator	
• Dimensions	30-in. diameter, 6’-6” high
• Operating Pressure	15 psig
9. Vacuum Separator	
• Dimensions	20 in. diameter, 5’-6” high
• Operating Pressure	0 to 5 in. w.g. vacuum
• Water discharge rate	Every 1.5-in. change in liquid level ~ 1.89 gal
• Condensate discharge rate	Every 1.5-in. change in liquid level ~ 1.89 gal
10. Effluent Condenser - Vapor/Glycol Heat Exchanger	
• Duty	100 mBtu/h
• Tube operating conditions (still vapors)	0 to 5 in. w.c. vacuum @ 212 °F
• Shell operating conditions (rich glycol)	30 psig @ 110 °F

Operators discovered that the burner (and reboiler) was not operating at consistent temperature after the QLD system was installed at the host site. The recovered fuel gas heating value sometimes exceeded that which could be efficiently burned. The system would upset and remain out of balance for extended periods because the burner was unable to burn all the gas. Consequently, the recovered fuel gas pressure would begin to increase such that the eductor was unable to pull an adequate vacuum. The vacuum separator pressure would rise and break the required -5” water glass (w.g.) partial vacuum. The entire system operation would destabilize. ECL installed three improvements to prevent this pressure buildup and to enable proper burner control:

Pressure-Relief Valve: ECL installed a pressure-relief valve (PRV) in the vacuum separator to open it to atmosphere when the recovered fuel gas pressure reached 30 psig. The PRV would close when the recovered fuel gas pressure dropped below 30 psig. This PRV is a safety device. The system utilizes this feature only during initial system start-up. The vent remains closed during normal operations.

Fuel Accumulator Vessel: ECL installed a 430-gallon accumulator vessel to dampen the effects of large swings in fuel gas volumes entering the reboiler burner. The accumulator vessel increased the fuel gas system's reserve volume during high recovery periods. This allows a relatively constant volume of fuel gas to be fed to the burner. A pressure-activated valve would open to atmospheric conditions if the gas pressure in the vessel exceeded 28 psig. This operation could produce air emissions, but this PRV is also a safety device which would actuate only under abnormal conditions.

Water-Injection System: ECL installed a compressed air-driven pump to inject a portion of the vacuum separator's recovered wastewater back into the reboiler. This would increase the reboiler load when necessary, enabling the burner to demand more fuel. Fuel gas pressure and effluent condenser temperature control this pump. The effluent condenser temperature is a key control point because very hot vapors result in inefficient hydrocarbon condensation. The pump operates when the fuel gas pressure is 20 psig or more and the overhead temperature is 120 °F or less. The pump automatically shuts down when the fuel pressure falls below 20 psig or the overhead temperature is greater than 120 °F. ECL specified the water pump with reserve capacity sufficient to handle all reasonably expected gas compositions at the test facility.

1.4. PERFORMANCE VERIFICATION OVERVIEW

1.4.1. Performance Verification Parameters

The GHG Center developed the QLD verification approach to provide credible performance data of interest to potential industry users and environmental regulators. Verification parameters consist of:

Operational Performance Parameters:

- sales gas moisture content and production rate
- glycol circulation rate
- makeup natural gas fuel flow rate

Environmental Performance Parameters:

- reboiler stack emission rates
- HAP destruction efficiency

The natural gas moisture content leaving the system is the QLD's primary performance indicator. This stream must not exceed 7 lb water / mmscf (lb/mmscf) gas. Verification tests, therefore, included direct natural gas moisture content and sales gas production rate measurements.

Process glycol circulation rate is another key QLD performance indicator. Over-circulation requires more pump energy, more makeup natural gas consumed to operate the reboiler, or more pollutants to be absorbed and eventually emitted to the atmosphere. Facilities subject to the 40 CFR Part 63 standard [5] (which includes the host site) must monitor glycol circulation rates to minimize such impacts. The GHG Center used an ultrasonic flow meter to verify lean glycol circulation rates during the verification tests.

The GHG Center also monitored the makeup natural gas flow rate fed to the reboiler. Makeup-gas data is useful information to technology users for estimation of possible QLD fuel savings.

Operational performance monitoring occurred after the completion of QLD start-up and shakedown and ECL subsequently announced the system to be functioning normally. These steps ensured the collection of representative data. The GHG Center monitored all operational parameters as one-minute averages for seven days. Section 2.2 reports the daily and overall production averages found during the monitoring period.

Environmental performance parameters quantified the reboiler exhaust stack criteria pollutant, greenhouse gases, and HAPs emission rates. Three 90-minute (nominal) emissions test runs verified all environmental parameters over a one-day test period while the system was operating at "normal conditions". The seven days of operational data prior to testing formed the basis for establishing normal operating conditions. The test plan specified the normal operating range as the rates represented by 75 percent of the individual one-minute operational data entries.

The GHG Center also verified HAP destruction efficiency to determine the QLD's ability to recover or destroy HAPs taken up from the sales gas by the glycol.

1.4.2. Measurement Approach

Table 1-2 summarizes the text matrix. It identifies the required measurements and type of data collected. Figure 1-5 illustrates the measurement system and provides numbered locations for each measurement. The following subsection provides a measurement strategy overview for each verification parameter. The test plan provides detailed background discussions and procedures.

Table 1-2. Verification Test Matrix

Verification Parameter	Location	Description[b]	Units	Method/ Instrument	Sampling Intervals[a]
Sales Gas Moisture Content and Production Rate	1	Sales gas moisture content	lb H_2O / mmscf gas	Electrolytic moisture transmitter	1-min averages, reported as daily averages and run averages
		Sales gas flow rate	mmscfd	Integral orifice meter	1-min averages, reported as daily averages and run averages
Glycol Circulation Rate	2	Lean glycol flow rate	gpm	Ultrasonic flow meter	1-min averages, reported as daily averages and run averages
Makeup Natural Gas Fuel Flow Rate	7	Makeup natural gas flow rate	scfh	Turbine flow meter	1-min averages reported as daily averages and run averages
		BTEX concentration in makeup natural gas	ppm	Sample collection by GHG Center, analysis by independent laboratory	3 gas samples collected per test run (if preliminary samples indicate BTEX > 10,000 ppm)
Reboiler Stack Emission Rates	4	CO_2, NO_X, CO, CH_4, THC, and HAP concentration & emission rates	ppm and lb/h	Varies, see Table 1-3	three test runs (90 minutes each), reported as average for each test run
HAP Destruction Efficiency	2	Lean glycol flow rate	gpm	Turbine flow meter	1-min averages, reported as average for each test run
		HAP concentration in lean glycol	ìg/mL	Sample collection by GHG Center, analysis by independent laboratory	4 liquid samples per test run, reported as average for each test run
	3	Rich glycol flow rate	gpm	Lean glycol flow rate corrected for water and hydrocarbon content	1-min averages, reported as average for each test run
		HAP concentration in rich glycol	ìg/mL	Sample collection by GHG Center, analysis by independent laboratory	4 liquid samples per test run, reported as average for each test run
	5	Wastewater flow rate	gpm	Prior to testing, determine discharge rate per "dump" and per inch of sight glass level change. Record times and number of each discharge dump occurring during test run	Each time discharge dump occurs
		HAP concentration in wastewater	ìg/mL	Sample collection by GHG Center, analysis by independent laboratory	4 liquid samples per test run, reported as average for each run
	6[c]	Condensate flow rate	gpm	Record condensate sight glass height before and after each dump. Use wastewater discharge rate in gal/in. to calculate condensate discharge rate in gal/dump	Each time discharge occurs
		HAP concentration in condensate product stream	ìg/mL	Sample collection by GHG Center, analysis by independent laboratory	4 liquid samples per test run, reported as average for each run

(continued)

Table 1-2. Verification Test Matrix (Concluded)

Verification Parameter	Location	Description[b]	Units	Method/ Instrument	Sampling Intervals[a]
HAP Destruction Efficiency	8	Vacuum separator vent gas flow rate	scfm	Assigned as 0 because vent was capped throughout testing	
		HAP concentration in vacuum separator vent gas	ìg/mL		
	9	Accumulator vessel vent gas flow rate	scfm	Dry gas meter, slack tube manometer, and thermocouple meter	Assigned as 0 because dry gas volume counter did not change throughout testing
		HAP concentration in accumulator vent gas	ìg/mL	Sample collection by GHG Center, analysis by independent laboratory	

[a] For destruction efficiency, a test run corresponds to the 90-minute stack run.

[b] HAPs are the sum of BTEX and n-Hexane.

[c] HAPs dissolved in the condensate product are reported for information purposes. They are not used to determine HAP destruction efficiency. See section 1.4.2.6

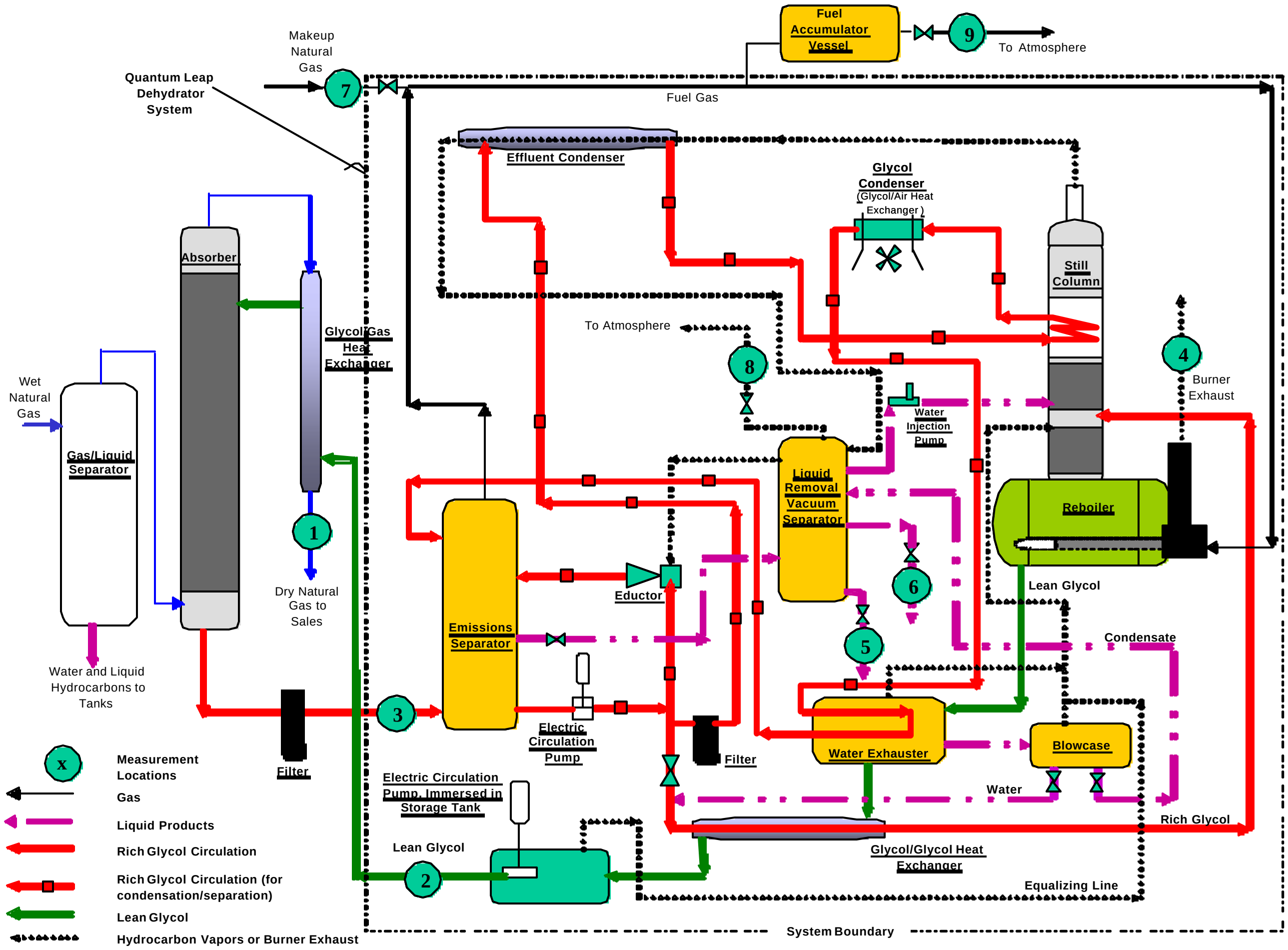

Figure 1-5. Measurement System Schematic

1.4.2.1. Sales Gas Moisture Content

The host site continuously monitors sales gas moisture as a part of normal operations (Location 1, Figure 1-5). The GHG Center used the one-minute average moisture data to measure the QLD's operational performance. Test personnel obtained the data files from the host site's central computer.

The host site had replaced the MEECO moisture sensor (as described in the test plan) with a new Panametrics brand sensor. The Panametrics meter provided the same performance: moisture measurement range of 0 to 20 lb/mmscf, lower detection limit (LDL) of 0.2 lbs/mmscf, and a rated accuracy of ± 5 percent of reading. Panametrics calibrated the meter with National Institute of Standards and Technology (NIST) - traceable instruments prior to installation.

1.4.2.2. Sales Gas Production Rate

The host site uses an Emerson MVS205 Multi-Variable Sensor orifice meter to document sales gas production. The GHG Center used the meter's one-minute average sales gas production data to measure the QLD's operational performance. Test personnel obtained the data files from the host site's central computer.

The sales gas meter contains a 4.00-inch orifice plate and is temperature and pressure compensated to 60 ^{o}F, 14.7 psia (gas industry standard conditions). Its operating range is 0 to 2 mmscfh with a rated accuracy of ± 1 percent of reading. Site personnel calibrated the flow meter with NIST-traceable reference standards prior to testing.

1.4.2.3. Glycol Circulation Rate

The GHG Center initially planned to use the site's Halliburton MC-II EXP turbine meter to measure glycol circulation rate (Location 2, Figure 1-5). However, a performance comparison with the GHG Center's ultrasonic meter (Controlotron 1010EP1) revealed a large discrepancy (greater than two percent allowed in the Test Plan). The site investigated potential turbine meter problems while the GHG Center and ECL evaluated the glycol pump's theoretical capacity. The consensus was that the ultrasonic meter reported flow rates that were within the expected range for this pump. Consequently, the GHG Center used ultrasonic meter for the verification test. Section 3.0 and associated Corrective Action Reports (CARs) document these findings.

The ultrasonic meter is a digitally integrated flow-metering system that consists of a portable computer and ultrasonic fluid flow transmitters. The meter determines fluid velocity by measuring ultrasonic pulse transit times between the transducers. A precision-mounting jig secures the transducers to the pipe at a known distance apart. The operator enters the fluid composition (100 percent TEG for this test), pipe diameter, material, wall thickness, and expected sonic velocity into the meter's computer. The flow meter determines the sonic velocity based on the known distance between the transducers under zero-flow conditions with the pipe full of fluid. It multiplies the fluid velocity by the internal area of the pipe, and reports one-minute average volumetric flow rate during operation.

The flow meter's overall rated accuracy is ± 1.0 percent of reading and can be used on pipe sizes ranging from 0.25 to 360 inches in diameter with fluid flow rates ranging from zero to 60 feet per second (fps).

1.4.2.4. Makeup Natural Gas Flow Rate

The QLD reboiler burner can accept up to 166 scfh makeup natural gas as supplemental fuel. A Halliburton MC-II EXP turbine meter installed on the one-inch (inside diameter) gas line upstream of the reboiler (Location 7, Figure 1-5) measured makeup gas flow. The site's central computer collects the one-minute average data and test personnel obtained the data files from the host site.

The Halliburton flow analyzer is a turbine meter and integral signal display and transmitter with a linear flow range sufficient to measure gas flows should the reboiler operate on makeup gas only (0 to 600 scfh). The manufacturer used a piston-type volume prover to calibrate the meter. It is temperature and pressure compensated, and provided mass flow output accurate to ± 1.0 percent at standard conditions.

1.4.2.5. Reboiler Stack Emission Rates

Cubix Corporation, an independent stack testing contractor located in Austin, TX, performed reboiler stack emissions testing to determine concentrations and emission rates for the following air pollutants: CO, THCs, GHGs (CO_2, NO_X, and CH_4), BTEX, and total HAPs (BTEX plus n-hexane). Cubix conducted three 90-minute (nominal duration) test runs for each parameter while the system was operating at normal conditions.

All the test procedures are well-documented Title 40 CFR 60 Appendix A reference methods. Table 1-3 summarizes reference methods performed for emissions testing supporting this verification. The test plan provides a detailed discussion of the test methods and QA/QC requirements.

Emission rates reported in Section 2.0 are in terms of parts per million by volume dry (ppmvd). These values, correlated with the stack volumetric flow rates in dry standard cubic feet per minute (dscfm), yield pound per hour (lb/h) emission rates for NO_X, CO, CH_4, VOC, hexane, BTEX, and HAPs. VOC emissions are the sum of all organic compounds minus methane and ethane emissions according to Colorado Department of Public Health and Environment regulations. HAP emissions at this facility are the sum of hexane and BTEX emissions.

Table 1-3. Emissions Testing Methods Summary

Measurement Variable	U.S. EPA Reference Method	Analyzer Type	Instrument Range
NO_x	7E	TEI Model 42C (chemiluminescence)	0 to 100 ppm
CO	10	TEI Model 48C (NDIR)	0 to 100 ppm
THC	25A	JUM Model VE-7 (FID)	0 to 100 ppm
O_2	3A	CAI Model 200 (Paramagnetic)	0 to 25%
CO_2	3A	CAI Model 200 (NDIR)	0 to 20%
CH_4	18	Hewlett Packard 5890a (GC/FID)	0 to 100 ppm
BTEX[a], n-Hexane	18	Hewlett Packard 5890a (GC/FID)	0 to 100 ppm
Exhaust gas volumetric flow rate	1A and 2C (modified)	Differential Pressure	9,000 to 11,000 scfh
Moisture	4	Gravimetric	0 to 100%

[a] Includes separate benzene, toluene, ethylbenzene, and xylene quantification

1.4.2.6. HAP Destruction Efficiency

Section 2.6 of the Test Plan discusses HAP destruction efficiency, the required measurements, and the calculations in detail. Destruction efficiency is the net HAPs entering the system boundary (from the glycol) minus that leaving the system from emissions sources divided by the net HAPs entering the system. Testers determined the HAPs inputs via the Atmospheric Rich/Lean Method for Determining Glycol Dehydrator Emissions (ARL) [8].

HAP emission sources at this site are: fugitive leaks, the reboiler burner exhaust stack, wastewater, and PRVs. The GHG Center determined that fugitive leaks are negligible because the fabricator certified the system to be leak-tight. This certification was documented, signed, and provided to the GHG Center. The burner stack may emit unburned HAPs to the atmosphere and HAPs dissolved in the wastewater can be released during disposal.

HAPs dissolved in the condensate stream are deemed to be “controlled” or “sequestered” and not considered an emission. This is consistent with 40 CFR Part 63 and is documented in the Test Plan.

1.4.2.7. Additional Supporting Measurement Details

The following sections discuss verification test events and conditions beyond those presented in the test plan.

1.4.2.7.1 Glycol Flow

Direct flow measurement of the rich glycol stream is difficult due to the presence of multi-pollutant, multi-phase (liquid, vapor) products. Therefore, the natural gas industry, EPA, and the Gas Technology Institute (GTI) normally assign the process circulation rate (measured on the lean glycol stream) as the rich glycol flow rate.

This causes a negative bias (approximately 4 percent during this verification) in the reported rich glycol flow rate because of the rich glycol’s higher water and hydrocarbon content. This bias is minimized by modifying the ARL method by correcting the lean glycol flow rate to yield the true rich glycol flow rate. The procedure required rich and lean glycol analyses for density, water content, and total hydrocarbon content. Analysts then applied these data to produce the correction. Appendix A describes the approach.

1.4.2.7.2 Lean Glycol Sample Condition

The lean glycol temperature was about 210 °F. The sample tubing passed through an ice water bath during sampling. This allowed the samples to cool before entering the sample vials. The rich glycol samples did not require cooling because the rich glycol temperature was close to the absorber temperature (approximately 90 to 100 ^{o}F). The rich glycol samples were extremely foamy. The foam developed as dissolved gas escaped when the glycol was exposed to atmospheric conditions during sampling. This is equivalent to sampling a conventional glycol dehydrator with no flash tank. The ARL method warns that volatile components in the glycol can be unavoidably lost during sampling under these conditions. Such losses would result in understatement of glycol hydrocarbon concentrations. Section 2.3.2 provides further discussion of this phenomena and its possible effects on the verification results.

1.4.2.7.3 Lab Analysis

Enthalpy Analytical of Durham, NC, analyzed the glycol samples for HAPs and moisture via gas chromatography/flame ionization detector (GC/FID) and Karl Fischer titration, respectively. The laboratory used a Hewlett-Packard 5890 Series II GC (with FID) and a hydrogen carrier gas. The capillary columns were Restek 20 meter (m) x 0.18 millimeter (mm) Rtx-1. The method detection limit (MDL) was as low as 6.0 micrograms per milliliter (ì g/ml) depending on the required dilutions.

1.4.2.7.4 Wastewater Discharge Rate

The GHG Center quantified the volume of nine wastewater discharges before the verification by capturing each discharge in a tared bucket, noting the bucket's full weight, and measuring the temperature. Center personnel also logged the changes in liquid level by reading an engineer's scale attached to the liquid sight glass on the vacuum separator. The water weight divided by the density at the recorded temperature yields the gallons per dump for each discharge. The sight glass level change divided by the gallons per dump yields gallons per inch of movement on the sight glass. Section 2.0 presents the results as 3.057 gal/dump or 1.283 gallons per inch (gal/in.) with a maximum variation of 1.2 percent.

GHG Center personnel logged the time of each wastewater dump during all test runs during the verification. The measured discharge rate (3.057 gal/dump) divided by the elapsed time between two successive discharges yielded the wastewater flow rate (gpm). For example, discharge number 323 occurred at 14:03 and discharge number 324 occurred at 14:31 (28 minutes later). The first test run started at 14:03, so, during the first minute, the system produced 3.057/28 or 0.109 gpm.

The field team leader collected wastewater samples from the petcocks located on the vacuum separator vessel instead of from the discharge traps described in the Test Plan (Location 5, Figure 1-5). His observation during an initial site visit was that the vacuum separator vessel had separate tapped and plugged ports available for liquid (wastewater and hydrocarbon) sampling. Discharge trap installation would have required extensive pipeline modifications. The GHG Center consequently determined that installation of petcocks directly into the separator vessel was the best sampling method. An April 4, 2003 CAR documented this determination.

The field team leader opened the vacuum separator manual vent valve to break the vacuum during each sampling event. This allowed the samples to be collected. The open valve caused a momentary process upset and the QLD system began to pressurize. The vacuum separator pressure quickly re-stabilized to desired negative gage pressure after closing the sample valve.

These upsets also caused perturbations in stack gas emission concentration. Test personnel observed this problem during the verification test runs. The GHG Center determined that the perturbations would not significantly affect the overall verification results because stack gas concentrations quickly returned to normal when the valve was closed. Also, installing the discharge traps at that point would have introduced significant delays into the test campaign. The stack test verification results therefore do not include the time periods corresponding to the liquid sampling disturbances. Section 3.0 describes the technique the GHG Center analysts used to identify these invalid time periods.

The laboratory analyzed the wastewater samples by the purge-and-trap method. All dilutions were six-fold, or one milliliter (ml) of sample plus 5 ml of MeOH solvent. The analyst used a Restek 60 m x 0.32 mm Rtx-1 capillary column. Other equipment and procedures were as described above for the glycol sample analysis.

The laboratory employed the same analysis procedures described earlier for the glycol samples except that all dilutions were 1001 to 1, or 10 microliters (ìl) of sample added to 10 ml solvent.

1.4.2.7.5 HAPs Emitted from Pressure-Relief Vents

The automatic PRVs at the accumulator vessel and the vacuum separator were potential intermittent (non-continuous) emission points. The PRV would open to atmosphere if the accumulator vessel gas pressure exceeded 28 psig. The vacuum separator PRV opens and emits gases to atmosphere only when gas pressures in the QLD system reach a level high enough to upset the overall system function. GHG Center personnel observed that this happened only during initial system start-up and shake-down activities. The vent remains closed during all normal operations once the pressure stabilizes.

The GHG Center developed measurement techniques for quantifying HAP emissions from both sources (Locations 8 and 9, Figure 1-5). ECL had stabilized the system such that high-pressure conditions no longer occurred during normal operations. Neither of the PRVs opened during the verification test. The GHG Center verified that the resulting HAP emission rate was zero lb/h. Internal CARs contain complete documentation on the PRVs.

1.4.2.7.6 HAPs Entering in Makeup Natural Gas

The GHG Center determined BTEX in the makeup natural gas to assess the possible effects on the total HAP inputs to the system boundary. Additional samples would be collected during verification testing if preliminary testing indicated BTEX levels in the natural gas were greater than 10,000 ppm.

The field team leader collected three makeup natural gas samples prior to the verification tests. Appendix D presents the results and they indicate that BTEX entering the system from the makeup gas is negligible. Additional sampling during the verification test runs was not required.

1.4.2.7.7 Miscellaneous Considerations

HAP destruction efficiency does not require the condensate product HAP mass flow rate. It is, however, useful data with which to complete an entire QLD system mass balance. The condensate production rate may also be useful to readers interested understanding the recovery potential of the saleable product. This report, therefore, presents condensate production rate (gpm) and HAPs (lb/h) within the condensate stream. The flow rate determination requires the gallons per inch approach described above for the wastewater flow rate determination.

Observation of condensate sight-glass level changes by field personnel quantified the condensate production rate. The GHG Center did not directly quantify the discharges because of its hazardous properties, especially when handled in open containers. The vacuum separator vessel collects both the wastewater and condensate, separated by a weir and bulkhead system. The cylindrical vessel’s diameter is constant throughout. This means that a one-inch level change in both sections of the vessel correspond to the same liquid volume. A one-inch level change in the condensate product’s sight glass corresponds to the same volume as measured by a one-inch level change in the wastewater sight glass, or 1.283 gal/in. as described above.

2.0 VERIFICATION RESULTS

2.1. OVERVIEW

Installation and start-up activities for the QLD system occurred in Winter of 2002. ECL then installed the fuel accumulator vessel, the water injection pump, and the vacuum separator and fuel accumulator PRVs in response to the conditions described in Section 1.2. ECL pronounced the system to be functioning properly in late March 2003. The GHG Center initiated verification testing in April 2003.

GHG Center personnel did not perform leak tests (soap screening) because the system fabricator performed industry-standard system pressure tests during and after final assembly. The fabricator performed air- and hydrostatic-pressure tests. Air testing consisted of using 125 psig compressed air to pressurize the pipe spools or assemblies. Operators then applied soap solution or submerged the assembly in water, noted any bubbling, and performed repairs as needed. Hydrostatic testing consisted of having operators fill the vessel or assembly with water and then pressurize it, watching for any leakage. The fabricator's certification listed no significant leaks. Physical wear, settlement, and vibration likely did not cause new leaks by the time the verification tests occurred because this was new equipment used in a new application. Although ECL performed repairs and modifications after the site installed the QLD, they also performed the appropriate leak checks prior to restarting the unit. The GHG Center, therefore, assigned the fugitive leak rate as negligible.

Operational performance testing occurred between April 23 and 29, 2003. The GHG Center acquired seven days of continuous sales gas moisture, sales gas flow, make-up gas flow, and glycol circulation rate data during this period. The QLD consistently met or exceeded specifications as summarized below:

- The moisture content of dry natural gas was well below the 7.00 lb/mmscf limit required by the operator throughout the entire monitoring period. Actual daily average values ranged between 0.89 and 1.28 lb/mmscf.
- The QLD enabled continuous operation of the sales gas stream, with daily average flow rates ranging between 26.8 and 29.3 mmscfd.
- The QLD system burned all uncondensable hydrocarbon vapors without venting them to the atmosphere. The system accomplished this with little or no makeup natural gas. Makeup natural gas flow rate was between 0.00 and 1.76 scfh, well below the 166 scfh initially expected.
- The daily average glycol circulation rate varied between 3.00 and 3.77 gpm.

Environmental performance testing occurred on April 30, 2003, after completion of operational tests on the previous day. The GHG Center representatives met with the ECL and Kerr-McGee representatives prior to emissions testing to verify that the seven-day operational test period had yielded results typical of normal plant operations. Each of the three test runs acquired between 70 to 85 minutes of stack emissions data, summarized as follows:

- Overall average emission rates for NO_x, CO, and VOC from the reboiler stack were 0.0817, 0.0005, and 0.0003 lb/h, respectively.
- HAP concentrations in the reboiler stack were non-detectable. Maximum HAPs leaving the system in the reboiler exhaust and wastewater were 0.0016 and 0.0220 lb/h, respectively.

- PRVs did not operate at any time during the entire test campaign, nor are releases anticipated during normal operations. Therefore, no expected emissions were assigned to PRV operation.
- HAP destruction efficiency was greater than 99.74 ± 0.01 percent.
- Average wastewater and condensate production rates were 6.36 and 2.88 gph, respectively.

The following subsections present the verification test data for each parameter.

2.2. OPERATIONAL PERFORMANCE

Table 2-1 summarizes daily performance data for the four primary operational performance parameters. The results are representative of 85 to 100 percent of one-minute data recorded in a 24-hour period except for the first test day (April 23). The table shows that the values for all key operational parameters are relatively consistent from day-to-day. This supports the conclusion that the QLD operations are stable.

Table 2-1. Pre-Test Operational Data and Establishment of Normal Operating Conditions[a]

Date	Hours Of Valid Data	Sales Gas Moisture Content[b]		Sales Gas Flow Rate[b]		Makeup Natural Gas Flow Rate[b]		Glycol Circulation Rate	
		(lb H2O/mmscf)		(mmscfd)		(scfh)		(gpm)	
		Range	Average	Range	Average	Range	Average	Range	Average
4/23/03	15.05	0.80 to 1.69	1.02	28.67 to 31.39	29.31	0.11 to 345.98	16.32	1.55 to 6.04	3.63
4/24/03	24.00	0.79 to 1.03	0.89	26.18 to 32.02	28.63	0.00 to 220.19	1.22	1.47 to 4.00	3.30
4/25/03	20.73	0.91 to 1.44	1.12	26.09 to 29.96	28.38	0.00 to 190.44	0.63	0.00[c] to 4.71	3.00
4/26/03	24.00	0.73 to 1.99	1.28	26.13 to 29.97	28.15	0.00 to 317.04	1.68	0.64 to 5.34	3.21
4/27/03	23.95	0.95 to 1.69	1.27	25.69 to 28.83	26.88	0.00 to 3.92	0.83	1.79 to 4.23	3.67
4/28/03	24.00	0.85 to 1.76	1.24	23.13 to 29.96	26.81	0.00 to 706.33	5.41	1.68 to 4.61	3.68
4/29/03	24.00	0.89 to 1.64	1.18	25.20 to 29.96	27.38	0.00 to 3.61	0.83	1.87 to 4.43	3.77
Overall Average			1.14		27.9		3.85		3.47
Normal Operating Conditions[a]		0.89 to 1.50		26.54 to 29.26		0.00 to 1.76		3.14 to 3.93	

[a] Normal operating condition is defined as the range represented by 75 percent of individual one-minute measurement values

[b] Source – Kerr-McGee operations.

[c] The flow meter reported zero during certain times on this date because of aeration in the pipeline. When the operator added makeup TEG to the system. The aeration ceased and the flow meter resumed normal operations.

The overall daily average sales gas moisture content was 1.14 lb/mmscf. The highest level recorded was 1.99 lb/mmscf which is well below the site's 7.00 lb/mmscf requirement. The normal operating range for this parameter (based on 75 percent of the one-minute data) is from 0.89 to 1.50 lb/mmscf.

The sales gas flow rate varied little throughout the test period. The overall average daily production rate was 27.9 mmscfd. The normal range for this parameter is from 26.5 to 29.3 mmscfd.

The glycol recirculation rate, measured on the lean side, averaged about 3.47 gpm. The circulation rate remained between 3 and 4 gpm during the majority of the monitoring period. Rates higher than 5 gpm were recorded for one hour on April 23 and about two minutes on April 26. The elevated rates are not typical, since they occurred for an extremely short period of time. The normal operating range for the glycol recirculation rate is between 3.14 and 3.93 gpm.

ECL expected the reboiler to consume up to 166 scfh of makeup natural gas (about 30 percent of burner capacity) in the initial design phase. Recovered hydrocarbon vapors would supply the remaining fuel requirement. Table 2-1 shows that the reboiler burner actually consumed significantly less makeup gas. This amounts to a significant fuel savings for the site operator and demonstrates complete use of waste gas that would normally be vented. The overall average makeup natural gas flow rate was 3.85 scfh. However, the normal operating range was well below this average (0.00 to 1.76 scfh). The data show some higher intermittent gas flow rates, but these generally lasted for less than 15 minutes in a 24-hour period. The verification data demonstrated that the QLD system is capable of recovering and using high-Btu, wet hydrocarbon vapors as a primary process fuel.

2.3. ENVIRONMENTAL PERFORMANCE

Environmental performance verification tests took place on April 30, 2003. The Test Plan required three 90-minute test runs to verify reboiler stack emissions performance and HAPs destruction efficiency. The GHG Center, however, deemed some data as invalid because wastewater and condensate sampling events disrupted the QLD process. Valid data varied between 70 and 85 minutes per test run. Section 3.0 discusses the invalidated data.

Table 2-2 shows test run times and duration. The table also summarizes average sales gas moisture content, average sales gas flow rate, average makeup natural gas flow rate, and the average glycol circulation rate. Figures 2-1 and 2-2 are operational data time series plots which correspond to the test runs. The data demonstrate that verification tests occurred while the system was operating at normal conditions. The average values observed during each test run are representative of the normal operating range established in the pre-test evaluation (see Table 2-1).

Table 2-2. Verification Test Period Operational Data Summary

	Run Times		Run Duration[a]	Average Sales Gas Moisture Content	Average Sales Gas Flow Rate	Average Makeup Natural Gas Flow Rate	Average Lean Glycol Flow Rate
	Start	Stop	(mins)	(lb H2O/mmscf)	(mmscfd)	(scfh)	(gpm)
Run 1	14:30	16:23	85	1.25	28.49	0.48	3.77
Run 2	17:01	18:30	70	1.36	28.45	0.84	3.60
Run 3	18:57	20:27	72	1.16	28.53	2.77	3.89
Overall Average				1.25	28.49	1.37	3.75

[a] Excludes times corresponding to invalid data

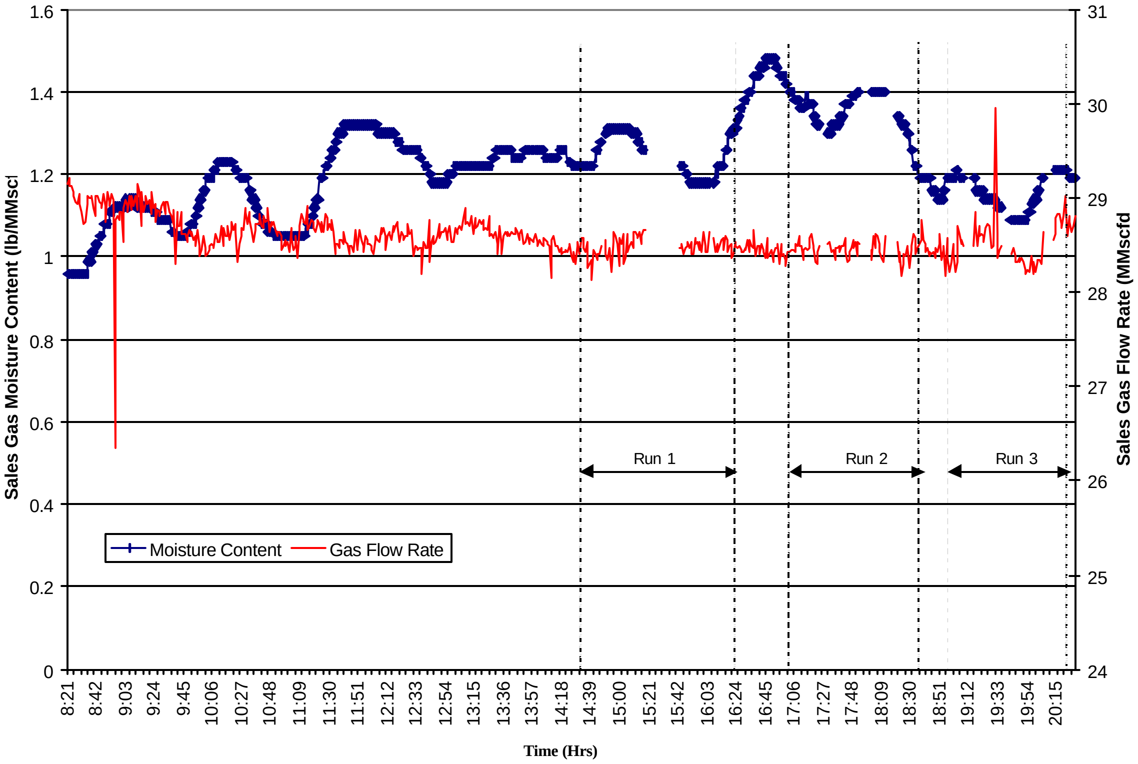

Figure 2-1. Operational Parameters Measured During Verification Test Period

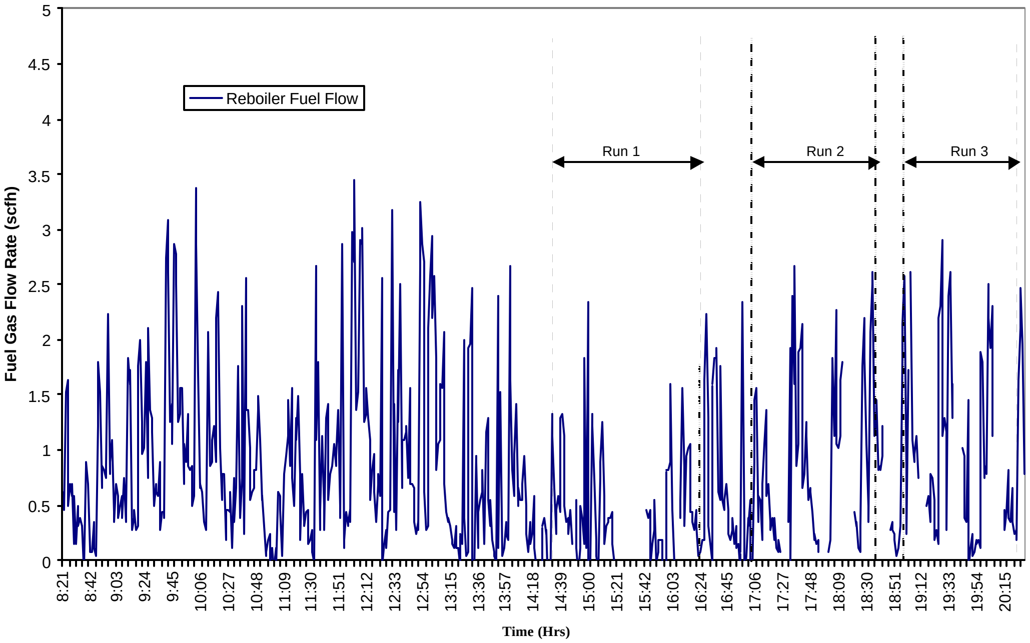

Figure 2-2. Fuel Gas Flow Rates Measured During the Verification Test Period

GHG Center personnel also monitored several key process variables although they were not required in the Test Plan. They were: absorber operating temperature and pressure, still column vapor exit temperature, and emissions separator operating temperature. They were measured and reported to provide the capability of comparing this system to other systems. Test personnel logged these data from instruments permanently installed at the site. Table 2-3 summarizes the data.

Table 2-3. Additional Process Operating Data for Verification Test Periods

Verification Test Run No.	Absorber Temperature (^oF)	Absorber Pressure (psig)	Still Column Vapor Exit Temperature (^oF)	Emissions Separator Temperature (^oF)
Run 1	98 - 130 [a]	1010	106 - 129	114.95 – 115.71
Run 2	102 - 105	1010	94 - 120	111.37 – 114.58
Run 3	90 - 94	1010	110 - 128	103.94 – 106.90

[a] This 130 ^oF reading is suspect. It occurred only once, and all other readings were 105 ^oF or less.

The following subsections present reboiler stack emissions and HAP destruction efficiency results.

2.3.1. Reboiler Stack Emissions Performance

All test runs conformed to the applicable reference method procedures (see Table 1-3). The reference method results are in terms of parts per million by volume, dry (ppmvd), corrected for moisture content. CO_2 emissions are in volume percent. These values, correlated with stack gas flow rates, yield lb/h emission rates as follows:

$$E_{lb/hr} = \frac{Q_{std} * MW * C_{poll}}{385.15 * 10^6} \qquad \text{Eqn. 1}$$

where:

$E_{lb/h}$ = emission rate (lb/h)
Q_{std} = stack gas volumetric flow rate (dscfh)
MW = pollutant molecular weight, pounds per pound mole (lb/lbmol)
C_{poll} = pollutant concentration (ppmvd)
385.15 = standard cubic feet per pound mole (scf/lb.mol)
10^6 = parts per million

All pollutant and gas emissions were relatively consistent between the three test runs. Table 2-4 summarizes the run average NO_X, CO, VOC, CH_4, CO_2 and HAP concentrations, emission rates and the overall average emissions from the reboiler stack.

Table 2-4. Reboiler Stack Emissions Summary

Verf. Test Run No.	Exhaust O_2	Stack Gas Velocity	Stack Flow Rate	NO_x Emissions		CO Emissions		VOC Emissions		CH_4 Emissions		CO_2 Emissions		Total HAP Emissions	
	%	ft/sec	dscfh	ppmvd	lb/h	ppmvd	lb/h	ppmvd	lb/h	ppmvd	lb/h	%	lb/h	ppmvd	lb/h
Run 1	6.4	23.64	10,793	67.8	0.0873	0.3	0.0003	0.4	0.0002	< 0.1	< 0.00004	9.5	117	< 0.6	< 0.0016
Run 2	6.7	23.72	10,369	66.0	0.0817	1.0	0.0007	0.8	0.0004	< 0.1	< 0.00004	9.2	108	< 0.6	< 0.0016
Run 3	6.8	24.27	10,359	61.6	0.0761	0.6	0.0004	0.5	0.0002	< 0.1	< 0.00004	9.1	107	< 0.6	< 0.0015
Avg.	**6.6**	**23.87**	**10,507**	**65.1**	**0.0817**	**0.6**	**0.0005**	**0.6**	**0.0003**	**< 0.1**	**<0.00004**	**9.3**	**111**	**< 0.6**	**< 0.0016**

Average NO_x emissions were 65.1 ppmvd and 0.0817 lb/h. Emissions of CO and VOCs were very low during all three test runs, averaging 0.6 ppmvd (0.0005 lb/h) and 0.6 ppmvd (0.0003 lb/h), respectively.

A continuously extracted stack gas sample, periodically injected into a gas chromatograph, provided the material for organic (CH_4, HAPs) concentration determinations. Test personnel performed six injections, each about 15 minutes apart, during each test run. The analyst determined that each HAP constituent was consistently below the instrument's detection limit (< 0.1 ppmvd). This equates to an average hourly emission rate of < 0.0016 lb/h which is well below the site's permit requirement. All methane results were also below the GC/FID's detection limit (< 0.1 ppmvd).

CO_2 concentrations averaged 9.3 percent, corresponding to an average 111 lb/h emission rate.

Test personnel conducted all sampling system QA/QC checks in accordance with test plan specifications. These included analyzer linearity tests, sampling system bias and drift checks, interference tests, and use of audit gases. Section 3 discusses the QA/QC check results.

2.3.2. HAP Destruction Efficiency

Table 2-5 summarizes HAP destruction efficiency for each test run and the overall average. Note that the test plan specified that ARL glycol sample analyses data correlated with the glycol flow rate form the basis for the quantity of HAPs entering the system. This means that an average of 9.09 lb/h net HAPs entering the system with less than 0.0236 lb/h leaving it results in a destruction efficiency exceeding 99.74 ± 0.01 percent. Section 3.2.5 discusses the accuracy derivation for this determination.

Table 2-5. HAP Destruction Efficiency

Verification Test Run No.	HAP$_{rich}$	HAP$_{lean}$	net HAP$_{in}$	HAP$_{wastewater}$	HAP$_{stack}$	HAP$_{vented}$	HAP$_{emitted}$	HAP DE
	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h	lb/h	%
Run 1	9.83	0.33	9.50	0.0209	<0.0016	0.00	0.0226	99.76
Run 2	8.37	0.37	8.00	0.0220	<0.0016	0.00	0.0236	99.70
Run 3	10.19	0.40	9.79	0.0232	<0.0015	0.00	0.0245	99.75
Average	**9.46**	**0.37**	**9.09**	**0.0220**	**0.0016**	**0.00**	**0.0236**	**99.74**
90% Confidence Interval	**1.62**	**0.06**	**1.62**	**0.0020**	**0.00015**		**0.002**	**0.01**

The overall HAP average mass rate in the condensate product stream was 16.41 lb/h. This means that net HAPs entering the system (as determined by the ARL method) were consistently less than the summed HAPs in the two effluent (stack gas and wastewater) and one product (condensate) streams. The glycol streams failed to account for approximately 7.34 lb/h of the total mass exiting the system.

The GHG Center targeted the rich glycol samples as the primary location where HAP mass loss could have occurred after ruling out potential flow measurement problems or bias. The field team leader withdrew rich glycol at absorber pressure (1010 psig) into a sampling vial at atmospheric pressure during each sampling event. The rich glycol foamed instantly as it entered the vial. The foam was not allowed to overflow the vial, it was capped immediately, and stored on ice according to the ARL procedure. The reader should note that these procedures directly correspond to the ARL sampling instructions for glycol dehydrators without flash tank gas separators. The method's Figure A-1 [9] specifies, in the absence of a flash tank, a sampling location between the charcoal filter and the reboiler. Section A.4.4 indicates that rich glycol from that sampling location "generally sprays from the sample line as a foamy aerosol" which is consistent with the field conditions.

Test personnel did, however, deviate from the ARL method in one respect. As documented in a GHG Center corrective action report (CAR), field personnel did not employ an iced cooling coil for the rich glycol samples because the rich glycol was at absorber temperature, or about 90 to 100 °F throughout the test runs. Section A.4.2 of the ARL method requires that the sample pass through an iced cooling coil, but "cooling the glycol sample is not necessary if the temperature of the glycol is less than 70 °F" [9]. It is possible that this temperature discrepancy may have negatively biased the rich glycol HAPs concentrations. The HAPs may have volatilized and escaped while the foamy glycol filled the sampling vials. The GHG Center cannot conclusively state whether this was the primary cause. GRI studies have found that the ARL method does negatively bias VOC, but not necessarily BTEX results [8,10].

This possible negative bias could cause a negative effect on the reported HAPs destruction efficiency. Table 2-5 shows that the destruction efficiency, based on average HAP inputs of 9.46 lb/h (as quantified by the ARL method) is 99.74 percent. If the HAP inputs are assumed to be at least equal to the sum of the wastewater, stack gas, and condensate HAPs (average 16.41 lb/h), the resulting destruction efficiency is 99.86 percent. The GHG Center therefore concludes that the QLD emits very little HAPs and that overall destruction efficiency is 99.74 percent (or more) in either scenario.

2.3.2.1. HAP Inputs from Glycol Streams

Table 2-6 summarizes the average glycol flow rates for the three test runs as measured with the ultrasonic flow meter. The lean glycol flow rates were between 3.77 and 3.92 gpm. The corrected rich glycol flow rates were between 3.77 and 4.05 gpm. The added water content and hydrocarbons increased rich glycol flow rate by about 4 percent.

Table 2-6. HAP Inputs From Glycol Streams

Run 1	**Concentration, C_{Lean} (ìg/mL)**										**V_{Lean}**	**HAP_{lean}**	
Lean 1	Sample 1		Sample 2		Sample 2a		Sample 3		**Average**				
									ìg/mL	**lb/gal**	**gpm**	**lb/h**	
n-Hexane	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.769	0.01	
Benzene	69.4		54.0		68.2		59.1		62.66	0.0005229	3.769	0.12	
Toluene	89.6		66.5		87.6		69.4		78.26	0.0006531	3.769	0.15	
Ethylbenzene	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.769	0.01	
p-Xylene	16.6		15.6		14.8		19.9		16.73	0.0001396	3.769	0.03	
o-Xylene	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.769	0.01	
Total HAP	**193.58**		**154.14**		**188.63**		**166.28**		**175.66**	**0.0014659**	**3.769**	**0.33**	
	Concentration, C_{Rich} (ìg/mL)										**V_{Rich}**	**HAP_{Rich}**	**Difference net HAP_{in}**
Rich 1	Sample 1		Sample 2		Sample 2a		Sample 3		**Average**				
									ìg/mL	**lb/gal**	**gpm**	**lb/h**	**lb/h**
n-Hexane	140.13		107.27		144.50		137.00		132.22	0.0011034	3.916	0.26	0.25
Benzene	1660.5		1424.8		1704.8		1394.5		1546.13	0.0129031	3.916	3.03	2.91
Toluene	2744.7		2393.9		2843.6		2293.2		2568.85	0.0214381	3.916	5.04	4.89
Ethylbenzene	58.98		51.47		62.31		48.01		55.19	0.0004606	3.916	0.11	0.10
p-Xylene	614.6		545.7		647.7		511.2		579.80	0.0048386	3.916	1.14	1.11
o-Xylene	137.67		120.91		144.49		113.18		129.06	0.0010771	3.916	0.25	0.24
Total HAP	**5356.52**		**4644.02**		**5547.40**		**4497.10**		**5011.26**	**0.0418210**	**3.916**	**9.83**	**9.50**
Run 2	**Concentration, C_{Lean} (ìg/mL)**										**V_{Lean}**	**HAP_{lean}**	
Lean 2	Sample 1		Sample 2		Sample 2a		Sample 3		**Average**				
									ìg/mL	**lb/gal**	**gpm**	**lb/h**	
n-Hexane	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.604	0.01	
Benzene	82.5		74.4		68.6		75.5		75.25	0.0006280	3.604	0.14	
Toluene	102.5		94.5		86.6		92.8		94.11	0.0007853	3.604	0.17	
Ethylbenzene	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.604	0.01	
p-Xylene	20.6		16.1		24.8		14.3		18.96	0.0001582	3.604	0.03	
o-Xylene	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.604	0.01	
Total HAP	**223.66**		**202.98**		**197.99**		**200.64**		**206.32**	**0.0017218**	**3.604**	**0.37**	
	Concentration, C_{Rich} (ìg/mL)										**V_{Rich}**	**HAP_{Rich}**	**Difference net HAP_{in}**
Rich 2	Sample 1		Sample 2		Sample 2a		Sample 3		**Average**				
									ìg/mL	**lb/gal**	**gpm**	**lb/h**	**lb/h**
n-Hexane	135.27		122.23		119.66		134.68		127.96	0.0010679	3.772	0.24	0.23
Benzene	1476.1		1461.7		1332.5		1467.7		1434.50	0.0119715	3.772	2.71	2.57
Toluene	2197.3		2355.2		2133.1		2275.6		2240.32	0.0186964	3.772	4.23	4.06
Ethylbenzene	44.96		47.96		42.70		43.75		44.84	0.0003742	3.772	0.08	0.07
p-Xylene	474.4		508.0		458.7		470.2		477.84	0.0039878	3.772	0.90	0.87
o-Xylene	106.65		112.41		100.60		103.05		105.68	0.0008819	3.772	0.20	0.19
Total HAP	**4434.72**		**4607.53**		**4187.29**		**4495.03**		**4431.14**	**0.0369797**	**3.772**	**8.37**	**8.00**
Run 3	**Concentration, C_{Lean} (ìg/mL)**										**V_{Lean}**	**HAP_{lean}**	
Lean 3	Sample 1		Sample 2		Sample 2a		Sample 3		Average				
									ìg/ml	lb/gal	gpm	lb/h	
n-Hexane	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.887	0.01	
Benzene	74.3		74.3		71.6		86.0		76.57	0.0006390	3.887	0.15	
Toluene	91.1		88.7		86.5		105.6		92.98	0.0007760	3.887	0.18	
Ethylbenzene	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.887	0.01	
p-Xylene	17.1		21.6		16.5		18.4		18.41	0.0001536	3.887	0.04	
o-Xylene	6.00	ND	6.00	ND	6.00	ND	6.00	ND	6.00	0.0000501	3.887	0.01	
Total HAP	**200.51**		**202.67**		**192.57**		**228.09**		**205.96**	**0.0017188**	***3.887***	**0.40**	

(continued)

Table 2-6. HAP Inputs From Glycol Streams (concluded)

Rich 3	**Concentration, C_{Rich} (ìg/mL)**						**V_{Rich}**	**HAP_{Rich}**	**Difference net HAP_{in}**
	Sample 1	Sample 2	Sample 2a	Sample 3	**Average**				
					ìg/mL	**lb/gal**	**gpm**	**lb/h**	**lb/h**
n-Hexane	144.62	128.69	144.76	135.22	138.32	0.0011544	4.047	0.28	0.27
Benzene	1652.1	1566.6	1576.0	1592.6	1596.84	0.0133263	4.047	3.24	3.09
Toluene	2609.8	2517.0	2529.8	2665.7	2580.59	0.0215361	4.047	5.23	5.05
Ethylbenzene	50.25	51.93	51.89	53.51	51.90	0.0004331	4.047	0.11	0.09
p-Xylene	524.0	542.0	544.3	550.5	540.19	0.0045081	4.047	1.09	1.06
o-Xylene	115.01	121.90	121.59	120.08	119.64	0.0009985	4.047	0.24	0.23
Total HAP	**5095.74**	**4928.21**	**4968.39**	**5117.57**	**5027.48**	**0.0419563**	**4.047**	**10.19**	**9.79**
Overall Avg	Sample 1	Sample 2	Sample 2a	Sample 3	**Average**		**Avg. Flow Rate**	**Avg. Mass Rate**	**Difference net HAP_{in}**
	ìg/mL	ìg/mL	ìg/mL	ìg/mL	ìg/mL	lb/gal	gpm	lb/h	lb/h
Lean - Total HAP	**205.92**	**186.60**	**193.06**	**198.33**	**195.98**	**0.0016355**	**3.753**	**0.37**	
Rich - Total HAP	**4962.33**	**4726.59**	**4901.03**	**4703.23**	**4823.29**	**0.0402523**	**3.912**	**9.46**	**9.09**

ND Non-detect or analytical result below the minimum detection limit (MDL)
V_{lean} Lean glycol flow rate, gpm
V_{rich} Rich glycol flow rate, gpm

Table 2-6 also summarizes the GC/FID results. The table shows that four lean and four rich samples were collected during each test run. The field team leader collected samples 2 and 2a sequentially and all other samples were collected about 20 minutes apart.

The lean glycol HAPs mass rate is smaller than the rich stream. This demonstrates that the QLD glycol regeneration process is indeed removing a significant mass of HAPs through condensation and combustion. The overall average HAP concentration in rich and lean glycol streams was 4823.29 ìg/mL and 195.98 ìg/mL, respectively. The primary HAP species present in both streams are benzene and toluene, followed by p-xylene.

Net HAPs entering the QLD system boundary ranged between 8.00 and 9.79 lb/h at a minimum and the overall average is 9.09 ± 1.09 lb/h with a 90 percent confidence interval.

2.3.2.2. HAP Outputs in Reboiler Exhaust Stream

Section 2.3.1 shows that HAP concentrations in the reboiler exhaust stream were below the instrument's detection limit. Table 2-7 summarizes the mass emission rate results. Note that the lb/h detection limits vary because the volumetric flow rate varied from run to run.

Table 2-7. Reboiler Exhaust Stream HAPs Outputs

Verification Run No.		Concentration, C_{Stack}	HAP_{Stack}
		ppm	lb/h
Run 1	n-Hexane	<0.1	<0.000241
	Benzene	<0.1	<0.000218
	Toluene	<0.1	<0.000258
	Ethylbenzene	<0.1	<0.000297
	p-Xylene	<0.1	<0.000297
	o-Xylene	<0.1	<0.000297
	Total HAP		**<0.00161**
Run 2	n-Hexane	<0.1	<0.000232
	Benzene	<0.1	<0.000210
	Toluene	<0.1	<0.000247
	Ethylbenzene	<0.1	<0.000286
	p-Xylene	<0.1	<0.000286
	o-Xylene	<0.1	<0.000286
	Total HAP		**<0.00155**
Run 3	n-Hexane	<0.1	<0.000232
	Benzene	<0.1	<0.000210
	Toluene	<0.1	<0.000247
	Ethylbenzene	<0.1	<0.000285
	p-Xylene	<0.1	<0.000285
	o-Xylene	<0.1	<0.000285
	Total HAP		**<0.00154**
Overall Avg.			**0.00157**

2.3.2.3. HAP Outputs in Wastewater Production Stream

Table 2-8 shows the wastewater discharge amounts per dump based on nine dump cycles. Five dumps occurred during Run 1 and 2, and three dumps occurred during Run 3 of the verification test. The field team leader collected these data prior to the test campaign. The data show that the discharge rate was repeatable: 3.057 ± 0.019 gal/dump or 1.283 ± 0.007 gal/in. Test planners expected this consistency because the repeatability of the pneumatically operated controllers were 1/1000 of an inch. The test plan anticipated that, for the size and configuration of the vacuum separator, the discharge repeatability would be better than ± 2.0 percent. The actual repeatability was about ± 0.6 percent.

Table 2-8. Pre-Test Wastewater Discharge Rate Determinations

Date	**Time**	**Time Diff**	**Dump**	**Tare**	**Full**	**Gain**	**Temp**	**Density**	**Discharge Rate**		**Sight Glass Readings**			**Dis-charge Rate**
											Start	End	Diff	
		min	ID	lb	lb	lb	degF	lb/gal	gal/dump	gpm	in	in	in	gal/in.
4/7/03	12:42		1	2.31	27.93	25.62	91	8.301810	3.0861					
	13:33	51	2	2.31	27.93	25.62	91	8.301810	3.0861	0.0605	3.4063	1.0000	2.4063	1.2825
	14:24	51	3	2.33	27.72	25.39	92	8.300227	3.0590	0.0600	3.3750	1.0000	2.3750	1.2880
	15:24	60	4	2.32	27.81	25.49	93	8.298644	3.0716	0.0512	3.3750	1.0000	2.3750	1.2933
	16:23	59	5	2.30	27.81	25.51	91	8.301810	3.0728	0.0521	3.4063	1.0000	2.4063	1.2770
4/8/03	10:12		23	2.30	27.32	25.02	101	8.285780	3.0196		3.0000	0.6250	2.3750	1.2714
	12:07	115	25	2.29	27.62	25.33	101	8.285780	3.0570		3.0156	0.6250	2.3906	1.2788
	12:56	49	26	2.30	27.50	25.20	103	8.282211	3.0427	0.0621	3.0000	0.6406	2.3594	1.2896
	15:10	134	29	2.30	27.27	24.97	111	8.267735	3.0202					
								Average:	**3.0572**				**Average:**	**1.2829**

Table 2-9 shows the elapsed times between dump cycles for each test run.

Table 2-9. Wastewater Production Rate During Verification Testing

Date	Time	Time Diff	Elaps. Min	Dump ID	Discharge Rate gal/dump[a]	Wastewater Production Rate Per Dump gpm		Elapsed Time Since Dump Min	Fraction of Time Relative to Run Duration[b]	Weighted Wastewater Production Rate[c] gpm	Run-Specific Average Wastewater Production Rate, $V_{Wastewater}$ gpm
4/30/03	14:03			323	3.0572						
	14:31	0:28	28	324	3.0572	0.1092	Run 1 Start: 14:30	1	0.008850	0.0010	
	15:00	0:29	29	325	3.0572	0.1054		29	0.256637	0.0271	
	15:39	0:39	39	326	3.0572	0.0784		39	0.345133	0.0271	
	16:06	0:27	27	327	3.0572	0.1132		27	0.238938	0.0271	
	16:31	0:25	25	328	3.0572	0.1223	Run 1 Stop: 16:23	17	0.150442	0.0184	0.101
	17:09	0:38	38	329	3.0572	0.0805	Run 2 Start: 17:01	8	0.089888	0.0072	
	17:27	0:18	18	330	3.0572	0.1698		18	0.202247	0.0344	
	17:52	0:25	25	331	3.0572	0.1223		25	0.280899	0.0344	
	18:23	0:31	31	332	3.0572	0.0986		31	0.348315	0.0344	
	18:50	0:27	27	333	3.0572	0.1132	Run 2 Stop: 18:30	7	0.078652	0.0089	0.119
	19:28	0:38	38	334	3.0572	0.0805	Run 3 Start: 18:57	31	0.344444	0.0277	
	19:57	0:29	29	335	3.0572	0.1054		29	0.322222	0.0340	
	20:25	0:28	28	336	3.0572	0.1092	Run 3 Stop: 20:27	30	0.333333	0.0364	0.098
Overall Average											**0.106**

[a] Based on the average discharge rate determined during pre-test evaluation (Table 2-8)
[b] Duration for Run 1 = 113 mins, Run 2 = 89 mins, and Run 3 = 90 mins
[c] Wastewater production rate multiplied by fraction of time between dumps

Wastewater total volume for Runs 1, 2, and 3 was 11.36, 10.61, and 8.83 gallons, respectively. Based on the elapsed times for each test run, the wastewater production rate varied between 0.101 and 0.119 gpm. The overall average production rate was 0.106 gpm.

Table 2-10 summarizes the laboratory analysis results for four wastewater samples collected during each test run. Benzene and toluene were the primary HAP constituents. Average concentrations ranged between 368 and 472 ìg/mL. Multiplication of these concentrations by the production rates shown in Table 2-9 yields the run-specific mass emission rates. The HAP emission rate for all three test runs was 0.0220 lb/h.

Table 2-10. HAPs Outputs in Wastewater Stream

	Concentration, $C_{Wastewater}$ (ìg/mL)										Wastewater Production Rate, $V_{Wastewater}$	HAP_{Water}
	Sample ID 1		Sample ID 2		Sample ID 2a		Sample ID 3		Average			
Run 1									ìg/mL	lb/gal	gpm	lb/h
n-Hexane	0.801	ND	1.001	ND	1.001	ND	1.001	ND	0.951	0.000008	0.101	0.00005
Benzene	200.489		227.145		313.737		289.688		257.764	0.002151	0.101	0.01298
Toluene	104.976		113.377		175.446		157.164		137.741	0.001150	0.101	0.00693
Ethylbenzene	0.971	J	1.279	J	1.918	J	1.642	J	1.453	0.000012	0.101	0.00007
m- and p-Xylene	8.352		9.058		16.928		15.516		12.463	0.000104	0.101	0.00063
o-Xylene	2.829	J	3.434	J	5.570		5.212		4.261	0.000036	0.101	0.00021
Total HAP	**318.417**		**355.294**		**514.600**		**470.223**		**414.634**	**0.003460**	**0.101**	**0.0209**
Run 2												
n-Hexane	0.400	ND	1.001	ND	1.464	J	1.001	ND	0.967	0.000008	0.119	0.00006
Benzene	186.603		271.942		146.598		284.810		222.488	0.001857	0.119	0.01328
Toluene	96.426		165.647		78.479		168.820		127.343	0.001063	0.119	0.00760
Ethylbenzene	0.855	J	1.635	J	1.001	ND	1.803	J	1.324	0.000011	0.119	0.00008
m- and p-Xylene	8.629		15.951		7.379		16.304		12.066	0.000101	0.119	0.00072
o-Xylene	2.671		5.173		2.485	J	5.408		3.934	0.000033	0.119	0.00023
Total HAP	**295.584**		**461.350**		**237.407**		**478.147**		**368.122**	**0.003072**	**0.119**	**0.0220**
Run 3												
n-Hexane	1.001	ND	1.001	ND	1.001	ND	1.001	ND	1.001	0.000008	0.098	0.00005
Benzene	275.285		272.485		291.060		307.250		286.520	0.002391	0.098	0.01407
Toluene	156.729		157.039		165.044		168.717		161.882	0.001351	0.098	0.00795
Ethylbenzene	1.609	J	1.555	J	1.706	J	1.677	J	1.637	0.000014	0.098	0.00008
m- and p-Xylene	15.815		15.510		16.673		16.276		16.068	0.000134	0.098	0.00079
o-Xylene	5.391		5.090		5.367		5.323		5.293	0.000044	0.098	0.00026
Total HAP	**455.829**		**452.680**		**480.850**		**500.245**		**472.401**	**0.003942**	**0.098**	**0.0232**
Overall Avg.												
Total HAP	**356.610**		**423.108**		**410.952**		**482.871**		**418.386**	**0.003**	**0.106**	**0.0220**

ND Non-detect or analytical result below the minimum detection limit (MDL)
J Analytical result between the MDL and the limit of quantification (LOQ)

2.3.2.4. HAP Outputs in Condensate Production Stream

The run-specific condensate production rate determination first requires an estimate of the condensate discharge rate (gal/dump). The gal/in. discharge rate would be identical for both product streams because the liquids collect in a common vessel and the condensate pneumatic level controller is identical to the wastewater level controller. GHG Center personnel recorded the initial and final condensate sight-glass levels before and after each dump cycle. The sight-glass level change (in.) multiplied by the wastewater discharge rate reported in Section 2.3.2.3 (1.283 gal/in.) yielded condensate discharge rate (gal/dump). Table 2-11 summarizes the results for each test run.

Table 2-11. Run-Specific Condensate Production Rate

Date	Time	Time Ref	Elaps Ref	Dump Ref	Condensate Sight-Glass Reading			Waste water Discharge Rate[a]	Condensate Discharge Rate[b]	Condensate Production Rate		Elapsed Time Since Dump	Fraction of Time Relative to Run Duration[c]	Weighted Condensate Production Rate[d]	Run-Specific Average Condensate Production Rate, $V_{Condensate}$
					Start	End	Diff								
		Diff	Min	ID	in.	in.	in.	gal/in.	gal/dump	gpm		Min		gpm	gpm
4/30/03	13:50			200	2.6250	0.3438	2.2813	1.2829	2.9267						
	14:45	0:55	55	201	2.5625	0.2500	2.3125	1.2829	2.9668	0.0539	Run 1 Start: 14:30	15	0.1327	0.0072	
	15:46	1:01	61	202	2.5938	0.1875	2.4063	1.2829	3.0871	0.0506		61	0.5398	0.0273	
	16:44	0:58	58	203	2.5938	0.3438	2.2500	1.2829	2.8866	0.0498	Run 1 Stop: 16:23	37	0.3274	0.0163	0.051
	17:25	0:41	41	204	2.5938	0.1875	2.4063	1.2829	3.0871	0.0753	Run 2 Start: 17:01	24	0.2697	0.0203	
	18:41	1:16	76	205	2.5938	1.1875	1.4063	1.2829	1.8041	0.0237	Run 2 Stop: 18:30	65	0.7303	0.0173	0.038
	19:19	0:38	38	206	2.5938	0.3438	2.2500	1.2829	2.8866	0.0760	Run 3 Start: 18:57	22	0.2444	0.0186	
	20:17	0:58	58	207	2.5938	0.3125	2.2813	1.2829	2.9267	0.0505	Run 3 Stop: 20:27	68	0.7556	0.0381	0.057
														Overall Average	0.048

[a] Based on the average discharge rate determined during pre-test evaluation (Table 2-9).
[b] Estimated by multiplying wastewater discharge rate by level change in sight glass reading.
[c] Duration for Run 1 = 113 minutes, Run 2 = 89 minutes, and Run 3 = 90 minutes.
[d] Wastewater production rate multiplied by fraction of time between dumps.

Two to three complete condensate dumps occurred during each test run. The overall average condensate production rate was 0.048 gpm. The condensate recovery rate was about half as much as the wastewater production rate.

Table 2-12 summarizes the laboratory analysis results for four condensate samples collected during each test run. Similar to the wastewater stream, benzene, toluene, and p-xylene were the primary HAP constituents in each condensate sample. Average HAP concentrations ranged between 637,339 and 714,412 ìg/ml. Multiplication of these concentrations by the production rates shown in Table 2-11 resulted in run-specific mass emission rates. The overall average HAP production rate from the condensate product stream was 16.41 lb/h.

Table 2-12. HAP Outputs in Condensate Production Stream

Run 1	**Concentration, C_{Water} (ìg/mL)**						**Condensate Production Rate, $V_{Condensate}$**	**HAP Condensate**
	Sample ID 1	Sample ID 2	Sample ID 2a	Sample ID 3	**Average**			
					ìg/mL	**lb/gal**	**gpm**	**lb/h**
n-Hexane	10,107	8,776	10,370	9,589	9711	0.08	0.051	0.25
Benzene	212,553	176,446	222,001	208,710	204928	1.71	0.051	5.21
Toluene	383,335	315,392	407,011	381,067	371701	3.10	0.051	9.45
Ethylbenzene	8,033	6,589	8,663	8,129	7854	0.07	0.051	0.20
m- and p-Xylene	84,897	69,741	90,867	85,705	82803	0.69	0.051	2.11
o-Xylene	18,307	15,027	19,666	18,573	17893	0.15	0.051	0.45
Total HAP	**717,233**	**591,971**	**758,578**	**711,773**	**694,889**	**5.80**	**0.051**	**17.67**
Run 2								
n-Hexane	9,790	10,707	9,514	9,259	9817	0.08	0.038	0.19
Benzene	206,344	225,489	200,974	197,164	207493	1.73	0.038	3.91
Toluene	379,359	415,395	370,220	363,980	382238	3.19	0.038	7.20
Ethylbenzene	8,192	9,157	8,315	8,191	8464	0.07	0.038	0.16
m- and p-Xylene	86,724	95,446	83,958	82,771	87225	0.73	0.038	1.64
o-Xylene	18,847	20,866	18,683	18,302	19175	0.16	0.038	0.36
Total HAP	**709,256**	**777,061**	**691,665**	**679,667**	**714,412**	**5.96**	**0.038**	**13.47**
Run 3								
n-Hexane	9,170	9,052	9,336	7,536	8773	0.07	0.057	0.25
Benzene	191,505	190,064	196,546	162,279	185098	1.54	0.057	5.25
Toluene	351,340	350,878	361,019	298,660	340474	2.84	0.057	9.67
Ethylbenzene	7,987	7,976	8,272	6,700	7734	0.06	0.057	0.22
m- and p-Xylene	80,639	80,386	82,471	68,505	78000	0.65	0.057	2.21
o-Xylene	17,838	17,814	18,260	15,124	17259	0.14	0.057	0.49
Total HAP	**658,479**	**656,169**	**675,904**	**558,803**	**637,339**	**5.32**	**0.057**	**18.09**
Overall Avg.								
Total HAP	**694,989**	**675,067**	**708,716**	**650,081**	**682,213**	**5.69**	**0.048**	**16.41**

3.0 DATA QUALITY ASSESSMENT

3.1. DATA QUALITY OBJECTIVES

The test plan specified methodologies, instruments, and QA/QC requirements which would ensure that the final results have known data quality. The test plan's stipulations lead to specific data quality objectives (DQOs) for each verification parameter. Each measurement that contributes to a verification parameter determination has stated data quality indicators (DQIs) which, if met, ensure achievement of the applicable DQO.

The establishment of DQOs begins with the determination of each verification parameter's desired confidence level. Test planners then identify the expected values of all contributing measurements and determine the tolerable error level. Table 3-1 summarizes the test plan's specified DQOs for each verification parameter. The table also shows those achieved during the test campaign.

Table 3-1. Verification Parameter Data Quality Objectives

Verification Parameter	Allowable Measurement Error [a]	Achieved
Sales Gas		
Flow Rate	± 1%	± 0.13%
Moisture Content	± 2 °C dewpoint	± 1 °C dewpoint
Glycol Circulation Rate	± 1%	± 0.4%
Makeup Natural Gas		
Makeup Natural Gas Flow Rate	± 1%	± 0.8%
BTEX Content	± 5%	n/a[c]
Reboiler Exhaust Stack Emissions		
Concentration (ppm or%)		
NO_x	± 2% of FS or 2 ppm	2.0 ppm
CO	± 2% of FS or 2 ppm	1.2 ppm
O_2	± 2% of FS or 0.5%	0.2%
CO_2	± 2% of FS or 0.5%	0.4%
THC	± 5% of FS or 5 ppm	2.0 ppm
CH_4	± 5% of FS or 5 ppm	0.1 ppm
HAPs	± 5% of FS or 5 ppm	0.6 ppm
Emission Rate (lb/h)[b]		
NO_x	± 0.0088 lb/h	0.0048 lb/h
CO	± 0.0053 lb/h	0.0009 lb/h
CO_2	± 16.2 lb/h	7.5 lb/h
THC	± 0.0031 lb/h	0.0009 lb/h
CH_4	± 0.00019 lb/h	0.000003 lb/h
HAPs	± 0.018 lb/h	0.0001 lb/h
HAP Destruction Efficiency	± 0.5%	± 0.01%

[a] Full scale (FS) during testing was 0 - 100 ppm. for NO_x, CO, THC, CH_4, and HAPs
Full scale during testing was 0 – 25% for O_2 and CO_2

[b] Stated as 7% of the emission rate when the concentration is at 100% of analyzer span and stack flow is 10,507 dscfh.

[c] Not available. Please refer to Section 3.2.3.

Analysts most often state the DQIs in terms of measurement accuracy, precision, and completeness. Table 3-2 specifies each DQI goal and those achieved during testing.

Table 3-2. Data Quality Indicator Goals and Results

Measurement Variable		Instrument Type / Manufacturer	Instrument Range (FS)[a]	Accuracy			Completeness	
				Goal[b]	Actual[c]	How Verified / Determined	Goal	Actual
Sales Gas	Flow Rate	Emerson Model MVS205 Orifice Meter	0 to 2 mmscfh	± 1% reading	± 0.13% reading	Field calibration with NIST-traceable reference standards	90% of 1-min average readings	Opr. Testing: 93% Env. Testing: 84%
	Moisture Content	MEECO (test plan) Panametrics (installed)	0 to 20 lb/mmscf	± 2 °C Dewpoint	± 1 °C Dewpoint	Calibration with NIST-traceable reference standard		Opr. Testing: 93% Env. Testing: 84%
Glycol Circulation Rate	Flow Rate	Controlotron Ultrasonic Flow Meter	Pipe diameter: 0.25 to 360 inch Flow velocity: 0 to 60 fps	± 1% reading	± 0.4% reading	Calibration with NIST-traceable reference standard		Opr. Testing: 85% Env. Testing: 84%
Makeup Natural Gas	Fuel Flow Rate	Haliburton MC-II EXP turbine meter	0 to 1,500 scfh	± 1% reading	± 0.8% reading	Calibration with NIST-traceable reference standard		Opr. Testing: 93% Env. Testing: 84%
	BTEX Content	GC/FID HP Model 5890 or Equivalent	0 to 10,000 ppm	% Diff. in 3 Pt. Calibration < 5%	n/a[d]	Calibration with certified standards	Pre-test: 2 samples	2 samples
Exhaust Stack Emissions	NO_X Concen.	Chemiluminescent/ TEI Model 42C	0 to 100 ppmv	± 2% FS or ± 2 ppmv	≤ 2.0% FS or ± 2.0 ppmv [c]	Calculated following EPA reference method calibrations (Before and after each test run)	three valid 90 minute runs (90- percent completeness)	Run 1: 85 mins Run 2: 70 mins Run 3: 72 mins
	CO Concen.	NDIR / TEI Model 48C	0 to 100 ppmv	± 2% FS or ± 2 ppmv	≤ 1.2% FS or ± 1.2 ppmv [c]			
	THC Concen.	FID / JUM Model VE-7	0 to 100 ppmv	± 5% FS or ± 5 ppmv	≤ 2.0% FS or ± 2.0 ppmv [c]			
	CO_2 Concen.	NDIR / CAI Model 200	0 to 25%	± 2% FS or ± 0.5%	≤ 1.7% FS or ± 0.4% [c]			
	O_2 Concen.	NDIR / CAI Model 200	0 to 25%	± 2% FS or ± 0.5%	≤ 0.9% FS or ± 0.2% [c]			
	CH_4 Concen.	GC/dual FID, HP Model 5890a	0 to 100 ppmv	± 5% FS or ± 5 ppmv	± 0.1 ppmv[f]			
	HAP Concen.				± 0.6 ppmv[f,g]			
	H_2O Content	NA	0 to 100%	± 5% reading	± 5% reading	NIST-traceable equipment calibrations (pitot, thermocouple, gas meter, and balance)		
	Stack Gas Flow Rate	Pitot and thermocouple	NA	± 5% reading	± 5% reading			

(continued)

Table 3-2. Data Quality Indicator Goals and Results (concluded)

Measurement Variable		Instrument Type / Manufacturer	Instrument Range (FS)[a]	Accuracy			Completeness	
				Goal[b]	Actual[c]	How Verified / Determined	Goal	Actual
HAPs in Liquid Streams	Wastewater Discharge Rate	NA	NA	Repeatability of ± 1% between dump cycles	± 0.6%	Manual collection and weighing of wastewater produced during a discharge dump	Minimum of 3 dump captures in pre-weighed container	9 dump cycles captured
	HAPs in rich glycol, lean glycol, wastewater, and condensate	GC/FID	0 to 1000 ppm, nominal	≤ 5% diff. in 3 pt. calibration	< 5% diff in cal. error	Minimum of 3 pt. calibration with certified standard.	3 samples per test run	4 samples per test run
				≤ 5% Maximum diff in duplicate injections	rich glycol: 2.9% [c] lean glycol: 4.5% [c] wastewater: 9.8% [c,e]	Duplicate sampling and analysis on at least one rich, lean, and wastewater sample.		

[a] FS: full scale

[b] In the Test Plan, FS for NO_x, CO, and THC was 0 - 100 ppm, and 0-50 ppm for CH_4 and HAPs. For O_2 and CO_2, FS was 0 – 25%. During the test, FS for all compounds except CH_4 and HAPs was same as those defined in the Test Plan. For CH_4 and HAPs, FS was changed to 0 - 100 ppm. The accuracy goals listed here represent the FS of instruments used during testing.

[c] Actual values shown represent the maximum system error observed throughout the test periods.

[d] See the discussion in Section 3.2.3

[e] The laboratory prepared and injected one duplicate sample aliquot, unlike the duplicate injections for the GC/FID analyses. Goal for this duplicate analysis was ± 10%.

[f] Cubix calibrated the GC/FID at low, medium, and high levels. Since stack gas concentrations were non-detectable, error at the low level calibration is the assigned error. See Appendix B-3.

[g] Represents compounded average error for all HAPs at low reference concentration.

3.2. DQO AND DQI RECONCILIATION

Data completeness goals are summarized in Table 3-2. “Completeness” is defined as the number or percent of valid determinations actually made relative to those specified in the Test Plan.

The goal for operational parameters was at least 90 percent valid data during each 24-hour segment of the 7-day monitoring period or during each test run. Nearly all one-minute data collected during 5 of the 7 days were valid. The remaining two days included 15.05 hours and 20.73 hours of one-minute data (Table 2-1). On average, 93 percent of the one-minute measurements data were valid and the GHG Center used those data to report operational performance results.

The field team leader discovered during the first environmental performance test run that sampling events at the vacuum separator caused process upsets. The reboiler stack CO (and other gas) concentrations would rise or drop abruptly when the manual vent valve was opened to break the vessel’s vacuum. The GHG Center invalidated data where CO concentration was greater than 90 percent of the average initial value for two consecutive data points and until the concentration reached 90 percent of a stable final value following the event.

Test personnel observed that the primary upset indicators were CO concentration step changes. The step changes were clear and well-defined during all but one sampling event. Other stack gas concentrations changed unpredictably during sampling events with known CO step changes. It was impossible to tell during the one sampling event with no CO step change whether other gas concentration changes were due to the sampling event or normal variability. Exclusive use of the CO step changes as a criterion may have left invalid data in the set. The GHG Center therefore invalidated the data collected during this sampling event. Cubix performed no gas chromatograph injections during this period.

The actual run durations were 85, 70, and 72 minutes for runs 1, 2, and 3, respectively, after analysts removed invalid data. The tests, therefore, did not meet completeness goals for Runs 2 and 3. The GHG Center believes that this does not affect the overall verification results because:

- Environmental performance results were extremely consistent from run to run, and
- Most regulatory instrumental analyzer test runs must acquire, at most, 60 minutes of valid data. This means that the test data are adequate for regulatory purposes.

It should also be noted that the test plan specified 90-minute test runs to accommodate the time required for the sampling events.

The Test Plan specified three liquid samples to be collected from each liquid stream per run. Table 3-2 shows that the field team leader collected four valid samples. This met the completeness goals.

Table 3-3 shows the planned and achieved accuracy goals. Instrument calibrations (by the manufacturer or performed in the field) or reasonableness checks form the basis for the achieved accuracies. Table 3-3 identifies the QA/QC checks performed during the tests and how these results contribute to DQI reconciliation. The following subsection discusses each instrument’s accuracy results and the effect on the corresponding DQO.

Table 3-3. Calibration Results and QC Checks

Parameter	**QA/QC Check**	**When Performed/ Frequency**	**Expected or Allowable Result**	**Maximum Results Measured**[a]
Sales Gas				
Flow Rate	Field calibration by manufacturer	Beginning of test	Differential pressure: 6 point cal. Static pressure: 4 point cal. Temperature: 1 point cal. Results should be less than 1% of NIST traceable reference values	Diff. pressure (10 pt. cal): ± 0.12% Static pressure (4 pt. cal): ± 0.12% Temperature (1 pt. cal): ± 0.01% Avg. flow rate error: +0.13%[g]
Moisture Content	Factory calibration by manufacturer	Most recently available records	± 2 °C dewpoint of NIST-traceable calibration standard	± 1 °C dewpoint
	Field check – adjust sampling rate into moisture meter	Beginning of test	Moisture reading at 50% and 200% of normal sampling rate should be 0.5 and 2 times the reading at normal rate	Not performed; documented in CAR
	Reasonableness check – compare with manually collected gas sample	2 samples per day of testing	± 21% of lab results	400% or 2.21 lb/mmscf
Glycol Circulation Rate				
Lean Glycol Flow Rate	Reasonableness check – compare with ultrasonic meter	Beginning of test	± 2% of NIST-traceable ultrasonic meter reading	For Run 1, avg. rate for site meter = 5.14 gpm, and avg. rate for ultrasonic meter = 3.82 gpm. Avg. percent difference = 34.6%. GHG Center used ultrasonic meter during testing.
	Factory calibration by manufacturer (Controlotron)	Beginning of test	± 1% of NIST-traceable calibration standard	± 0.4%
Makeup Natural Gas				
Flow Rate	Factory calibration by manufacturer	Beginning of test	± 1% of NIST-traceable calibration standard	± 0.8%
BTEX Content	Calibration of GC/FID with gas standards	Prior to analysis	± 5% of reference value	n/a. See discussion in Section 3.2.3
	Duplicate analysis	Each sample	± 5% difference	Not Performed
Reboiler Stack Emissions				
NO_X	NO_2 converter efficiency	Once before testing begins	98% efficiency or greater	99.2%
NO_X, CO, CO_2, O_2	Analyzer calibration error test	Daily before testing	± 2% of analyzer span or less	NO_X: 0.9% of span or 0.9 ppmvd CO: 1.9% of span or 1.9 ppmvd CO_2: 0.96% of span or 0.24% O_2: 1.12% of span or 0.28%
	System bias tests	Before and after each test run	± 5% of analyzer span or less	NO_X: 2.0% of span or 2.0 ppmvd CO: 1.2% of span or 1.2 ppmvd CO_2: 1.7% of span or 0.4% O_2: 0.9% of span or 0.2%
	Calibration drift test	After each test	± 3% of analyzer span or less	NO_X: 0.5% of span or 0.5 ppmvd CO: 1.5% of span or 1.5 ppmvd CO_2: 0.6% of span or 0.2% O_2: 0.9% of span or 0.2%
THC	System bias tests	Before and after each test run	± 5% of analyzer span or less	2.0% of span or 2.0 ppmvd
	System calibration drift test	After each test	± 3% of analyzer span or less	0.7% of span or 0.7 ppmvd

(continued)

Table 3-3. Calibrations and QC Checks (concluded)

Parameter	**QA/QC Check**	**When Performed/ Frequency**	**Expected or Allowable Result**	**Maximum Results Measured**[a]
CH_4	Duplicate analysis	Each sample	± 5% difference	NA[b]
	GC/FID calibration	Prior to analysis of 6 samples per run	± 5 ppm or less	0.1 ppmv[c]
HAP Content	Duplicate analysis	Each sample	± 5% difference	NA[b]
	GC/FID calibration	Prior to analysis of 6 samples per run	± 5 ppm or less	0.6 ppmv[c,d]
Stack Gas Flow Rate	Thermocouple calibration	Once after testing	± 1.5% of average stack temp. recorded during final test run	0.22%
		Liquid Measurements		
Wastewater Discharge Rate	Determine wastewater discharge rate for 3 dumps (i.e., collect liquid in tared container and monitor sight glass level change per dump cycle).	Beginning of test	± 2% difference in discharge rate (gal/dump and gal/in.)	For 9 dump cycles, 95% confidence interval was ± 0.6% of mean discharge rate
HAP Content	Calibration of GC/FID with gas standards by certified laboratory	Prior to analysis	± 5% of reference value	Pre- and post-test calibration error < 5% of reference value
	Duplicate injection	Each sample	± 5% difference	Rich glycol: 2.9%[e] Lean glycol: 4.5%[e] Condensate: 2.0%[e]
	Duplicate analysis	One sample	± 5% difference	Rich glycol: 2.3% [e] Lean glycol: 45.1% [e,f] Wastewater: 9.8% [e,f] Condensate: not performed[f]
	3 benzene audit samples	Prior to analysis	± 5% of certified concentration	For audit concen. in range of: Rich glycol Results: -10.1%[f] Lean glycol and wastewater results: -6.5% [f] Condensate results: 4.2%
	Comparison with internal standard	3 liquid samples	± 5% of spike levels	Rich glycol: 8.0% [e,f] Lean glycol: 7.4% [e,f] Wastewater: 22% [e,f] Condensate: 9% [e,f]

[a] See Appendix B and C for individual test run results.

[b] Not Applicable. Cubix performed on-line sampling for CH_4, BTEX, and n-hexane. This eliminated the need for duplicate grab (bag) samples. Instead, Cubix conducted six individual sample injections during each test run.

[c] Cubix calibrated the GC/FID at low, medium, and high levels. Since the measured stack gas concentration was non detectable, error at the low level is the assigned error. See Appendix B for results for each compound.

[d] Represents compounded average error for all HAP species at low reference concentration.

[e] Represents maximum value observed for a HAP compound. See Appendix C for results for each compound.

[f] See Section 3.2.5.1 for discussion.

[g] The host facility (not the manufacturer) performed the most recent calibration with NIST-traceable instruments. Total flow rate error is quoted from the calibration certificate.

3.2.1. Sales Gas Flow Rate and Moisture Content

The DQO and DQI goal for sales gas flow rate was ± 1 percent. The DQI for sales gas moisture was ± 2 °C dewpoint.

Kerr McGee calibrated sales gas flow meter with NIST-traceable analyzers on March 12, 2003. Analysts employed ten differential-pressure, four static-pressure, and a single-point temperature standard. Table 3-3 shows that the calibration checks were below the target levels. The calibration certificate states that overall flow meter error was ± 0.13 percent.

The moisture analyzer manufacturer subjected the instrument to a 14-point NIST-traceable calibration on December 14, 2001. The Test Plan Table 3-2 specifies this instrument must be accurate to "± 5 percent of reading". The manufacturer states this specification is incorrect. The instrument specification should be "± 2 °C dewpoint". All calibration results were less than ± 1 °C dewpoint.

The Test Plan specified a reasonableness check to be performed on the moisture analyzer. The field team leader collected two sales gas samples and determined the moisture content length-of-stain ("Draeger" brand) tubes. The results were as follows:

Table 3-4. Comparison Between Length-of-Stain Moisture Content and Analyzer Reading

	Draeger Tube Result		Analyzer Reading	Difference	
Time	**mg/mL**	**lb/mmscf**	**lb/mmscf**	**%**	**lb/mmscf**
15:32	0.05	3.12	1.26	248	1.86
19:58	0.10	6.24	1.13	552	2.56
Average	**0.08**	**4.68**	**1.20**	**400**	**2.21**

It is evident that this reasonableness check is not a valid cross-check of the instrument's performance. This is understandable because Draeger specifies that the method standard deviation for mid-range readings (i.e., 0.5 mg/L) is ± 15 to 20 percent of reading. The method detection limit is 0.05 mg/L and, at small concentrations, the percentage errors can become very large.

3.2.2. Glycol Circulation Rate

The test plan specified a maximum glycol circulation rate error of 1.0 percent. A reasonableness check indicated that the site's flow meter output did not agree with the ultrasonic flow meter within the 2 percent specified in the Test Plan. The site average lean glycol flow rate for a one-hour comparison test was 5.14 gpm while the GHG Center's flow meter reported 3.83 gpm (a difference of 34.6 percent). The GHG Center calculated the pump's theoretical flow capacity at 4.13 gpm based on the manufacturer's specifications and assuming a 95 percent efficiency. This agrees very closely with the actual instantaneous ultrasonic flow meter measurements taken during steady-state operations. The ultrasonic flow meter is therefore the source of the reported glycol circulation rates.

The manufacturer calibrated the GHG Center's ultrasonic flow meter on October 11, 2002. Lab personnel subjected the instrument to a four-point NIST-traceable calibration using 1.9-inch carbon steel pipe. The calibration range varied between 10.3 and 50.6 gpm. The error at 10.3 gpm, which is closest to the flow rates observed during testing, was 0.4 percent of reading. This value is assigned as the error achieved, which satisfies the 1 percent goal.

3.2.3. Makeup Natural Gas Flow Rate

The Test Plan specified a 5-point calibration of the makeup natural gas meter to be within ± 1 percent. The manufacturer's calibration certificate dated February 7, 2002, shows that–at from 20 to 100 percent of the meter's design capacity of 1500 actual cubic feet per hour (acfh)–maximum error was ± 0.8 percent.

The field team leader collected three makeup natural gas samples to determine if significant BTEX was entering the system through that gas stream. This could bias the HAP destruction efficiency results. Empact Analytical Systems, Inc. (Empact), performed the extended natural gas analysis.

The Test Plan specified that the lab would calibrate the GC/FID prior to each sample analysis, perform duplicate injections, and analyze each sample "in duplicates to determine total measurement error" (Section 3.4). Empact personnel have stated that the analysts did not perform these steps as described. This lab employed the ASTM D6730 method for detailed hydrocarbon analysis. The method requires two GC machines: (1) the primary for major gas constituents (including non-hydrocarbons) and (2) the secondary for the selected HAPs.

Analysts checked the primary GC with a certified standard daily. The high heating value response must be within 1.0 percent of the standard. They then compared the two systems' response to the pentane in the samples. Identical response implies that the two systems were responding similarly. Analysts then entered the method's published reference factors for the selected HAP components to the secondary machine. The secondary GC was not directly challenged with certified standards.

The laboratory's procedure did not conform to the Test Plan, so the GHG Center is unable to determine if the laboratory met the ± 5.0 accuracy goal. This accuracy was to have been shown by duplicate injections of a certified standard, which the laboratory did not perform. In addition, the laboratory records for the primary GC's certified standard challenge, the pentane cross-responses, and how they relate to overall accuracy are not available. These omissions, however, have minimal effect on the HAPs destruction efficiency because of the low makeup natural gas flow rates observed during the test runs.

The Test Plan specified that makeup natural gas BTEX could significantly impact HAPs destruction efficiently only if concentrations exceeded 10,000 ppm. The laboratory results in Appendix D show that makeup gas BTEX as 310 ppm or less for all three samples. Even if BTEX had equaled 10,000 ppm, total BTEX entering the burner would have been very low as shown by the following calculations:

- BTEX mass per volume per ppm (assuming equal proportions of all constituents) = 3.90 mg/m^3 per ppm [11], or 2.435 x 10-7 lb/ft^3 per ppm;
- Total BTEX at 10,000 ppm = 2.44 x 10-3 lb/ft^3;
- BTEX inputs to the burner, at 1.37 scfh (the average makeup natural gas flow rate) = 3.34 x 10^{-3} lb/h.

It is highly unlikely that this 3.34 x 10^{-3} lb/h of BTEX would have been unaffected as it passed through the combustion zone. The non-detectable BTEX concentrations in the stack support this conclusion. If all the BTEX had passed through and up the stack intact, the total HAPs escaping from the system would have been (Table 2-5):

- 0.02 lb/h from the wastewater,
- 0.0013 lb/h in the stack gas, and
- 0.0034 lb/h in the makeup natural gas passed through the combustion zone to the stack.

In this case, destruction efficiency would have been 0.0247/9.09, or 99.73 percent, as compared to the 99.74 percent reported in Section 2.3.2. This analysis, then, indicates that the QA/QC discrepancies described here do not significantly affect the test results.

3.2.4. Reboiler Stack Emissions

EPA reference method requirements form the basis for the DQOs specified in the test plan. Each method specifies sampling and calibration procedures and data quality checks. This ensures collection of run-specific instrument and sampling system drift and accuracy data throughout the emissions tests. The data quality indicator goals required to meet the DQOs consisted of an assessment of sampling system error (bias) and drift for NO_x and THC, bias and drift for CO, CO_2, and O_2, and GC/FID calibration for HAPs. The following subsections discuss the achieved goals as presented in Tables 3-2 and 3-3. Appendix B summarizes all calibration, linearity, bias, and drift results.

3.2.4.1. NO_x and THC

Test personnel performed NO_X and THC sampling system calibration error tests prior to each test run. All calibrations employed EPA Protocol No. 1 calibration gases. The four NO_X and THC calibration gases were zero, 25, 45, and 85 to 90 percent of span.

Table 3-2 shows that the system calibration error goal for NO_x was ± 2.0 ppm. The maximum actual measured error was precisely this value. The maximum system error was ± 2.0 ppm for THC which is less than the ± 5.0 ppm goal.

Test operators established the NO_X analyzer's linearity at the beginning of the test day. Its span was 0 to 100 ppm. The results shown in Appendix B indicate excellent instrument linearity with calibration errors of 0.94 percent of span or less.

System response to the zero and mid-level calibration gases provided a measure of drift and bias at the end of each test run. The maximum sampling system drift was 0.51 ppm for NO_x and 0.67 ppm for THC, which were both below the method's maximum allowable drift. Testers also performed a NO_X converter efficiency test as described in Section 3.5 of the test plan. The converter efficiency was 99.2 percent, which exceeds the 98-percent goal specified in Table 3-3.

3.2.4.2. CO, $CO_{2,}$ and O_2

CO, CO_2, and O_2 drift and bias checks were similar to those described for NO_X and THC. Maximum drift was 1.5 percent of span for CO, 0.6 percent of span for CO_2, and 0.9 percent of span and O_2. All test runs, therefore, met the drift and bias goals.

3.2.4.3. HAPs

The test plan specified EPA Method 18 for determining stack gas organic concentrations. Test operators injected calibration gas standards into the GC to establish a concentration standard curve prior to sample analysis. The operator repeated the injections until the average of all desired compounds from three separate injections agreed to within 5.0 percent of the certified value. Appendix B summarizes the results. The acceptance criterion was met for all compounds.

The analysts injected the mid-range standard to quantify instrument drift at the completion of each test. The analyst would repeat the calibration process used for the average of the two calibration curves to determine concentrations if he observed a variance larger than 5.0 percent. Appendix B shows that no variance was more than 5.0 percent.

Method 18 also specifies a recovery study. The analyst checked the entire sampling system with a mid-level calibration gas. Repeated injections were analyzed until the area counts of the desired compounds from three separate injections agreed to within 5 percent of their average. The difference between the average response from the gas injected through the probe and injected directly must be less than 10 percent. All recoveries conformed to this specification (Appendix B).

3.2.4.4. Moisture Measurement

Cubix calibrated the dry gas meter used for moisture testing prior to field use in accordance with EPA methodology. Testers also conducted a post-test calibration check with a primary standard bell prover. The pre- and post-test calibrations differed by less than 5.0 percent as required by the reference method.

3.2.4.5. Emission Rate Measurement Error

The test plan's DQO for mass emission rate was ± 7.0 percent for all pollutants. The basis for this is the allowable concentration measurement errors compounded with the ± 5.0 percent stack flow rate error. The test plan based each pollutant's concentration error on that analyzer's full-scale reading. The test plan also describes how each analyzer error contributes to the overall emission rate error.

An example follows: Assume the stack flow rate is 10,507 dry standard cubic feet per hour (dscfh) and the NO_X concentration is equal to the analyzer's 100 ppm span. Pollutant mass flow rate is the concentration multiplied by the exhaust stack flow rate (Eqn. 1, Section 2.3.1). The corresponding NO_X emission rate is 0.125 lb/h. Seven percent of this is 0.0088 lb/h, so the NO_X lb/h determination must be accurate to ± 0.0088 lb/h to meet this DQO. Table 3.1 summarizes the planned and achieved emission rate DQOs for all the pollutants.

The stack flow measurement methods specify pre- and post-test thermocouple calibrations at the average stack gas temperature, as referenced to a NIST-traceable thermometer. The thermocouple and reference thermometer readings must be within 1.5 percent of each other to be acceptable. This temperature measurement error, combined with the Type-S pitot calibration, stack gas moisture measurement, and composition uncertainties yield an overall ± 5.0 percent (of reading) volumetric flow rate measurement error [12].

The highest NO_X, CO, THC, and HAP measurement errors were 2.0 ppm, 1.2 ppm, 2.0 ppm, and 0.6 ppm, respectively. Propagation of these errors with the 5.0 percent stack flow rate error results in an emission rate error to be 0.0048 lb/h or less in all cases. Table 3-1 shows that the tests met DQOs for all criteria and hazardous pollutants.

3.2.5. HAP Destruction Efficiency

The test plan specified that HAP destruction efficiency measurement error must be less than 0.5 percent. The plan also describes how actual error achieved requires propagation of multiplicative and additive concentration and flow rate measurement errors.

The achieved error for each measurement (summarized in Table 3-5) yields an overall destruction efficiency error of 0.01 percent absolute percentage units. The absolute error is relatively small because the total error for $HAP_{emitted}$ and HAP_{in} are very small, or ± 0.173 ± 0.0003 lb/h, respectively. These tests, therefore, met the DQO for HAP destruction efficiency.

3.2.5.1. Liquid Analysis Data Quality

The laboratory developed pre- and post-test calibration curves for each HAP constituent using a minimum of three calibration standards. The lab analyzed all calibration levels in duplicate with required agreement within 5.0 percent of the mean of the two injections. Calibration levels bracketed the concentrations of the lean glycol, rich glycol, wastewater, and condensate samples.

Lab personnel performed duplicate sample injections. The concentration report is the average of the two injections. Table 3-6 summarizes the highest percent difference observed for lean glycol, rich glycol, and condensate samples. The percent difference for all samples was less than 5 percent, which met the specified goal.

Table 3-5. Destruction Efficiency Error Determination

	Measurement			Avg. Result	Measurement Error		Source / Comment
					Relative (%)	**Absolute[b]**	
HAPs in Lean Glycol Stream	Flow Rate	V_{lean}	gpm	3.753	± 0.4	± 0.015	Accuracy of ultrasonic flow meter
	Concentration	Cl_{lean}	lb/gal	0.002	± 25.25	± 0.0004	Weighted average lean glycol concentration error for all HAP constituents
	Mass Emission Rate	HAP_{lean}	lb/h	0.368	± 25.25	± 0.093	Error propagation for multiplication function
HAPs in Rich Glycol Stream	Flow Rate	V_{rich}	gpm	3.912	± 0.9	± 0.035	Error for lean glycol flow rate plus 0.5% error assigned to other measurements (e.g., water content, density)
	Concentration	C_{rich}	lb/gal	0.040	± 1.25	± 0.001	Weighted average rich glycol concentration error for all HAP constituents
	Mass Emission Rate	HAP_{rich}	lb/h	9.462	± 1.54	± 0.145	Error propagation for multiplication function
		HAP_{in}	**lb/h**	**9.094**	**± 1.90%**	± 0.173	Error propagation for subtraction function
HAPs in Wastewater	Flow Rate	$V_{Wastewater}$	gpm	0.106	± 0.6	± 0.0006	Assigned as the 95%-confidence interval of wastewater discharge rate
	Concentration	$C_{Wastewater}$	lb/gal	0.003	± 0.99	± 0.0000	Weighted average concentration error for all HAP constituents in wastewater
	Mass Emission Rate	$HAP_{Wastewater}$	lb/h	0.022	± 1.16	± 0.0003	Error propagation for multiplication function
HAPs in Condensate[a]	Flow Rate	$V_{Condensate}$	gpm	0.048	± 0.6	± 0.0003	Assigned as the 95%-confidence interval of wastewater discharge rate
	Concentration	$C_{Condensate}$	lb/gal	5.693	± 10.00	± 0.569	Weighted average concentration error for all HAP constituents in condensate
	Mass Emission Rate	$HAP_{Condensate}$	lb/h	16.409	± 10.02	± 1.643	Error propagation for multiplication function
HAPs in Stack	Flow Rate	V_{Stack}	dscfh	10,507	± 5.0	± 525	Assigned as specified in reference method
	Concentration	C_{Stack}	ppm ÷ MW	57.469	± 1.07	± 0.613	Weighted average GC calibration error for all HAP constituents in condensate
	Mass Rate	HAP_{Stack}	lb/h	0.002	± 5.11	± 0.0001	Error propagation for multiplication function
		$HAP_{Emitted}$	**lb/h**	0.023	± 1.15	± 0.0003	Error propagation for addition function
Intermediate Calculation: $HAP_{emitted}/HAP_{in}$			proportion	0.00256	± 2.21	0.0000566	Error propagation for division function
HAP Destruction Efficiency		**DE**	**%**	**99.74**	± 0.00567[c]	**0.0000566**	Error propagation for subtraction function

[a] Not used to compute destruction efficiency because HAPs contained in the condensate products is assigned to be controlled.

[b] See right-most "Measurement" column for units.

[c] Rounds to ± 0.01%.

Table 3-6. Maximum Percent Difference in Duplicate Injection Results

	n-Hexane	Benzene	Toluene	Ethylbenzene	m- and p– Xylene	o-Xylene
Lean Glycol	0.2%	4.5%	4.2%	NA	3.6%	NA
Rich Glycol	2.9%	1.5%	1.4%	1.7%	1.4%	1.3%
Condensate	2.0%	1.3%	1.1%	1.1%	1.3%	1.1%

The laboratory did not perform duplicate injections of the wastewater samples. The analyst prepared and analyzed a duplicate aliquot for the first sample from each test run with required agreement within 10.0 percent for each analyte. The detailed lab report shows that all wastewater purge-and-trap analyses met this criterion.

The laboratory also selected one sample from each batch of lean glycol, rich glycol, and wastewater samples for duplicate preparation and analysis. Appendix C presents the results. The percent difference between the rich glycol initial and duplicate preparation concentrations ranged between 1.5 and 2.3 for the six HAP constituents analyzed. The percent difference was much greater (16.6 to 45.1 percent) for the lean glycol sample. The reason for the high error is unclear, but because the lean glycol concentration levels were very small, they do not contribute significantly to the overall lean HAP mass flow rate error. The duplicate analysis results for the wastewater sample were similar to rich glycol sample.

The benzene, toluene, and m, p-Xylene results presented in Appendix C-2 show large discrepancies between the duplicate lean glycol sample preparations. The analytical laboratory (Enthalpy Analytical, Durham, NC) attributes this to inhomogeneity in the liquids. Benzene and other HAPs do not necessarily mix uniformly in TEG and the mixtures can stratify easily. The laboratory had observed similar differences for samples taken before the test campaign. These differences also appeared in the rich glycol and wastewater duplicate preparations and analyses in the pretest samples. The matrix spike and recovery results imply that the laboratory properly executed the sample dilutions and other procedures.

Analysts spiked a 3.75-ml aliquot of a lean glycol sample and 3.5-ml aliquots of a rich glycol and a condensate sample with known amounts of the target analytes. They then analyzed the spiked samples. Appendix C summarizes the spike amounts and the resulting recovery efficiencies. All spike recovery efficiencies were between 88.1 and 109 percent.

The lab prepared a stock solution containing 80 ìg/mL of all six wastewater analytes. The analyst added 25 uL of this prepared solution to 2.5 mL of a 1001-fold dilution of sample 1 (Run 1). Appendix C summarizes the results. The recovery efficiencies ranged from 104 to 122 percent.

The GHG Center submitted three "blind" audit samples for analysis. Each contained benzene concentrations similar to those expected in the glycol and condensate samples. Table 3-7 summarizes the percent difference between the reported and certified concentrations. The results suggest that the laboratory under-reported benzene in the rich and lean glycol and over-reported it in the condensate. This could have affected the mass balance discussed in Section 2.3.2.

Table 3-7. Benzene Audit Results

Blind Sample ID	Certified Concentration	As-Analyzed Concentration	Percent Difference
	ìg/mL	ìg/mL	
B1090309	200	187	-6.5
B3010280	2,000	1,799	-10.1
B3010279	20,000	20,833	4.2

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4.0 TECHNICAL AND PERFORMANCE DATA SUPPLIED BY ENGINEERED CONCEPTS, LLC

Note: This section provides an opportunity for Engineered Concepts, LLC to provide additional comments concerning the QLD and its features not addressed elsewhere in this report. The GHG Center has not independently verified the statements made in this section.

The QLD process can be incorporated by retrofitting dehydrators presently installed in the field or by integrating the process into the design of new dehydrators. Either package will produce a hydrocarbons emissions control system eliminating the need for auxiliary equipment such as an effluent condenser, flare stack, or thermal oxidizer.

The QLD process covered by this report utilizes a condensing water exhauster to super-dry the process glycol. This allows high dew point depressions and efficient sales gas dehydration. The condensing water exhauster technology replaced the gas stripping employed for this purpose in the previous reboiler used at this site. Elimination of the gas stripping reduced gas consumption by more than 27 mscfd. Total still column vent emissions from the previous reboiler, including all of the gas used for gas stripping, were collected and routed to a thermal oxidizer.

For the QLD process to operate properly, the burner system must be able to throttle over the entire firing range. The QLD system uses specially designed throttling burners first introduced by Olman Heath Company. For new dehydrators incorporating the QLD system, throttling burners will be supplied with the package. On retrofit dehydrators the existing burners may need to be replaced with throttling burners.

Because the QLD process collects and compresses the hydrocarbons, these vapors are fed directly into the standard reboiler fuel train with only minor modifications. Alternately, the vapors can also be routed through a low pressure fuel line to other equipment at the site. This is a significant improvement over systems that collect the vapors at or near atmospheric pressure.

The host site had electricity available. Where electricity is not available (such as at remote wellhead locations) the QLD system incorporates an electric engine/generator set capable of producing 5 kW of 240/480 VAC power. The engine/generator set is rated for 40,000 hours of continuous service and uses natural gas for fuel.

The condensing water exhauster and side stream glycol cooling are able to save approximately $12,500 natural gas annually (based on $2.00 per mscf). This analysis assumes:

- TEG concentration of 99.8 percent using Nb=1 for a “Stahl” Stripping Column,
- 3 scf stripping gas per gallon of TEG circulated (Gas Processors Suppliers Association, Eleventh Edition, 1998, Figure 20-65)

The following table illustrates a full analysis of the typical utility consumption and QLD emissions as compared to a conventional dehydration system.

	Conventional Dehydrator		QLD
Lean TEG circulation rate, gpm (1)	4		4
Reboiler fuel required, Btu per day (1)	(11.8 mm)		(13.4 mm)
Pump used	Kimray	electric	Electric
Make-up fuel consumed, Btu per day NHV (1) (2)	0	(6.5 mm)	negligible (3)
Gas required to power Kimray pump, scfd (4)	32,256	0	0
Excess flash gas NHV, Btu per day (5)	(40.1 mm)	0	0
Gas stripping required, scfd (6)	17,280	17,280	0
Gas stripping NHV, Btu per day	(19.3 mm)	(19.3 mm)	0
Power required for pump, hp	0	3.8	3.8
Power required for circ pump, hp	0	0	6.3
Power required for fan cooler, hp	0	0	10
Total power consumed by motors, hp	0	3.8	20.1
Total energy consumed by motors, Btu / day (7)	0	(0.8 mm)	(4.1 mm)
Condensate recovered, BPD	negligible (8)	negligible (8)	2.3
Condensate recovered, Btu per day	negligible	negligible	11.4 mm
Net energy consumed by process, Btu per day (9)	(71.2 mm)	(31.9 mm)	(6.1 mm)
Hydrocarbon emissions, lbs per day (10)	3437	1715	negligible (11)

(1) Based on assumed reboiler firing efficiency of 50 percent and for design basis of 25 mmscfd at 1000 psig, 120 ^{o}F inlet gas temperature and 99.8 percent TEG by weight. Figures are based on BRE Prosim modeling program results.

(2) Assumes that gas from flash separator is routed to reboiler burner. Flash gas would include gas used to power Kimray pump (if applicable).

(3) QLD required essentially zero makeup fuel from the plant system.

(4) Kimray power gas is 5.6 scf per gallon at 1000 psig.

(5) Flash gas in excess of that required to fire the reboiler.

(6) Stripping gas rate is 3 scf per gallon based on using packed gas stripping column and 99.8 percent wt TEG.

(7) For QLD, assume 20.1 total horsepower, 24-hour operation, 2545 Btu per horsepower, and 30 percent efficiency. Total energy usage is:

$$4.1 \text{ mmBtu per day} = \frac{20.1 * 24 * 2545}{0.3 * 1000000}$$

(8) For modeling purposes only it was assumed that a condenser was installed on still column effluent outlet and a condenser temperature of 120 ^{o}F.

(9) Summed heat values: Condensate minus the sum of excess flash gas, stripping gas, reboiler fuel, and pump power consumption

(10) Still column emissions after condenser plus excess gas from flash separator. Includes all hydrocarbon emissions (BTEX, VOCs, HAPs, methane etc).

(11) Miniscule quantities of hydrocarbons were dissolved in the condensed water phase.

It is apparent that QLD outperforms a conventional dehydrator based on energy consumption and emissions.

The QLD system designers estimated that a conventional dehydrator at this site would require a Kimray PV-type gas-assisted glycol pump. The Kimray Oil and Gas Equipment Controls Catalog, Section G, Page 8, states that this pump would use 5.6 scf of gas per gallon of glycol circulated at 1000 psig. At four gallons per minute, total daily usage would be:

$$32256 \text{ scfd} = 5.6 * 4 * 60 * 24$$

Annual gas savings, based on $2.00 per mscf, would be:

$$\$23546 = (32256/1000) * 2.00 * 365.$$

This contrasts with the $14,600.00 estimated in Section 1.2. The reader should note that this analysis is conservative because natural gas prices have recently risen to above $5.00/mscf in some areas.

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APPENDIX A

Appendix A-1

Rich Glycol Flow Rates

The ARL method involves:

- Measurement of chemical concentrations in the lean glycol (lb/gal)
- Measurement of chemical concentrations in the rich glycol (lb/gal)
- Measurement of the lean glycol volumetric flow rate (gpm)
- Calculating the chemical concentration differences (lb/gal)
- Multiplying the concentration difference by the lean glycol flow rate to yield the chemical's mass flow rate (lb/min)

The calculated mass flow rate for each compound is assigned to be the same in both streams (rich and lean). This approach assumes that mass contribution from water present in the rich glycol is negligible in the overall mass balance. The rich glycol volumetric flow will always be slightly greater than the lean glycol flow because of added water, BTEX, and other hydrocarbons absorbed from the natural gas stream.

The reboiler and still column in the QLD system remove the diluents (thereby producing the lean glycol) upstream of the flow measurement device. The ARL method, therefore, slightly under-reports actual mass flow for the chemicals of interest because it assumes that the lean and rich glycol flows are identical.

A more accurate approach is to estimate the rich glycol flow rate by correcting for the chemical species present in the rich stream. In fact, the GRI-GLY Calc dehydrator emissions modeling program includes such a correction. The key to implementing this approach is that while the water, BTEX, and hydrocarbon concentrations are different between the rich and lean glycol flows, the stream's TEG mass content does not change (except under process upset conditions). The following glycol stream properties were obtained to quantify the rich glycol flow rate:

- Rich and lean glycol density (g/ml)
- Rich and lean glycol water content (weight percent)
- Rich and lean glycol total hydrocarbons content (ìg/ml)

This flow rate is used in Equation 3 to more accurately report HAPs entering the QLD system boundary. The following paragraphs discuss the analysis, provide an example, and present the test results.

The first step quantified the TEG mass flow rate throughout the system. The lean glycol mass flow rate was:

$$\dot{m}_{lean} = \dot{V}_{lean}\, r_{lean} \qquad \text{Eqn. A-1}$$

where:

$\dot{m}_{lean}$ = lean glycol mass flow rate (ìg/min)
$\dot{V}_{lean}$ = lean glycol volumetric flow rate (measured by the Ultrasonic meter), gpm x 3785.41 = (ml/min)
r_{lean} = lean glycol density (ì g/ml)

The lean glycol mass flow rate represented the sum of the water, hydrocarbons, and TEG mass flows. The TEG mass flow rate was therefore:

$$\dot{m}_{TEG} = \dot{m}_{lean} - \left(\dot{m}_{H2O,lean} + \dot{m}_{\Sigma HC,lean}\right) \tag*{Eqn. A-2}$$

where:

$\dot{m}_{TEG}$ = TEG mass flow rate (ìg/min)
$\dot{m}_{H2O,lean}$ = water mass flow rate in the lean glycol (î g/min)
$\dot{m}_{\Sigma HC,lean}$ = total hydrocarbon mass flow rate in the lean glycol (ìg/min)

The laboratory reported weight percent water and total hydrocarbon mass per unit volume. These data, combined with the measured lean glycol volumetric flow rate, yield the water and total hydrocarbon mass flow rates as follows:

$$\dot{m}_{H_2O,lean} = \left(\frac{H_2 0_{wt\%,lean}}{100} r_{lean}\right)\dot{V}_{lean} \tag*{Eqn. A-3}$$

$$\dot{m}_{\Sigma HC,lean} = \left(\Sigma HC_{lean}\right)\dot{V}_{lean} \tag*{Eqn. A-4}$$

where:

$H_2O_{wt\%,lean}$ = lean glycol water content (weight percent)
ΣHC_{lean} = concentration of hydrocarbons in lean glycol (î g/ml)

BTEX and hexanes constitute the majority of these hydrocarbons. All test runs showed that their area in the lean glycol sample chromatograms averaged from 58.3 to 72.1 percent of all hydrocarbon peaks recorded. The laboratory did not speciate other hydrocarbons, but they state that the FID response to these hydrocarbons will be linear. Therefore, 176 ìg/ml of BTEX and hexanes with an area percent of 62.2 yields total hydrocarbons of 1/0.622 x 176, or 282 ìg/ml. Analysts computed the average area percent of the BTEX and hexanes for each test run and applied the concept according to the following equations

$$\Sigma HC_{lean} = \frac{\Sigma HAP_{lean}}{Area\,\%_{lean}} \tag*{Eqn. A-5}$$

where:

ΣHAP_{lean} = summation of BTEX and hexanes for each sample, average value for all samples in each run (ìg/ml)
$Area\%_{lean}$ = average BTEX and hexanes area percent for all samples in each run (%)

TEG mass flow rate is:

$$\dot{m}_{TEG} = \dot{V}_{lean}\left(r_{lean} - \frac{H_2O_{wt\%,lean}}{100} r_{lean} - \Sigma HC_{lean}\right) \tag*{Eqn. A-6}$$

Rich glycol volumetric flow rate was derived from the following equations:

$$\dot{m}_{TEG} = c_{TEG,rich}\dot{m}_{rich} = c_{TEG,rich}\dot{V}_{rich} r_{rich} \tag*{Eqn. A-7}$$

$$\dot{V}_{rich} = \frac{\dot{m}_{TEG}}{c_{TEG,rich}\,\mathbf{r}_{rich}} \qquad \text{Eqn. A-8}$$

where:

$c_{TEG,rich}$ = TEG concentration in the rich glycol (proportion)
$\dot{m}_{rich}$ = rich glycol mass flow rate (ìg/min)
$\dot{V}_{rich}$ = rich glycol volumetric flow rate, ml/min ÷ 3785.41 = (gpm)
$\mathbf{r}_{rich}$ = rich glycol density (ìg/ml)

Rich glycol TEG concentration was:

$$c_{TEG,rich} = \frac{\mathbf{r}_{rich} - \frac{H_2O_{wt\%,rich}}{100}\mathbf{r}_{rich} - \Sigma HC_{rich}}{\mathbf{r}_{rich}} \qquad \text{Eqn. A-9}$$

where:

$H2O_{wt\%rich}$ = rich glycol water content (weight percent)
ΣHC_{rich} = summation of all rich glycol hydrocarbons (ì g/ml)
rich = rich glycol density (ìg/ml)

The ΣHC_{rich} value in equation A-4 was the average of the summed BTEX and hexanes corrected to the area percent hydrocarbons.

Substituting Equation A-9 into Equation A-8 yields a rich glycol volumetric flow rate of:

$$\dot{V}_{rich} = \frac{\dot{m}_{TEG}}{\mathbf{r}_{\mathrm{rich}} - \frac{H_2O_{wt\%,rich}}{100}\mathbf{r}_{rich} - \Sigma HC_{rich}} \qquad \text{Eqn. A-10}$$

The following table provides a sample calculation for Run 1, taken from the field data.

Table A-1. Rich Glycol Volumetric Flow Rate Calculation for Run 1

Parameter	Units	Value
$\dot{V}_{lean}$	gpm	3.7688
$\dot{V}_{lean}$	ml/min	14266.4
r_{lean}	ìg/ml	1.125×10^{6}
$H2O_{wt\%,lean}$	wt%	0.552
ΣHAP_{lean}	ìg/ml	176
$Area\%_{lean}$	area%	62.2
ΣHC_{lean}	ìg/ml	282
$\dot{m}_{TEG}$	ìg/min	1.596×10^{10}
r_{rich}	ìg/ml	1.119×10^{6}
$H2O_{wt\%rich}$	wt%	3.25
ΣHAP_{rich}	ìg/ml	5011
$Area\%_{rich}$	area%	80.1
ΣHC_{rich}	ìg/ml	6256
$\dot{V}_{rich}$	gpm	3.916

This example shows that the additional mass of water and hydrocarbons results in the rich glycol flow rate to be about 4 percent higher than the lean glycol flow rate. Table A-2 presents the results for each test run.

Table A-2. Determination of Rich Glycol Flow Rates

Run1 Sample#	V_{Lean} gpm	V_{Lean} ml/min	SampleID	Rho_{Lean} g/ml	Rho_{Lean} ìg/ml	Sample ID	$H2O_{Lean}$ wt%	HAP_{Lean} ìg/ml	HAP $Area\%_{Lean}$ AreaPct	HC $Total_{Lean}$ ìg/ml	m_{TEG} ìg/min	Sample ID	Rho_{Rich} g/ml	Rho_{Rich} ìg/ml	Sample ID	$H2O_{Rich}$ wt%	HAP_{Rich} ìg/ml	HAP $Area\%_{Rich}$ AreaPct	HC $Total_{Rich}$ ìg/ml	V_{Rich} gpm
1a						2001	0.486	*194*	*70.0*						1001	3.35	*5357*	*80.0*		
2			4002	1.125		2002	0.512	*154*	*58.3*			3002	1.119		1002	3.31	*4644*	*79.9*		
2a						2003	0.539	*189*	*58.4*						1003	3.05	*5547*	*80.4*		
3						2021	0.672	*166*							1021	3.27	*4497*			
Averages	*3.7688*	14266.4		1.125	1.1250 x 10^{6}		0.552	176	62.2	282	1.596 x 10^{10}		1.119	1.1190 x 10^{6}		3.25	5011	80.1	6256	3.9161

Run2 Sample#	V_{Lean} gpm	V_{Lean} ml/min	SampleID	Rho_{Lean} g/ml	Rho_{Lean} ìg/ml	Sample ID	$H2O_{Lean}$ wt%	HAP_{Lean} ìg/ml	HAP $Area\%_{Lean}$ AreaPct	HC $Total_{Lean}$ ìg/ml	m_{TEG} ìg/min	Sample ID	Rho_{Rich} g/ml	Rho_{Rich} ìg/ml	Sample ID	$H2O_{Rich}$ wt%	HAP_{Rich} ìg/ml	HAP $Area\%_{Rich}$ AreaPct	HC $Total_{Rich}$ ìg/ml	V_{Rich} gpm
1a						2005	0.601	*224*	*61.8*						1005	3.38	*4435*	*78.3*		
2			4006	1.136		2006	0.625	*203*	*57.7*			3006	1.12		1006	3.2	*4608*	*79.7*		
2a						2007	0.626	*198*	*60.7*						1007	3.13	*4187*	*81.1*		
3						2008	0.564	*201*	*62.5*						1008	3.12	*4495*	*79.2*		
Averages	*3.6035*	13640.8		1.136	1.1360 x 10^{6}		0.604	206	60.7	340	1.540 x 10^{10}		1.120	1.1200 x 10^{6}		3.21	4431	79.6	5569	3.7716

Run3 Sample#	V_{Lean} gpm	V_{Lean} ml/min	SampleID	Rho_{Lean} g/ml	Rho_{Lean} ìg/ml	Sample ID	$H2O_{Lean}$ wt%	HAP_{Lean} ìg/ml	HAP $Area\%_{Lean}$ AreaPct	HC $Total_{Lean}$ ìg/ml	m_{TEG} ìg/min	Sample ID	Rho_{Rich} g/ml	Rho_{Rich} ìg/ml	Sample ID	$H2O_{Rich}$ wt%	HAP_{Rich} ìg/ml	HAP $Area\%_{Rich}$ AreaPct	HC $Total_{Rich}$ ìg/ml	V_{Rich} gpm
1a						2009	0.575	*201*	*61.8*						1009	3.11	*5096*	*79.1*		
2			4010	1.132		2010	0.684	*203*	*58.8*			3010	1.122		1010	3.08	*4928*	*78.6*		
2a						2011	0.564	*193*	*72.1*						1011	3.24	*4968*	*79.1*		
3						2012	0.583	*228*	*59.9*						1012	3.11	*5118*	*81.3*		
Averages	*3.8871*	14714.1		1.132	1.1320 x 10^{6}		0.602	206	63.2	326	1.655 x 10^{10}		1.122	1.1220 x 10^{6}		3.14	5027	79.5	6322	4.0466

APPENDIX B

Emissions Testing QA/QC Results

Appendix B-1. Summary of Daily Reference Method Calibration Error Determination

Date	Gas	Range	Value	Response	Difference	Calibration Error (% of Span)*
		(ppm for NO_x, CO, and THC; % for O_2 and CO_2)				
4/30/03	NO_x	100	0.0	0.09	0.09	0.09
(Runs 1 - 3)			25.1	25.19	0.09	0.09
			44.6	44.67	0.07	0.07
			84.5	85.44	0.94	0.94
	CO	100	0.0	0.00	0.00	0.00
			24.9	23.27	1.63	1.63
			45.3	43.87	1.43	1.43
			90.8	88.86	1.94	1.94
	CO_2	25	0.0	0.03	0.03	0.12
			11.96	11.72	0.24	0.96
			4.00	3.81	0.19	0.76
			20.0	19.83	0.17	0.68
	O_2	25	0.0	0.02	0.02	0.08
			11.97	12.12	0.15	0.60
			4.00	4.10	0.10	0.40
			21.0	21.28	0.28	1.12
						Error (% of cal gas)*
	THC	100	0.0	0.47	0.47	
			25.5	25.17	0.33	1.29
			45.7	44.63	1.07	2.34
			89.0	90.3	1.30	1.46

* Allowable calibration error is 2% of span.

Appendix B-2. Summary of Reference Method System Bias and Drift Checks

Analyzer Spans: NO$_x$ = CO = THC = 100 ppm, CO$_2$ = O$_2$ = 25%

			Initial Cal	Run Number		
				1	2	3
NO$_x$ Zero		**System Response (ppm)**	0.08	0.59	0.89	0.38
	0.09	**System Bias (% span)**	-0.01	0.50	0.80	0.29
		Drift (% span)	na	0.51	0.30	0.51
NO$_x$ Mid (Hi)		**System Response (ppm)**	84.01	83.51	83.44	83.84
	85.44	**System Bias (% span)**	-1.43	-1.93	-2.00	-1.60
		Drift (% span)	na	0.50	0.07	0.40
CO Zero		**System Response (ppm)**	0.00	0.10	0.10	0.00
	0.00	**System Bias (% span)**	0.00	0.10	0.10	0.00
		Drift (% span)	na	0.10	0.00	0.10
CO Mid		**System Response (ppm)**	43.40	44.90	45.10	45.10
	43.87	**System Bias (% span)**	-0.47	1.03	1.23	1.23
		Drift (% span)	na	1.50	0.20	0.00
CO$_2$ Zero		**System Response (ppm)**	0.30	0.20	0.10	0.10
	0.03	**System Bias (% span)**	1.08	0.68	0.28	0.28
		Drift (% span)	na	0.40	0.40	0.00
CO$_2$ Mid		**System Response (ppm)**	11.30	11.45	11.30	11.42
	11.72	**System Bias (% span)**	-1.68	-1.08	-1.68	-1.20
		Drift (% span)	na	0.60	0.60	0.48
O$_2$ Zero		**System Response (ppm)**	0.13	0.20	0.25	0.06
	0.02	**System Bias (% span)**	0.44	0.72	0.92	0.16
		Drift (% span)	na	0.28	0.20	0.76
O$_2$ Mid		**System Response (ppm)**	12.22	12.22	12.13	12.04
	12.12	**System Bias (% span)**	0.40	0.40	0.04	-0.32
		Drift (% span)	na	0.00	0.36	0.36
THC Zero		**System Response (ppm)**	0.00	0.03	0.00	0.00
	0.47	**System Bias (% span)**	-0.47	-0.44	-0.47	-0.47
		Drift (% span)	na	0.03	0.03	0.00
THC Mid		**System Response (ppm)**	46.57	46.60	46.00	45.33
	44.63	**System Bias (% span)**	1.94	1.97	1.37	0.70
		Drift (% span)	na	0.03	0.60	0.67

Allowable system bias is 5% span, allowable drift is 3% span.

Appendix B-3. Summary of GC/FID Calibration Results

pre test low gas	ref value ppm	inj 1	inj 2	inj 3	avg	diff 1	diff 2	diff 3	max difference	relative error%	absolute error ppm
Methane	5.02	549	526	542	539.00	10.00	13.00	3.00	13.00	2.41	0.12
n-Hexane	5.03	3826	3826	4068	3906.67	80.67	80.67	161.33	161.33	4.13	0.21
Benzene	4.9	3984	3984	3736	3901.33	82.67	82.67	165.33	165.33	4.24	0.21
Toluene	4.8	4014	4014	4011	4013.00	1.00	1.00	2.00	2.00	0.05	0.00
Ethylbenzene	4.5	3748	3748	3879	3791.67	43.67	43.67	87.33	87.33	2.30	0.10
o-Xylene	4.8	3558	3558	3507	3541.00	17.00	17.00	34.00	34.00	0.96	0.05
m-Xylene	4.2	3049	3049	3164	3087.33	38.33	38.33	76.67	76.67	2.48	0.10

pre test mid gas	ref value ppm	inj 1	inj 2	inj 3	avg	diff 1	diff 2	diff 3	max difference	repeatability %	absolute error ppm
Methane	50.2	5701	5402	5750	5617.67	83.33	215.67	132.33	215.67	3.84	1.93
n-Hexane	50.4	37102	35023	34126	35417.00	1685.00	394.00	1291.00	1685.00	4.76	2.40
Benzene	50.6	35873	37287	36962	36707.33	834.33	579.67	254.67	834.33	2.27	1.15
Toluene	48.7	39496	43519	41503	41506.00	2010.00	2013.00	3.00	2013.00	4.85	2.36
Ethylbenzene	48.7	41149	43781	41972	42300.67	1151.67	1480.33	328.67	1480.33	3.50	1.70
o-Xylene	42.7	37977	41546	39962	39828.33	1851.33	1717.67	133.67	1851.33	4.65	1.98
m-Xylene	45.3	36631	39616	37117	37788.00	1157.00	1828.00	671.00	1828.00	4.84	2.19

pre test hi gas	ref value ppm	inj 1	inj 2	inj 3	avg	diff 1	diff 2	diff 3	max difference	repeatability %	absolute error ppm
Methane	100	11384	10821	11900	11368.33	15.67	547.33	531.67	547.33	4.81	4.81
n-Hexane	101	67628	70172	73001	70267.00	2639.00	95.00	2734.00	2734.00	3.89	3.93
Benzene	99.1	71325	74034	72208	72522.33	1197.33	1511.67	314.33	1511.67	2.08	2.07
Toluene	99.2	77633	78861	77587	78027.00	394.00	834.00	440.00	834.00	1.07	1.06
Ethylbenzene	99.2	73475	72497	76150	74040.67	565.67	1543.67	2109.33	2109.33	2.85	2.83
o-Xylene	99.2	73166	71481	74490	73045.67	120.33	1564.67	1444.33	1564.67	2.14	2.12
m-Xylene	99.2	71269	68884	71848	70667.00	602.00	1783.00	1181.00	1783.00	2.52	2.50

post test mid gas	ref value ppm	inj 1	inj 2	inj 3	avg	diff 1	diff 2	diff 3	max difference	repeatability %	absolute error ppm
Methane	50.2	5975	5789	5764	5842.67	357.33	171.33	146.33	357.33	6.12	3.07
N-Hexane	50.4	36136	37704	36739	36859.67	719.00	2287.00	1322.00	2287.00	6.20	3.13
Benzene	50.6	38482	38248	38099	38276.33	1774.67	1540.67	1391.67	1774.67	4.64	2.35
Toluene	48.7	42821	43477	42730	43009.33	1315.00	1971.00	1224.00	1971.00	4.58	2.23
Ethylbenzene	48.7	44238	44035	43208	43827.00	1937.33	1734.33	907.33	1937.33	4.42	2.15
o-Xylene	42.7	40512	42657	41642	41603.67	683.67	2828.67	1813.67	2828.67	6.80	2.90
m-Xylene	45.3	39301	39630	38877	39269.33	1513.00	1842.00	1089.00	1842.00	4.69	2.12

Overall stack gas HAPs concentration error is an additive function of the individual HAPs concentration errors. Such errors compound as the square root of the summed individual absolute errors, squared [13]. The following table shows the error propagation for stack gas HAPs. Each individual concentration was taken as 0.1 ppm because this was the method's lower detection limit. The relative errors, upon which the absolute errors are based, are taken from the "pre-test low gas" calibrations summarized above.

Stack Gas HAPs Error Propagation

Chemical	**Molecular Weight, lb/lb.mol**	**PPM**	**Mass, ìg/m^3**	**Relative Error, Percent**	**Absolute Error, ìg/m^3**
Hexane	86.18	0.1	8.618	4.13	0.3559
Benzene	78.00	0.1	7.800	4.24	0.3307
Toluene	92.00	0.1	9.200	0.05	0.0046
Ethylbenzene	106.17	0.1	10.617	2.30	0.2442
p-Xylene	106.17	0.1	10.617	2.48	0.2633
o-Xylene	106.17	0.1	10.617	0.96	0.1019
Compounded Absolute Error = square soot (sum [individual error]^2)					**0.6127**

APPENDIX C

Liquid Analysis QA/QC Results

Appendix C-1. Rich Glycol-Duplicate Sample Preparation and Spike Analysis Results

	Duplicate Analysis					Spike Analysis					
	Sample ID		Concentration (ng/mL)		% Dif-ference	Sample ID		Spike Amount	Catch Weight - Native Amount	Catch Weight - Spiked Sample	% Recovery
	Run No.	Sample No.	Initial	Duplicate		Run No.	Sample No.	ìg	ìg	ìg	
n-Hexane	Run 1	2	107 ND	106 ND	1.5	Run 2	1	35.9	78.9	114	98.1
Benzene	Run 1	2	1,425	1,454	2.1	Run 2	1	437	861	1334	108.0
Toluene	Run 1	2	2,394	2,443	2	Run 2	1	734	1282	2022	101.0
Ethyl-benzene	Run 1	2	51.5	52.7	2.3	Run 2	1	19.0	26.2	45.1	99.3
m- and p-Xylene	Run 1	2	546	558	2.2	Run 2	1	182	277	457	99.1
o-Xylene	Run 1	2	121	124	2.3	Run 2	1	38.4	62.2	100	98.5

ND	Non-detect or analytical result below the minimum detection limit (MDL)
J	Analytical result between the MDL and the limit of quantification (LOQ)

MDL = 1.00 ug/mL
LOQ = 2.00 ug/mL

Appendix C-2. Lean Glycol-Duplicate Sample Preparation and Spike Analysis Results

	Duplicate Analysis							Spike Analysis					
	Sample ID		Concentration (ng/mL)					Sample ID		Spike Amount	Catch Weight - Native Amount	Catch Weight - Spiked Sample	
	Run No.	Sample No.	Initial		Duplicate		% Diff	Run No.	Sample No.	ìg	ìg	ìg	% Recovery
n-Hexane	Run 2	2	6.00	ND	6.00	ND	0.0	Run 3	3	26.1	0.0	27.7	106.0
Benzene	Run 2	2	54.0		85.4		45.1	Run 3	3	52.4	53.8	103.0	93.7
Toluene	Run 2	2	66.5		102		42.3	Run 3	3	51.8	66.0	112.0	88.1
Ethylbenzene	Run 2	2	6.0	J	6.0		0.0	Run 3	3	26.0	0.0	24.1	92.9
m- and p-	Run 2	2	15.6		18.4		16.6	Run 3	3	26.0	11.5	35.6	92.6
o-Xylene	Run 2	2	6.0	J	6.0		0.0	Run 3	3	25.6	0.0	24.2	94.7

ND Non-detect or analytical result below the minimum detection limit (MDL)
J Analytical result between the MDL and the limit of quantification (LOQ)

MDL = 1.00 ug/mL
LOQ = 2.00 ug/mL

Appendix C-3. Wastewater-Duplicate Sample Preparation and Spike Analysis Results

	Sample ID		Duplicate Analysis			Spike Analysis			
			Concentration (ng/mL)		% Difference	Spike Amount	Catch Weight - Native Amount	Catch Weight - Spiked Sample	% Recovery
	Run No.	Sample No.	Initial	Duplicate		ìg	ìg	ìg	
n-Hexane	Run 1	1	801 ND	803 ND	0	200	0	210	105
Benzene	Run 1	1	200,489	198,778	0.9	200	501	745	122
Toluene	Run 1	1	104,976	102,520	2.4	200	262	478	108
Ethyl-benzene	Run 1	1	971 J	880 ND	9.8	200	2.43	211	104
m- and p-Xylene	Run 1	1	8,352	8,176	2.1	200	20.9	232	105
o-Xylene	Run 1	1	2,829 J	2,679	5.4	200	7.07	215	104

ND	Non-detect or analytical result below the minimum detection limit (MDL)
J	Analytical result between the MDL and the limit of quantification (LOQ)

MDL = 2.00 ng
LOQ = 8.00 ng

Appendix C-4. Condensate Product–Spike Analysis Results

	Spike Analysis					
	Sample ID		Spike Amount	Catch Weight-Native Amount	Catch Weight - Spiked Sample	% Recovery
	Run No.	Sample No.	ìg	ìg	ìg	
n-Hexane	Run 2	1	35.9	34.2	69.5	98.4
Benzene	Run 2	1	437	721	1195	109.0
Toluene	Run 2	1	734	1326	2071	102.0
Ethyl-benzene	Run 2	1	19.0	28.6	48.8	106.0
m- and p-Xylene	Run 2	1	182	303	487	101.0
o-Xylene	Run 2	1	38.4	65.9	105	102.0

MDL = 1.00 ug/mL
LOQ = 2.00 ug/mL

Appendix C-5. Rich and Lean Glycol Moisture Content–Duplicate Analysis Results

		RICH GLYCOL		% Difference	LEAN GLYCOL		% Difference
Sample ID		**Moisture Content**			**Moisture Content**		
Run No.	**Sample No.**	**Initial**	**Duplicate**		**Initial**	**Duplicate**	
Run 1	1	3.380	3.310	-1.05	0.487	0.485	-0.21
	2	3.100	3.050	-0.81	0.508	0.516	0.78
	2a	3.050	3.050	0.00	0.550	0.531	-1.76
	3	3.300	3.250	-0.76	0.681	0.664	-1.26
Run 2	1	3.350	3.400	0.74	0.608	0.595	-1.08
	2	3.180	3.220	0.63	0.616	0.634	1.44
	2a	3.120	3.140	0.32	0.634	0.619	-1.20
	3	3.120	3.120	0.00	0.558	0.570	1.06
Run 3	1	3.100	3.130	0.48	0.566	0.584	1.57
	2	3.100	3.060	-0.65	0.692	0.676	-1.17
	2a	3.240	3.230	-0.15	0.561	0.567	0.53
	3	3.080	3.140	0.96	0.589	0.578	-0.94
				-0.02			-0.19

NOTE:

$$\% \ Difference = \left(\frac{Duplicate}{Average\ (Initial, Duplicate)} \ x100 \right) - 100$$

APPENDIX D

Pre-Test Makeup Natural Gas Analysis Data

Appendix D-1. Pre-Test Makeup Natural Gas Analysis

EMPACT ANALYTICAL SYSTEMS, INC

997 US HIWAY 85
BRIGHTON, CO 80603
(303) 637-0150

EXTENDED NATURAL GAS ANALYSIS (*DHA)

PROJECT NO. :	**0302069**	ANALYSIS NO. :	**01**
COMPANY NAME :	**SRI**	ANALYSIS DATE:	FEBRUARY 28, 2003
ACCOUNT NO. :	P.O. RD30712	SAMPLE DATE :	FEBRUARY 26, 2003
PRODUCER :		TO:	
LEASE NO. :		CYLINDER NO. :	205
NAME/DESCRIP :	MAKE-UP GAS #3 @ 13:16		

******FIELD DATA******

SAMPLED BY:	RGR	AMBIENT TEMP.:	
SAMPLE PRES. :		GRAVITY :	
SAMPLE TEMP. :			
COMMENTS :			

COMPONENT	MOLE %	MASS %	GPM@ 14.65	GPM@ 14.73
HELIUM	0.016	0.003	---	---
HYDROGEN	0.000	0.000	---	---
OXYGEN/ARGON	0.000	0.000	---	---
NITROGEN	0.386	0.502	---	---
CO2	3.013	6.160	---	---
METHANE	76.906	57.315	---	---
ETHANE	11.841	16.541	3.1498	3.1670
PROPANE	4.323	8.855	1.1847	1.1911
I-BUTANE	0.816	2.203	0.2655	0.2669
N-BUTANE	1.422	3.844	0.4461	0.4485
I-PENTANE	0.499	1.672	0.1816	0.1826
N-PENTANE	0.361	1.209	0.1301	0.1308
HEXANES PLUS	0.417	1.696	0.1648	0.1653
TOTALS	100.000	100.000	5.5226	5.5522

BTEX COMPONEN	**MOL**	**WT%**
BENZENE	0.019	0.070
ETHYLBENZENE	0.000	0.000
TOLUENE	0.007	0.029
XYLENES	0.000	0.001
TOTAL BTEX	0.026	0.100

(CALC: GPA STD 2145-94 & TP-17 @14.696 & 60 F)

BTU @	**14.65**	**14.73**
GROSS DRY REAL :	1222.56	1229.24
GROSS WET REAL :	1201.19	1207.87
DENSITY (AIR=1):		0.7454
COMPRESSIBILITY FACTOR :		0.99648

****DHA (DETAILED HYDROCARBON ANALYSIS/NJ 1993) ; ASTM D6730***

THIS DATA HAS BEEN ACQUIRED THROUGH APPLICATION OF CURRENT STATE-OF-THE-ART ANALYTICAL TECHNIQUES. THE USE OF THIS INFORMATION IS THE RESPONSIBLITY OF THE USER. EMPACT ANALYTICAL SYSTEMS, ASSUMES NO RESPONSIBLITY FOR ACCURACY OF THE REPORTED INFORMATION NOR ANY CONSEQUECES OF IT'S APPLICATION.

EMPACT ANALYTICAL SYSTEMS, INC

997 US HIWAY 85
BRIGHTON, CO 80603
(303) 637-0150

EXTENDED NATURAL GAS ANALYSIS (*DHA)

PROJECT NO. :	**0302069**	ANALYSIS NO. :	**01**
COMPANY NAME :	**SRI**	ANALYSIS DATE:	FEBRUARY 28, 2003

COMPONENT	PIANO #	MOLE %	MASS %	GPM 14.65	GPM 14.73
HELIUM		0.016	0.003	---	---
HYDROGEN		0.000	0.000	---	---
OXYGEN/ARGON		0.000	0.000	---	---

Appendix D-1. Pre-Test Makeup Natural Gas Analysis, Cont.

NITROGEN		0.386	0.502	---	---
CO2		3.013	6.160	---	---
METHANE	P1	76.906	57.315	---	---
ETHANE	P2	11.841	16.541	3.1498	3.1670
PROPANE	P3	4.323	8.855	1.1847	1.1911
I-BUTANE	I4	0.816	2.203	0.2655	0.2669
N-BUTANE	P4	1.416	3.823	0.4440	0.4464
2,2 DIMETHYLPROPANE	I5	0.006	0.021	0.0021	0.0021
I-PENTANE	I5	0.499	1.672	0.1816	0.1826
N-PENTANE	P5	0.361	1.209	0.1301	0.1308
2,2 DIMETHYLBUTANE	I6	0.011	0.042	0.0046	0.0046
CYCLOPENTANE	N5	0.014	0.046	0.0041	0.0041
2,3 DIMETHYLBUTANE	I6	0.023	0.091	0.0094	0.0094
2 METHYLPENTANE	I6	0.091	0.366	0.0376	0.0378
3 METHYLPENTANE	I6	0.050	0.199	0.0203	0.0204
N-HEXANE	P6	0.092	0.370	0.0376	0.0378
2,2-DIMETHYLPENTANE	I7	0.002	0.011	0.0009	0.0009
METHYLCYCLOPENTANE	N6	0.033	0.128	0.0117	0.0117
2,4 DIMETHYLPENTANE	I7	0.004	0.018	0.0019	0.0019
2,2,3 TRIMETHYLBUTANE	I7	0.001	0.003	0.0005	0.0005
BENZENE	A6	0.019	0.070	0.0053	0.0053
3,3 DIMETHYLPENTANE	I7	0.001	0.004	0.0005	0.0005
CYCLOHEXANE	O6	0.022	0.085	0.0075	0.0075
2 METHYLHEXANE	I7	0.009	0.042	0.0042	0.0042
2,3 DIMETHYLPENTANE	I7	0.003	0.012	0.0014	0.0014
1,1 DIMETHYLCYCLOPENTANE	N7	0.002	0.010	0.0008	0.0008
3 METHYLHEXANE	I7	0.008	0.035	0.0037	0.0037
1,C 3 DIMETHYLCYCLOPENTANE	N7	0.002	0.010	0.0008	0.0008
1,T 3 DIMETHYLCYCLOPENTANE	N7	0.002	0.008	0.0008	0.0008
3 ETHYLPENTANE	I7	0.000	0.002	0.0000	0.0000
1,T 2 DIMETHYLCYCLOPENTANE	N7	0.003	0.012	0.0012	0.0012
N-HEPTANE	P7	0.008	0.037	0.0037	0.0037
METHYLCYCLOHEXANE	N7	0.010	0.045	0.0040	0.0040
2,2-DIMETHYLHEXANE	I8	0.000	0.002	0.0000	0.0000
ETHYLCYCLOPENTANE	N7	0.000	0.001	0.0000	0.0000
2,5-DIMETHYLHEXANE	I8	0.000	0.001	0.0000	0.0000
2,4-DIMETHYLHEXANE	I8	0.000	0.001	0.0000	0.0000
1C,2T,4-TRIMETHYLCYCLOPENTANE	N8	0.000	0.001	0.0000	0.0000
3,3-DIMETHYLHEXANE	I8	0.000	0.001	0.0000	0.0000
1T,2C,3-TRIMETHYLCYCLOPENTANE	N8	0.000	0.001	0.0000	0.0000
TOLUENE	A7	0.007	0.029	0.0023	0.0023
2,3-DIMETHYLHEXANE	I8	0.000	0.001	0.0000	0.0000
2-METHYLHEPTANE	I8	0.000	0.002	0.0000	0.0000
4-METHYLHEPTANE	I8	0.000	0.001	0.0000	0.0000
3-METHYLHEPTANE	I8	0.000	0.001	0.0000	0.0000
1C,2T,3-TRIMETHYLCYCLOPENTANE	N8	0.000	0.002	0.0000	0.0000
1T,4-DIMETHYLCYCLOHEXANE	N8	0.000	0.001	0.0000	0.0000
1,1-DIMETHYLCYCLOHEXANE	N8	0.000	0.001	0.0000	0.0000
1T,2-DIMETHYLCYCLOHEXANE	N8	0.000	0.001	0.0000	0.0000
N-OCTANE	P8	0.000	0.002	0.0000	0.0000
1,3-DIMETHYLBENZENE (M-XYLENE)	A8	0.000	0.001	0.0000	0.0000
TOTALS		100.000	100.000	5.5226	5.5522

EMPACT ANALYTICAL SYSTEMS, INC

997 US HIWAY 85
BRIGHTON, CO 80603
(303) 637-0150

EXTENDED NATURAL GAS ANALYSIS (*DHA)

PROJECT NO. : **0302069**
COMPANY NAME : **SRI**
ACCOUNT NO. : P.O. RD30712
ANALYSIS NO. : **02**
ANALYSIS DATE: FEBRUARY 28, 2003
SAMPLE DATE : FEBRUARY 26, 2003

Appendix D-1. Pre-Test Makeup Natural Gas Analysis, Cont.

PRODUCER :
TO:
LEASE NO. :
CYLINDER NO. : 265
NAME/DESCRIP : MAKE-UP GAS #1 @ 12:58
FIELD DATA
SAMPLED BY: RGR
AMBIENT TEMP.:
SAMPLE PRES. :
GRAVITY :
SAMPLE TEMP. :
COMMENTS :

COMPONENT	MOLE %	MASS %	GPM@ 14.65	GPM@ 14.73
HELIUM	0.016	0.003	---	---
HYDROGEN	0.000	0.000	---	---
OXYGEN/ARGON	0.000	0.000	---	---
NITROGEN	0.376	0.489	---	---
CO2	3.024	6.182	---	---
METHANE	76.962	57.345	---	---
ETHANE	11.819	16.508	3.1439	3.1611
PROPANE	4.271	8.749	1.1704	1.1768
I-BUTANE	0.808	2.180	0.2629	0.2643
N-BUTANE	1.405	3.797	0.4408	0.4432
I-PENTANE	0.502	1.681	0.1827	0.1837
N-PENTANE	0.367	1.229	0.1322	0.1329
HEXANES PLUS	0.450	1.837	0.1784	0.1789
TOTALS	100.000	100.000	5.5113	5.5409

BTEX COMPONEN	MOL	WT%
BENZENE	0.019	0.068
ETHYLBENZENE	0.000	0.001
TOLUENE	0.011	0.045
XYLENES	0.001	0.006
TOTAL BTEX	0.031	0.120

(CALC: GPA STD 2145-94 & TP-17 @14.696 & 60 F)

BTU @	14.65	14.73
GROSS DRY REAL :	1222.61	1229.29
GROSS WET REAL :	1201.24	1207.92
DENSITY (AIR=1):		0.7456
COMPRESSIBILITY FACTOR :		0.99651

DHA (DETAILED HYDROCARBON ANALYSIS/NJ 1993) ; ASTM D6730

THIS DATA HAS BEEN ACQUIRED THROUGH APPLICATION OF CURRENT STATE-OF-THE-ART ANALYTICAL TECHNIQUES. THE USE OF THIS INFORMATION IS THE RESPONSIBLITY OF THE USER. EMPACT ANALYTICAL SYSTEMS, ASSUMES NO RESPONSIBLITY FOR ACCURACY OF THE REPORTED INFORMATION NOR ANY CONSEQUECES OF IT'S APPLICATION.

EMPACT ANALYTICAL SYSTEMS, INC
997 US HIWAY 85
BRIGHTON, CO 80603
(303) 637-0150

EXTENDED NATURAL GAS ANALYSIS (*DHA)

PROJECT NO. : **0302069**
ANALYSIS NO. : **02**
COMPANY NAME : **SRI**
ANALYSIS DATE: FEBRUARY 28, 2003

COMPONENT	PIANO #	MOLE %	MASS %	GPM 14.65	GPM 14.73
HELIUM		0.016	0.003	---	---
HYDROGEN		0.000	0.000	---	---
OXYGEN/ARGON		0.000	0.000	---	---
NITROGEN		0.376	0.489	---	---
CO2		3.024	6.182	---	---
METHANE	P1	76.962	57.345	---	---
ETHANE	P2	11.819	16.508	3.1439	3.1611
PROPANE	P3	4.271	8.749	1.1704	1.1768
I-BUTANE	I4	0.808	2.180	0.2629	0.2643
N-BUTANE	P4	1.399	3.776	0.4387	0.4411
2,2 DIMETHYLPROPANE	I5	0.006	0.021	0.0021	0.0021
I-PENTANE	I5	0.502	1.681	0.1827	0.1837
N-PENTANE	P5	0.367	1.229	0.1322	0.1329
2,2 DIMETHYLBUTANE	I6	0.011	0.042	0.0046	0.0046

Appendix D-1. Pre-Test Makeup Natural Gas Analysis, Cont.

METHANOL	X1	0.003	0.005	0.0004	0.0004
CYCLOPENTANE	N5	0.014	0.045	0.0041	0.0041
2,3 DIMETHYLBUTANE	I6	0.022	0.090	0.0090	0.0090
2 METHYLPENTANE	I6	0.091	0.365	0.0376	0.0378
3 METHYLPENTANE	I6	0.050	0.198	0.0203	0.0204
N-HEXANE	P6	0.093	0.371	0.0380	0.0382
2,2-DIMETHYLPENTANE	I7	0.002	0.011	0.0009	0.0009
METHYLCYCLOPENTANE	N6	0.033	0.128	0.0117	0.0117
2,4 DIMETHYLPENTANE	I7	0.004	0.019	0.0019	0.0019
2,2,3 TRIMETHYLBUTANE	I7	0.001	0.004	0.0005	0.0005
BENZENE	A6	0.019	0.068	0.0053	0.0053
3,3 DIMETHYLPENTANE	I7	0.001	0.005	0.0005	0.0005
CYCLOHEXANE	O6	0.023	0.088	0.0078	0.0078
2 METHYLHEXANE	I7	0.011	0.050	0.0051	0.0051
2,3 DIMETHYLPENTANE	I7	0.003	0.015	0.0014	0.0014
1,1 DIMETHYLCYCLOPENTANE	N7	0.002	0.011	0.0008	0.0008
3 METHYLHEXANE	I7	0.009	0.044	0.0041	0.0041
1,C 3 DIMETHYLCYCLOPENTANE	N7	0.003	0.012	0.0012	0.0012
1,T 3 DIMETHYLCYCLOPENTANE	N7	0.002	0.010	0.0008	0.0008
3 ETHYLPENTANE	I7	0.001	0.003	0.0005	0.0005
1,T 2 DIMETHYLCYCLOPENTANE	N7	0.003	0.015	0.0012	0.0012
N-HEPTANE	P7	0.013	0.059	0.0060	0.0060
1,C 2 DIMETHYLCYCLOPENTANE	N7	0.000	0.001	0.0000	0.0000
METHYLCYCLOHEXANE	N7	0.014	0.066	0.0056	0.0056
2,2-DIMETHYLHEXANE	I8	0.001	0.004	0.0005	0.0005
ETHYLCYCLOPENTANE	N7	0.000	0.002	0.0000	0.0000
2,5-DIMETHYLHEXANE	I8	0.001	0.003	0.0005	0.0005
2,4-DIMETHYLHEXANE	I8	0.001	0.003	0.0005	0.0005
1C,2T,4-TRIMETHYLCYCLOPENTANE	N8	0.000	0.002	0.0000	0.0000
3,3-DIMETHYLHEXANE	I8	0.000	0.001	0.0000	0.0000
1T,2C,3-TRIMETHYLCYCLOPENTANE	N8	0.000	0.001	0.0000	0.0000
TOLUENE	A7	0.011	0.045	0.0037	0.0037
2,3-DIMETHYLHEXANE	I8	0.000	0.002	0.0000	0.0000
2-METHYLHEPTANE	I8	0.001	0.007	0.0005	0.0005
4-METHYLHEPTANE	I8	0.001	0.003	0.0005	0.0005
3-METHYLHEPTANE	I8	0.001	0.005	0.0005	0.0005
1C,2T,3-TRIMETHYLCYCLOPENTANE	N8	0.001	0.005	0.0005	0.0005
1T,4-DIMETHYLCYCLOHEXANE	N8	0.001	0.003	0.0005	0.0005
1,1-DIMETHYLCYCLOHEXANE	N8	0.000	0.001	0.0000	0.0000
1T,2-DIMETHYLCYCLOHEXANE	N8	0.000	0.002	0.0000	0.0000
N-OCTANE	P8	0.002	0.009	0.0010	0.0010
2,3,5-TRIMETHYLHEXANE	I9	0.000	0.001	0.0000	0.0000
1,1,4-TRIMETHYLCYCLOHEXANE	N9	0.000	0.001	0.0000	0.0000
4,4-DIMETHYLHEPTANE	I9	0.000	0.001	0.0000	0.0000
ETHYLCYCLOHEXANE	N9	0.000	0.001	0.0000	0.0000
2,5-DIMETHYLHEPTANE	I9	0.000	0.001	0.0000	0.0000
ETHYLBENZENE	A8	0.000	0.001	0.0000	0.0000
1,3-DIMETHYLBENZENE (M-XYLENE)	A8	0.001	0.003	0.0004	0.0004
1,4-DIMETHYLBENZENE (P-XYLENE)	A8	0.000	0.002	0.0000	0.0000
1,2-DIMETHYLBENZENE (O-XYLENE)	A8	0.000	0.001	0.0000	0.0000
N-NONANE	P9	0.000	0.002	0.0000	0.0000
TOTALS		100.000	100.000	5.5113	5.5409

EMPACT ANALYTICAL SYSTEMS, INC
997 US HIWAY 85
BRIGHTON, CO 80603
(303) 637-0150

EXTENDED NATURAL GAS ANALYSIS (*DHA)

PROJECT NO. : **0302069**
COMPANY NAME : **SRI**
ACCOUNT NO. : P.O. RD30712

ANALYSIS NO. : **03**
ANALYSIS DATE: FEBRUARY 28, 2003
SAMPLE DATE : FEBRUARY 26, 2003

Appendix D-1. Pre-Test Makeup Natural Gas Analysis, Cont.

PRODUCER :
LEASE NO. :
NAME/DESCRIP : MAKE-UP GAS #2 @ 13:09
FIELD DATA
SAMPLED BY: RGR
SAMPLE PRES. :
SAMPLE TEMP. :
COMMENTS :

TO:
CYLINDER NO. : 218
AMBIENT TEMP.:
GRAVITY :

COMPONENT	MOLE %	MASS %	GPM@ 14.65	GPM@ 14.73
HELIUM	0.022	0.004	---	---
HYDROGEN	0.000	0.000	---	---
OXYGEN/ARGON	0.006	0.009	---	---
NITROGEN	0.388	0.506	---	---
CO2	3.021	6.182	---	---
METHANE	76.928	57.378	---	---
ETHANE	11.842	16.557	3.1500	3.1672
PROPANE	4.300	8.817	1.1784	1.1848
I-BUTANE	0.813	2.196	0.2645	0.2659
N-BUTANE	1.422	3.850	0.4461	0.4485
I-PENTANE	0.499	1.673	0.1816	0.1826
N-PENTANE	0.367	1.230	0.1322	0.1329
HEXANES PLUS	0.392	1.598	0.1543	0.1548
TOTALS	100.000	100.000	5.5071	5.5367

BTEX COMPONEN	**MOL**	**WT%**
BENZENE	0.017	0.062
ETHYLBENZENE	0.000	0.001
TOLUENE	0.006	0.025
XYLENES	0.000	0.003
TOTAL BTEX	0.023	0.091

(CALC: GPA STD 2145-94 & TP-17 @14.696 & 60 F)

BTU @	**14.65**	**14.73**
GROSS DRY REAL :	1221.04	1227.71
GROSS WET REAL :	1199.70	1206.37
DENSITY (AIR=1):		0.7447
COMPRESSIBILITY FACTOR :		0.99648

DHA (DETAILED HYDROCARBON ANALYSIS/NJ 1993) ; ASTM D6730

THIS DATA HAS BEEN ACQUIRED THROUGH APPLICATION OF CURRENT STATE-OF-THE-ART ANALYTICAL TECHNIQUES. THE USE OF THIS INFORMATION IS THE RESPONSIBLITY OF THE USER. EMPACT ANALYTICAL SYSTEMS, ASSUMES NO RESPONSIBLITY FOR ACCURACY OF THE REPORTED INFORMATION NOR ANY CONSEQUECES OF IT'S APPLICATION.

EMPACT ANALYTICAL SYSTEMS, INC
997 US HIWAY 85
BRIGHTON, CO 80603
(303) 637-0150

EXTENDED NATURAL GAS ANALYSIS (*DHA)

PROJECT NO. : **0302069**
COMPANY NAME : **SRI**
ANALYSIS NO. : **03**
ANALYSIS DATE: FEBRUARY 28, 2003

COMPONENT	PIANO #	MOLE %	MASS %	GPM 14.65	GPM 14.73
HELIUM		0.022	0.004	---	---
HYDROGEN		0.000	0.000	---	---
OXYGEN/ARGON		0.006	0.009	---	---
NITROGEN		0.388	0.506	---	---
CO2		3.021	6.182	---	---
METHANE	P1	76.928	57.378	---	---
ETHANE	P2	11.842	16.557	3.1500	3.1672
PROPANE	P3	4.300	8.817	1.1784	1.1848
I-BUTANE	I4	0.813	2.196	0.2645	0.2659
N-BUTANE	P4	1.416	3.828	0.4440	0.4464
2,2 DIMETHYLPROPANE	I5	0.006	0.022	0.0021	0.0021
I-PENTANE	I5	0.499	1.673	0.1816	0.1826
N-PENTANE	P5	0.367	1.230	0.1322	0.1329
2,2 DIMETHYLBUTANE	I6	0.010	0.041	0.0042	0.0042

Appendix D-1. Pre-Test Makeup Natural Gas Analysis, Cont.

METHANOL	X1	0.003	0.005	0.0004	0.0004
CYCLOPENTANE	N5	0.012	0.041	0.0035	0.0035
2,3 DIMETHYLBUTANE	I6	0.023	0.092	0.0094	0.0094
2 METHYLPENTANE	I6	0.089	0.355	0.0367	0.0369
3 METHYLPENTANE	I6	0.047	0.190	0.0190	0.0191
N-HEXANE	P6	0.087	0.348	0.0356	0.0358
2,2-DIMETHYLPENTANE	I7	0.002	0.010	0.0009	0.0009
METHYLCYCLOPENTANE	N6	0.030	0.118	0.0106	0.0106
2,4 DIMETHYLPENTANE	I7	0.004	0.017	0.0019	0.0019
2,2,3 TRIMETHYLBUTANE	I7	0.001	0.003	0.0005	0.0005
BENZENE	A6	0.017	0.062	0.0047	0.0047
3,3 DIMETHYLPENTANE	I7	0.001	0.004	0.0005	0.0005
CYCLOHEXANE	O6	0.019	0.076	0.0065	0.0065
2 METHYLHEXANE	I7	0.008	0.036	0.0037	0.0037
2,3 DIMETHYLPENTANE	I7	0.002	0.011	0.0009	0.0009
1,1 DIMETHYLCYCLOPENTANE	N7	0.002	0.008	0.0008	0.0008
3 METHYLHEXANE	I7	0.007	0.031	0.0032	0.0032
1,C 3 DIMETHYLCYCLOPENTANE	N7	0.002	0.009	0.0008	0.0008
1,T 3 DIMETHYLCYCLOPENTANE	N7	0.002	0.008	0.0008	0.0008
3 ETHYLPENTANE	I7	0.000	0.002	0.0000	0.0000
1,T 2 DIMETHYLCYCLOPENTANE	N7	0.002	0.011	0.0008	0.0008
N-HEPTANE	P7	0.007	0.032	0.0032	0.0032
1,C 2 DIMETHYLCYCLOPENTANE	N7	0.000	0.001	0.0000	0.0000
METHYLCYCLOHEXANE	N7	0.008	0.038	0.0032	0.0032
2,2-DIMETHYLHEXANE	I8	0.000	0.002	0.0000	0.0000
ETHYLCYCLOPENTANE	N7	0.000	0.001	0.0000	0.0000
2,5-DIMETHYLHEXANE	I8	0.000	0.001	0.0000	0.0000
2,4-DIMETHYLHEXANE	I8	0.000	0.001	0.0000	0.0000
1C,2T,4-TRIMETHYLCYCLOPENTANE	N8	0.000	0.001	0.0000	0.0000
1T,2C,3-TRIMETHYLCYCLOPENTANE	N8	0.000	0.001	0.0000	0.0000
TOLUENE	A7	0.006	0.025	0.0020	0.0020
2-METHYLHEPTANE	I8	0.000	0.002	0.0000	0.0000
4-METHYLHEPTANE	I8	0.000	0.001	0.0000	0.0000
3-METHYLHEPTANE	I8	0.000	0.001	0.0000	0.0000
1C,2T,3-TRIMETHYLCYCLOPENTANE	N8	0.000	0.002	0.0000	0.0000
1T,4-DIMETHYLCYCLOHEXANE	N8	0.000	0.001	0.0000	0.0000
1T,2-DIMETHYLCYCLOHEXANE	N8	0.000	0.001	0.0000	0.0000
N-OCTANE	P8	0.001	0.003	0.0005	0.0005
1,1,4-TRIMETHYLCYCLOHEXANE	N9	0.000	0.001	0.0000	0.0000
ETHYLBENZENE	A8	0.000	0.001	0.0000	0.0000
1,3-DIMETHYLBENZENE (M-XYLENE)	A8	0.000	0.002	0.0000	0.0000
1,4-DIMETHYLBENZENE (P-XYLENE)	A8	0.000	0.001	0.0000	0.0000
N-NONANE	P9	0.000	0.001	0.0000	0.0000
TOTALS		100.000	100.000	5.5071	5.5367