State of the Art of Compact Separators for Production Measurement – from Lab to the Field

Drs. Ram S. Mohan and Ovadia Shoham
TU Major Research Consortia

- TUPREP
- TUDRP
- TUFFP
- TUPDP
- TUALP
- E/CRC
- TUSMP
- TUCTMR

- PETROLEUM RESERVOIR EXPLOITATION
- DRILLING RESEARCH
- TU-FLUID FLOW
- PARAFFIN DEPOSITION
- DELAYED COKING (TUDCP)
- TU-SEPARATION TECHNOLOGY PROJECTS
- ARTIFICIAL LIFT
- EROSION / CORROSION RESEARCH CENTER
- SAND MANAGEMENT
- COIL TUBING MECHANICS RESEARCH
TUSTP Mission and Vision

- Advance the State-of-the-Art of Multiphase Cyclonic Separation Technology for Gas/Oil/Water/Sand Flow

- Long-term Cooperation between University, Industry and Government is Envisioned to Better Understand, Analyze, and Design Compact Separators and Compact Separation Systems
TUSTP Research Areas

Flow Characterization
- Gas-liquid
- Liquid-liquid
- Solid-liquid

Dispersion Characterization (DCR) & Foam Characterization (FCR)

Flow Conditioning
- Slug Damper
- Helical pipe
- Balanced Feed Manifold

Control and Measurement
- Control
- Measurement (DDS)

Compact Separators
- GLCC©
- LLCC©
- LLHC
- GLSC©
- HPS©
- CMSS©
TUSTP Deliverables

- GLCC©vx9.2: GAS-LIQUID CYLINDRICAL CYCLONE
- LLCC©vx2.0: LIQUID-LIQUID CYLINDRICAL CYCLONE
- FlowpatOW-vx1.2: OIL-WATER FLOW PATTERN
- DPDLOWDisp-vx1.0: Pressure Gradient OIL-WATER
- Hydrocyclone-vx4.0: DEOILING & DESANDING HYDROCYCLONE
- FLOPATNvx2.6: GAS-LIQUID FLOW PATTERN PREDICTION
- Slug Damper vx2.1: GAS-LIQUID FLOW CONDITIONING
- Add-in Libraryvx1.4
Multiphase Production System
Gas/Liquid Separation Applications

- Compact Separators
- Flow Characterization
- Flow Conditioning
- Control and Measurement

Network Simulation
Slug Control
Gathering Station
Process Control
 Slug Catcher, Separator Design
Steady State Flow Modeling
Transient Flow Modeling
Multiphase Pipeline and Riser Design
Production Simulation
Reservoir Simulation
Production Logging
Well Testing

Wellhead Processing
Process Control
Multiphase Pumping
Multiphase Metering
Artificial Lift
Downhole
Seafloor Processing

Corrosion, Scale & Hydrate Control
UPM FORUM
UPSTREAM PRODUCTION MEASUREMENT
History of GLCC© Installations
GLCC® Field Applications
(over 6500 as of 12/2016)

- Separator Size Comparison
- Metering Loop with Single-Phase Meters
- Metering Loop with Multiphase Meters (Gas Knockout)
- GLCC as a Pre-separator for De-bottlenecking
- GLCC as a Bulk Separator
- High Pressure GLCC for Wet Gas Application
- Portable GLCC
- Offshore Application
- Mining Application
- GLCC for Severe Slugging Applications
- Low API Gravity Application (12 °API)
- Other Applications
  - GLCC after First Stage Compressor
  - GLCC for Raw Gas Lift
  - GLCC as a Gas Scrubber
  - GLCC in a Multiphase Pumping Loop
Separator Size Comparison

**Separation Devices:**
- **Vertical Separator:** (9ft x 35ft)
- **Horizontal Separator:** (19ft x 75ft)
- **GLCC© Compact Separator:** (5ft x 20ft)

**Reference:**
GLCC® Historical Development

- Originally Developed by Chevron in La-Habra, CA (Dr. Gene Kouba, early ‘90s)
- GLCC®/Net Oil Computer Configuration (early ‘90s)
- Device Patented in 1994
Field Application Design
Chevron Single Well Test Loop

- More than Forty units in one Oklahoma field
- Up to 1200 bpd and 80 GOR with one basic design
- 38 deg API crude with water cuts up to 95%
- Beam pumping units with pulsating flow
- 0.5 ft X 9 ft
- 50 psia, 80 F
Chevron Multiphase Metering Loop
- Multiple Well Testing

- Oklahoma
- 0.5 ft x 11 ft
- 1500 - 2000 bbl/d
- 500 - 800 Mscf/d
- 25 psia, 75 F
GLCC®s in West Texas (Single Well Testing)

- Gross liquid rates from 5 to 2000 bpd
- Gas rates to 50 Mscfd
- Field allocation factor better than 0.97
Field Application Design

GLCCS IN WEST TEXAS (MICROMOTION INC.)

- High gas rates from primary lift wells and ESPs
- Gas rates up to 2 MMscfd
- 2-inch ELITE meter on gas flow
- Density measurement for CO₂ fraction
GLCCs in West Texas (Multiple Wells Manifolded) Micromotion Inc.

- GLCCs used to replace 15 troublesome three-phase separators
- Multiple Wells
- Wide range of flow rates due to multiple lift techniques:
  - Beam lift, plunger lift, RotoFlex, ESP, primary
GLCC© as Part of a Wellhead Desander
BP’s Wytch Farm (UK)

✓ Field Test at BP’s Wytch Farm
✓ 6” GLCC for control of GLR input to desander
✓ Combination worked well
✓ Optimal solid/liquid separation
✓ 2-5% GCU
Automated Well Test Unit
– Minas Indonesia

- 3 ft ID, 11 ft tall
- 76 psia, 360 F
- 6,000 bbl/d, 10.0 MMscf/d
- Integrated liquid level control
Bulk Separation Application – Minas Indonesia

- 5 ft ID, 20 ft tall
- 185 psia, 360 °F
- 200,000 bbl/d, 71 MMscf/d
- Integrated liquid level control with Dead band filter
Confirmed operation of dual inlet during extremely high liquid rates.

Slugging Mitigation: Field Test for Model Validation
Multiphase Metering Loop Application – Lake Maracaibo, Venezuela

- Offshore Platform
- 1 ft x 11 ft
- 24 Wells
- 43 - 3033 bbl/d
- 683 – 4597 Mcf/d
- 60 psia, 130 F
12 API Oil - Bakersfield, CA

12” Column
3” Inlet
2” CMF- Liquid
Very Low GOR
Level Control
Temperature:
120 to 250 F.
GLCC® in Chevron Nigeria
“Raw” Gas Lift

HIGH PRESSURE SOURCE WELL

HIGH PRESSURE LIFT GAS

LOW PRESSURE GAS LIFT WELL

TO LIQUID FLOWLINE

1998 SPE Production Separation Workshop
GLCC© for “Raw” Gas Lift - Chevron Nigeria
China Offshore Platform GLCC© for Wet Gas Metering (CNOOC)

(Natural Gas and Condensate)

Courtesy Veritas-MSI (China)
China Offshore Platform GLCC© for Wet Gas Metering (CNOOC)

(Natural Gas and Condensate)
GLCC© for Well Test Metering Skid
(Shengli Oil Field - CNPC)

(Courtesy Veritas-MSI (China))

(Upstream Production Measurement)
GLCC© for Well Test Metering Skid
(Sinopec)

Courtesy Veritas-MSI
(China)
High Pressure GLCC© with AFE for Wet Gas Application (CEESI Test Loop)

Tested at CEESI 200 – 1000 psia
AFE extended gas rate limits

(Rated for 1500 psia)
CPI - DURI AREA-10  GLCC©s
WITH SLUG DAMPER (Indonesia)
Field Application Design

- GLCC with Slug Damper
  (Courtesy SMS, Inc.)
Field Application Design

➢ GLCC HEAVY OIL FIELD TEST UNIT

✓ Oils: 14, 19, 29 API
✓ P = 100 – 200 psig
✓ T = 120 F
✓ wc = 0 – 100
✓ Q_L = 1500 – 8000 bblpd
✓ Q_g = 250 – 1500 mscf/d
Field Application Design

- INFIELD DRILLING
  - 10” Column
  - 1” R Meter - Gas
  - 2” F-Series Liquid
  - Full level Control
  - Dual Control Valves
Field Application Design

- GAS WELL WITH CONDENSATE

- 10” Column
- 3MMSCFD GAS – 20 BPD Gross
- 2” F-Series Gas
- 1” F-Series Liquid
- Capacity 12MM
Field Application Design

- Liquid Metering Loop
  (Mining Applications
  – Premier Instruments, Colorado)

  ✓ 6 inch ID, 9ft tall
  ✓ 250-800 psi, 300-425 F
  ✓ 857-6860 bbl/d liquid,
    5-40 MMscft/d gas
  ✓ Level control by GCV
    implemented by Premier
    Instruments Inc.
Field Application Design

- GLCC Metering Skids for Exxon, Chad (Premier Instruments)
Field Application Design

- GLCC IWT LOOP FOR POZA RICA, MEXICO (Wet Gas Application)

GLCC installed by Emerson Process Management - IWT
Portable GLCC© Well Test Unit
- Texaco, Bakersfield
Portable GLCC® – Gas Production

Courtesy SMS, Inc.
Portable GLCC® – Well Test Skid (PEMEX, Mexico)
“Bear Cyclone” by Calscan, Canada

Calscan has developed The Bear Cyclone Separator Package

- Innovated high efficiency Cyclone Separator
- Easy to install
- Modern non venting control system – Zero Green House Gas Emission
- Small foot print
- All Electric Control System
- Low power flow computer for gas & liquid measurement
Field Application Design

- GLCC AFTER FIRST STAGE COMPRESSOR

Chevron – Cymric Field, CA
Field Application Design

- GLCC AS A GAS SCRUBBER (AMAZON JUNGLE – BRAZIL)
Field Application Design

GLCC METERING SKID
(SMS INC. - OXY-ELK HILLS- CA)
Solar Battery Powered
Field Application Design

- 10” GLCC 48 WELL HEADER
  - 10” Column
  - Multi Liquid Flow Ranges
  - Multi Gas Flow Ranges
Field Application Design

- MID-GRAVITY OIL 22 TO 28 API

Courtesy SMS, Inc.
Field Application Design

- Texaco GLCC Multiphase Metering Loop for Eugene Island
  - 6” Column, total Height – 9’2”
  - 6MMSCFD GAS – 10,000 BPD Liquid
  - 2000 psi, Schedule 80
  - Inlet – 4 inch
  - Gas leg – 2” (with Control Valve)
  - Liquid leg – 2” (with Control Valve)
  - Well test measurement of produced oil, gas and water
Aera Energy has over 150 units in one field
Field Application Design

- 12” GLCC - Courtesy SMS, Inc.
  - 12” Column
  - 10” Inlet
  - Coriolis Gas and Liquid
  - High Gas Rates, Low Liquid
  - Slug Factors Over 30
  - Level Control
  - Temperature: 120° to 250° F.
Field Application Design

- 10” GLCC Courtesy SMS, Inc.

- 10” Column
- Self Leveling
- 1” R Meter- Gas
- 1” F Meter- Liquid
- Auto Pump Off Control
- 24 Hour Continuous Data to Host with Auto Alarm Functions
Field Application Design

DUAL GAS RUNS

- Unit will Automatically switch Gas Meters when Flow Rate exceeds Set-Point
- 1” R Meter - Gas
- 2” Vortex - Gas
- 2” F Meter - Liquid
- Full level Control
Field Application Design

18” GLCC Courtesy SMS, Inc.

- 18” Column
- 4” Inlet
- Solar Powered
- 2” CMF- Liquid
- 1” CMF- Gas
- Level Control
- Gas Demister Installed
- Gas Scrubber, Process Gas used for Control
Field Application Design

- 24” GLCC Courtesy SMS, Inc.
- Low Gas Volumes
- High Liquid Volumes
- Solar Powered
GLCC removes breakout gas from water on Unocal Thailand’s Pailin Platform

Courtesy: NATCO/Cameron
Submersible Well

- 18” Column
- 24 API
- Single Well
- No Control Valve Required
GLCC Applications

EXTERNAL PRE-SEPARATION
1st Subsea GLCC® - Petrobras
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<th>No.</th>
<th>APPLICATION CLASSES</th>
<th>CONTROL STRATEGIES</th>
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<td>1</td>
<td>Remote Powerless GLCC Operation</td>
<td>X</td>
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<tr>
<td>2</td>
<td>Remote GLCC Operation With Power</td>
<td>X</td>
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<tr>
<td>3</td>
<td>Well Testing (Recombined Flow)</td>
<td>X X X X X X X X X X X X</td>
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<td>4</td>
<td>Bulk Separation (Separator Stand Alone)</td>
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<td>5</td>
<td>Downstream Surge Tank Control</td>
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<td>6</td>
<td>Separation of Wet Gas (raw Gas Lift)</td>
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<td>7</td>
<td>(Liquid Dominated)</td>
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<td>8</td>
<td>Separator subjected to Severe Slugging</td>
<td>X</td>
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<tr>
<td>9</td>
<td>Integrated Separation systems</td>
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<td>10</td>
<td>GLCC with Liquid Hydrocyclones</td>
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<td>11</td>
<td>GLCC Upstream of pumps</td>
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<td>12</td>
<td>GLCC with Conventional Separators</td>
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<td>Subsea Application</td>
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<td>Free Water Knockout with LLCC</td>
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<td>18</td>
<td>GLCC/LLCC Integrated System Control</td>
<td>X</td>
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<td>19</td>
<td>GLCC for Environmental Applications</td>
<td>X</td>
</tr>
<tr>
<td>20</td>
<td>COMPACT Multiphase Separation System (CMSS) Control</td>
<td>X</td>
</tr>
</tbody>
</table>
Field Testing

- MPFMs (including GLCC© Loop) Testing by Saudi Aramco in Shaybah Field in 2008
- Measurements Compared to SA Testing Skid
- Twenty Eight Tests Conducted; Medium to Very High GOR
GLCC© MPFM Schematic – Saudi Aramco

Dimension: 4000×1700×3700
Weight: 6500 kg
Design: 900 lb ANSI
Design T: 212 F

Courtesy Multiphase Systems Integration (MSI, LLC)
Test Conditions

- Liquid: 1000-8000 BPD;
- Watercut: 0-30%
- Gas rate: 1-22 MMSCFD
- Gas-Oil-Ratio (GOR): 750 – 7500 SCF/BBL
- Gas-Volume-Fraction (GVF): 63 – 97%
GLCC© MPFM Accuracy
– Oil Flow Rate

Stock tank Oil Flow Rate (SBOPD)

± 10%
Acceptable Error Band

MSI MULTIPHASE OIL RATE
(SBOPD)

ARAMCO TEST SKID OIL RATE(SBOPD)

 Courtesy Multiphase Systems Integration, LLC (MSI)
GLCC® MPFM Accuracy – Gas Flow Rate

Gas Flow Standard conditions (MMSCFD)

± 15% Acceptable Error Band

 Courtesy Multiphase Systems Integration, LLC (MSI)
Prototype of Compact Multiphase IWS System - China

Courtesy Multiphase Systems Integration, LLC (MSI)
Schematic of InLine Water Separation System (IWS)

Oil-in-water: < 50 ppm
% of water removal: 70% - 80%

- GLCC: Gas-Liquid Cylindrical Cyclone for gas-liquid separation
- LLPS: Liquid-Liquid Pipe Separator for oil-water pre-separation
- LLCC: Liquid-Liquid Cylindrical Cyclone for bulk oil-water separation
- LLHC-1: Liquid-Liquid Hydro Cyclone for pre-deoiling
- LLHC-2: Liquid-Liquid Hydro Cyclone for deoiling

Photograph of InLine Water Separation System (IWS) Installed in the Field

IWS Separation Efficiency and Oil in Water Concentration

CompactSep™ - Compact Subsea Gas-Liquid Separator for High-Pressure Wellstream Boosting

O. Kristiansen, Ø. Sørensen, and O. R. Nilssen, Statoil

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This paper was prepared for presentation at the Offshore Technology Conference held in Houston, Texas, USA, 2–5 May 2016.

(a) Subsea liquid boosting and free gas flow. (b) Comparison of conventional (left) and CompactSep (right) booster stations. Grid size is 1x1 m. Illustration: FMC Technologies

Figure 1—Subsea booster station concept for liquid boosting and free gas flow.
Background and Objectives

- Subsea separation successfully implemented on the Troll and Tordis fields (Statoil), Pazflor (Total), Marlim (Petrobras), and Perdido and BC-10 (Shell).
- The objective of this work was to qualify a two-stage, compact, inline gas-liquid separation system with full turndown and slug handling capabilities, consisting of already proven components - Gas-Liquid Cylindrical Cyclone (GLCC©) and one InLine DeLiquidiser.
- Conducted by Joint Industry Project with Statoil as operator and Chevron, Petrobras, Total, and FMC Technologies as participants.
(b) Ejector layout with both gas and liquid polishers.
(a) The GLCC is seen at the centre. The InLine DeGasser is at the left and the DeLiquidiser is elevated and behind the GLCC.
Key Conclusions

- The CompactSep system combines the GLCC’s liquid capacity with the DeLiquidiser’s gas capacity. The work developed and qualified an inline separator system with full turndown and slug handling capability at a wide range of realistic conditions.

- At design fluid conditions (crude oil, 50 bar):
  - Gas qualities requirement was GVF > 0.995, with measured result of GVF between 0.995 and 0.999.
  - Liquid quality requirement was GVF < 0.1, with measured results of GVF between 0.02 and 0.1
  - The liquid separation efficiency was typically 99 to 99.9%.
Before........

...from this....
After........

...to this !
TUSTP Home Page
http://www.tustp.org

TULSA UNIVERSITY SEPARATION TECHNOLOGY PROJECTS (TUSTP) was established in 1994 as a Joint Industry Project (JIP) with the goal of advancing state-of-the-art compact phase separation technology for gas, oil, and water flows.

TUSTP research is supported by 15 leading national and international companies in the petroleum industry. We envision a long-term cooperation with the petroleum industry conducting projects to better understand, analyze and design separation systems.