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TUSTP COMMISSIONS THREE-PHASE FLOW FACILITY AND PARTICIPATES IN WORLD'S LARGEST GLCC PROJECT

BACKGROUND

The petroleum industry has relied in the past mainly on conventional, vessel-type separators to process wellhead production of oil-water-gas flow. Since the early 1990's the industry has been giving considerable attention to compact separators, such as the Gas-Liquid Cylindrical Cyclone (GLCC©[1]), due to their significant advantages, namely, simplicity in construction, compactness, possessing low weight, and having low capital and operational costs. The GLCC separator has the potential of use for well testing metering systems, control of gas-liquid ratio (GLR) for multiphase meters, pumps and de-sanders, gas scrubbing for flare gas and wet gas metering, external pre-separation upstream of existing conventional separators, and primary surface or sub-sea separation. The GLCC is also being considered for downhole applications.

Established in 1994, the mission of Tulsa University Separation Technology Projects (TUSTP) is to advance the state-of-the-art of compact separation technology for gas/oil/water flow. The first compact separator to be studied has been the GLCC separator. Emphasis is placed on the measurement and understanding of the hydrodynamic flow behavior in compact separators and the development of design tools for the industry. Long-term cooperation with the industry is envisioned in conducting projects to better understand, analyze, and design compact separators and compact separation systems.

NEW THREE-PHASE FLOW LOOP COMMISSIONED

Past TUSTP studies on compact GLCC separators have been carried out for two-phase gas-liquid flow. These studies demonstrated successfully the capability of the GLCC for partial or full separation of gas-liquid mixtures. The present project attempts to extend the GLCC capabilities for oil-water-gas three-phase separation. The objective of the project on "Design and

[1] GLCC© - Gas-Liquid Cylindrical Cyclone - copyright, The University of Tulsa, 1994.

Development of GLCC Compact Separators for Three-Phase Flow" funded by DOE (see project description below) is to investigate the feasibility of the GLCC as a bulk separator. Is it possible to utilize the GLCC for bulk separation of oil-water liquid phase for knock out of free water? If proven successful, this will significantly simplify the separation facilities downstream.

As part of the DOE project, a new oil/water/air three-phase indoor flow loop has been designed and constructed in the College of Engineering and Natural Sciences research building, located in the North Campus of TU. This indoor facility will enable year around data acquisition and simultaneous testing of different compact separation equipment. The new facility is a fully instrumented state-of-the-art two-inch flow loop, enabling testing of single separation equipment or combined separation systems.

The three-phase flow loop, as shown in Figure 1, consists of a metering and storage section and a modular test section. The metering and storage section includes air compressor, water and oil storage tanks, pumps, Micromotion® mass flow meters and a downstream 3-phase conventional separator. The modular test section consists of 4 test stations. This flexibility enables the testing of single separation equipment, such as a Gas-Liquid Cylindrical Cyclone, Liquid-Liquid Cylindrical Cyclone (LLCC©[2]), Liquid Hydrocyclones (LHC), conventional separators or any combination of these equipment, in parallel or series, forming a compact separation system. Control valves placed along the flow loop control the flow into and out of the test sections. The flow loop is also equipped with several temperature sensors and pressure transducers for measurement of the in-situ pressure and temperature conditions. All output signals from the sensors, transducers and metering devices are collected at a central panel. A state-of-the art data acquisition system, built using LabView® software, is used to both control the loop and acquire data.

Currently, experimental data acquisition is carried out on an oil/water Liquid-Liquid Cylindrical Cyclone separator. Two three-phase GLCC configurations will be studied. The first one is a single-stage GLCC where the gas is removed from the top, the oil from the middle/center of the GLCC, and the water tangentially from the bottom of the GLCC. The second configuration is a two-stage GLCC system whereby the gas is separated from the liquid phase in the first stage, and the oil is separated from water in the second stage. Finally, a Liquid

[2] LLCC© - Liquid-Liquid Cylindrical Cyclone - copyright, The University of Tulsa, 1998

Hydrocyclone will be tested to clean the water stream. These are the components of a compact separation system that are envisioned to be used in the field in the future.

WORLD'S LARGEST GLCC INSTALLED

New GLCC field applications designed utilizing the TUSTP GLCC simulator, have been installed by Caltex Pacific Indonesia (CPI) in the Light Oil Steam Flooded (LOSF) project in Minas, Indonesia. The project was executed by Drs. Jack Marrelli from Texaco and Gene Kouba from Chevron. The largest GLCC (60 in.-ID) for bulk separation/metering and three 36-in. ID metering GLCCs for well test metering applications have been recently installed. The bulk separation/metering GLCC 5 ft ID and 20 ft tall is shown in Figure 2. The GLCC operates at 170 psia and 360^0F, handling liquid and gas production rates of 180,000 bpd and 71 MMscfd, respectively. The GLCC is equipped with control valves on the gas and liquid legs and a sophisticated control system for liquid level control. TUSTP personnel were closely involved in designing these GLCCs and the respective control systems. The 36-inch diameter well testing GLCC operates at 170 psi and 360^0F, handling liquid and gas production rates up to 7000 BBl/d and 4.5 MMscfd, respectively. The control philosophy for this GLCC was also developed by TUSTP.

The successful application of GLCC technology in the LOSF project will prolong the producing life of Minas field well into the 21^{st} century and help postpone Indonesia from becoming a net importer of oil. It has also enabled Indonesia to explore this technology for other areas such as Duri. Comprehensive sensitivity analysis of the conventional separators vs. GLCCs demonstrated that GLCC application for Duri Area-10 alone is estimated to improve the metering accuracy considerably and save about $3.2 Million over conventional separators. The performance of gravity separators is highly dependent on the emulsion viscosity as well as the gas and the liquid flow rates, whereas the relatively higher "g" forces generated in the GLCC minimize the sensitivity to these parameters and the corresponding predicted loss in separator performance and enhance the metering accuracy. Due to the significant reduction in the size (about $1/4^{th}$ of the dimensions of conventional vertical separators) that would be realized using GLCC technology, an accelerated delivery schedule is also realized. Currently TUSTP is developing the control strategy for 8 automated well testing GLCCs of 10 inch diameter and 8 bulk separation/metering GLCCs of 36 inch diameter for Duri Area-10 application. Based on the

success of the GLCC technology in Duri, it will be considered for Areas 11, 12, 13 and others as well.

INDUSTRIAL MEMBERSHIP

Current TUSTP membership is: Chevron, Conoco, Ecopetrol (Colombia), Elf (France), Jiskoot, Micro-Motion, Modular Production Equipment (MPE), Pemex (Mexico), Petrobras (Brazil), Premier Instruments, Schlumberger (France), Texaco, Unocal and Westinghouse.

LEVERAGE OF FUNDING

In an effort to leverage TUSTP funding and to expand the JIP activities, TUSTP has submitted proposals to the U.S. Department of Energy (DOE) and to the Oklahoma Center for the Advancement of Science and Technology (OCAST). Both proposals have been funded and are ongoing. Two additional proposals are under consideration by the National Science Foundation (NSF).

The total budget of the DOE project on "Design and Development of GLCC Compact Separators for Three-Phase Flow" is $766,063 for five years, namely, October 1, 1997 - September 30, 2002. Efforts in the first year of the project were aimed at the design and commissioning of the new three phase-flow compact separator loop. In the second (current) year experimental data are being acquired for oil-water bulk separation in a Liquid-Liquid Cylindrical Cyclone (LLCC) separator prototype for flow. Future work will include oil/water/gas separation in a three-phase GLCC compact separator and field testing with real crudes at high pressure.

The OCAST proposal is titled, "Performance Enhancement of GLCC Compact Separators" with a budget of $290,475 for the period August 1, 1998 - July 31, 2001. This project is aimed at developing a laboratory prototype Gas-Liquid Cylindrical Cyclone compact separator that has been upgraded with field data for optimum performance, employing a closed-loop control system. Significant technical accomplishments of the first year are first level laboratory model GLCC fabrication and target designs, identification of control strategies of the GLCC equipped with active control system, and experimental data acquisition and local measurements. The future activities will focus on mechanistic and CFD modeling, experimentation for control strategy validation and dynamic simulation of GLCC control.

TECHNOLOGY TRANSFER

TUSTP aims at rapid deployment of GLCC systems through concurrent technology transfer and assisting member companies implement the new Gas-Liquid Cylindrical Cyclone (GLCC) technology. In addition to the recent Indonesian project carried out by Caltex Pacific Indonesia (CPI) (described above), TUSTP personnel have been involved in several different field application designs for member companies. These include multiphase metering loops (Chevron, Texaco and PDVSA, Venezuela); partial separation (Chevron, Okan, Nigeria and Arco, Alaska); GLCC as an external pre-separator (Petrobras, Brazil); and, GLCC as a Primary Separator (UNOCAL overseas). Over 120 GLCCs are in operation in the USA and overseas.

STUDENT INVOLVEMENT IN TUSTP RESEARCH

Ten graduate students have completed their studies in TUSTP in the past five years. Following are the names of the students and their thesis/dissertation titles. The completed studies served as reports to the participating member companies:

- Mauricio Prado: "A Block Implicit Numerical Solution Technique for Two-Phase Multidimensional Steady-State Flow" (Ph.D., PE, 1995).
- Inta Arpandi: "A Mechanistic Model for Two-Phase Flow in Gas-Liquid Cylindrical Cyclone Separators" (MS, PE, 1995).
- Ashoutosh Joshi: "Two-Phase Flow in Gas-Liquid Cylindrical Cyclone Separators - Experiments and Modeling" (MS, PE, 1995).
- Ferhat Erdal: “CFD Simulations of Single-Phase and Two-Phase Flow in Gas-Liquid Cylindrical Cyclone Separators” (MS, ME, 1996).
- Brenno Motta: "Rotational Two-Phase Flow in Gas-Liquid Cylindrical Cyclone Separators" (Ph.D., PE, 1997).
- Shaya Movafaghian: "The Effects of Geometry, Fluid Properties, and Pressure on the Flow Hydrodynamics in Gas-Liquid Cylindrical Cyclone Separators” (MS, PE, 1997).
- Shoubo Wang: “Control System Analysis of Gas-Liquid Cylindrical Cyclone Separators” (MS, PE, 1997).
- Luis Gomez: “A State-of-the-Art Simulator and Field Application Design of Gas-Liquid Cylindrical Cyclone Separators” (MS, PE, 1998).

- Ivan Mantilla: "Bubble Trajectory Analysis in Gas-Liquid Cylindrical Cyclone Separators" (MS, PE, 1998).
- Williams Chirinos: "Liquid Carry-over in Gas-Liquid Cylindrical Cyclone Separators" (MS, PE, 1998).

Nine graduate students and three undergraduate students are currently involved in TUSTP research activities, as follows:

Graduate Students:

- Ferhat Erdal: "Local Measurements and CFD Simulation of Two-Phase Flow in Gas-Liquid Cylindrical Cyclone Separators" (Ph.D., ME).
- Luis Gomez: "Gas Carry-under in Gas-Liquid Cylindrical Cyclone Separators" (Ph.D., PE).
- Edelmira Afanador: "Oil-Water Separation in Liquid-Liquid Cylindrical Cyclone (LLCC) Separators" (MS, PE).
- Carlos Oropeza: "Three Phase-Flow in Gas-Liquid Cylindrical Cyclone Separators" (Ph.D., PE).
- Shoubo Wang: "Control Strategy Development and Design for Gas-Liquid Cylindrical Cyclone Separators" (Ph.D., PE).
- Juan Caldentey: "Modeling Oil/Water Separation in Liquid Hydrocyclones (LHC)" (MS, PE).
- Shankar Earni: "Predictive Control for Gas-Liquid Cylindrical Cyclone Separators Using Slug Detection" (MS, ME)
- Reyes Ramirez: "Flow Conditioning in Helical Pipes" (MS, ME).
- Carlos Gomez: "Testing of oil/water Liquid Hydrocyclones (LHC) and improved Mechanistic Model" (MS, PE).

Undergraduate Students:

- Daniel Kretchmer (BS, ME)
- Javier Gonzales (BS, PE).
- Jose Severino (BS, PE).

Three faculty members are involved in TUSTP research, namely

- Dr. Ovadia Shoham (PE), Director;
- Dr. Ram Mohan (ME), Associate Director and PI on DOE and OCAST projects; and
- Dr. Siamack Shirazi (ME), co-PI.

IMPROVED INSTRUMENTATION

A Laser Doppler Velocimeter (LDV) purchased by Dr. Siamack Shirazi for the Mechanical Engineering Department has been utilized by Ferhat Erdal to measure local axial and tangential velocities along the GLCC diameter. The measurements are conducted on portable, single-phase test facility. Turbulent intensities in axial and tangential directions were also measured. The LDV enhances TUSTP research significantly as it can verify the CFD simulations and the velocity distributions used in the mechanistic model. The new data confirm that the flow is highly non-symmetrical around the axis of the GLCC. They also indicate downward flow near the wall of the GLCC and upward flow near the center but off the axis of the test section. Tangential velocity measurements show that free vortex occurs near the wall region and forced vortex occurs near the center of the GLCC.

PUBLICATIONS

A total of 18 publications have been presented by TUSTP since September 1994, including 6 refereed publications. Five new publications were presented recently by TUSTP, including: 2 accepted for the SPE ATCE, Houston (October 1999); 1 presented at the June 1999 DOE Oil & Gas conference in Dallas; 2 presented at the ASME ETCE in Houston (February1999) and published in the ASME JERT (March 1999 issue).

LONG TERM PROJECTS

Possible future long term projects of compact separators include the study of other compact separator configurations such as tee junctions, auger, vortex tube, etc., enhancement of convective heat transfer, down-hole configurations, variable area inlets, modern control systems, compact separation systems, including several separation units in series such as a GLCC with a hydrocyclone etc., high pressure real crudes field testing, handling foam and emulsion, and sand handling capabilities and the effect of solids in erosion of compact separators.

Figure 1: TUSTP New DOE Three-Phase Flow Loop Facility

Figure 2: World's Largest GLCC Commissioned by Caltex Pacific Indonesia (CPI)