Project Title:

Design and Development of Gas-Liquid Cylindrical Cyclone Compact Separators for Three-Phase Flow

Name of Report: Semi-Annual Technical Progress Report

Reporting Period Start Date: October 1, 2001

Reporting Period End Date: March 31, 2002

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Date Report was Issued: April 29, 2002

DOE Award Number: DE-FG26-97BC15024

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Submitted to: The U.S. Department of Energy

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April 2002

1. Disclaimer

2. Abstract

This report presents a brief overview of the activities and tasks accomplished during the first half year (October 1, 2001 – March 31, 2002) of the fifth project year budget period (October 1, 2001 – September 30, 2002). An executive summary is presented initially followed by the tasks of the current budget period. Then, detailed description of the experimental and modeling investigations are presented. Subsequently, the technical and scientific results of the activities of this project period are presented with some discussions. The findings of this investigation are summarized in the "Conclusions" section followed by relevant references.

The fifth project year activities are divided into three main parts, which are carried out in parallel. The first part is continuation of the experimental program that includes a study of the oil/water two-phase behavior at high pressures and control system development for the two-phase LLCC©. This investigation has been extended for three-phase GLCC as well. The second part consists of the development of a simplified mechanistic model incorporating the experimental results and behavior of dispersion of oil in water and water in oil. This will provide an insight into the hydrodynamic flow behavior and serve as the design tool for the industry. Although useful for sizing GLCC©s for proven applications, the mechanistic model will not provide detailed hydrodynamic flow behavior information needed

to screen new geometric variations or to study the effect of fluid property variations. Hence it will be validated with a more rigorous approach of computational fluid dynamics (CFD) simulation. Multidimensional multiphase flow simulation at high pressures and for real crude conditions will provide much greater depth into the understanding of the physical phenomena and the mathematical analysis of three-phase GLCC© design and performance. In the third part, design guidelines for three-phase GLCC© field applications by the industry will be developed. These design guidelines will form the basis for high-pressure real crude conditions.

3. Table of Contents

4. Executive Summary

The objective of this five-year project (October, 1997 – September, 2002) is to expand the current research activities of Tulsa University Separation Technology Projects (TUSTP) to multiphase oil/water/gas separation. This project is executed in two phases. Phase I (1997 - 2000) focuses on the investigations of the complex multiphase hydrodynamic flow behavior in a three-phase Gas-Liquid Cylindrical Cyclone (GLCC©[1]) Separator. The activities of this phase include development of a mechanistic model, a computational fluid dynamics (CFD) simulator, and detailed experimentation on the three-phase GLCC©. The experimental and CFD simulation results are suitably integrated with the mechanistic model.

The goal of Phase II (Project years 4 and 5 - 2000 to 2002) is to conduct field-scale testing of GLCC© technology at high pressure and with real crudes. This is crucial for validating the GLCC© design for field applications and facilitating easy and rapid technology deployment. Tasks will include design, fabrication and testing of a high pressure GLCC© facility. Design criteria for industrial applications will be developed based on these results and will be incorporated into the mechanistic model by TUSTP.

This report presents a brief overview of the activities and tasks accomplished during the first half year (October 1, 2001 – March 31, 2002) of the budget period (October 1, 2001 – September 30, 2002). The total tasks of the budget period are given initially, followed by the technical and scientific results achieved to date from the experimental and modeling investigations. The report concludes with a summary/conclusion and a list of references.

5. Tasks of the Current Budget Period (Oct. 1, 2001 – Sept. 30, 2002)

Objective: High Pressure Data Acquisition and Field Design and guidelines.

a. Design, fabrication and installation of second generation High Pressure 3-phase GLCC©.
b. Detailed experimental data for liquid carry-over.
c. Detailed experimental data for gas carry-under.

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

d. Incorporation of high pressure GLCC results into mechanistic model.
e. Development of design guidelines for GLCC field application for the industry.
f. Interim reports and Phase II final report preparation

6. Experimental and Modeling Investigations

The goal of Phase II (Project years 4 and 5) is to conduct field-scale testing of GLCC© technology at high pressure and with real crudes. Tasks include design, fabrication and testing of a high pressure GLCC© facility. The results of this testing will be incorporated by The University of Tulsa (TU) personnel into the TUSTP mechanistic model and be used by TUSTP to develop design criteria to assist industry with implementation of GLCC© systems in field operations.

Two types of 3-phase GLCC© configurations have been developed in this study, namely single stage GLCC© and dual stage GLCC©. Schematic of these two configurations are shown in Figure 1 and 2 respectively. Feasibility of these two configurations have been established in the Phase I investigations at The University of Tulsa. The detailed results of this study are documented in Oropeza (2001). The GLCC© for the high pressure, real crude experimental investigation has been built at Colorado Engineering Experiment Station Inc. (CEESI) using steel pipes, so as to withstand pressures as high as 1500 psi, and is equipped with several temperature and pressure transducers to enable evaluation of the hydrodynamic flow phenomena. A schematic of the modified GLCC for high GOR applications (Figure 3) shows the GLCC test section with dual annular film extractor for high GOR applications at high pressures. It is a 6” GLCC with a 6” inclined inlet pipe and a tangential inlet nozzle with an opening area of 25% percent of the inlet pipe cross section area. The liquid film extractor is located just above both the inlets. A liquid control valve in the liquid leg is used to control the liquid level using the liquid level signal provided by the liquid level sensor, and a gas control valve in the gas leg is used to control the operating pressure using the pressure signal provided by the pressure transducer. The photograph of this GLCC for high GOR applications and being tested at high-pressure conditions in CEESI is shown in Figure 4. The modular design of the GLCC© will allow easy modification of the inlet, outlet and piping configurations.

Fig. 1 – Schematic of Single-stage 3-Phase GLCC© System

- Oropeza (2001)

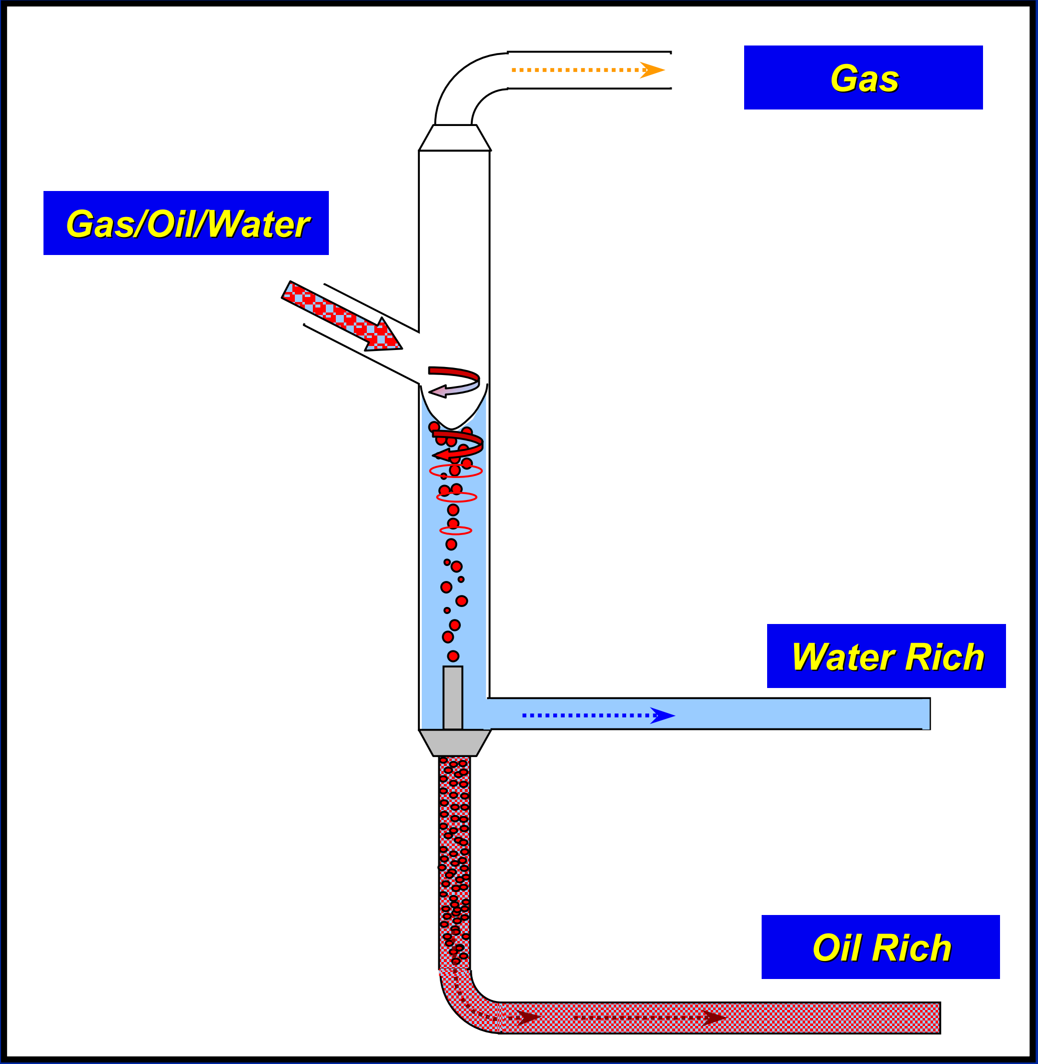
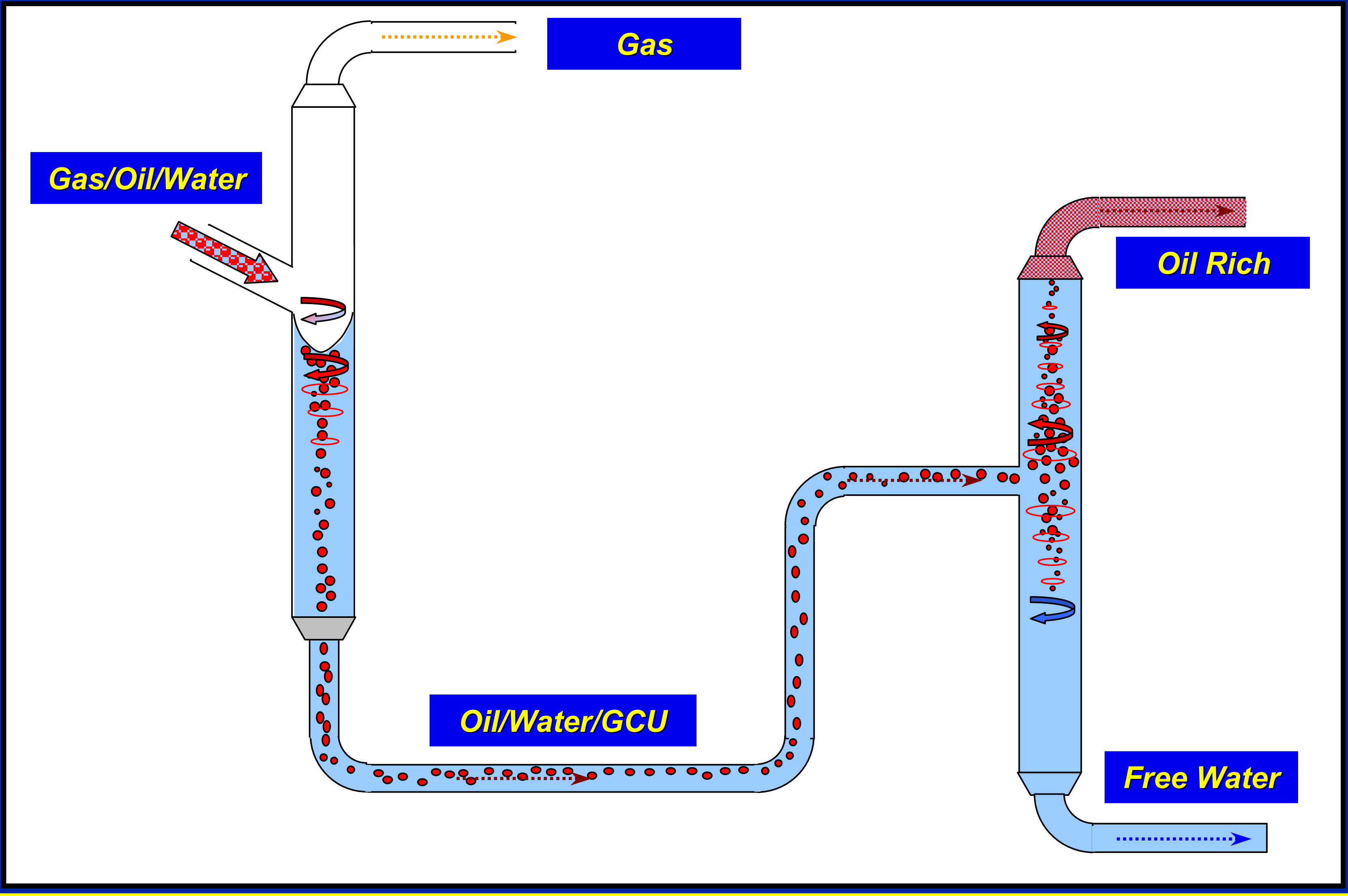


Fig. 2 – Schematic of 2-stage 3-Phase GLCC© System



Initial experimentation has been conducted on the above GLCC© prototype by TUSTP at CEESI, in collaboration with TUSTP member companies (ChevronTexaco), and data analysis is in progress. Hardware modifications have been completed to enhance the applicability of the GLCC© for high GOR (gas-oil ratio) conditions. Detailed testing of the GLCC© separators upto 500 psi have been completed and currently testing at 1000 psi is in progress. The mechanistic modeling of liquid carry-over and gas carry-under are continued in the fifth year for integration with the respective constitutive models.

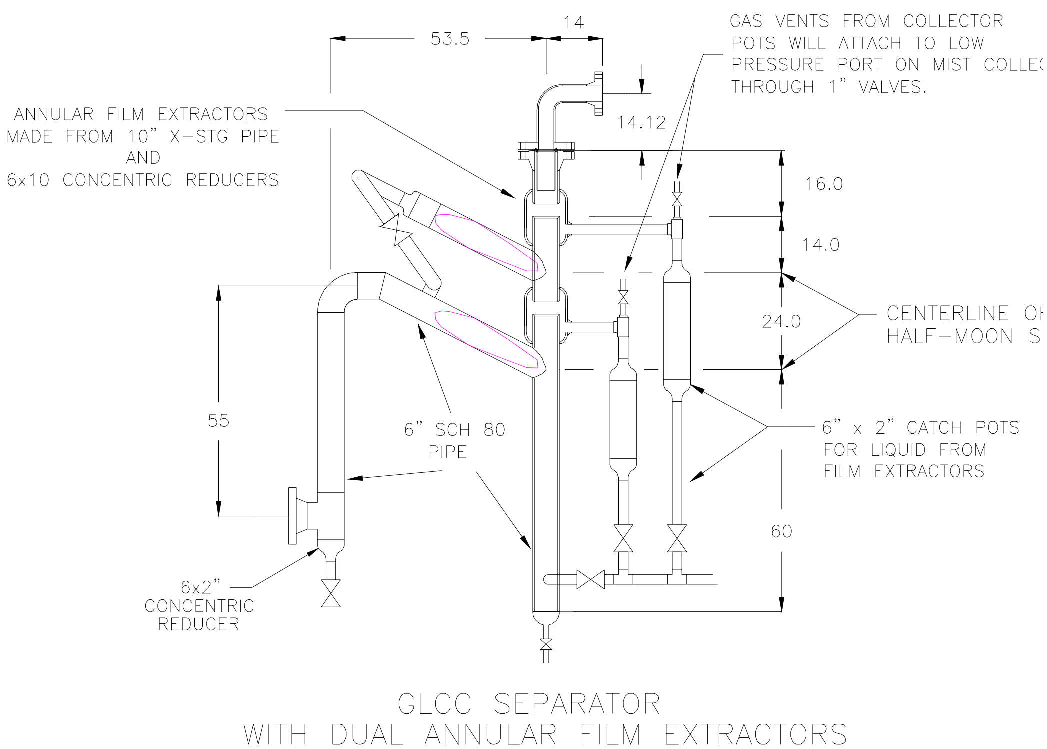


Figure 3 – Modified GLCC for High GOR Applications

In addition to the inlet flow rates of the respective phases, the following measurements are acquired for each experimental run:

1. Absolute pressure, temperature and pressure drop in the GLCC©;
2. Equilibrium liquid level using differential pressure transducers;
3. Zero net liquid flow hold-up at high pressures and comparison with low pressures.

4. Churn region and droplet region lengths (in the upper part of the GLCC©) as limiting conditions;
5. Global separation efficiency namely oil fraction in the water outlet, water fraction in the oil outlet;
6. Bulk measurement of liquid carry-over in the gas leg.

Figure 4 – High Pressure GLCC Test Facility at CEESI

The mechanistic model developments initiated in the first phase of the project are continued during the second phase, which will lead to an integrated model. A mechanistic model for operational envelope of liquid carry-over and gas carry-under will be developed for the prediction of the hydrodynamic flow behavior and performance of the three-phase GLCC© separator.

The input parameters to the model would include the following:

- Operational parameters: range of oil-water-gas flow rates, pressure and temperature;

- Physical properties: oil, gas and water densities, viscosities and surface tensions;
- Geometrical parameters: complete geometric description of the GLCC© such as, GLCC© configurations, inlet pipe I.D, inclination angle and roughness, outlet piping I.D, length and roughness;

The mechanistic model will enable determination of the performance characteristics of the GLCC©, namely:

- plot of the operational envelopes for both liquid carry-over and gas carry-under at high pressures;
- percent liquid carry-over and gas carry-under beyond the operational envelopes;
- oil in water and water in oil fractions;
- pressure drop across the GLCC©;
- liquid level in the separator;

The simplified integrated mechanistic model will enable insight into the hydrodynamic flow behavior in the three-phase GLCC©. It will allow the user to optimize the GLCC© design accounting for tradeoffs in the I.D, height and inlet slot size of the GLCC©. The model will also provide the trends of the effect of fluid physical properties and the information required for determining when active controls will be needed.

The experimental data acquired at high pressures in the GLCC© and other available data from complex three-phase systems, such as flow splitting at tee junctions, will be used to test and refine the numerical code. For the current project, the CFD model as described by Erdal (2000) will be used for initial parametric studies of possible design modifications to the GLCC©. Moreover, the model will provide detailed performance prediction for untried applications for which no data are available, such as high-pressure, sub-sea separation.

7. Results and Discussion

As a part of the tasks identified for the current budget period, the following specific technical and scientific activities have been completed:

A. Oil/Water LLCC© Control

The feasibility of using Liquid-Liquid Cylindrical Cyclone (LLCC) as a free water knockout device for bulk separation of oil-water mixtures in the field strongly depends on the implementation of control systems due to its compactness, less residence time and possible inlet flow variations. In this investigation (Afanador, 1999, Mathiravedu, 2001), the LLCC control dynamics have been studied extensively both theoretically and experimentally.

A unique control strategy is developed for LLCC separators, which can provide a much superior performance as it involves the direct measurement of a control parameter of immediate concern. This strategy is capable of maintaining clear water in the underflow and simultaneously maximizing the flow rate in the underflow stream. It tries to maintain the optimal split ratio that depends upon the inlet water concentration and inlet mixture velocity. A linear model has been developed for the first time for LLCC separators equipped with underflow watercut control, which enables simulation of the system dynamic behavior.

Control system simulator (Fig. 5) is developed using Matlab/Simulink software. Detailed dynamic simulations demonstrate the following: (a) LLCC control system can handle different combinations of the inlet water and oil flow disturbances. The system can be brought back to the desired set point very fast. However, the optimal split ratio may not be the same for all flow conditions. (b) The control valve dynamics are much less. As the life of the control valve is limited, creating a lot of control valve dynamics can wear out the control valve early.

A novel experimental facility is designed and constructed (Fig. 6) to study the LLCC performance for the control system, the controller characteristics and the system dynamics in terms of underflow watercut and control valve dynamics. Detailed experimental investigations are conducted to evaluate the system sensitivity and dynamic behavior of the proposed control strategy. The results (Figs. 7 and 8) demonstrate that the developed control system is capable of controlling the underflow watercut over a range of flow conditions (inlet water concentrations ranging from 40% to 95%) namely, stratified flow, dispersion of oil in water with a water layer at the bottom, double dispersion of oil in water and dispersion of water in oil. The time responses of the underflow watercut and the control valve show that the system can be restored to the set point very fast (Fig. 9). It may also be noted that, as the

Fig. 5 - LLCC© Control System Simulator

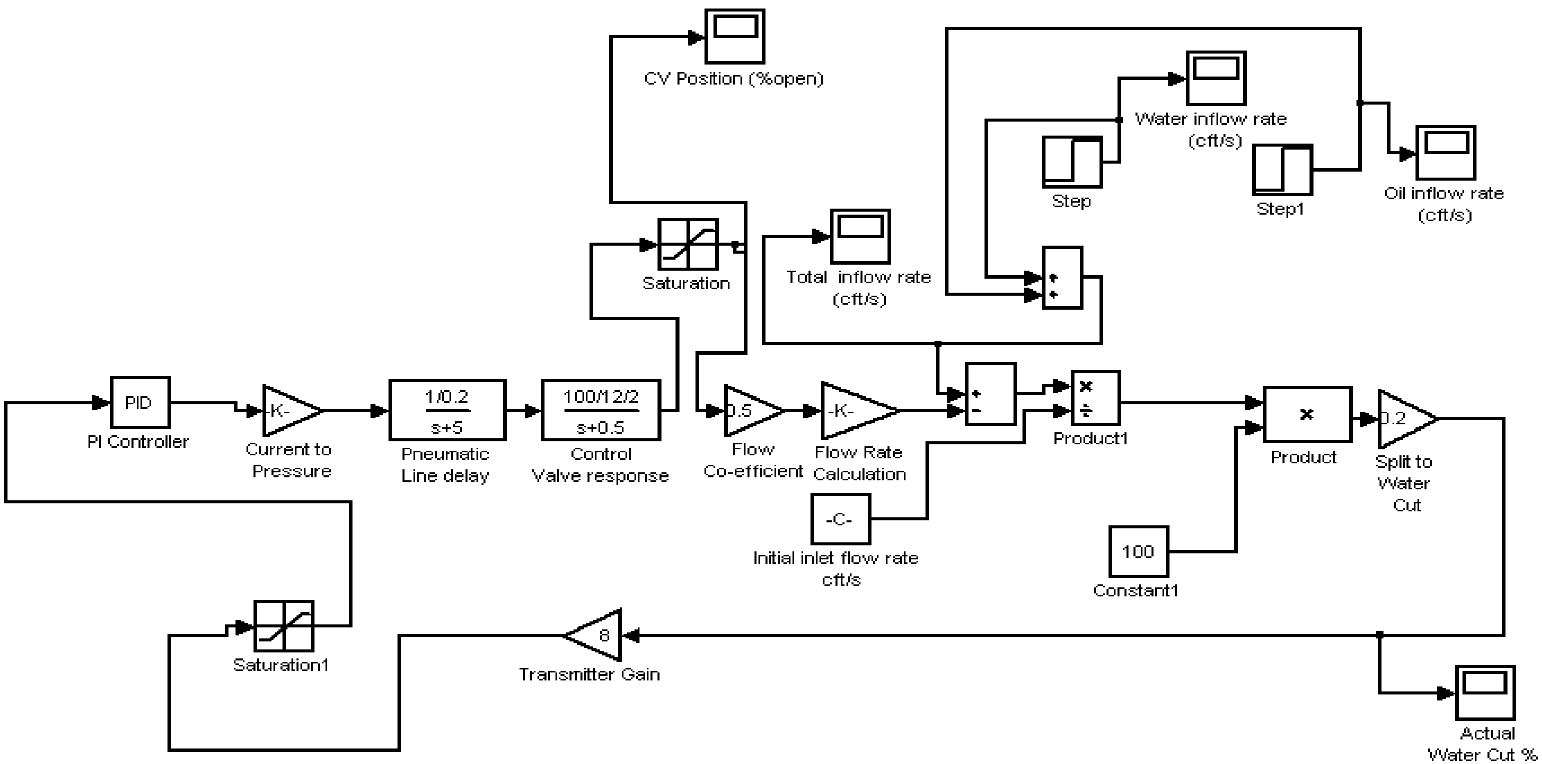
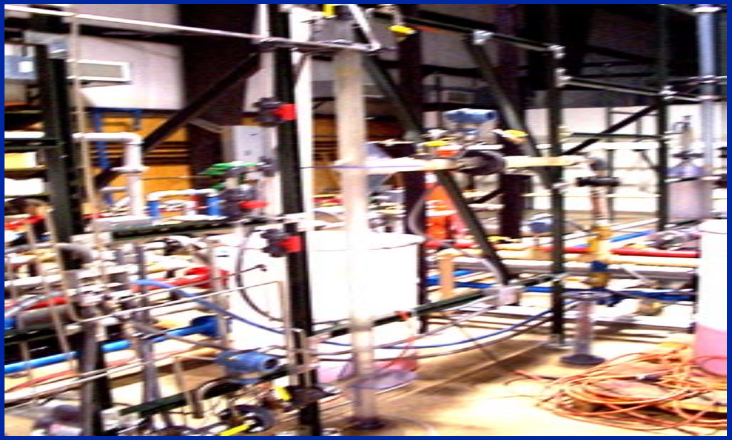


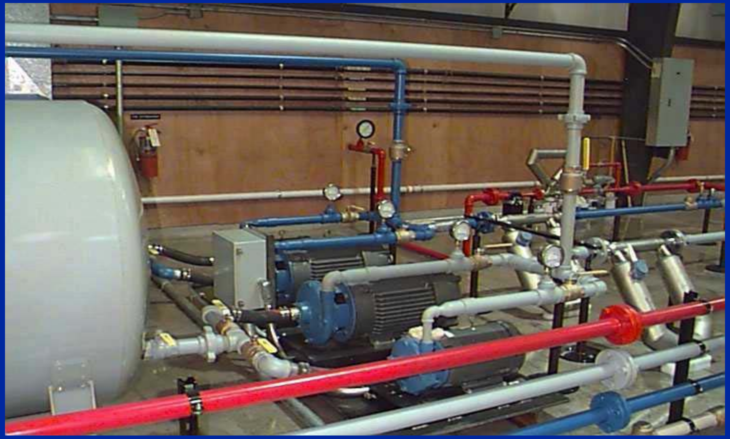
Fig. 6 - LLCC© Experimental Facility

Experimental Facility

LLCC Test Section



Metering Section



LabView's Front Panel

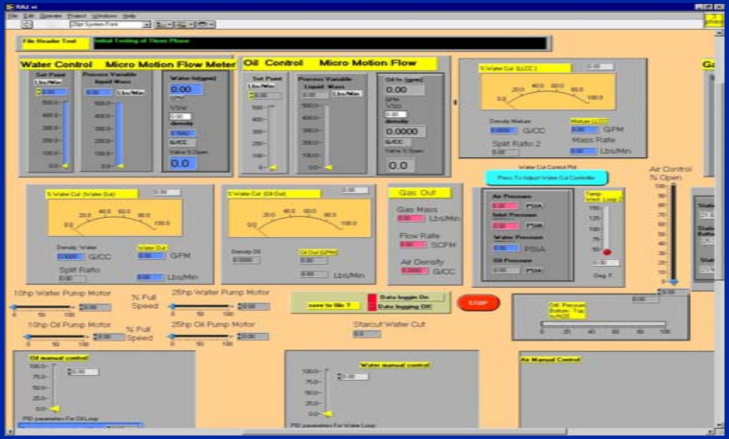


Fig. 7 - Water Continuous Flow

Effect of Inlet Water Concentration

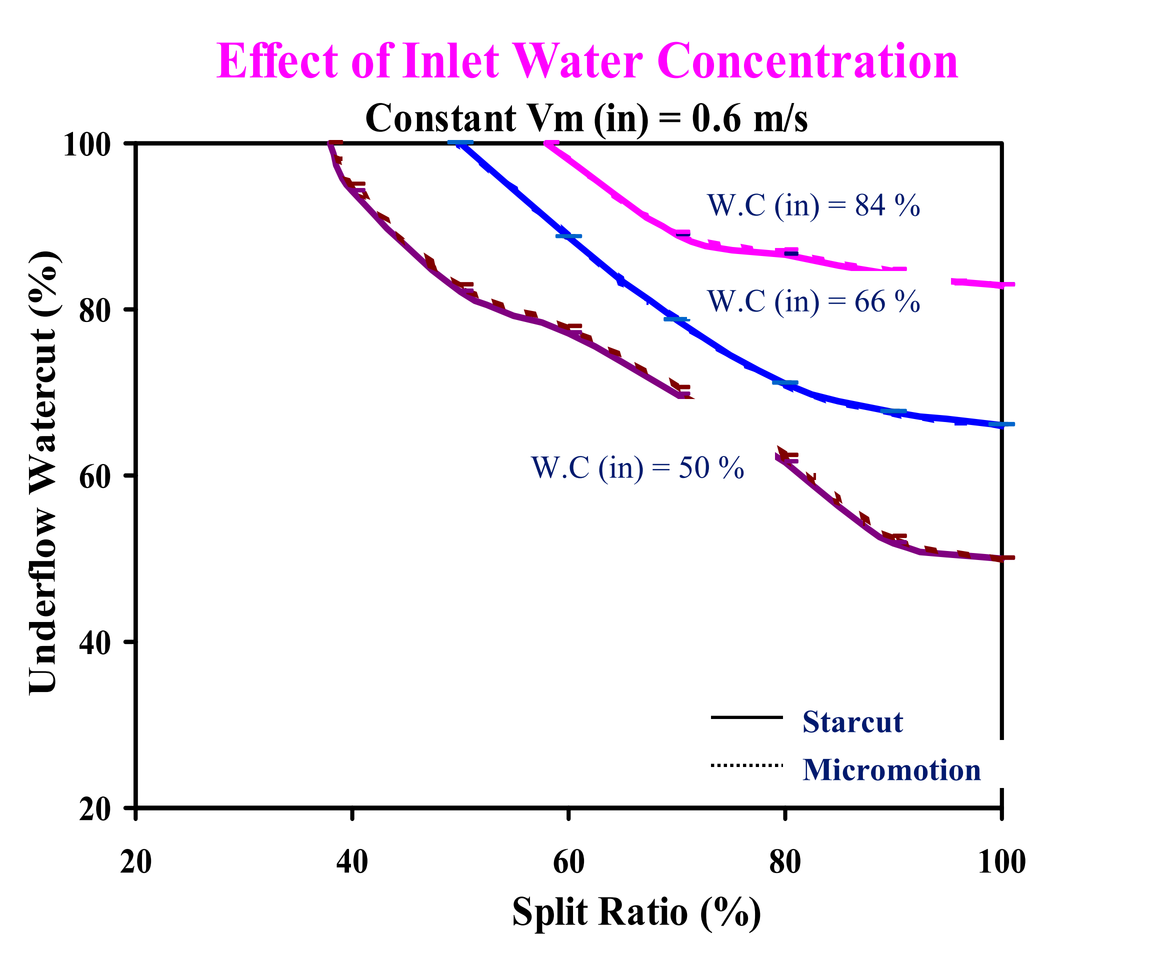


Fig. 8 - Optimal Split Ratio Phenomenon

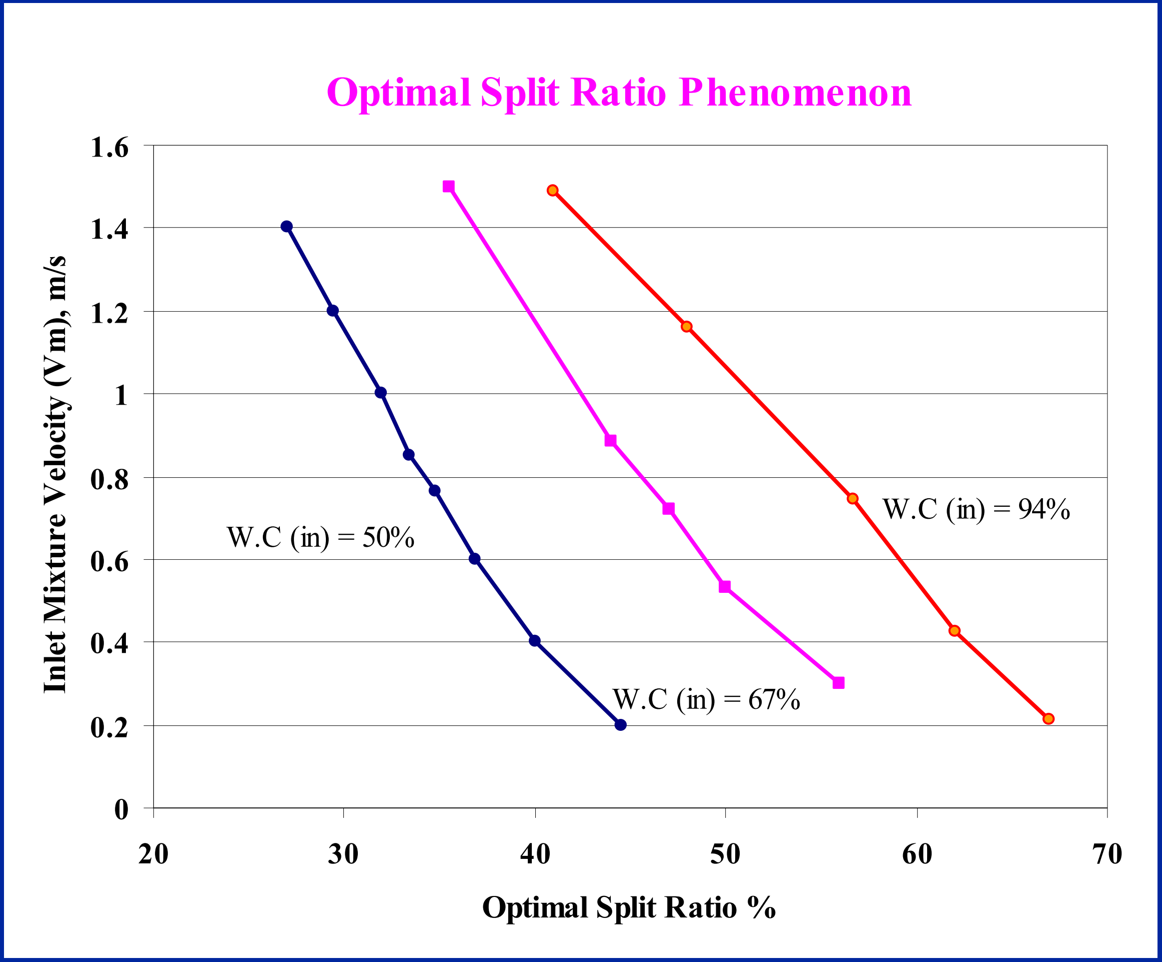
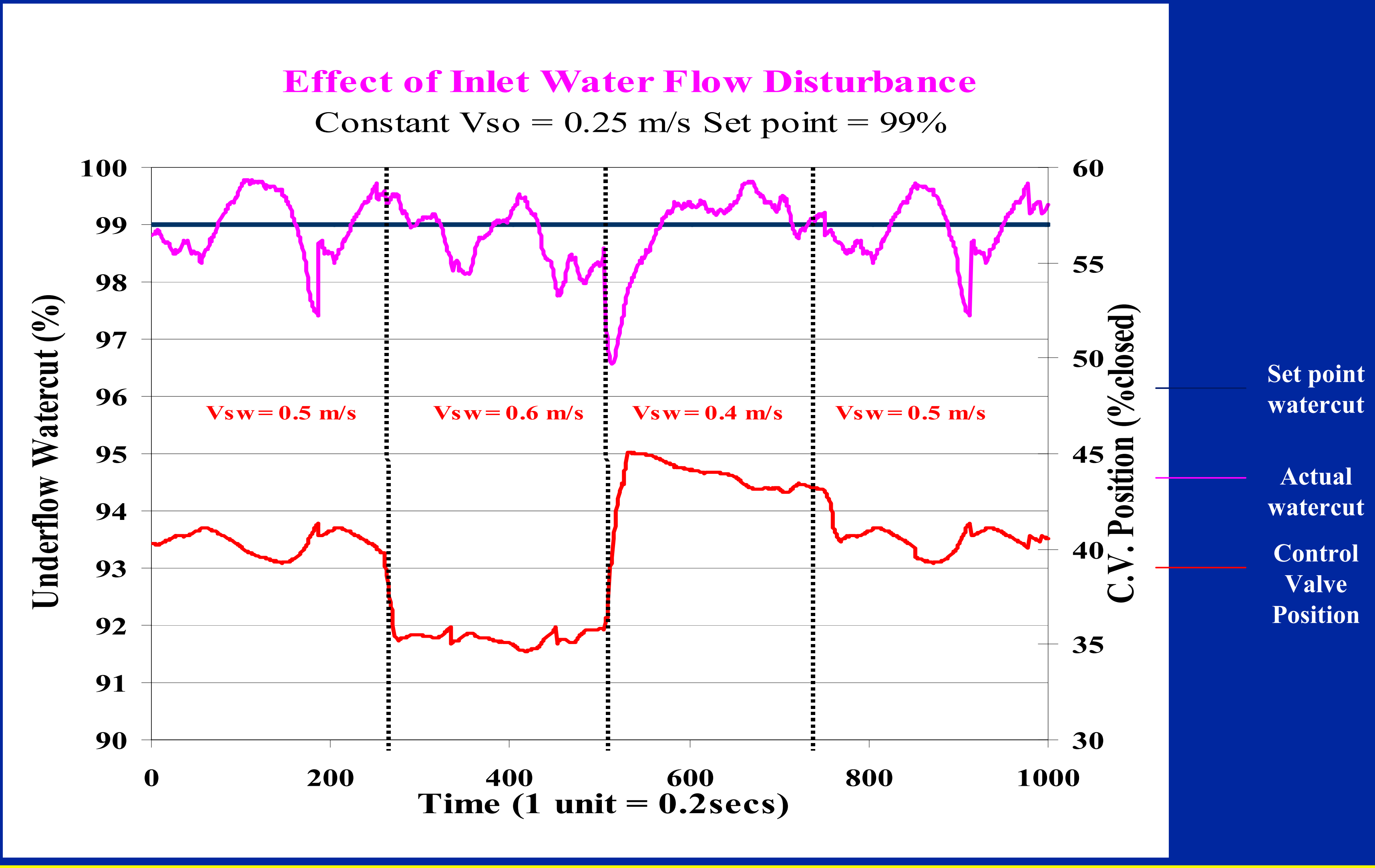


Fig. 9 - LLCC With Control System

Effect of Inlet Water Flow Disturbance



disturbance increases, the dynamics of the system will also increase. Detailed results of this study are documented in Mathiravedu (2001) and Mathiravedu et al. (2002).

B. Three-Phase GLCC© Separator

The objective of this project is to investigate the feasibility of GLLCC© as a bulk separator. Is it possible to utilize the GLLCC© for bulk separation of the oil-water liquid phase for free water knock out? If proved successful, this will significantly simplify the separation facilities downstream.

GLCC© Configurations: Two three-phase flow separation configurations are studied. The first one is a single-stage GLLCC© (Fig. 1) where the gas is removed from the top, the oil from the middle/center of the GLLCC©, and the water tangentially from the bottom of the GLLCC©. The second configuration is a two-stage system (Fig. 2), whereby the gas is separated from the liquid phase in the first GLCC© stage, and the oil is separated from water in the second LLCC© stage.

The hydrodynamics of multiphase flow in Liquid-Liquid Cylindrical Cyclone (LLCC) and Gas-Liquid-Liquid Cylindrical Cyclone (Figs. 10, 11) compact separators have been studied experimentally and theoretically for evaluation of their performance as free water knockout devices. In both GLLCC and the LLCC configurations, no complete oil-water separation occurs. Rather, both separators perform as free water knockouts, delivering a clean water stream and an oil rich stream.

A new state-of-the-art, two-inch, three-phase, fully instrumented flow loop has been designed and constructed. Experimental data on oil-water separation efficiency in the LLCC and the GLLCC have been acquired. A total of 260 runs have been conducted for the LLCC for water-dominated flow conditions. Four different flow patterns in the inlet have been identified, namely, Stratified flow, Oil-in-Water Dispersion – Water Layer flow, Double Oil-in-Water Dispersion flow and Oil-in-Water Dispersion flow (Fig. 12). The flow pattern prediction map for LLCC is shown in Fig. 13. For all runs, an optimal split ratio exists, where the flow rate in the water stream is maximum with 100% water cut. The value of the optimal (maximum) split ratio depends upon the existing flow pattern. For the Stratified and Oil-in-Water Dispersion - Water Layer flow patterns, this maximum split ratio is about 60%. For the Double Oil-in-Water Dispersion and Oil-in-Water Dispersion flow patterns, the

Fig. 10 - Single-Stage GLLCC© in Operation

Fig. 11 - Oil-Water Interface

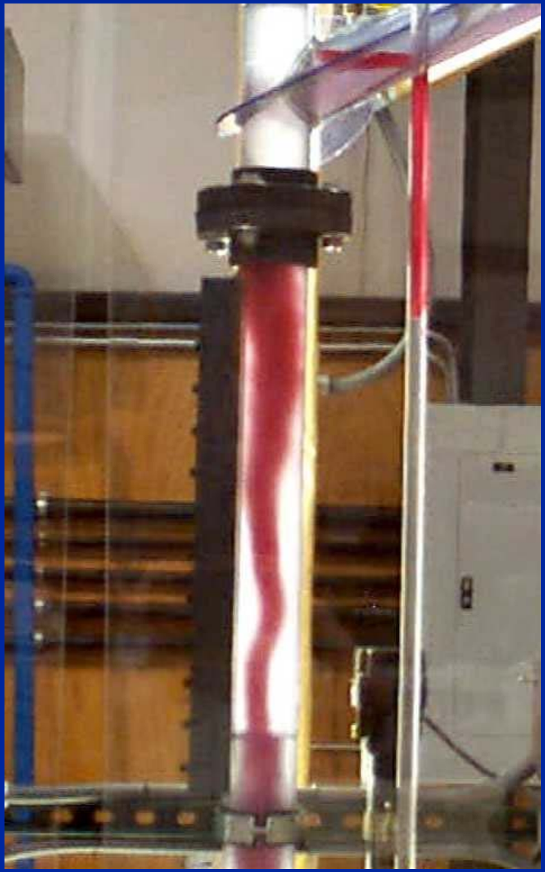
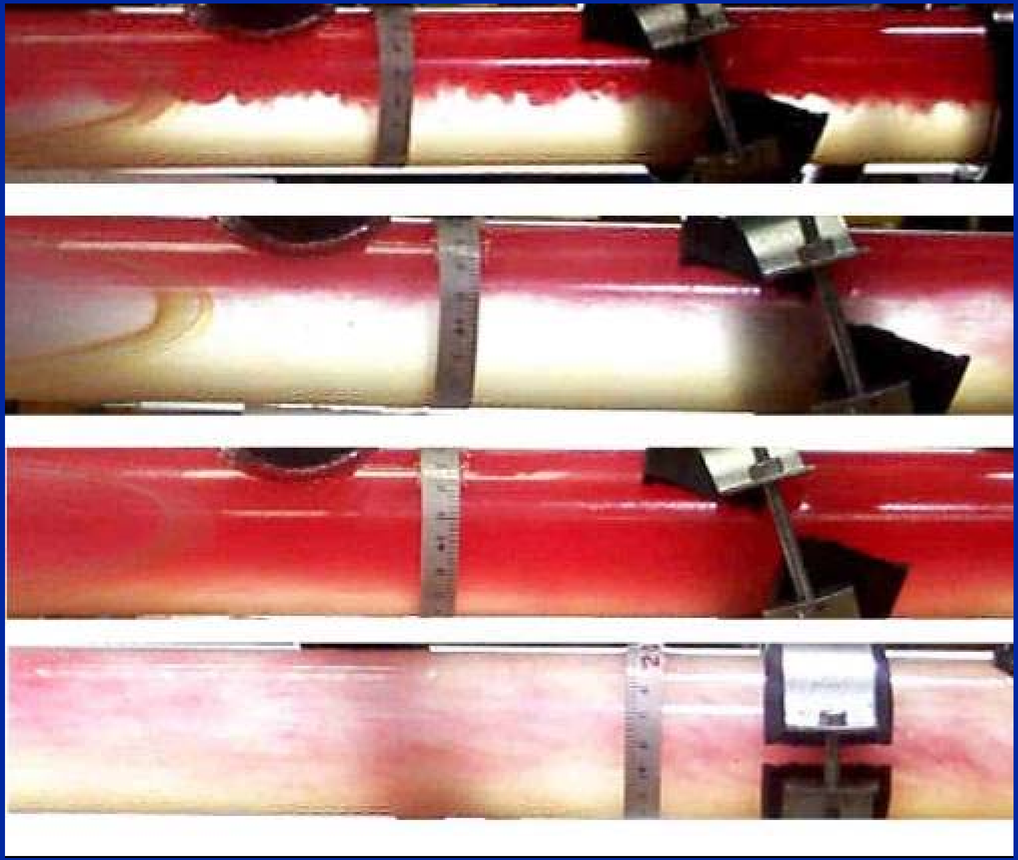


Fig. 12 – Observed LLCC© inlet Flow Pattern



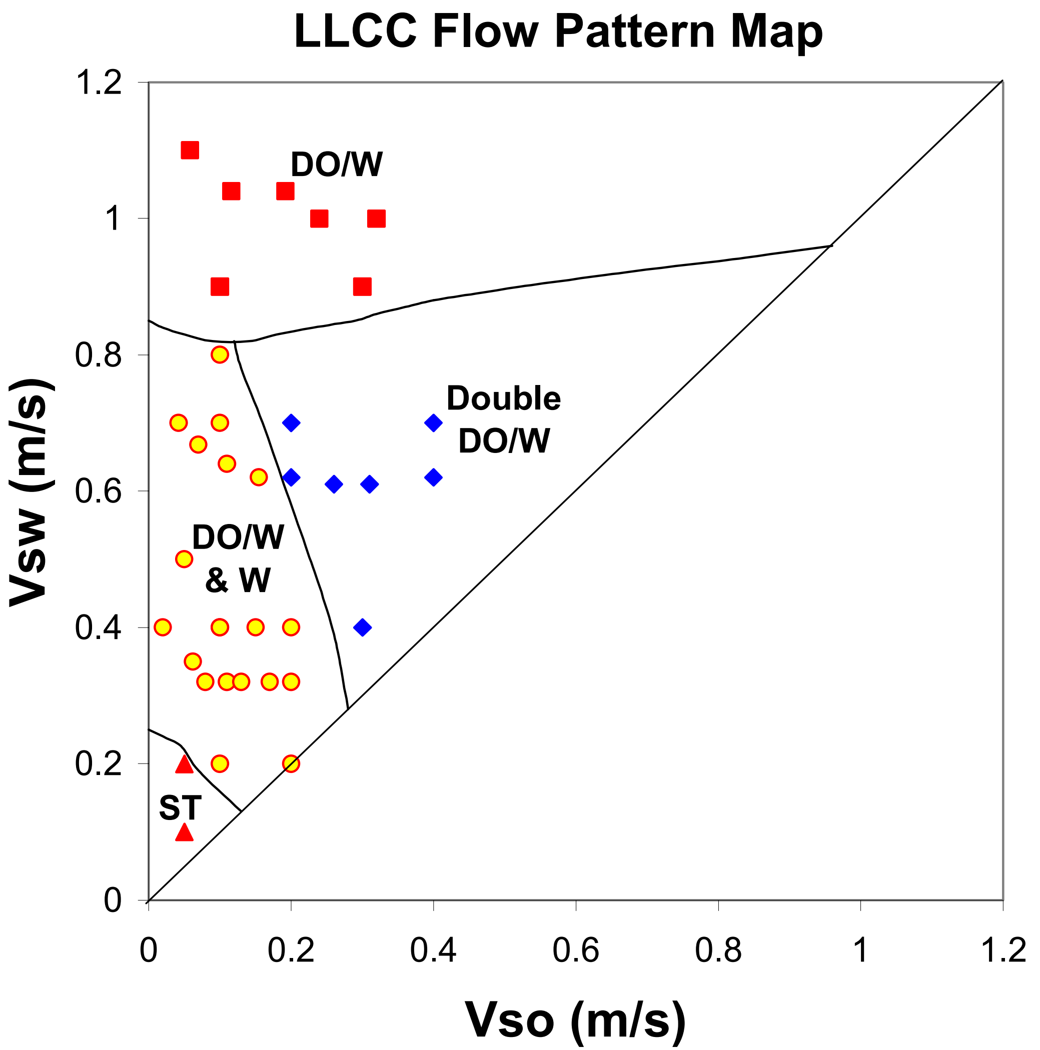
Stratified (ST)

Dispersion – Water Layer (DO/W & W)

Double Dispersion (D DO/W)

Dispersion (DO/W)

Fig. 13 – LLCC Flow Pattern Prediction Map



maximum split ratio ranges from 50% to 20%, decreasing with the increase of oil content in the inlet stream.

Experimental data on oil-water separation efficiency in the GLLCC have been acquired. A total of 220 experimental runs have been conducted, including the oil-water separation efficiency for different combinations of oil and water superficial velocities, and varying the split ratio for each combination. The GLLCC separation efficiency data reveal that it performs, in addition to the separation of the gas phase, also as a free water knockout. This occurs only for very low oil concentrations at the inlet, below 10%. Also, lower separation efficiencies are observed, as compared to the LLCC configuration.

Novel mechanistic models have been developed for the prediction of the complex flow behavior and the separation efficiency in the LLCC and GLLCC. The models consist of several sub-models, including inlet analysis, nozzle analysis, droplet size distribution model, and separation model based on droplet trajectories in swirling flow.

Comparisons between the experimental data and the LLCC and GLLCC model predictions show excellent agreement (Figs. 14, 15). The models are capable of predicting both the trend of the experimental data as well as the absolute measured values. The developed models can be utilized for the design and performance analysis of the LLCC and GLLCC. The detailed results of this study are documented in Oropeza (2001).

C. Preliminary Foam Flow Testing in GLCC© Separator Technology

Scope: Utilization of a GLCC as a mechanical foam-breaker in upstream separation facilities

The presence of centrifugal forces to separate the gas from the liquid in a GLCC compact separator enables the possibility of using it as a foam-breaker during the production process. Some preliminary studies have been conducted (Bikerman (1953)) that show that the shear stress due to the high centrifugal forces could lead to a distortion of the foam frames and then increase the liquid drainage rate. The preliminary TUSTP tests (Movafaghian, et al. (2000)) have encouraged us to continue in this direction.

The objective is to study the impact of GLCC on the foam flow at low pressures using the TUSTP facility. In order to achieve this, one must modify the current TUSTP outdoor design to handle foam fluid with the injection of an anionic surfactant solution in proper proportion in order to generate the three "phases" liquid/foam/gas.

Fig. 14. LLCC© Model-Data Comparison (DO/W & W)

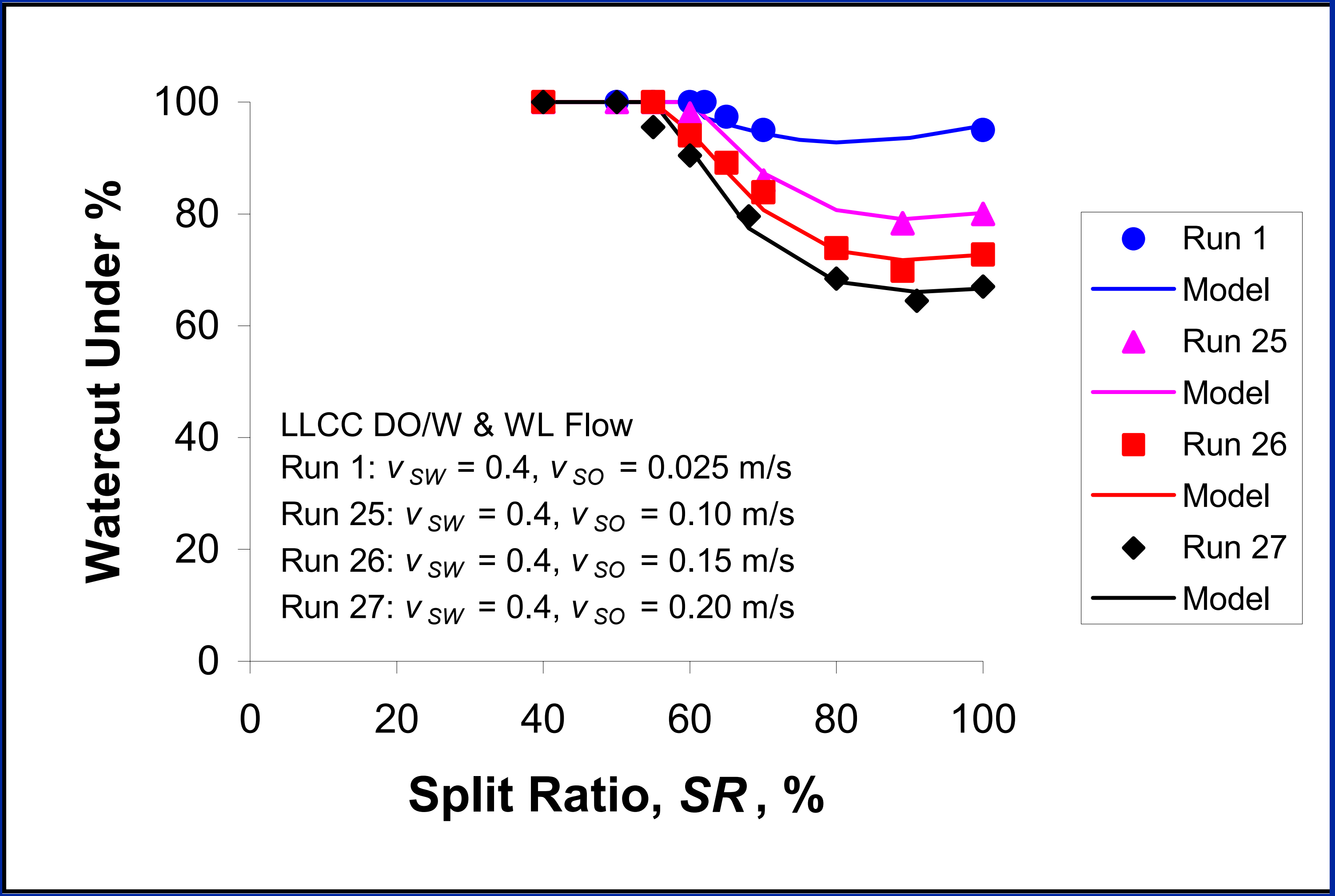
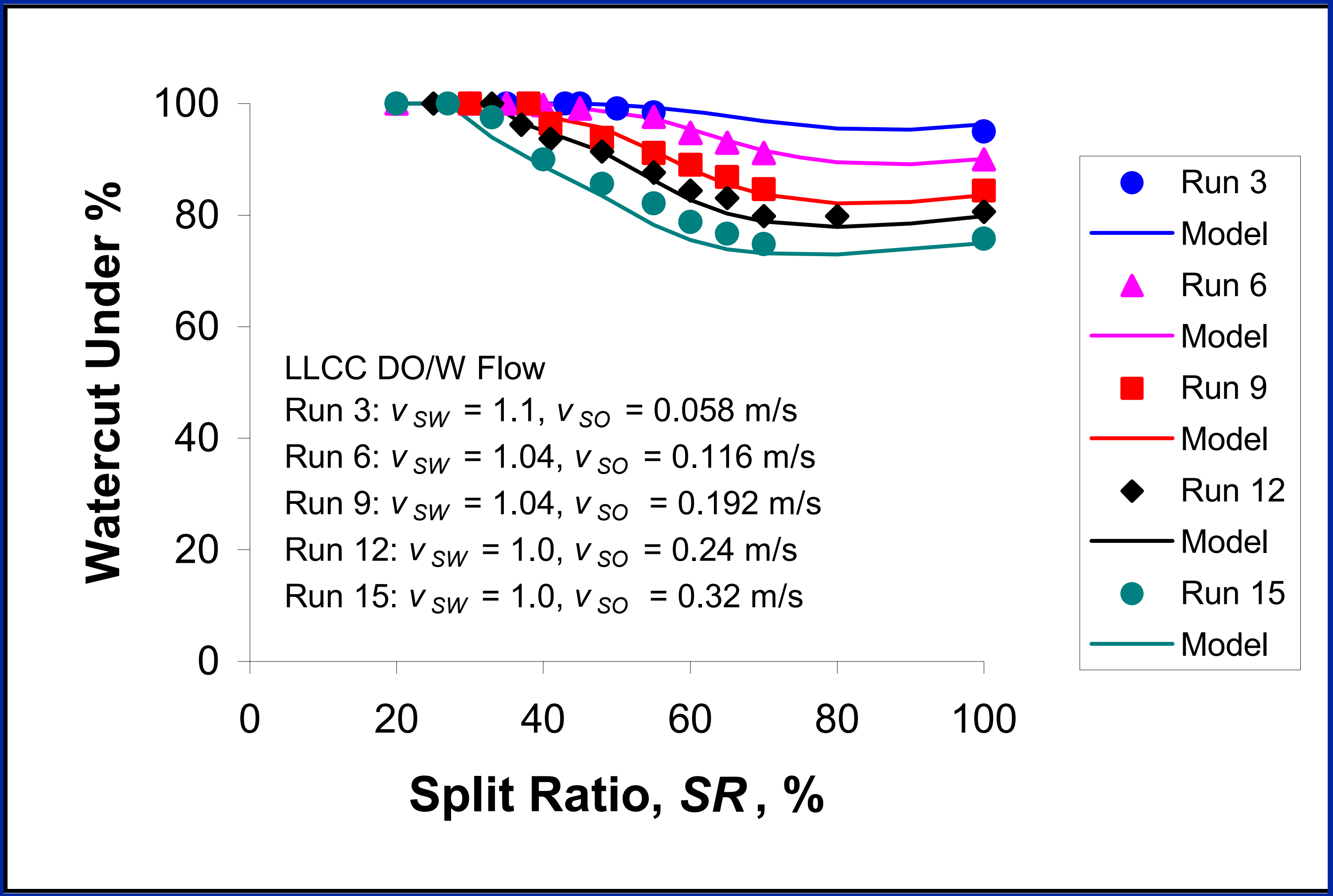


Fig. 15. LLCC© Model-Data Comparison (DO/W)



The preliminary experimental observations resulting from these design modifications have shown that for low gas velocities (10ft/s) in the GLCC, foam was carried-over into the gas leg. Whereas, for high gas velocities (>40 ft/s), the foam was broken and a swirling film of liquid was produced in the GLCC upper part. This swirling liquid film can then be removed using the Annular Film Extractor design for the wet gas application. That has already been confirmed by the first experiments. We are then able to reach for some specific conditions, which will enable us to obtain clean gas.

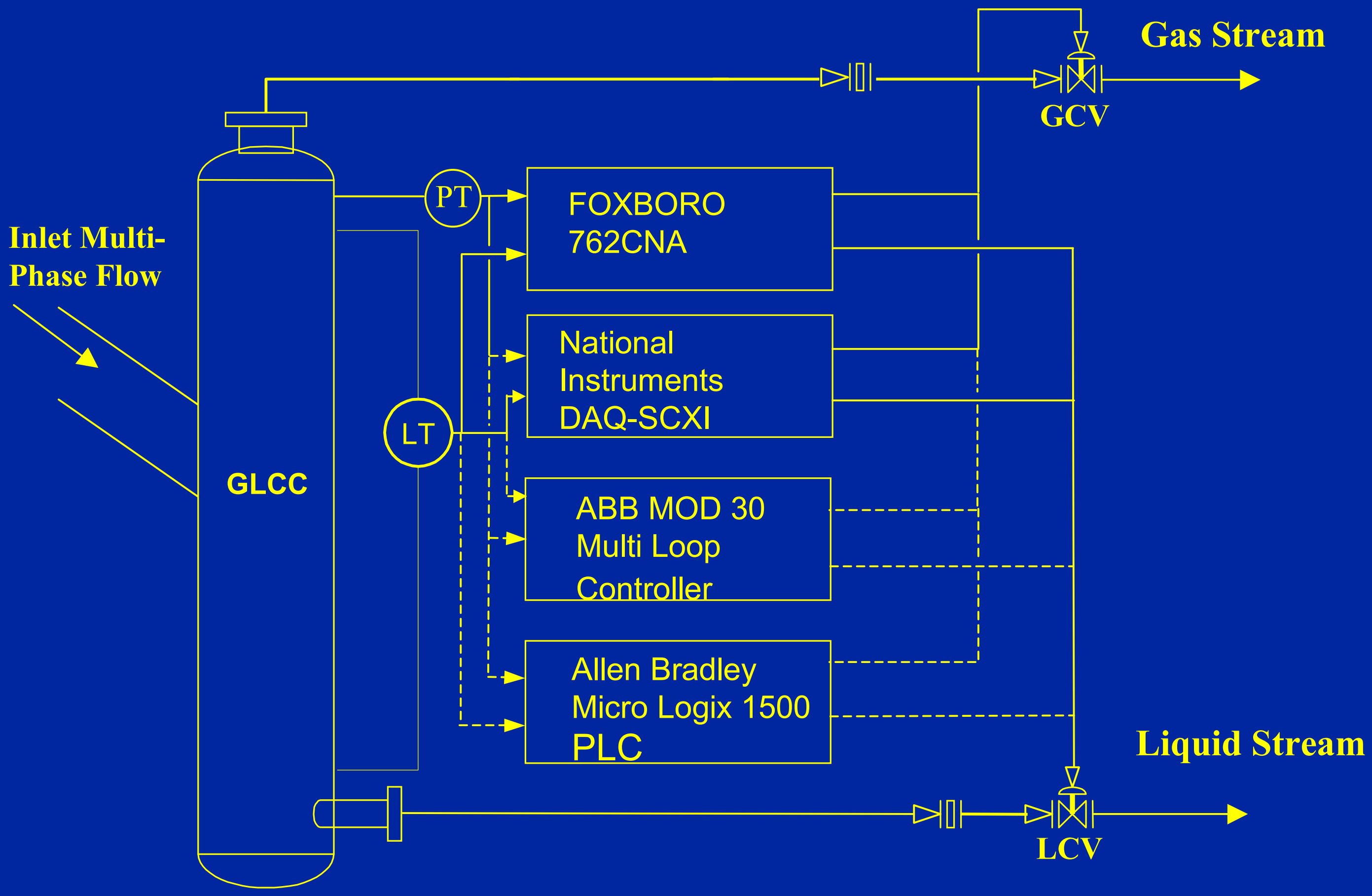
Following these qualitative results, one has to orient the future plans by characterizing the notion of efficiency in matter of foam breaking. Some inner parameters like the coalescence time and the liquid drainage rate will aid in better understanding of GLCC impact on foam breaking. Also the chemical action of a de-foamer at the GLCC inlet has to be tested. The next tests will consider the use of high viscosity fluids at high-pressure conditions.

D. Implementation of GLCC Adaptive Control Strategies using Hardware Controllers

The main objective is to investigate the integrated control strategies by implementing hardware controllers and Programmable Logic Controller instead of software based controllers. Feedback control strategies for GLCC were studied and implemented by Wang (2000) using Labview as the data acquisition system and using software controllers. Hardware controllers are much more robust, autonomous and cost effective compared to Data Acquisition Systems. Three different hardware controllers were identified for meeting the objective, namely, Foxboro 762CNA, ABB MOD 30ML and Allen Bradley Micrologix 1500-PLC. The hardware controller schematic is shown in Fig. 16.

Foxboro 762CNA is a double loop controller with PID/EXACT (Expert Adaptive Controller Tuning) configurations while a MOD30ML controller is a four PID loop controller. PLC-1500 is a programmable logic controller of multi PID loop capability. Foxboro 762CNA controller has been implemented successfully to maintain liquid level and pressure inside the GLCC. The results have shown that liquid level can be maintained with very less dynamics in the liquid control valve, there by increasing the life of the control valve. EXACT control is a patented algorithm by Foxboro used for this purpose. This algorithm is a self tuning algorithm but which checks the process five times every second and

Fig. 16. Hardware Controller Schematic



24 hrs a day to determine the change in PID settings for change in the in flow conditions. Sudden change in the control valve position was observed during the self-tuning period of EXACT control. The fine-tuning of EXACT control parameters have not yet been investigated, however the liquid level has been maintained with the tolerable limits even during the self-tuning period.

Future work for this project, include the implementation of ABB MOD 30ML controller and investigation of control strategies using PLC.

E. GLCC Separators for Wet Gas Applications

Objectives: As more and more GLCCs are deployed in the field, the need for high GOR and wet gas applications becomes critical for oil and gas industry to handle high gas rates above the velocity for onset of annular/mist flow. The GLCC design is not optimized for these applications due to liquid carry-over in the form of droplets and annular liquid film. The objectives of this study are to design a novel GLCC capable of separating liquid from a wet gas stream; conduct experimental investigations to evaluate the GLCC performance improvement in terms of operational envelope for liquid carry-over; and, measure the liquid extraction from the gas stream.

The experimental results (Wang, et al., 2001) include the operational envelopes for liquid carry-over and measurement of liquid extraction by the annular film extractor (AFE). These results are used to quantify GLCC separation efficiency.

The lower pressure tests (Figs. 17 and 18) show that:

- The operational envelope for liquid carry-over is expanded in the high gas velocity region
- The liquid film extractor has 100% efficiency at low liquid rates (Vsl<0.5 ft/s)
- The liquid carry-over for a regular GLCC is in the range of 1%-3% of the inlet liquid at lower pressures.

The high-pressure tests (Figs. 17 and 18) show that:

- The onset of liquid carry-over occurs at the velocity ratio of 1.3 for all the test pressures.

Fig. 17 - High Pressure Results: Regular GLCC Efficiency

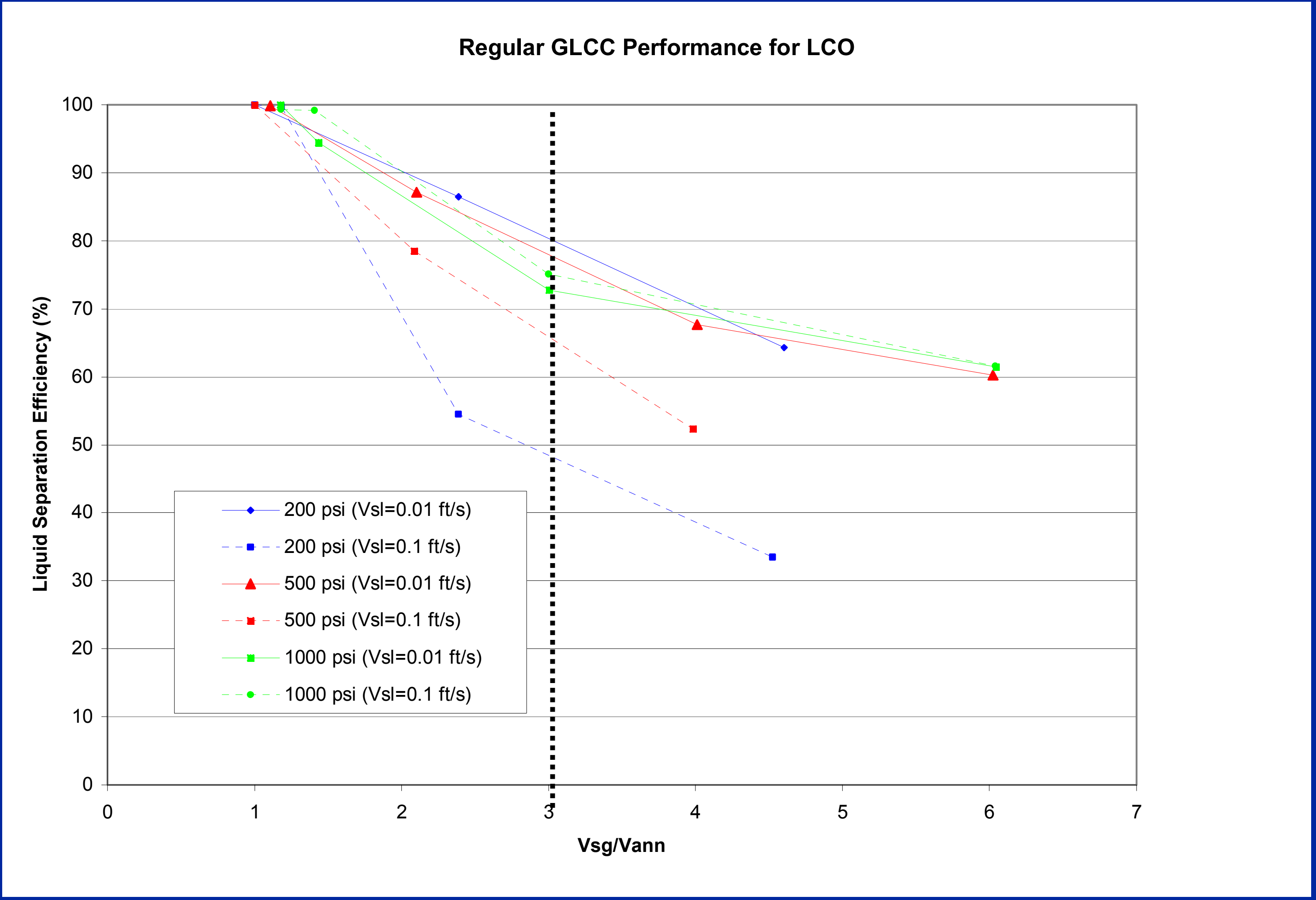
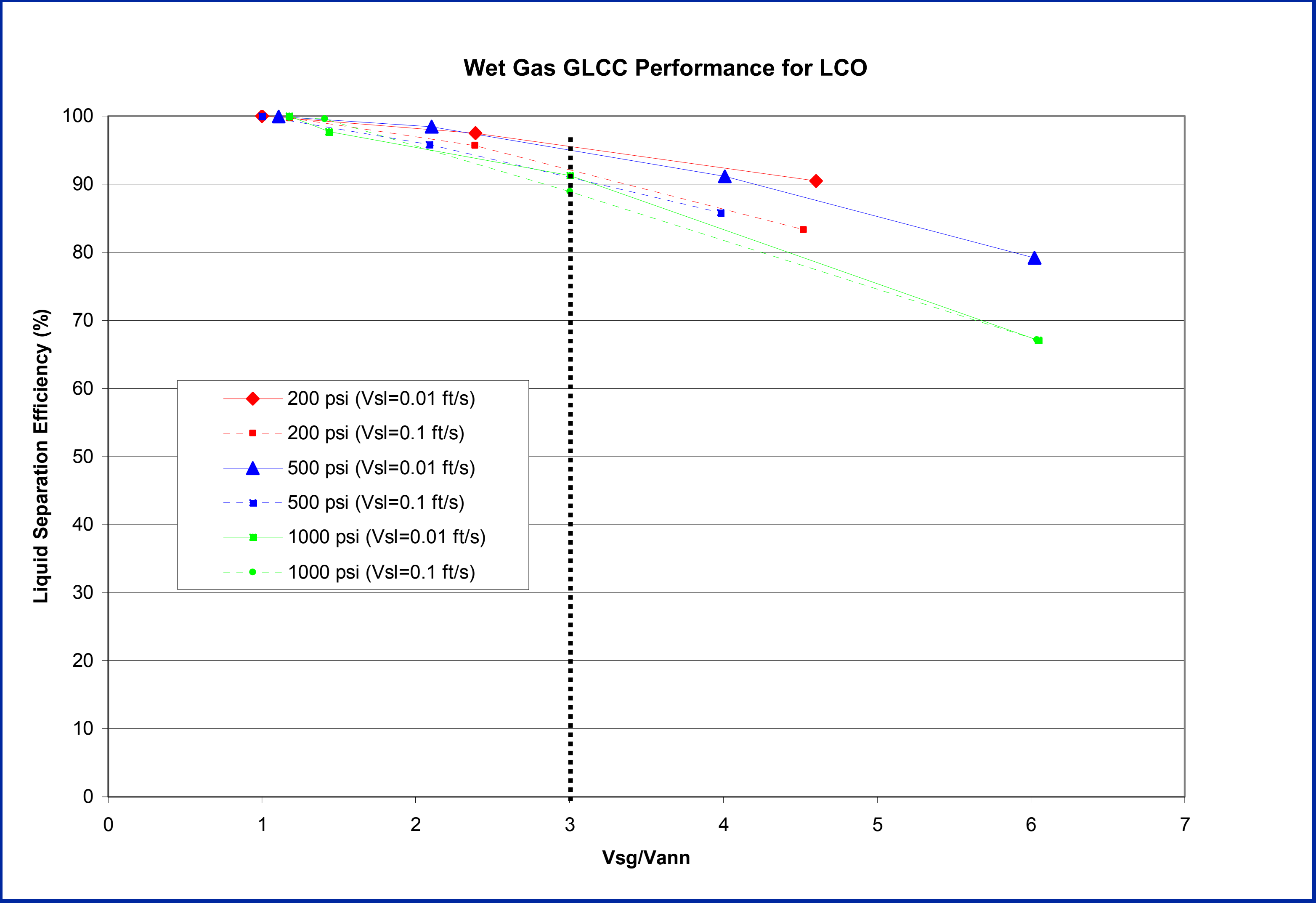


Fig. 18 - Wet Gas GLCC Efficiency - Single AFE



- The wet gas GLCC has very high liquid separation efficiency (>90%) compared to the original GLCC for Vsg/Vann<3.
- The separation efficiency increases about 5% by adding the second AFE.

Design guidelines for wet gas GLCC are developed to enable the commercial fabrication of the GLCC. These design guidelines are shown in Figs. 19 and 20 and will be expanded in specific design criteria for industrial applications and are being incorporated into the mechanistic model by TUSTP.

F. Mechanistic Model for Dispersed Two-Phase Swirling Flow

A fundamental understanding of the hydrodynamics of the flow and of the physical phenomena associated with the separation processes in gravity based separators as well as centrifugal separators, such as gas-liquid cylindrical cyclones (GLCC) and hydrocyclones, is a key for their design and operation with a high degree of reliability. The difficulty in developing accurate performance predictions of these separators is largely due to the complexity of the flow behavior of the swirling two-phase flow, taking place in the separators.

In this investigation (Gomez, 2001), a novel mechanistic model is developed to characterize two-phase swirling flow in a Gas-Liquid Cylindrical Cyclone (GLCC) separator. This model is capable of determining the dispersed phase distribution in a swirling, continuous phase, applicable for both heavier swirling medium, namely liquid phase, as well as lighter swirling medium, namely, gas phase. An Eulerian-Lagrangian approach is adopted to characterize the diffusion of the dispersed phase, droplets and bubbles. Experimental data were acquired for air-water flow and air high viscosity oil. The data include the velocity field (tangential, axial and turbulent intensity), and measurements of the volume of the gas phase separated in the swirling flow.

The distribution of the phases is defined in terms of their phase dynamics quantified by their velocity field in radial and axial directions. The velocity field measurements were compared with CFD simulation showing very good agreement. A semi-empirical correlation for the prediction of the axial and tangential velocity distributions was developed, based on the swirl intensity concept. The dispersed phase particle (droplets or bubbles) velocities are

Fig. 19 - Design Guidelines: Wet Gas GLCC Dimensions

- **GLCC diameter**
  - Vsg/Vann = 2-3 for efficiency above 90%
  - Vsl<0.5 ft/s
- **Inlet dimensions**
  - Diameter: <=Dglcc
  - Inclination angle: -20 to –30 degree
  - Length: 5-10 Dglcc
  - Nozzle: 20-25% of A_{GLCC}
- **GLCC height**
  - Upper section (above inlet): depends on AFE
  - Lower section (below inlet): depends on retention time for GCU

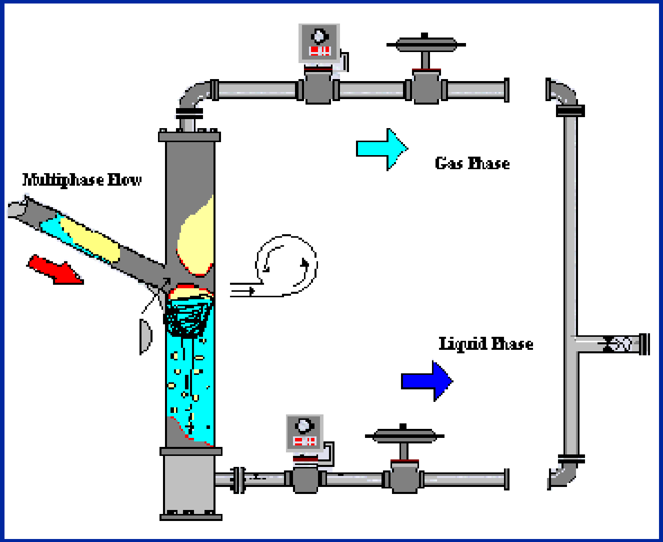


Fig. 20 - Design Guidelines: AFE Dimensions

- Annular Liquid film extractor dimensions
  - Location: based on liquid droplet trajectory (d_{100})
  - Annulus: corresponding to free falling film
  - Spacing: liquid film bridging (1/3-1/4 of Dglcc)
  - Liquid collection section:
    liquid return pipe dimension
  - Liquid return pipe: stratified flow

obtained from a Lagrangian approach. The dispersed and the continuous phase velocities were utilized in the Eulerian diffusion equation to predict the void fraction distribution in the swirling flow. The resulted separated gas phase was computed and compared with the experimental data, showing good agreement. The developed model can be used for the design of gas-liquid or liquid-liquid cyclonic separators.

8. Conclusions

The GLCC for the high pressure, real crude experimental investigation has been tested at Colorado Engineering Experiment Station Inc. (CEESI), so as to withstand pressures as high as 1500 psi. This device is equipped with several temperature and pressure transducers to enable evaluation of the hydrodynamic flow phenomena. Detailed testing of the GLCC separators upto 500 psi have been completed and currently testing at 1000 psi is in progress.

The feasibility of using Liquid-Liquid Cylindrical Cyclone (LLCC) as a free water knockout device for bulk separation of oil-water mixtures is proved. A unique "direct" control strategy is developed and implemented, capable of obtaining clear water in the underflow line and maintaining maximum underflow rate. Dedicated control system simulations are conducted using Matlab/Simulink software to simulate the real system dynamic behavior. Detailed experimental investigations demonstrate that the proposed control system is capable of controlling the underflow watercut around its set point by obtaining maximum free-water knockout for a wide range of flow conditions (inlet water concentration of > 40% and an inlet mixture velocity of < 1.5 m/s).

Similar to the LLCC separator, in GLLCC also, no complete oil-water separation occurs. Rather, it performs as a free water knockout device, delivering a clean water stream and an oil rich stream. Novel mechanistic models have been developed for the prediction of the complex flow behavior and the separation efficiency in the LLCC and GLLCC. The models consist of several sub-models, including inlet analysis, nozzle analysis, droplet size distribution model, and separation model based on droplet trajectories in swirling flow. Comparisons between the experimental data and the LLCC and GLLCC model predictions show excellent agreement. The developed models can be utilized for the design and performance analysis of the LLCC and GLLCC.

The preliminary experimental observations of GLCC foam studies have shown that for low gas velocities (<10ft/s) in the GLCC, foam was carried-over into the gas leg. Whereas, for high gas velocities (>40 ft/s), the foam was broken and a swirling film of liquid was produced in the GLCC upper part. This swirling liquid film can then be removed using the Annular Film Extractor.

The three different hardware controllers have been identified for GLCC control, namely, Foxboro 762CNA, ABB MOD 30ML and Allen Bradley Micrologix 1500-PLC. Foxboro 762CNA controller has been implemented using EXACT algorithm successfully to maintain liquid level and pressure inside the GLCC. The results have shown that liquid level can be maintained with very less dynamics in the liquid control valve, there by increasing the life of the control valve.

A modified GLCC for wet gas applications, which can withstand pressures as high as 1500 psi, has been developed and tested. The low pressure (< 30psia) experimental results show that the operational envelope for liquid carry-over expands in the high gas velocity region (up to 60 ft/s) and the liquid film extractor has 100% efficiency at low liquid rates (Vsl<0.5 ft/s). The liquid carry-over for a regular GLCC is in the range of 1-3% of the inlet liquid. The high-pressure (upto 1000 psi) tests show that the onset of liquid carry-over occurs at the velocity ratio of 1.3. The wet gas GLCC has very high liquid separation efficiency (>90%) compared to the original GLCC for Vsg/Vann<3. The separation efficiency increases about 5% by adding the second AFE. Design guidelines for wet gas GLCC are developed to enable the commercial fabrication of the GLCC.

A novel mechanistic model is developed to characterize two-phase swirling flow in a Gas-Liquid Cylindrical Cyclone (GLCC) separator. This model is capable of determining the dispersed phase distribution in a swirling, continuous phase, applicable for both heavier swirling medium, namely liquid phase, as well as lighter swirling medium, namely, gas phase.

9. References

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