44TH TURBOMACHINERY & 31ST PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 14 – 17 2015
GEORGE R. BROWN CONVENTION CENTER

SIMULATOR TO TRAIN OPERATORS ON NEWLY INSTALLED PUMPING EQUIPMENT

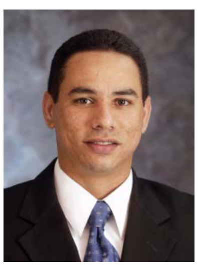
Jeffrey A. Bennett
Research Engineer
Southwest Research Institute
San Antonio, TX, USA

Augusto Garcia-Hernandez
Group Leader R&D
Southwest Research Institute
San Antonio, TX, USA

Moisés León Dorantes
Superintendent
PEMEX Exploracion y Produccion
Ciudad del Carmen, Mexico

Marco Antonio Muñoz Prior
Mechanical Engineer Electrician
PEMEX Exploracion y Produccion
Ciudad del Carmen, Mexico

Jeffrey A. Bennett is a research engineer in the Pipeline Simulation group at Southwest Research Institute. He has two years' experience primarily focused on simulating transient events of liquid and gas flow networks, which also includes training simulator development and pump performance measurements. Mr. Bennett holds a joint MSc in Turbomachinery Aeromechanics from the Royal Institute of Technology and the Université de Liège. He also holds a BS in mechanical engineering from Virginia Tech.



Augusto Garcia-Hernandez leads the Pipeline Simulation group at Southwest Research Institute. He has 12 years' experience in flow hydraulics including upstream and downstream systems. Mr. Garcia-Hernandez's principal interests are in oil and gas industry related projects pertaining to pipeline flow, flow assurance, facility field evaluations, instrumentation and measurements, data analysis, centrifugal compressors, pumping systems and gas turbines, and mechanical system design. Mr. Garcia-Hernandez holds an MS in Petroleum Engineering from the University of Tulsa and a BS in Mechanical Engineering from the Universidad Central de Venezuela.

Mr. Leon Dorantes graduated as a Mechanical Engineer from the Instituto Politecnico Nacional. He joined Petroleos Mexicanos in 1982, having occupied several positions in the area of Construction and Mechanical Maintenance. At the moment, he is a Superintendent in the Coordination of Transport and Oil Distribution, where he manages the development of strategic projects and infrastructure optimization for the export and transport of crude oil in the northeast marine regions of the Gulf of Mexico.

Mr. Muñoz Prior is a Mechanical Engineer Electrician in the area of Design and Optimization of Crude Oil Infrastructure and manages technical support in applications of pumps, gas turbines, and FSO. In 2000, he joined Petroleos Mexicanos, having occupied positions as Field Engineer in the Operation and Maintenance area. He graduated from the Veracruzana University and mastered in Sciences in Mechanical Engineering Option Energy by the Instituto Politecnico Nacional.

ABSTRACT

New screw pumps were installed at an existing offshore oil platform that originally housed only centrifugal pumps, thus creating the need to safely train operators on the new equipment. Therefore, a training simulator was developed with control screens identical to those provided by the manufacturer providing a safe and low-cost way for training operators. The simulator was designed with the ability to control the entire pumping system, so that any operating scenario could be created in addition to the preloaded cases. Screens were added to provide insight into the operating behavior of the system and to allow the chance to try alternative operating procedures. The simulator developed provides a means for the platform operators to comply with API 1120, ASME B31Q, RP 1161 and RP T-2.

This paper will focus on describing the need for creating a training simulator, the approach to creating the simulator, will present some example screenshots, and present the system insight that is gained by allowing operators to learn about the system hydraulics.

NOMENCLATURE

American Petroleum Institute	API
Gas Turbine	GT
Human Machine Interface	HMI

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

Petróleos Mexicanos	PEMEX
Process Flow Diagram	PFD
Piping and Instrumentation Diagram	P&ID
Terminal Maritima Dos Bocas	TMDB

INTRODUCTION AND BACKGROUND

The Rebombeo platform is an offshore booster pump facility that receives crude oil from several platforms located 80 km upstream and is responsible for transporting the oil 80 km downstream to the nearest processing facility located onshore. A view of the platform is shown in Figure 1, and a screenshot of the simulator showing the pipeline network is shown in Figure 3. Predicted changes in crude oil composition have led the platform operators to replace four of the ten centrifugal pumps with screw pumps in order to more efficiently transport the heavier oil. As screws pumps are positive displacement machines, they behave quite differently than their centrifugal counterparts. In order to continue smooth operation of the platform it is necessary to train the operators on the new equipment while minimizing impact on the system that will continue to operate. It was, therefore, decided to create a training simulator to better prepare operators by providing an opportunity to learn about the screw pumps and challenges related to their operation as they interact with the centrifugal pumps that continue to operate [1]. It is anticipated that training with the simulator will reduce the risk of mistakes while operating the pumps. The operator needs were reviewed and it was determined that in order for the simulator to be successful it must be: 1) interactive, 2) emulate the screens of the manufacturer's control interface, and 3) realistically represent the system response. Additionally, it was determined that the simulator must be capable of simulating pump start-up and shutdown, the opening and closing of valves, the monitoring of alarms, and the monitoring of pipeline conditions for a range of operating conditions. To provide the most realistic system response the simulator must represent the new screw pumps, the existing centrifugal pumps, and the pipeline flow network. This paper will present the process for developing a simulator, provide examples of screens developed for the Rebombeo platform and discuss the applications and benefits of the simulator.

Figure 1. Rebombeo Platform

SIMULATOR DEVELOPMENT PROCESS

Simulators consist of two primary components, the computational model and the human machine interface. The computational model represents the pumps and major components of the Rebombeo platform along with the pipeline network starting from the upstream platforms and leading to the onshore receiving facility. The computational model is built and tuned such that it provides realistic steady state and transient predictions of the pumps and flow network for selected operating conditions. The human machine interface (HMI) is the portion of the simulator that users have access to, and is developed to look and feel like the manufacturer's control system. The HMI is developed in a separate software package and is linked to the computational model as shown in Figure 2. The combination of the HMI and computational model allows future operators to simulate a wide variety of prepared and user developed scenarios in order to learn how the system will react and to learn the proper control responses.

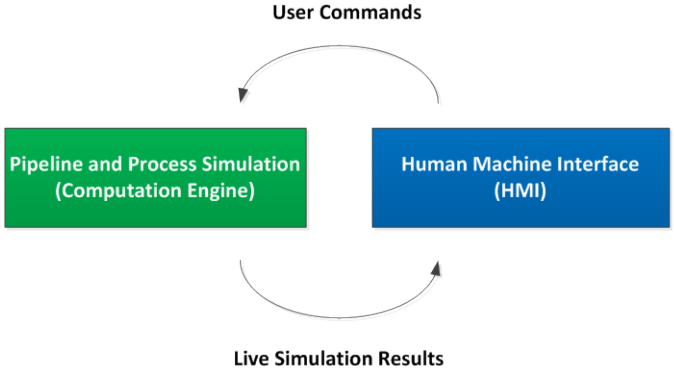


Figure 2. Simulator Software Interaction

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

Pipeline Model

The simulator development begins with the creation of the computational model. This is a very involved process that requires large amounts of relevant system data in order to create a computational model that adequately represents the system. Initially information such as process flow diagrams (PFDs) and piping and instrumentation diagrams (P&IDs) are reviewed to identify the major components including pumps, control valves, check valves, separators, headers, and primary piping. Detailed information for each of the major components is then reviewed and input into the computational model. After the model has been created it is compared against available field data for validation [2,3].

The system model includes the fluid sources originating at different production platforms, all piping between production platforms, the booster platform "Rebombeo," and the on-land processing storage receiving facility. A more detailed model of the booster platform was developed to determine the effect of the change in viscosity on the capacity of the system as well as to evaluate critical transient scenarios such as pipeline shutdown and cold start-up. This model includes the pipelines L1, L2, and L3 from the platform to TMDB. A schematic of the system-model is presented in Figure 3. In addition, all the major piping components within the suction and discharge manifold and headers of the platform have been incorporated as well as the ten existing centrifugal pumps and four projected screw pumps. Various emulsion viscosity models were reviewed to match the viscosity behavior of the crude oil transported, since an emulsion with up to 30% water-cut has been reported in various chemical analyses. The computational model was developed using an industry standard commercial software package. This software is able to accurately model steady state and rapid transient events. Moreover, this software has been validated against real data and it has been used to model very complex and large oil/gas systems. The computational model solves non-linear systems of differential equations at each time step using the method of characteristics. A transient analysis consists of a linearized solution of partial differential equations.

A hydraulic analysis was performed on the pipeline system and included physical processes and parameters such as heat transfer [4], friction losses, valve operation, elevation profiles, and pump curves characteristics. The field and theoretical pump performance data was used in the model to determine the transport capacity with the degraded and theoretical equipment. The analysis quantified various parameters such as pressure, velocity, fluid properties, and temperature along the pipeline for the different operating conditions. Several scenarios were evaluated to generate system curves and define the effect of transporting a heavier crude oil (16º API). In addition, the system was assessed with the operation of the existing equipment and the installation of four new screw pumps, considering the hydraulic degradation measured in the field.

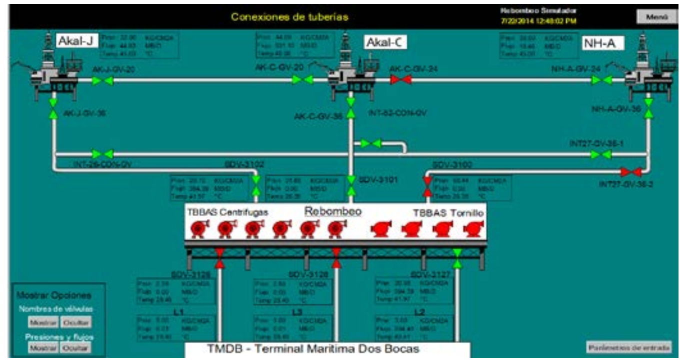


Figure 3. Schematic of the Crude Oil Pipeline System from the Production Platforms to TMDB (Simulator Screenshot)

To validate the pipeline model of the system, steady-state flow and pressure measurements collected at the platform, given a specified configuration, were compared to that same configuration replicated in the hydraulic simulation. For the validation to be complete, several different operating points were evaluated. A baseline operating condition was used to tune the pipeline model and account for losses, which are not accounted for directly in the model. The simulation was run at other operating points and compared to the collected data. This analysis provided quantitative results as to the predictive capability of the hydraulic model. The model validation includes the suction and discharge headers localized pressure losses, pump performance curves, and pipeline pressure drop (Line 2). The results of this validation indicate a relative difference of the pump model in the range of 0.4% to 1.2% , while the pipeline model presents relative difference of 1.12% when it is compared to data after tuning.

EMULSION VISCOSITY MODEL

The hydraulic behavior of the system is highly dependent on the viscosity of the fluid. Different rheological properties were found for the different crude oil mixtures transported by the system. Normally, a crude oil of approximately 19 - 21º API is transported by the system while its water-cuts change from 5% up to 30%. Thus, an emulsion of water-in-oil is present in the transport system. Different studies have indicated that the viscosity of the crude oil is affected considerably by the presence of water; even more, its rheological behavior could change, as well as its general properties. The pure crude oil is normally considered a Newtonian fluid based on its shear rate – shear stress relationship (linear) where the slope of that relationship is known as the viscosity of the fluid. While an emulsion could present a non-Newtonian behavior, an apparent viscosity value is used. The viscosity of water-in-oil emulsions tend to increase with the water-cut until a point known as the inversion point where a further increase of the water-cut

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

converts the mixture in an oil-in-water emulsion. Thus, the continuous phase goes from oil to water and the disperse phase inverses as well. The inversion point is highly dependent on the emulsifiers or stabilizing agents used to form the mixture, and for this case it is located at approximately 50-60% water-cut.

Oil-water mixtures flowing in a pipeline can develop different flow patterns depending on the velocity of the flow and the properties of the oil and the water. At low velocities gravitational forces and the density difference between the oil and the water can lead to a stratified flow regime. This type of flow regime is characterized by the segregation of the oil and the water, resulting in a layer of water flowing at the bottom of the pipe and a layer of oil flowing at the top of the pipe. However, most practical applications involve liquid velocities that are high enough to create mixing between the oil and the water, resulting in a dispersed flow where one of the phases is dispersed in the form of droplets into the other (continuous) phase. Three methods can be used for calculating the viscosity of liquid for oil/water mixtures. These are the phase fraction method, the inversion point method, and the relative viscosity correlation method. Various correlations were reviewed and compared against measured fluid properties. Figure 4 presents the comparison of some of the correlation models used.

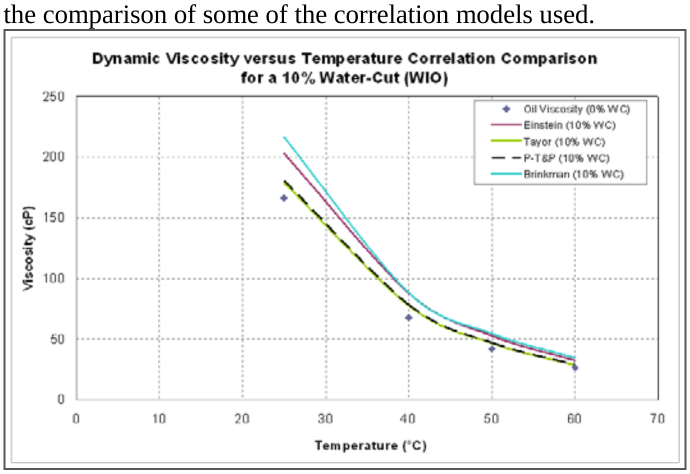


Figure 4. Predicted Mixture Viscosity for an Oil/Water Mixture with 10% Water [5-12]

Thus, after a detailed comparison it was found that the Phan-Thien & Pham (P-T&P) correlation and Taylor correlation yield very similar results. The Einstein and Brinkman correlation predict a higher viscosity than that predicted with the P-T&P and Taylor correlations. Thus, the P-T&P correlation was selected for this model as it is the most recent one of the four and because a good correlation was obtained between the model and the fluid data. An example of the viscosity model results is presented in Figure 5.

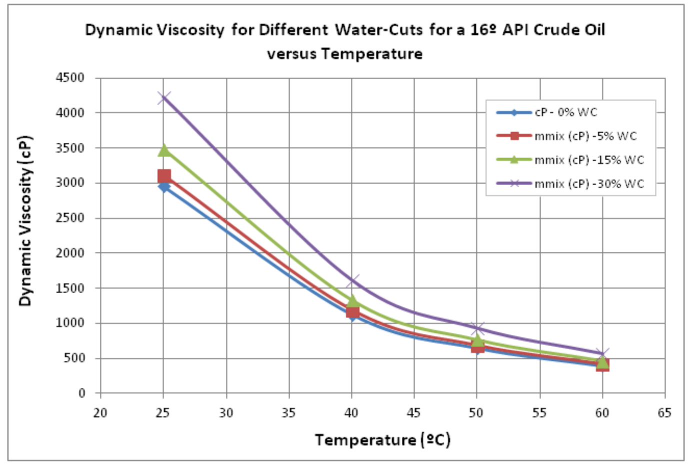


Figure 5. API Crude Oil Mixture Viscosity versus Temperature for the Different Water Cuts

The calculated rheological model for the crude oil emulsions were incorporated into the simulator and a fluid data base was created to facilitate its implementation since significant variations in the fluid properties such as API and water-cut will affect the hydrodynamics of the entire system including the pumping equipment. Various fluid properties screens were developed for the simulator to facilitate their application and for better visualization of the crude oil batches that move in the system. An example of a dynamic viscosity monitoring screen is presented in Figure 6.

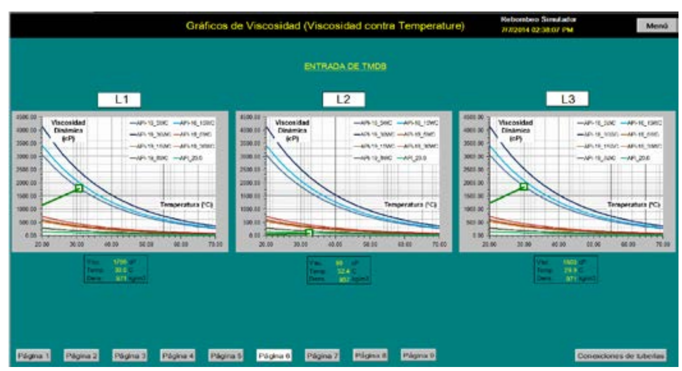


Figure 6. Simulator Screen with Crude Oil Dynamic Viscosity versus Temperature for the Different Water Cuts

PUMP FIELD PERFORMANCE

Field performance tests [13] were conducted to determine the existing status of the units and to obtain its performance curves. The tests were performed on the offshore platform following the guidelines provided in the ASME PTC 8.2 Standard [14] (performance testing for centrifugal pumps). Several points were recorded during the tests; however, due to system limitations, only a small flow rate range could be tested.

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

The original pump performance curve of the TB-4 at 6,550 rpm (measured with water) was corrected for viscosity according to the ANSI/HI 9.6.7-2004 standard [15] (Effects of Liquid Viscosity on Rotordynamic Pump Performance). Then, the predicted pump performance at the reduced speed (about 4,827 rpm) for both water and the crude oil with a viscosity of 125 cSt was estimated using affinity laws. Due to system limitations, a sweep of the entire curve was not possible and the minimum flow point was not included during the test. Both head and flow measurements were used to estimate performance degradation based on the corrected original pump curve as shown in Figure 7.

A total of 15 operating points were recorded and the average deviation from the corrected original curve was estimated to be about 13.8% in head for each handled flow during the TB-4 performance test. Brake horsepower measurements were available by using a strain gage based torque meter installed on the TB-4 pump shaft. Such measurements were used to estimate the efficiency of the pump for the handled flows during the test. Thus, the deviation from the theoretical efficiency curve was estimated to be about 9-10%.

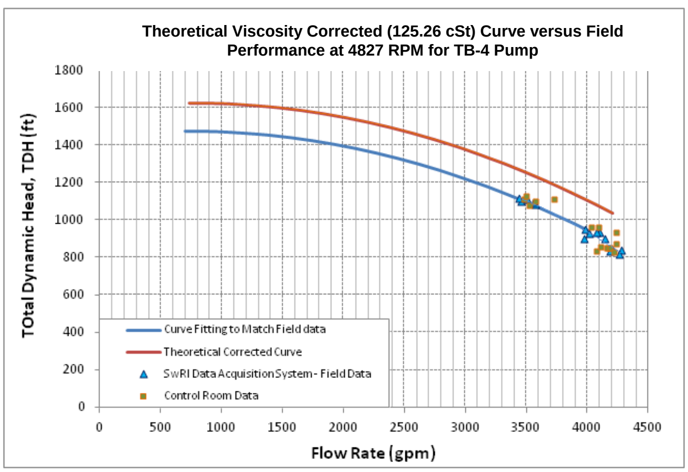


Figure 7. Theoretical Viscosity Corrected Curve versus Field Performance at 4827 RPM for TB-4 Pump

Figure 8 shows a comparison of the performance tests results and the corrected performance curve for the TB-6 pump. The average deviation from the corrected original curve was estimated about 4.47% in head for each handled flow during the TB-6 performance test. The obtained difference between the theoretical and the measured were incorporated in the pump model as hydraulic degradation for the low and high capacity pumps respectively since there was not an initial test to compare the data against.

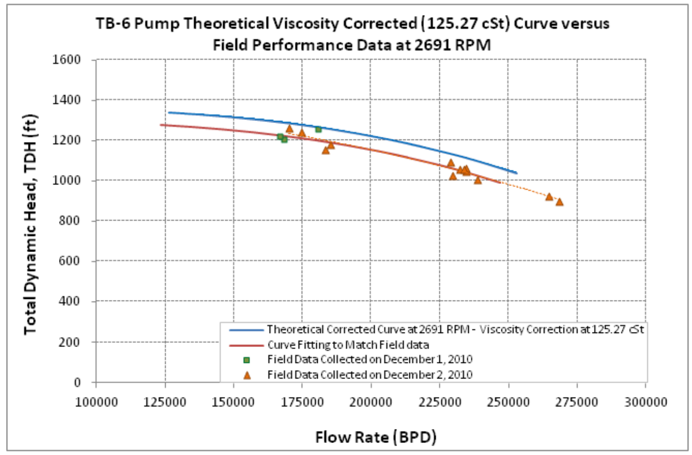


Figure 8. Steady-State Conditions for the TB-6 during the Field Performance Test

HUMAN MACHINE INTERFACE

The human machine interface is developed after the computational model has been created and validated. This process began by reviewing the control screens on the Rebombeo platform to identify what screens the operators will have access to, and to understand the commands that are sent to the pumps and control valves from the control screens. This task is accompanied by reviewing the operation manuals of the pumps and control screens. After the review is complete, the important screens for implementation in the simulator are selected. Next begins the iterative process of developing a simulator screen, connecting it to the computational model, and testing connectivity. A single screen can have many data points being read and a variety of buttons, therefore, it is advisable to test each simulator screen as it is developed to ensure that the desired links behave as intended. Each simulator screen is a graphical emulation of the corresponding control screen including data links to the computational model to read system conditions live. Buttons are included that are linked to the simulator to submit a sequence or perform an action. It may be necessary to develop additional screens that complement the control screens to allow set-up of the computational model, such as pre-loading scenarios, or to further understanding of the system hydraulics by sharing pressure and flow profiles throughout the pipeline network. An overview of the simulator development process is shown below in Figure 9.

Different pump operational modes were programmed in the simulator based on the actual system configuration. Those operational modes include suction and discharge pressures, flow, and machine speed; in addition, alarms, trip commands, and load sharing control logics were programmed and included in the simulator as similar as the real system. The simulator was tuned and validated against real conditions and all the control logic were reviewed at the platform.

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

The second phase of the pump model development was to program all the start-up and shutdown commands and sequences, control logics, load sharing control and special commands, safety protection sequences and actions, and alarms. The new screw pump trains use a torque converter to control the speed of the machine instead of the gas turbine alone as in other conventional trains. Therefore, to properly train operators the detailed sequences used for start-up and shutdown were incorporated into the pipeline model and linked to the interface screens. It was very critical to tune or refine all these parameters since they will delimit the operation of the new pumping train system and they must be very well understood by the operators. Thus, a comparison of the control logics and other sequences with the existing pumping system was conducted with the help of the control specialist of the platform. Several iterations were performed to properly refine and adjust them to an acceptable point.

DEVELOPED SIMULATOR SCREENS

The simulator developed for the Rebombeo platform ended up comprising of fifty-five screens. Twenty-two screens that mimic actual control screens and thirty-three additional screens to provide the ability to preload scenarios and to provide further insight into the system hydraulics. This section shares four screens in addition the flow network screen shown earlier in this article.

Figure 10 shows the valve control screen for a screw pump. From this screen operators are able to submit sequences required for preparing the pump for start-up and shutdown. Additionally the operator is able to put the pump into recycle mode as necessary. Figure 11 shows an overview of all of the pumps on the platform including the existing six centrifugal pumps plus the four recently installed screw pumps. This screen helps operators visualize available flow paths in order to better understand the current operating conditions. Figure 12 shows the primary operation control screen for a screw pump. From this screen the operator can submit start-up and shutdown sequences as well as monitor the current status of the pump during those sequences. Figure 13 shows a screen that plots the pressure as a function of time at the suction and discharge of each screw pump. This is an example of a host of screens that provide real time trending measurements at key platform locations in order to provide insight into the system hydraulics.

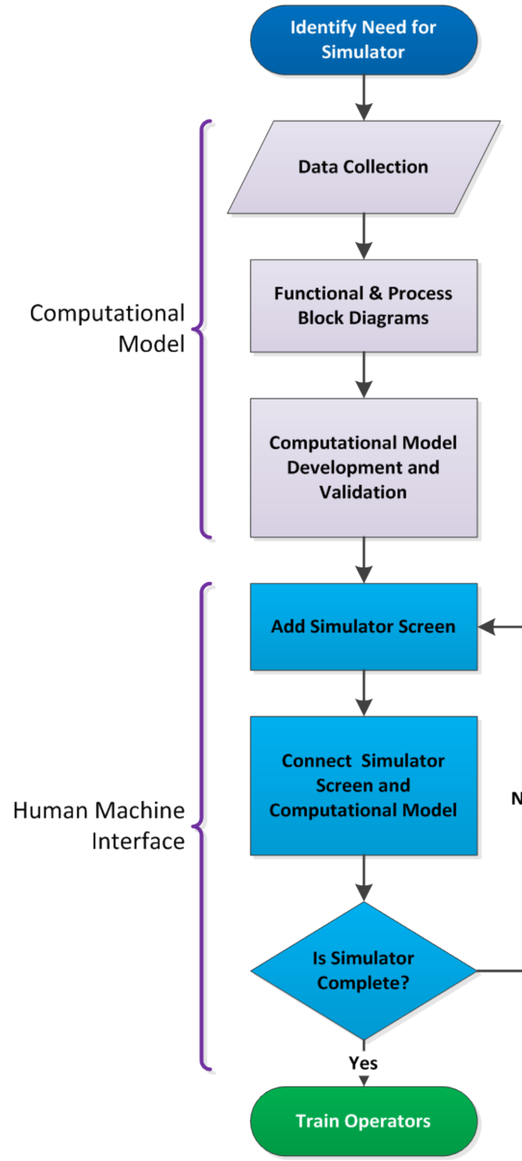


Figure 9. Overview of Simulator Development Process

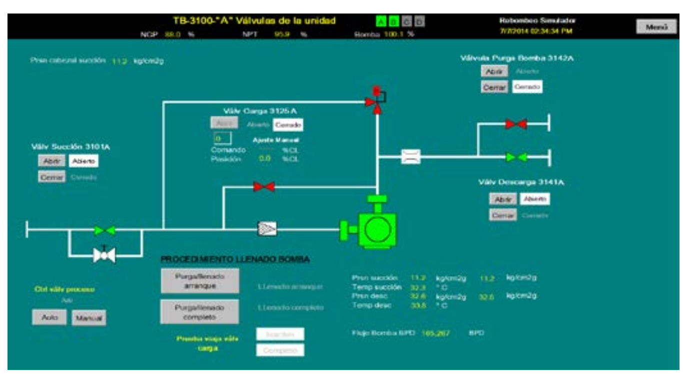


Figure 10. Screw Pump Valve Control Screen

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

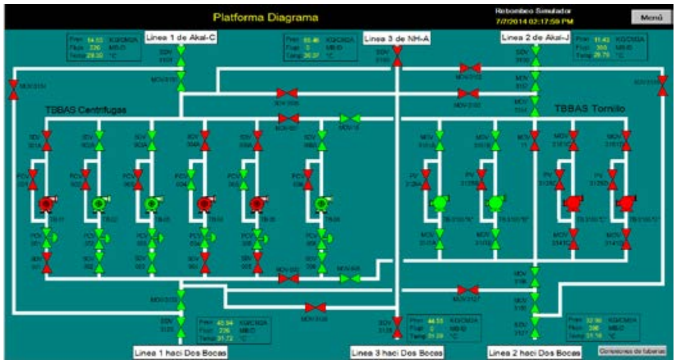


Figure 11. Platform Pump Overview Screen

Figure 12. Screw Pump Operation Control Screen

Figure 13. Pressure Trending Screen

APPLICATIONS AND BENEFITS

The primary use of the simulator is for training operators. Operators are tested on a variety of typical scenarios including start-up, shutdown, and a change in operating conditions. The simulator development helps meet the operator's objectives for improving operational safety and reliability through training and certification of operators. These objectives follow international guidelines as set out in API 1120 (Training and Qualification of Liquid Pipeline Maintenance Personnel); ASME B31Q (Pipeline Personnel Qualification); RP 1161 (Recommended Practice for Pipeline Operator Qualification); RP T-2 (Qualification Programs for Offshore Production Personnel). In addition, the simulator is being used as an engineering tool to analyze unusual operating conditions, changes in the production, determine pumping system best configuration, conduct "what if" analyses, determine the effect of different batches in the transport capacity, and transient predictions of possible upset conditions that could originate an undesired shutdown of the entire system.

Engineering Applications

As a part of the engineering analysis the technical personnel can visualize the simulated current operating conditions in an operating envelop that incorporates the system and pump curves as well as the limit of the system as shown in Figure 14; therefore, they can make an educated decision for the best system configuration for a particular production scenario.

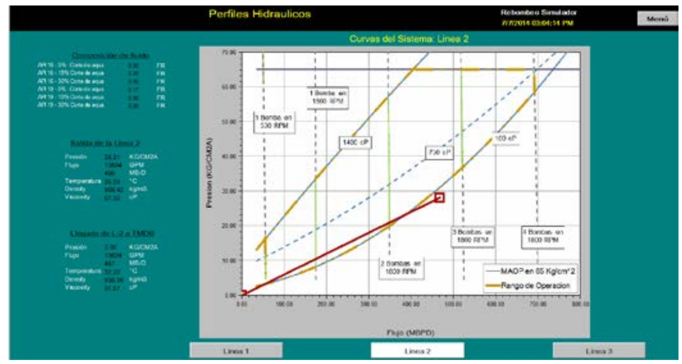


Figure 14. System and Pump Curves with Predefined Operating Envelope

Avoidance of unnecessary trips, efficient machine operation, and optimal machine nomination are typical situations that can be assessed by the operator with the help of the simulator; thus, they can take more appropriate decisions during the system normal operation. In addition, the simulator can be used as an engineering tool to determine the maximum capacity of the system for a given set of conditions, forecast critical conditions, evaluate possible process upset scenarios and their effect on the machinery and the entire system, and determine system limitations for specific conditions such as low suction pressure, drastic changes in the fluid viscosity and water-cuts, and ambient conditions.

A "what if" analysis is a very common and efficient technique used in the risk assessment and management of many systems and processes since diverse, critical, unexpected or abnormal situations can be analyzed to provide possible solutions or actions to uncommon situations. Thus, this helps to reduce the unknown component of the operation while improving the reliability of the system. The developed simulator provides the capability to conduct "what if" analysis and parametric studies of diverse variables and parameters such as pressures, flow, temperature, fluids viscosities and temperatures, and pipeline pressure. For example, one application is the calculation of the system minimum suction pressure and machine nomination that

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

would be required to maintain the design capacity while transporting a 16º API versus a 19º API crude oil during the summer or winter seasons since the pressure losses and pumping capacity are affected by the viscosity and temperature of the system. A difference of 31% in the minimum suction pressure was obtained between the 16 API and 19 API crude oils for the nominal capacity.

Another critical situation that can be evaluated with the simulator is the transient originated when a new machine is brought on-line while other machines are running. Critical suction pressures could be reached when a new machine is started or even loaded since some amount of the total mass will be flowing through the new running machine leaving the existing running machine with a lower suction flow or pressure; thus, their operating points are affected. Therefore, it is vital to determine if there is enough flow or pressure in the system to start or load a new machine.

Other typical scenarios or applications that can be assessed with the simulator include: 1) diverse steady-state conditions (machines' nomination); 2) critical transient conditions such as start-ups, emergency and normal shutdowns; 3) load-sharing and auto control of operating modes; 4) system optimization; and 5) control logics and sequence optimization.

Personnel Training

Simulator training courses begin with an overview of hydraulics and the differences between screw and centrifugal pumps including working principle and operational considerations. Training operators to use the simulator includes an overview of its objectives, capabilities and applications. This is followed by a detailed step-by-step start-up sequence for the simulator which is followed by a series of exercises/examples to be performed using the simulator. The exercises conducted with the simulator include: pump start-up and shutdown, switching lines and open/close valves, change of fluid properties, water hammer effect, change of operating conditions, and visualization of flow rate, pressure, temperature, and viscosity trends.

As a result of this project all the platform operators were trained in how to use the simulator and mimic critical conditions with it. During the different training sessions the operators were challenged to start-up and shutdown machines, and modify operating conditions. Approximately, 80% of the tested operators did not need any instruction to conduct the required actions since all the commands and screens were similar to the real system while the remaining 20% felt a little hesitant in operating the simulator for lack of fluency with the computer tool ("flight simulator"); they worried about failing the test. ("Simulation crashes cost just a few minutes and no lives while a real event could be unmeasured sometimes.") After those training sessions, an implementation plan was developed for the application of the developed simulator as a continuous education training tool for all platform existing and new operators while they are working on a required simulator testing for further operators' qualification compliance.

CONCLUSIONS

A training simulator was developed for newly installed screw pumps at an offshore booster pump platform. The simulator development process was shared detailing the creation of a computational model and an accompanying human machine interface that mimics the control screens available on the platform. Several screens from the developed simulator were presented. Lastly the applications and benefits of the simulator were shared. The developed simulator provides a means for the platform operators to comply with API 1120, ASME B31Q, RP 1161 and RP T-2.

As a result of this work all of the platform operators were trained to use the simulator and practice handling critical scenarios. After the training sessions, an implementation plan was developed to use the simulator for training new operators and for the continuous training of existing operators for qualification compliance.

REFERENCES

1. Leon Dorantes, M., M. A. Muñoz Prior, A. Garcia-Hernandez, H. A. Delgado-Garibay "Reduction of Operational Risk through the Development and Usage of a Hydraulic Simulator to Train Operators." Paper presented at the Congreso Mexicano del Petróleo, Cancún, México, Junio 2013.

2. Garcia-Hernandez, A., and Bennett, J. A., 2015, Tutorial: Transient Modeling and Analysis of Centrifugal Compressors, Middle East Turbomachinery Symposium III, Tutorial Number 11, Gas Turbine Conference.

3. Garcia-Hernandez, A. J., M. A. Wilcox and K. Brun. "Hydraulic Modeling and Simulation of Pumping Systems (Tutorial Sessions)." Paper presented at the 26th International Pump User Symposium, Houston, TX, March 2010.

4. IEEE Standard 442-1981, "IEEE guide for soil thermal resistivity measurements," ISBN 0-7381-0794-8. See also soil thermal properties.

5. Pal, R. and Rhodes, E. "A Novel Viscosity Correlation for Non-Newtonian Concentrated Emulsions." Journal of Colloid and Interface Science, Vol. 107, No. 2, October 1985.

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

6. Dan, D. and Jing, G. "Apparent Viscosity Prediction of non-Newtonian Water-in-Crude Oil Emulsions." Journal of Petroleum Science and Engineering 53 (2006) 113-122.

7. Grassi, B., Strazza, D., and Poesio, P. "Experimental Validation of Theoretical Models in Two-Phase High-Viscosity Ratio Liquid-Liquid Flows in Horizontal and Slightly Inclined Pipes." International Journal of Multiphase Flow 34 (2008) 950-965.

8. Stogia, G., Tartarini, P., and Stalio, E. "Experimental Analysis of Flow Regimes and Pressure Drop Reduction in Oil-Water Mixtures." International Journal of Multiphase Flow 34 (2008) 1161-1174.

9. Abedine, R., Abedine, A., Eslamiyakhfrouzan, N., "A New Correlation for Prediction of Undersaturated Crude Oil Viscosity." Petroleum & Coal 52 (1) 50-55, 2010.

10. Zhang, H.-Q., Vuong, D.H., and Sarica A C. "Modeling High-Viscosity Oil/Water Flows in Horizontal and Vertical Pipes." SPE 135099. SPE Annual Technical Conference and Exhibition, Florence, Italy 19-22 September 2010.

11. Atmaca S., Sarica S., Zhang H.-Q., and Al-Sarkhi, A.S. "Characterization of Oil/Water Flows in Inclined Pipes." SPE-115485. SPE Annual Technical Conference and Exhibition, Denver 21-24 September 2009.

12. Johnsen, E.E. and Ronningsenh .P. "Viscosity of "live" water-in-crude-oil emulsions: experimental work and validation of correlations." Journal of Petroleum Science and Engineering 38 (2003) 23-36.

13. Garcia-Hernandez, A., Bennett, J.A., Leon Dorantes, M., Muñoz Prior, M. A., "Evaluation of a Pumping System to Aid Machine Performance Testing," Paper was presented at the Pipeline Simulation Interest Group (PSIG) Annual Conference, Baltimore, MD, May 2014.

14. ASME PTC-8.2 standard (Centrifugal Pumps)

15. ANSI/HI 9.6.7-2004 standard (Effects of Liquid Viscosity on Rotordynamic Pump Performance).

ACKNOWLEDGEMENTS

The authors would like to thank PEMEX Exploration and Production for allowing us to present the results of this project as well as PEMEX personnel for their support during the study. We also are grateful to the Rebombeo platform personnel who supported us during the review of the pump control screens.

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

APPENDIX A – High Resolution Simulator Screenshots

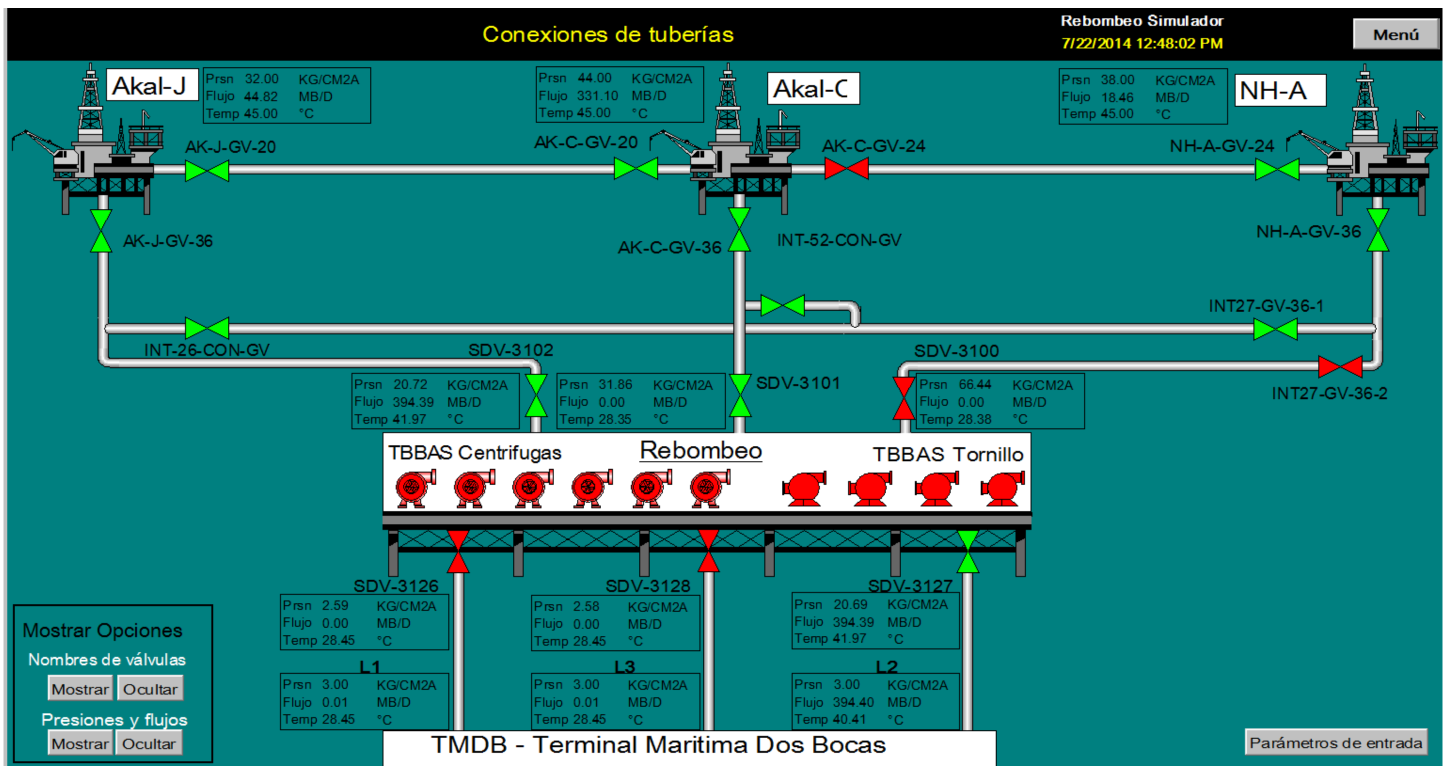


Figure 3. Schematic of the Crude Oil Pipeline System from the Production Platforms to TMDB (Simulator Screenshot)

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

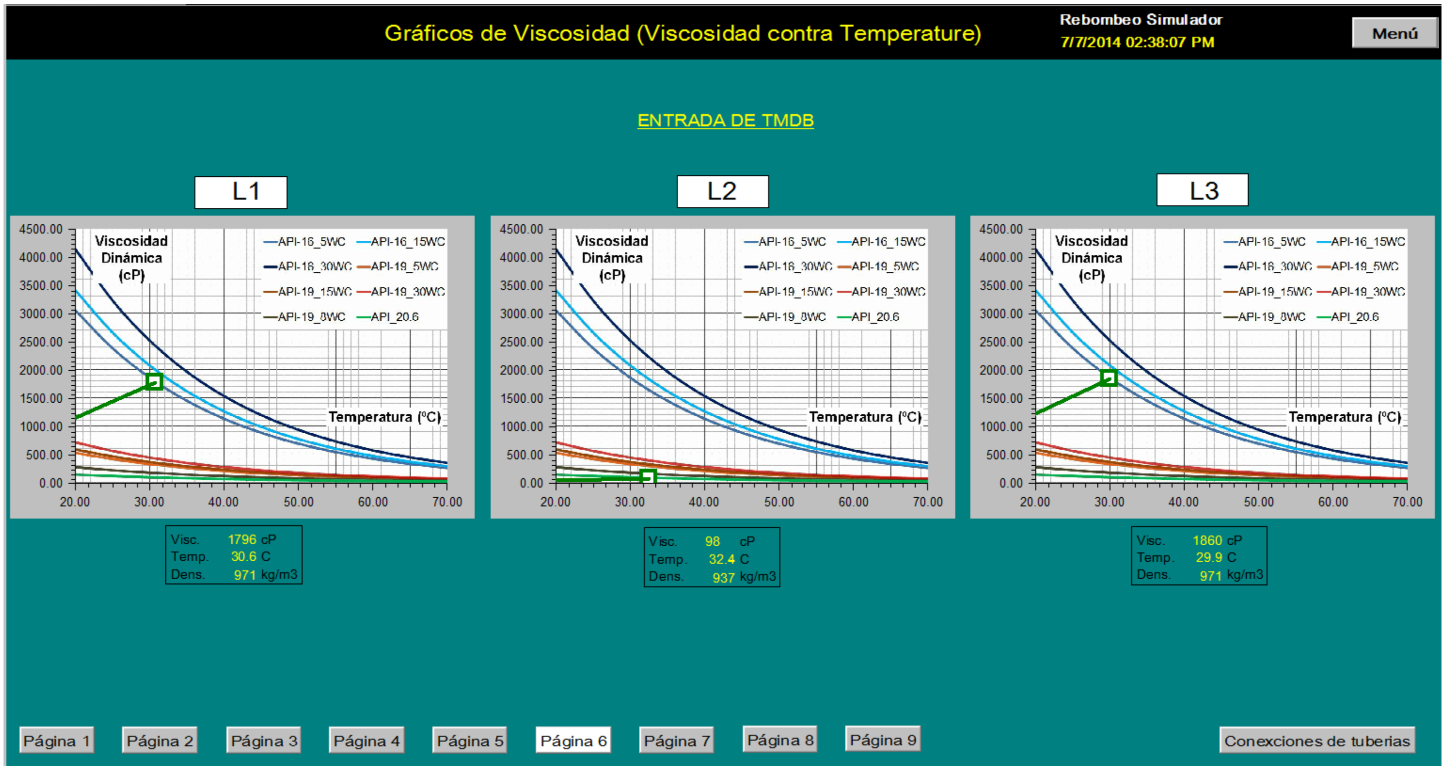


Figure 6. Simulator Screen with Crude Oil Dynamic Viscosity versus Temperature for the Different Water Cuts

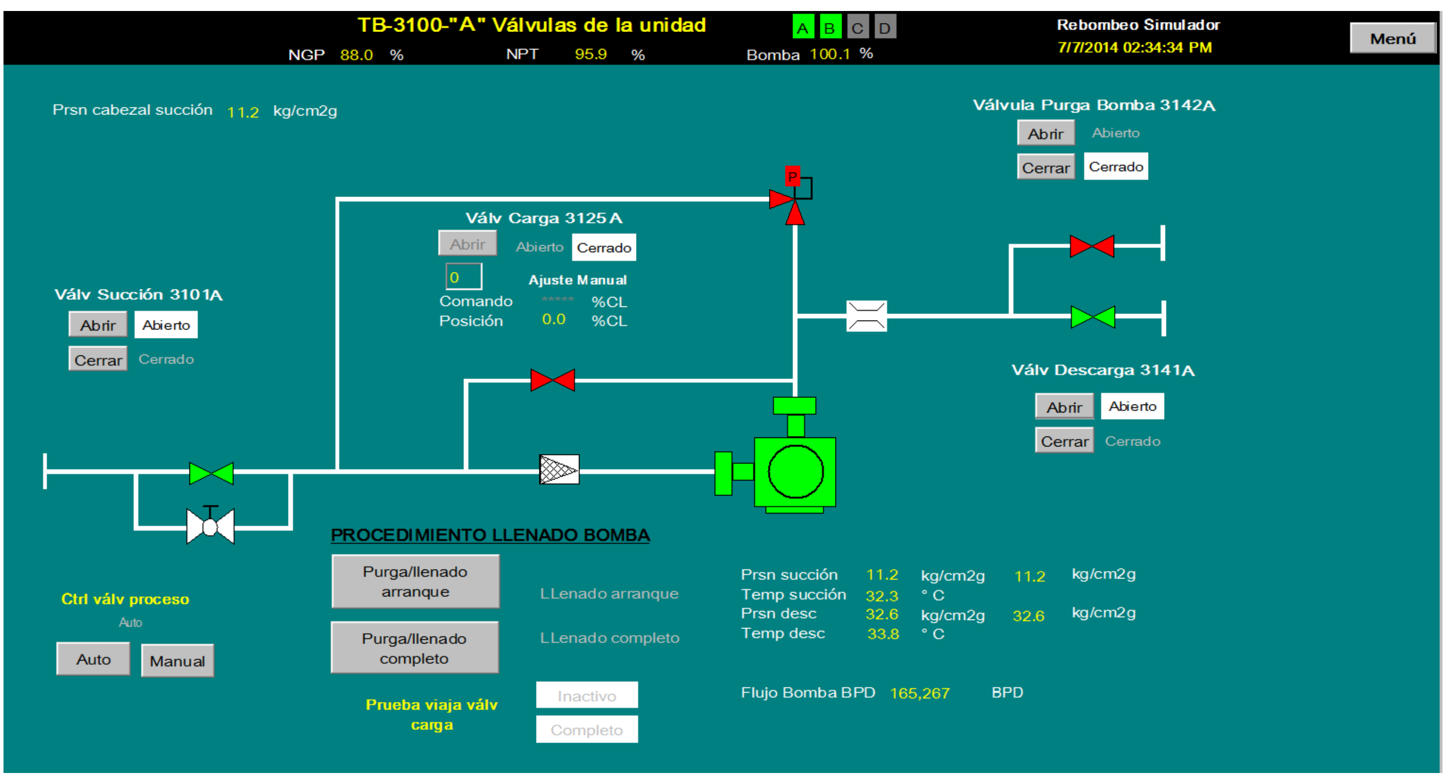


Figure 10. Screw Pump Valve Control Screen

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

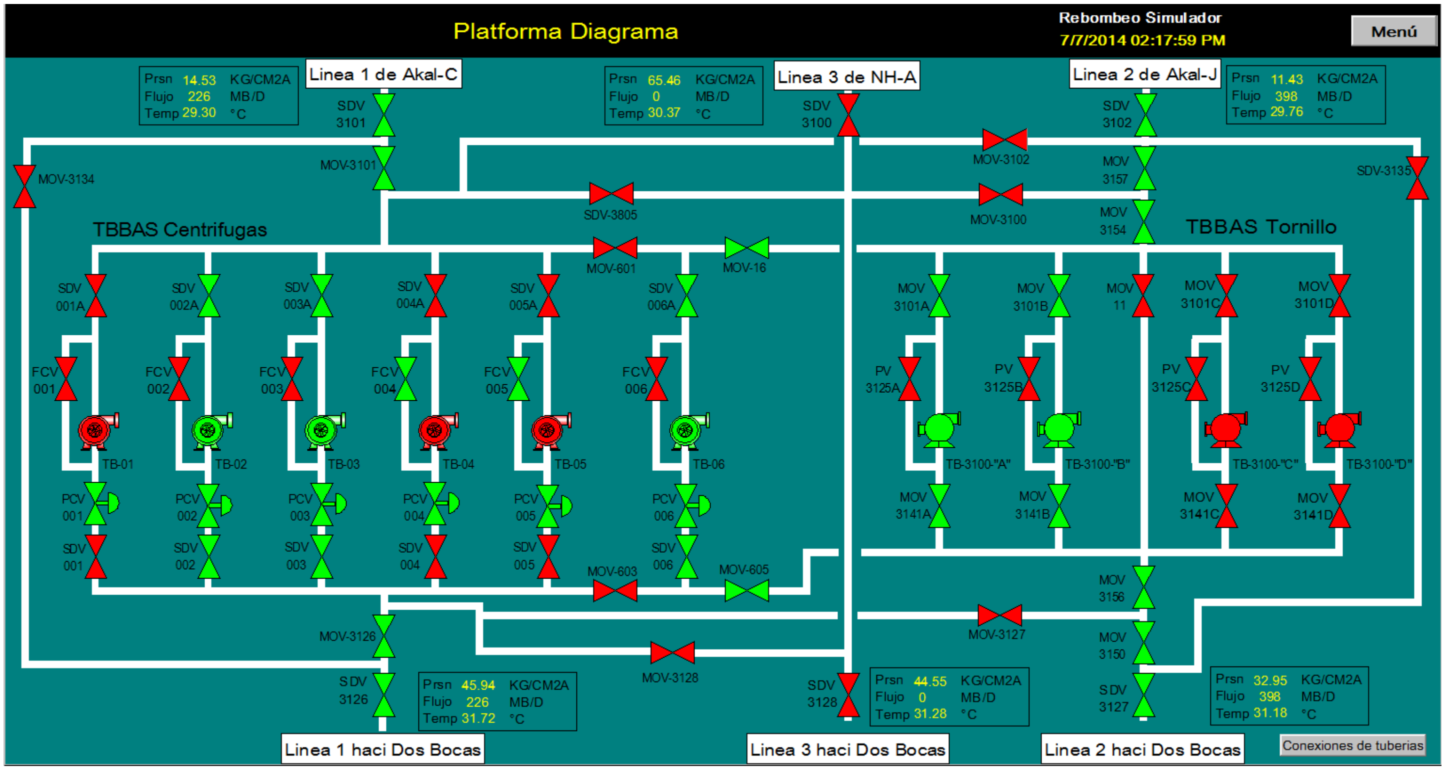


Figure 11. Platform Pump Overview Screen

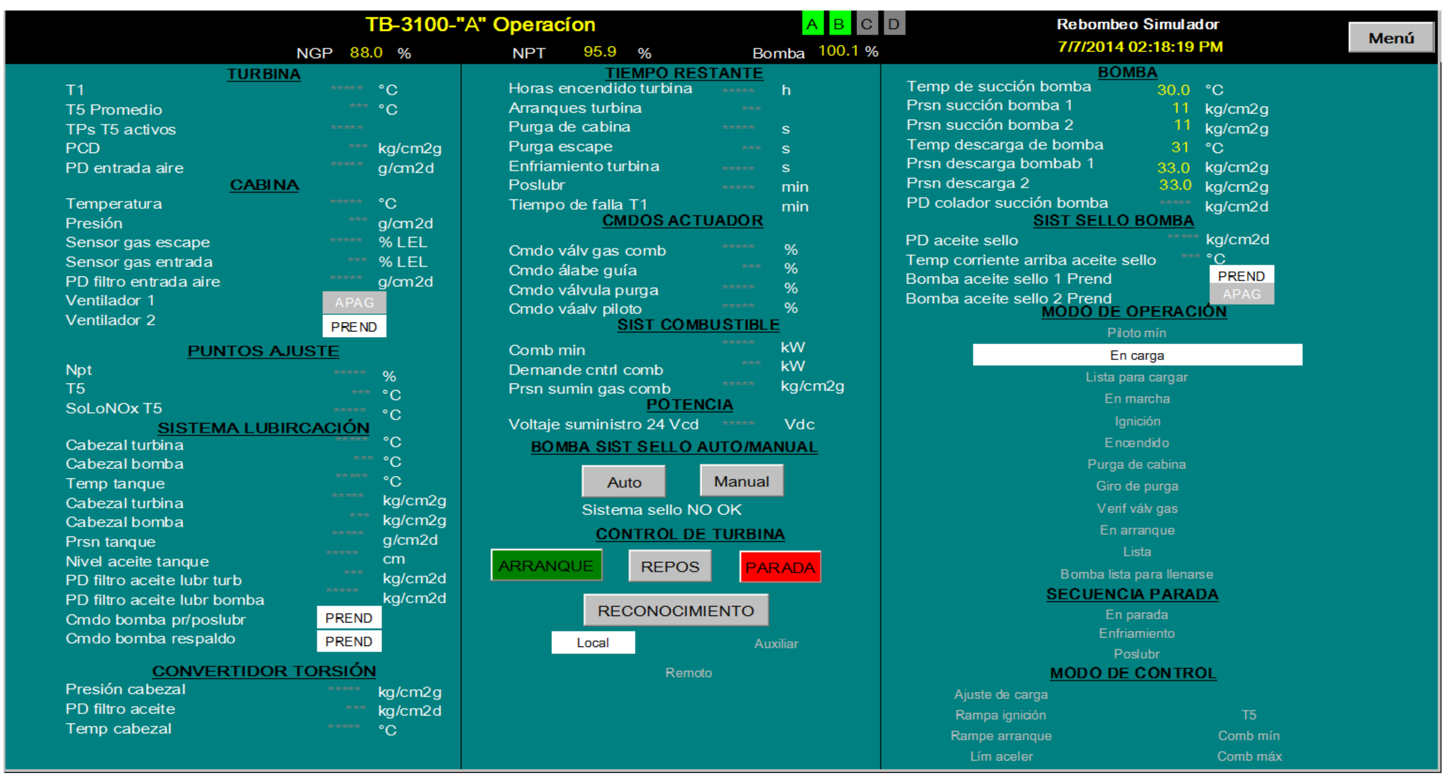


Figure 12. Screw Pump Operation Control Screen

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station

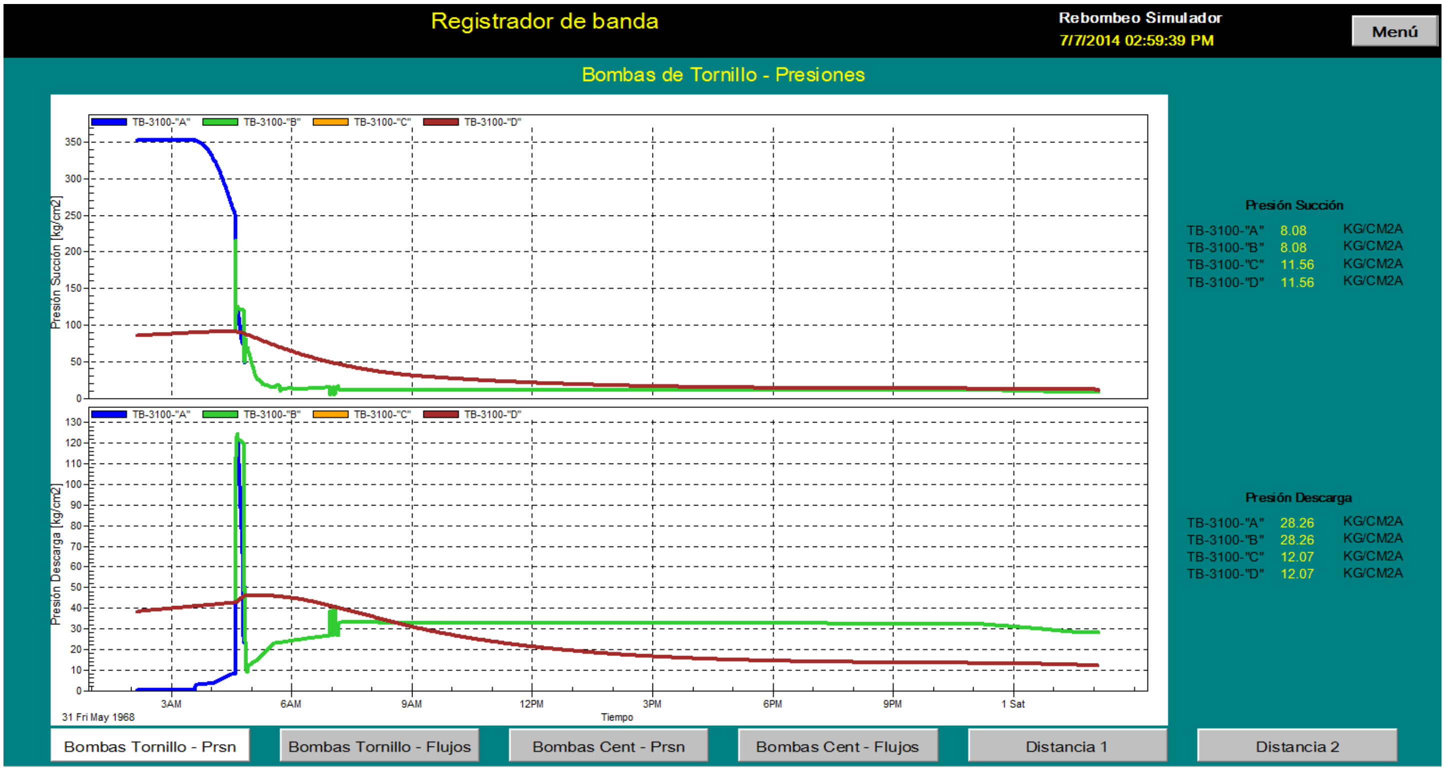


Figure 13. Pressure Trending Screen

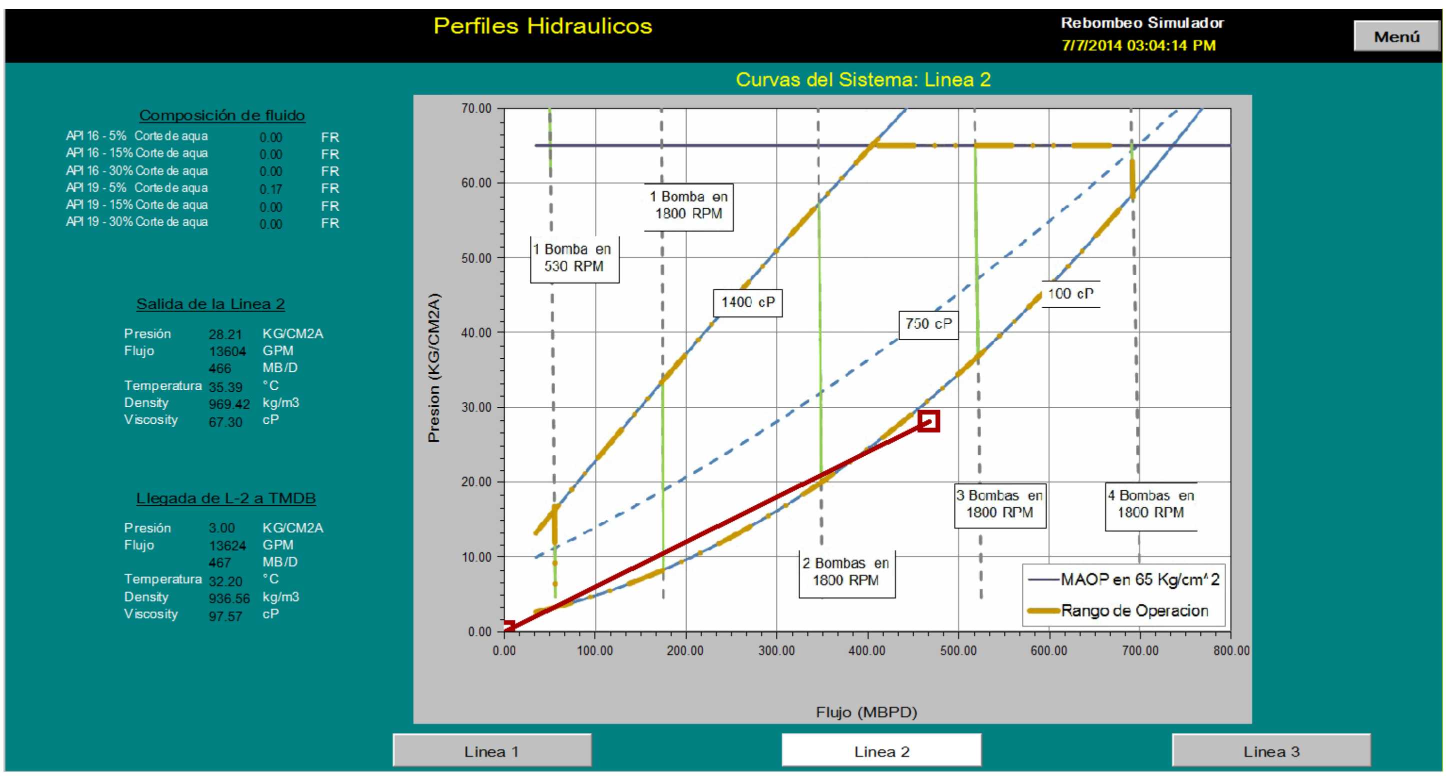


Figure 14. System and Pump Curves with Predefined Operating Envelope

Copyright© 2015 by Turbomachinery Laboratory, Texas A&M Engineering Experiment Station