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# WELLCOMP MULTIPHASE FLOW METER -Oxy field experience with replacement of traditional well test separators

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**WELLCOMP MULTIPHASE FLOW METER**

Oxy field experience with replacement of traditional well test separators

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## SUMMARY

Over the past five years, Occidental has been working on proving technology for separation and metering of multiphase wellhead fluids to replace conventional well test systems. The technology selected has over the past two and one half years been in operation in the Occidental operated Block 15 of the Ecuador Oriente.

Occidental has faced and addressed several challenges, however, the technology is proven to the operator of Block 15 as justifiable on the original grounds of having environmental, economic, operational, and technical merit over conventional test separation. This new technology well test equipment holds great promise for meeting the needs of timely and accurate well test data, which are so essential for maximizing oilfield recovery and ensuring sound reservoir management.

This paper details Occidental's experience with the WellComp well test system from lab to full field replacement of traditional test separator systems. These experiences reveal not only the benefits but the "real world" problems associated with introducing new technology into the field. Although the paper presents the basic operation and specific experiences related to the WellComp system, many benefits and solutions may be helpful in application to any new well test technology introduced into a production operation.

## ECUADOR BLOCK 15

In February 1985 OEPC signed a risk service contract for Ecuador Block 15. The next seven years saw the discovery and subsequent proving up of commercial oil reserves, leading to the approval of the Block 15 Development Plan in July 1992 by PetroEcuador.

Block 15 is in an area of intense international environmental scrutiny. As shown on *Figure* 1, the Occidental block contacts three national ecological preserves of international profile, with a fourth Area added in 1994. Within this operating sphere, the Occidental development plan was approved as a model of environmentally responsible oil development in recognition of the rich ecological heritage present in the Upper Amazon Basin of Ecuador.

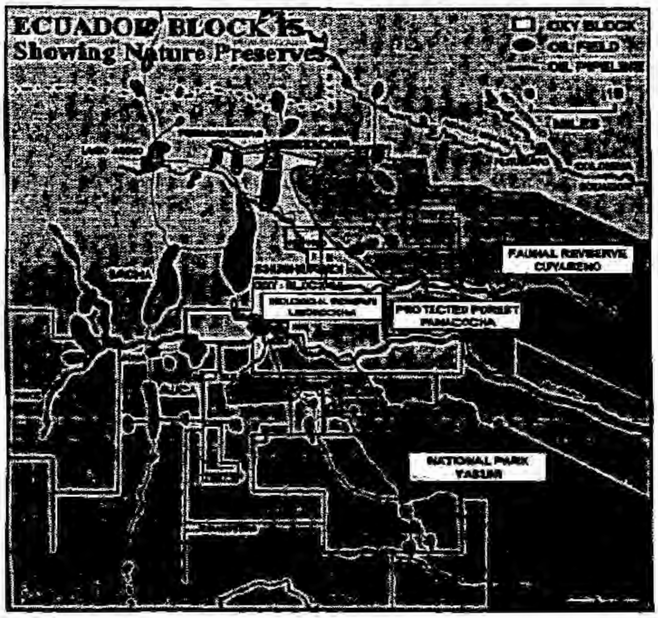


**Figure 1**

The current development of the Jivino-Laguna and Napo fields is shown in *Figure* 2. Presently the fields are developed with twenty producing wells and two water injection wells. Four to ten directional producing wells are drilled off each well island. Individual well testing is done through test manifolds at each well island. A multiphase gathering pipeline carries the commingled production to the Central Production Facility (CPF). Separation of the bulk fluids takes place at the CPF, where:

- oil is processed to pipeline conditions and pumped to the PetroEcuador pipeline at Shushufindi for onward transmittal into the trans-Andean pipeline;
- water is separated and processed to an acceptable standard for injection in the subsurface;
- gas is dehydrated and used for fuel with the excess flared.

The development consists of the following key components, to minimize the impact of sub-surface oil development on the Amazon rain forest:

- directional well drilling from four principal well islands;
- burying well flowlines and trunklines;
- injection of produced water in compatible sub-surface reservoirs;
- well testing at flowline conditions from sub surface multiphase pumping without benefit of further surface pressure boosting to the single separation facilities.

Proven technology was available to Occidental in 1990, to accomplish all of the above components except the last. Occidental set about at that time to gain experience with and prove up technology that could be recommended to PetroEcuador as part of an ecological balanced oil development for Block 15; the later component was critical not only in environmental terms but for costs and proper technical management of the encountered oil reservoirs.


**Figure 2**

## SELECTION AND TESTING OF THE WELLCOMP

The initial design criteria of the wellhead testing of Block 15 wells was to:

- test well effluents produced by subsurface Electrical Submersible Pump (ESP) at Well head Pressure (WHP) of 2.8 mPa (400 psig) and 93 ° C (200 ° F);
- have flow ranges between 160 and 1,270 $m^3$/day (1,000 and 8,000 bfpd) and water cuts varying between 5 and 95 %;
- have gas produced in GOR ranges of 18 to 62 $Sm^3/Sm^3$ (100 to 350 scf/stb );
- have accuracy of measurement to be within 10 % on oil/gas/water rates;
- have recombination after analysis to bulk line and be pumped using subsurface ESP to central gathering and separation point.

After a review starting in late 1990 of the then available technology, the FloComp II unit (predecessorto the WellComp) was identified and was judged to be the most developed technology in meeting these five requirements. Accordingly, a single FloComp II was purchased in June 1991 for testing and evaluation within the fields operated by Occidental in the USA, with similar crude characteristics to those found in Ecuador. It was predicted, that should the technology be proven in Ecuador it would have future economic benefit through use in many similar Occidental developments, including multi-platform offshore developments.

In November 1991, the unit was tested in the Kern Front field of Bakersfield, California. Twenty tests were conducted on 19 different wells. The purpose of this testing was to monitor at low rates the separation and metering characteristics on low gravity crudes. Well fluid rates ranged from 5 to 127 $m^3$/ day (30 to 800 bfpd) and water cuts varying from 62 to 95 %. The results were deemed successful with an average absolute deviation of:

- oil rate against tank metered volumes of 10 % and,
- water cut against conventional grind out measurements of 5 %.

Based on these tests, Occidental proceeded to file a development plan for Block 15 built with the WellComp as the pivotal technology. This plan was approved by PetroEcuador in August 1992.

One of the main advantages of the WellComp equipment was the reliance on predominately proven technologies. The use of coriolis meters and vortex shedding meters on well testing equipment was an established applied technology within Occidental operated fields, and the static analysis chamber technology, although unproven, was easily tested in a lab, independent of actual flowing conditions in the field.

The proposed Ecuador development would produce from three separate reservoirs with:

- oil gravities of 0.95 from 0.89 S.G. (18 and 28 degrees API);
- water salinities varying from 400 to 43,000 ppm $Cl^-$;
- gas gravities varying between 0.84 and 1.29 S. G., due to varying oil PVT properties and $CO_2$ spatial variations within the productive zone.

Since the relative proportion of these gravities within a given well would be unknown, the sensitivity of the analysis chamber results to these inlet fluid stream density variations was a source of concern. Prior to placing the order for the units, further operational testing in the laboratory was deemed necessary on the analysis chamber of the WellComp equipment.

Tests were set up in the laboratory of WellComp in Orange, California to test the unit accuracy with emulsified fluids and various mixtures of heavy/light crudes with varying amounts of fresh/salt water and air. These results showed agreement within 10 % of the theoretical fluid volumes, and encouraged Occidental to proceed with another field trial prior to ordering for Ecuador. The 10% deviation appeared to be predominately a result of variations in internal coating of the chamber with the heavy crude. These results spawned a new analysis chamber development by Paul Munroe, that would eliminate these coating variation effects.

## WELLCOMP DESCRIPTION

In November 1992, the WellComp was shipped to the Occidental Johnson-Grayberg lease near Midland, Texas for final testing. These tests were to confirm previous testing in accuracy of measured oil, water and gas and to test the operation of an upstream fluid conditioner under higher gas production rates. These tests required the simultaneous flow of up to six wells in order to approximate the rates of the Ecuador wells. Overall, these tests were a overriding success and confidence builder for Occidental, they indicated an average error as compared to the proven well test facilities on: oil/water cut of +/- 1.6 % and total fluid of +/- 1.8 %. Gas measurement was out of range for the Occidental test facilities, therefore this portion of the test was not achieved.

*Figure* 3 shows a pictorial of the basic equipment contained within a WellComp. A quick overview of the basic operation follows:

Incoming three-phase flow enters the fluid conditioner where slugs and large bubbles of free gas are removed from the liquid stream. Essentially, the fluid conditioner is similar to a two- phase separator system, with the exception that well-entrained gas is allowed to flow with the liquid out the bottom of the unit (a "1-1/2 phase" separator is far smaller than traditional 2-phase separator system). This liquid/entrained gas mixture is metered volumetrically through a volumetric meter, and ultimately recombined with the free gas stream at the exit of the unit. Free gas is metered from the top of the fluid conditioner through a vortex shedding meter. A differential pressure gas regulator and a liquid throttling valve maintain separator fluid level, ensuring operation through severe slugging and allowing accurate operation from 100% gas through 100% liquid flow regimes.

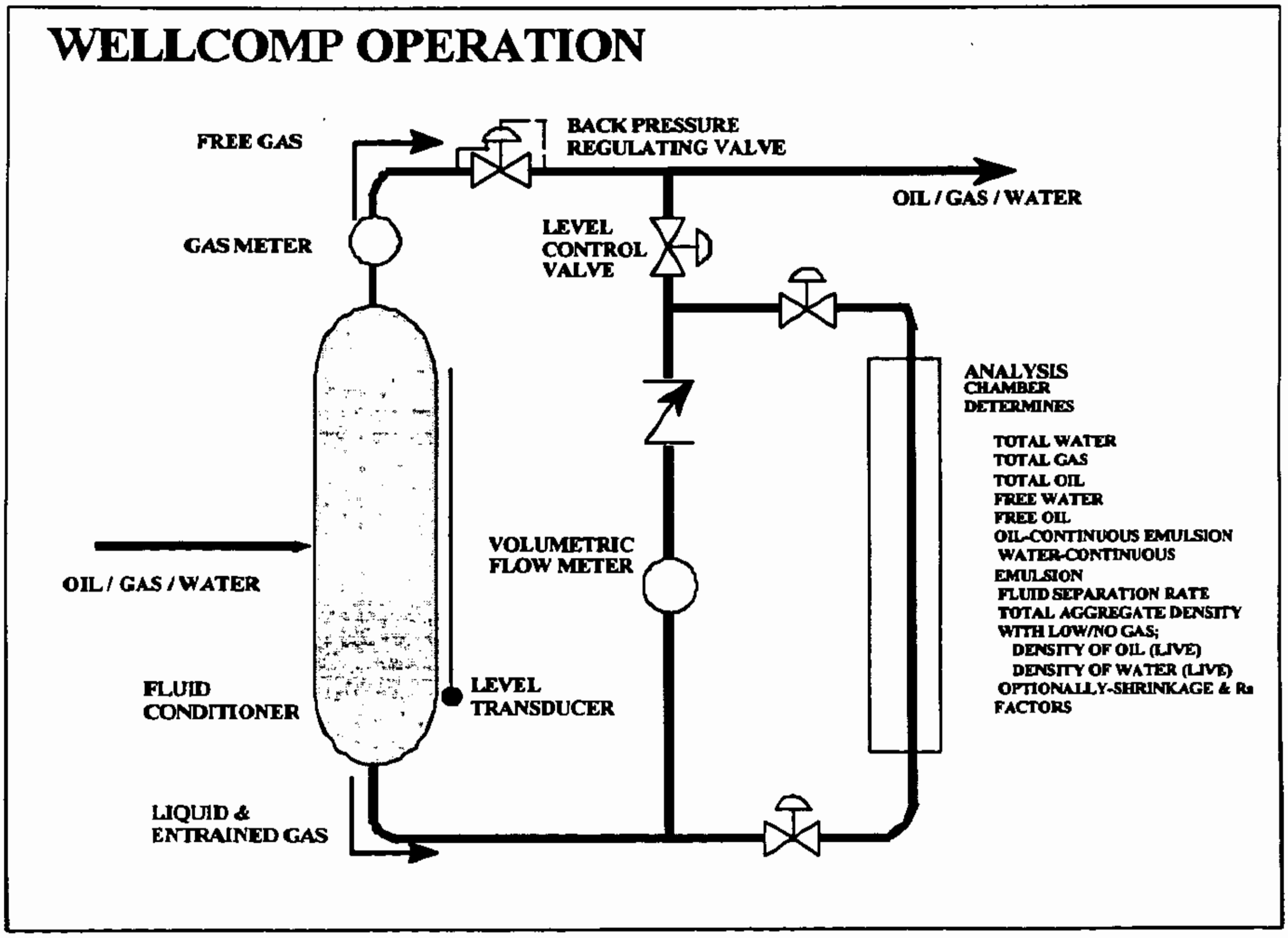


Figure 3

Every five minutes, the 3-phase primarily liquid flow from the bottom of the fluid conditioner is diverted from the volumetric metering device through a section of pipe named the analysis chamber. Valves top and bottom are shut to trap a sample in this two meter vertical section of pipe. A volumetric analysis is performed on this static sample over a four minute period for oil, water, and gas content. The established volumetric fractions of oil, water, and gas are multiplied by the total volumetric rate to produce the flow rates of each component. Pressure and temperature transducers are used to correct each component to standard conditions, and gas rates are added to standardized free gas rates measured from the gas leg. These results from the five minute "Mini-Test" are stored in a local data acquisition system, and a new test commences. This cycle repeats for a predetermined period, set by the operator, at which time all mini-test results are averaged for a "Final-Test" record to be displayed and stored in the database.

The analysis chamber uses a differential pressure transducer to establish the aggregate density of the static sample. This measurement predominately determines the gas vs. liquid (water & oil) content in the chamber. A proprietary probe will make 150-300 separate capacitance readings vertically over the two meter length of the analysis chamber. The result is a profile as shown in *Figure* 4. This measurement predominately measures the water vs. hydrocarbon (oil & gas) content in the chamber. A solution to three equations in three unknowns is used to permit analysis of fluids from a fully emulsified to a fully stratified state. The analysis also determines the percentage of fluids that remain emulsified at the completion of the five minute equilibration period. *Figure* 5 shows a local LCD panel that displays well test results both graphically and in tabular format, allows calibration of equipment and entry of an automated sequence of well tests (integral command of automated test manifold valves).

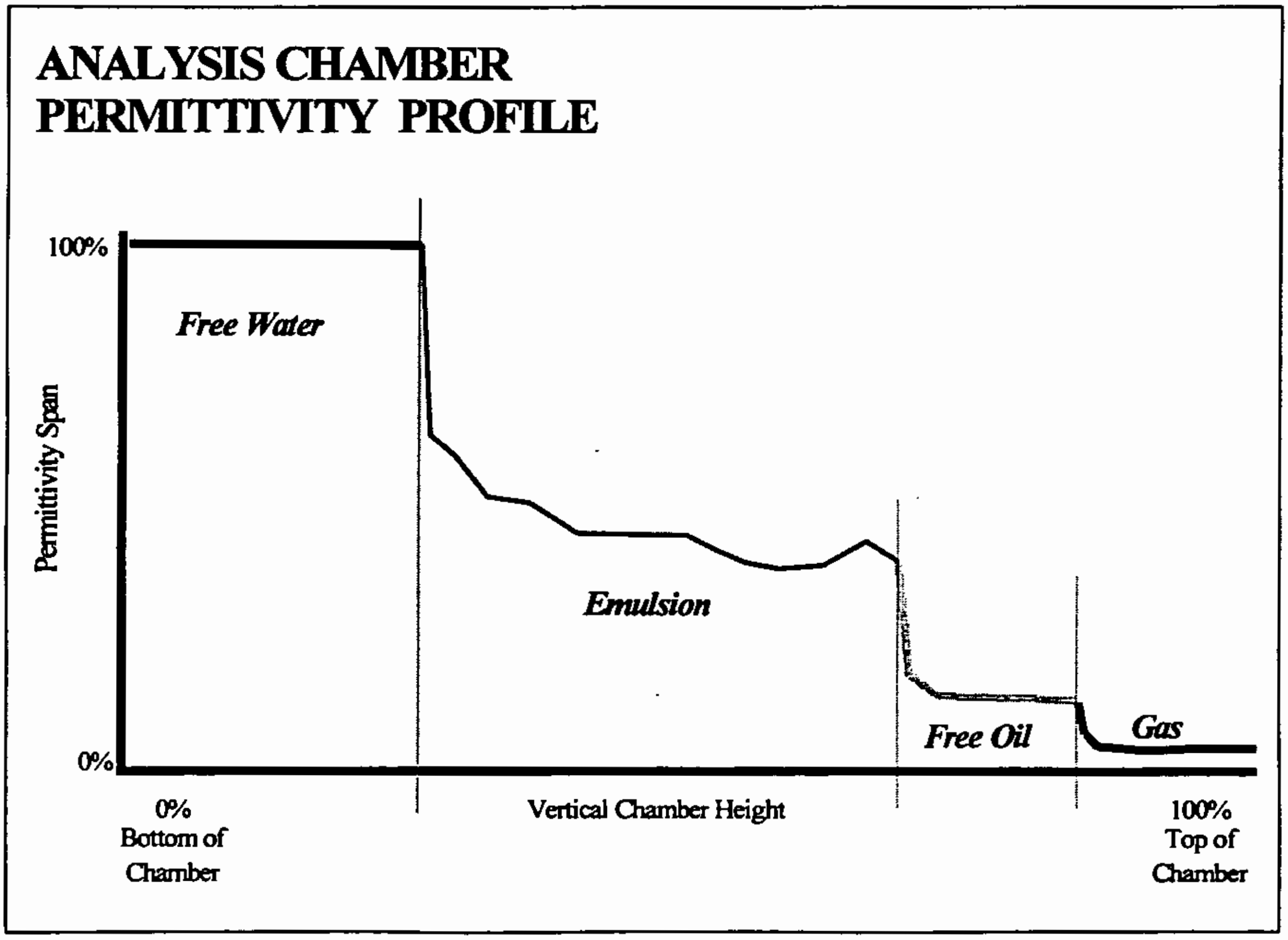


**Figure 4**

## BLOCK 15 INSTALLATIONS

In December 1992, five additional standard model 400 WellComp units with high gas fluid conditioner were purchased for use in Ecuador. The first two of the units arrived in Ecuador in April 1993. On May 1, 1993 production started through early oil facilities situated on the Jivino A platform. This unit performed from inception giving daily accurate well test data under Amazon jungle ambient conditions with only a tarp for cover from the rain. Subsequent installations during the early oil phase were completed on the Laguna A and Jivino C platforms. In August 1993 the CPF was commissioned and an additional installation was made on the Jivino B platform. Finally, with the discovery of the Napo field in early in 1995, the unit already in place on the Laguna A platform was accepted by PetroEcuador for accurate segregated testing of the Napo field produced fluids. A typical well island hook up is shown on *Figure* 6.

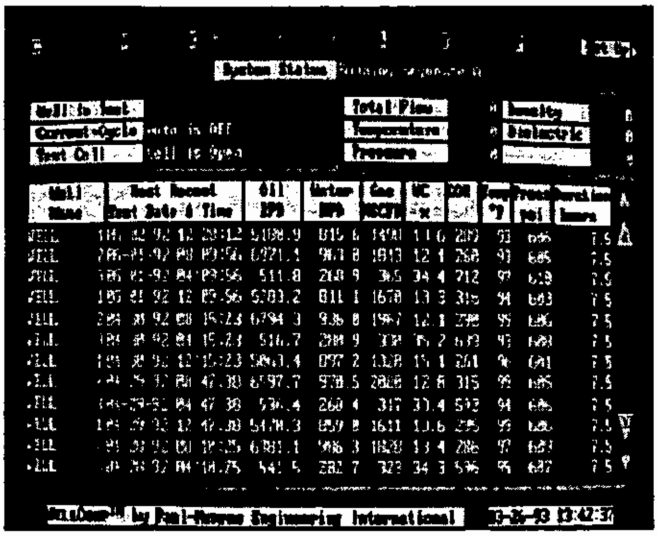


Figure 5

In the early portion of the application of this technology in well tests on initially completed wells and for the entire production stream from May to August of 1993, the WellComp measurement was compared against conventional test separation metering equipment. After confidence was gained in the application of this technology, use of other test methods have not been necessary.

### Current Operation and Allocation of Produced Fluids

Oil, gas, and water production from individual wells are measured in each well island (Jivino-A, Jivino-B, Jivino-C and Laguna-A) on a daily basis, through the WellComp units. Wells are producing at an average wellhead pressure of 1.7 mPa (250 psig) and 93 ° C (200 °F).

Producing wells are usually tested for a period of two hours, with a minitest performed every five minutes (as detailed above). The production test figures, for oil, gas and water for a particular well, is an average of the 24 minitest performed in the two hours period.

Production data from Block 15 is collected and controlled per well daily. Once the production for the Block has been determined, a Block correction factor (or lease factor) is calculated to guarantee that the total sum of oil, and gas and water production per well is equal to the total production of theBlock. The lease factors for oil, gas and water are used to adjust the net oil production for each one of the producing wells, giving the allocated production of oil, gas and water.

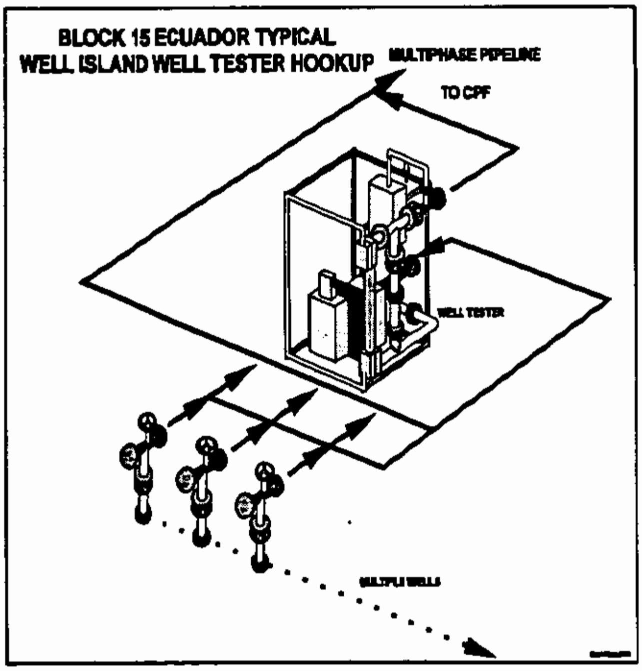


Figure 6

The daily oil lease factor and the number of wells in operation are shown in *Figure* 7 from March 1994 to July 1995. The daily oil lease factor is defined as the:

> Cumulated individual well tests at standard conditions for a 24 hour period using the last accepted test for the individual well, compensated for the down time if any that the well experienced during the period, divided by the stanadard condition oil measured by the fiscalization meter for the same 24 hour period compensated for any stock level changes.

In the graph the WellComp averaged test readings corrected for well down time and stock level changes are compared against the block oil fiscalization meter.[1] Data quality have improved and special events are shown annotated on the curve, during a period of increased system complexity with the number of wells quadrupling over the period shown.
Of special note is the period preceding July 1994 (note 1). Paul Munroe technicians, combined with a trained OXY expert made adjustments to the four WellComp units and corrected several hardware problems. Lease factors in subsequent months improved greatly. A second significant upward trend in the lease factor began in January 1995, which forced re-examination of the units (note 2). It was discovered that various individuals with access to the WellComp configuration menus had different interpretations of some key calibration parameters. Additional training in the proper calibration setup of the units, combined with tight control over changes made to the calibration resulted in a sharp improvement in lease factor.

It must be kept in mind that this data is not a laboratory comparison of WellComp data against a single standard measurement. Significant errors can come into this data which are not dependent on the WellComp, for example errors in: wells on or off, stock level changes, temperature and pressure corrections to crude oil, wells cleaning up, and frequency of testing. This measurement is primarily dependent on the WellComp data and as such is the primary field data quality standard used by Occidental for the test measurement.

Data from individual well islands is taken by floppy diskette to the CPF for integration into the well allocation software. The "Production Operator's Workstation and Reporting" (POWAR) computer system is currently used for collecting data in the field and then moving it through the CPF oil accounting system. Reporting requirements are handled automatically within the program: test information, downtime, stock volumes and balancing, proration factors, etc..

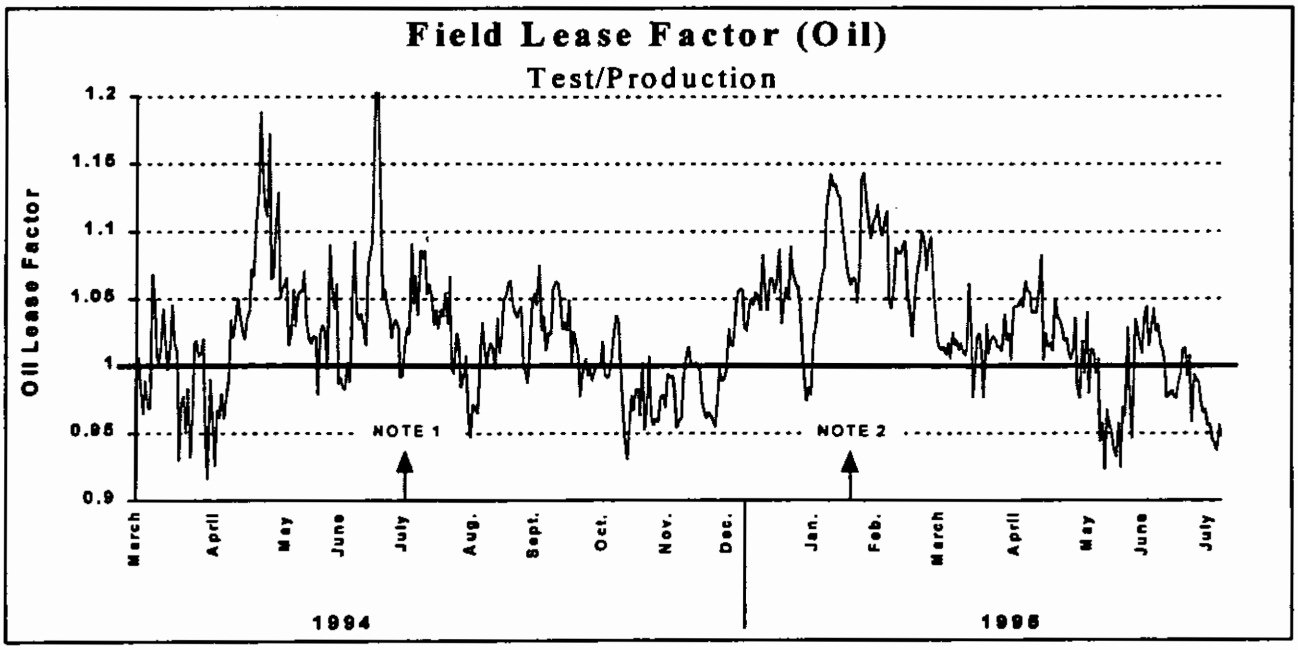

Figure 7

An interface to POWAR was developed for production allocation at reservoir level for wells with commingled production, and for generation of special production reports formats required by the Company and by the Government.

### Operating Parameters and Flowrate Ranges

At the initial start-up of the first WellComp unit at Jivino A in May 1993, apparent discrepancies to the LACT production figures were detected because WellComp was displaying the production figures at the line operating conditions and the LACT figures were given at standard conditions. The WellComp unit was then calibrated to display the data at the same standard conditions as the LACT unit.

To optimize the accuracy of the four WellComp Units installed in Jivino-Laguna-Napo field, the following data for each well on the four production well islands was predetermined and programmed into the Units: (1) density of oil, water, and gas at operating conditions; (2) shrinkage factor for oil that corrects the oil measured at operating conditions to standard condition, taking into consideration the effects of dissolved gases, temperature and pressure; and (3) dissolved gas factor ($R_s$) that indicates the volume of gases coming out of solution as the oil drops to ambient conditions. Update and adjustment of this data improves overall accuracy in wells producing from multizone completions, where the possibility of widely varying oil and water densities exist.

The following table shows the overall range of well flowrates measured by the 4" WellComp in Block 15 and the range of fluid characteristics handled.

## OPERATIONAL CHALLENGES

During the two and one half years the WellComps have been in operation in Block 15 numerous challenges have been met and overcome. These are important parameters to keep in mind wherever technology of this type is considered for application.

### Strong Working Relationship between Vendor and Operator

Based on this experience, the successful application of oilfield technology requires the close coordination between the technology developer (Paul Munroe Engineering) and the technology user (Occidental). Most of the successful efforts during the program resulted from close coordination; In contrast, most of the setbacks in the program were a

| | RANGES OF FLOW RATES | | | FLUID CHARACTERISTICS | | |
|---|---|---|---|---|---|---|
| | Oil m³/d (bopd) | Water m³/d (bwpd) | GAS- Sm³/day (mcfpd) | Oil Grav. S.G (API) | Water salinity ppm Cl⁻¹ | GAS GRAV. Air = 1 |
| **Minimum** | 24 (150) | 0 | 28 (1) | 0.95 (17.1) | 400 | 0.84 |
| **Maximum** | 1,200 (7,500) | 1,200 (7,400) | 11,000 (400) | 0.89 (27.0) | 43,000 | 1.29 |

[1] The fiscalization meter is a: Daniel Industries 6 inch dual case positive displacement meter, with a flowrate design of 30,000 bopd under conditions of 0.91 s.g. oil at 88 °C, with proving by means of: Daniel Industries Bi-Directional mechanical displacement meter prover.

result of poor coordination and lack of goal alignment between Paul Munroe Engineering and Occidental personnel. It is important that early goal alignment be pursued between the developer and the user of oilfield technology of this type.

**Strong Management Commitment**

Field personnel familiar with traditional test separators were initially skeptical regarding the accuracy and functionality of the WellComp equipment. A strong commitment by management to utilize this equipment and to maximize the use of the abundant information produced by the unit was essential to overcome this initial resistance. Attitudes from the beginning of the program changed dramatically once technical personnel took ownership of the equipment and began maintaining it themselves. Now there is unanimous consent among field personnel that this equipment is a superior replacement for traditional test separators. In general, any new-technology equipment placed into the oilfield typically requires strong sponsorship by management to ensure the overall success of the program.

**Technical Support and Training**

Twice in the last two and one half years the lease allocation factors have forced a major look at both the hardware and software of the units to confirm the best possible data is being obtained from the units for proper management of the Block 15 reservoirs. The first evaluation resulted in some major operational revelations:

In the case of traditional three-phase separators, it is essential to have knowledgeable personnel operate and maintain the equipment, and to collect, correct, analyze, and assemble well test results. They must use their experience and judgement about the historical data from a given tested well, in order to provide accurate well test data and diagnose production equipment problems. Although the WellComp promised to eliminate many of the "expert" personnel requirements and reduce the human subjectivity of final test results, initial underestimation of the type of support required for operation and maintenance of the equipment became an obstacle for the success of the program.

Since the overall technology was new, and the latest developments were to be included by the time equipment was to be delivered, a great deal of dependence was placed on the manufacturer for operation and maintenance of the equipment over the first year. Inexperienced technicians from Paul-Munroe and the lack of an OXY technical expert trained in the operation of the WellComp unit amplified the initial teething problems. Upon realization of these shortcomings, Paul-Munroe responded with higher qualified technicians and OXY committed to a training program for OXY field technicians to take over operation and maintenance of the equipment. The strategy was successful, and the equipment has been operated and maintained by OXY personnel for the past one and a halfyears with minimal support from Paul-Munroe.

The second evaluation of the equipment due to lease factor allocation factor analysis revealed inconsistencies in those calibration parameters which directly affect the final test results. Additional training with regard to requirements for the key calibration parameters, and tighter control over changes made to these parameters has resulted in reliable well test data from all sites.

**Automation Valves**

The initial Block 15 manifold and WellComp order envisioned, that wells be routinely automatically cycled into test with well status and test flags (on/off) signal to the CPF Process Logic Controller (PLC). This portion of the project was cancelled after partial automation of three wells. This has resulted in a continued need for permanent production staff at each production island to turn wells into test and locally monitor equipment on an hourly basis. This has reduced the economic benefits of the system to the operator. It is recognized, that this is not ideal since a partially automated system results in minimal economic benefit compared to a fully automated system.

## CONCLUSIONS

The following general conclusions have been reached with respect to the five years of experience Occidental and Paul Munroe have with testing and field proving of wellhead testing technology.

1. Lab and field trials prior to full field utilization are important to addressing early the critical technology issues prior to application; and led to a successfully field application.
2. The cost of technical support for operation of the units in a remote international location were underestimated by Occidental at the time the unit was selected. In spite of this overall unit cost increase (considering the additional cost of technical support for fifteen months) the WellComp units have maintained a cost advantage over traditional well site testing in Block 15.
3. Irrespective of personnel costs associated with the maintenance of the WellComps, the maintenance material costs have averaged to date less than the value of one barrel of oil equivalent per unit day of operation.
4. Some additional technical support on hardware and software is required on an on-going basis, but this is not inordinate and the Occidental staff maintenance of the units is going well and in line with the maintenance of other oil field application technology in use by Occidental.
5. The WellComp unit has proven to be key to meeting the environmental goals for the project to allow multiphase flow to a central producing station, with no compromise on well test data for effective reservoir management in Block 15.
6. Test accuracy obtained from the unit exceed conventional test separation capabilities and indeed initial Occidental objectives over a wide range of flow conditions.
7. The automation benefits of the system have been reduced by the lack of actuators on the test manifold valves tied back to the central station. Were this to be carried through it is anticipated that further economic automation benefits would be realized from the WellComp units in Block 15.

## FURTHER TECHNICAL ADVANCEMENTS - POST BLOCK 15

Several technical advances have been made over the past two and one half years since installation of the original WellComp units. New computer hardware and software on the unit provides connectivity to multiple devices. The unit may be controlled, and data downloaded via an infrared palmtop or notebook PC, and may simultaneously communicate with a local PC operator station, a remote SCADA system (MODBUS slave RTU), and a local RTU for valve automation. Curves for shrinkage and $R_s$ may be entered (instead of single point entries), and calibration of most instruments have been automated. Additionally, extended on-line diagnostic capabilities report failures and miscalibration on many instruments.

Fluid conditioner designs have advanced, and level control now includes adaptive gain algorithms to provide robust operation over a wide range of flow conditions, without the need for operator interaction.

Developments continue to fully utilize the computer ability to set-up, calibrate, diagnose, and report data on the WellComp unit. Work also continues to reduce the size of the fluid conditioner and keep the overall footprint to a minimum.

One of the challenges facing Occidental is how to use the large volume of reliable data now available from the WellComp, and to integrate and link that data to other Block 15 production system components. The data available from the WellComp and linkage to other system components is the next step in advancing the use of the technology. Other system components to which the WellComp is currently not linked, include the Variable Speed Drive (VSD) for the downhole ESPs and the automation and control system at the CPF.

This linkage is important so the entire production process can be improved. At present the different system components are reviewed functionally rather than in a process manner. A true process look will require integration of data an understanding as a process rather than a series of functions relating to one another, e.g. Maintenance and Production.

## Closing Remarks

Our objective as an industry in multiphase flow measurement is and should remain:

"Have available to the oil and gas producer and in-line wellhead device, which can provide and integrate to a daily basis, accurate three phase (gas, oil, water) flowrates and fractions independent of transient fractional variations in volume or gravity of the three phases."

The technology has not arrived to accomplish this lofty and worthwhile objective. The WellComp however, is a significant intermediate step on this particular path of technical evolution.

# References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.