Title: Summary of Measuring and Metering CO2 for Enhanced Oil Recovery Methods and Problems by Fred DeBusk

SUMMARY OF MEASURING AND METERING CO2 FOR ENHANCED OIL RECOVERY METHODS AND PROBLEMS

Note:

The summary below is taken from tapes made by Fred DeBusk at the conference noted above that was held on November 13, 1984 at the New Mexico Junior College, Hobbs, New Mexico. Some parts of the tapes are difficult to hear so portions of the program were skipped and some of the information covered may not be as it was presented.

The members of the panel were:
Program

Introduction and Background
of the ProblemJ.J. Taber
Director
Petroleum Recovery
Research Center
Socorro, NM
Introduction of Speakers
by Panel CoordinatorF. David Martin
Senior Engineer
Petroleum Recovery
Research Center
Socorro, NM
TopicPanel Member
Properties of Carbon Dioxide
Density
Coefficient of Expansion
Temperature Effects

Impurities-Absent-
Hank Hankinson
Sr. Staff Associate
Process Engineering
Phillips Petroleum Company
Bartlesville, OK
Experience with the CO2 Pipeline
to the SACROC UnitCarl Fesmire
Senior Engineer
Chevron U.S.A., Inc.
Midland, TX
Metering CO2 for Allcoation
-- Wellhead MeasurementsB.J. "Joe" Alford
Sr. Staff Facilities Engineer
Shell Western E&P, Inc.
Houston, TX
Measurement of CO2 by Means of Turbine
Meters and Densitometers as used in the
Sheep Mountain PipelineHarvey Lewis
Advisor, Engineering

Services Dept.
AARCO Pipeline Co.
Houston, TX
Plant Startup and Trouble-shootingRobert M. Ross
Fluid Measurements
Specialist
Amerada Hess Corp.
Tulsa, OK
Clarification and DiscussionPanel Members
Questions and CommentsAudience

INTRODUCTION
David Martin
Petroleum Recovery Center

CO_2 is different from any other gas when we attempt to measure it. The purpose of today's conference is to present actual operating experience in this measurement. This will reflect actual experiences of users and cover areas of information not in print to date. As evidenced by the attendance there is a great need and interest in this subject. The purpose of this conference is to share the experiences and attempt to establish the state of the art of CO_2 measurement.

Mr. Hankinson of Phillips Petroleum was unable to attend so his presentation on properties will be touched on by other panel members. We have allocated 10 minutes for each speaker for introductory remarks followed by a question and answer section with no time limit.

CARL FESMIRE - CHEVRON USA
EXPERIENCE WITH THE CO_2 PIPELINE TO THE SACROC UNIT
(Note: Presentation was difficult to hear so portions were missed on the tape.)

The original work was on the compression of CO_2 in the supercritical region. The data was good enough to produce a pipeline simulation employing properties of CO_2 in the range they operate since they had good data and were able to successfully model their line. They have CO_2 in a mixed composition with small amounts of other components. They found that these trace components had a considerable effect on the compressibility factors and the data they developed was in the 600 - 1000 psig range and higher. They now wish they had done more work on the lower pressure ranges because of their present needs. The equation they use is a modified BWR that they developed based on their compositions with up to several percent non CO_2 components. What the industry needs is an agreed upon set of data that will allow everybody to get the same readings covering all measurement from the production wellhead, to the pipeline, to the injection wells with recognition of the variable compositions that exist.

B.J. "JOE" ALFORD
METERING CO_2 FOR ALLOCATION - WELLHEAD MEASUREMENTS

Shell production of CO_2 is under the control of the production department and is needed for reservoir studies primarily and allocation. They designed their system in 1983 and put it in service in 1984. The wells operate in the 750 PSIG, 55F range of conditions. The well deliveries are in the range of 20 MMCF/day using cluster facilities with a centralized test separator. The fluid is separated for measurement and then recombined for compression.

There is two stage compression, first stage to 500 psig to 1000 psig and second stage 1000 to 2000 psig. With the compression the "CO_2 arrives at the pipeline at 100F which gives a density of approximately 49#/cubic foot". Thus, the Cortez pipeline operates in the "dense fluid" Super-critical State". Because of its fairly constant conditions it is fairly easy to measure using an orifice meter and densitometer with a flow computer. We are satisfied with our measurement based on our daily balances. They point out that the pipeline and total production use the same measurement equipment at the entrance to the pipeline and the cluster measurements allocated back from this measurement. There are two compressor stations and six cluster points around each compressor station. Surveillance is kept on the well clusters. The pipeline meter stations are located as far away from the compressors as possible to minimize pulsation effects. In each cluster there is individual well allocation. The manifold at each cluster is the same. The test separator is a three phase separator removing water from liquid CO_2 at 52lbs/cubic ft., and gaseous CO_2 at 9lbs/cubic ft.

The liquid and gaseous CO_2 are measured separately and recombined. All of the measurements are made in standard cubic feet (the liquid is converted to standard cubic feet of gas equivalent) and the total well production is reported in standard cubic feet. These are a total of forty measuring points so cost was an important consideration and they were prepared to sacrifice accuracy to keep the costs down. The orifice is used for both the liquid and gaseous CO_2 measurement with densitometer for liquid and Fpv corrections for the gas. The liquid is calculated based on differential pressure and density as the measured variables and yielding pounds per hour. The gas is calculated using a Daniel Flow Computer using a matrix table to enter the supercompressibility values. These are nine values entered into the flow computer based on pressure, temperature and composition. These work OK as long as the measured parameters stay in the range of the original data set in the matrix.

If we had to start over again we would use weight, not cubic feet conversions, because of the lack of good data. This is due to the impact of the possibility factor of CO_2 on the calculation. This may still be the answer. We would like industry to find and adopt an equation of state which everyone could accept instead of everyone having a different modified B.W.R. equation.

HARVEY LEWIS - ARCO PIPELINE COMPANY
MEASUREMENT OF CO2 BY MEANS OF TURBINE METERS
AND DENSITOMETERS USED IN THE SHEEP MOUNTAIN PIPELINE

We have a wide variation in opeating conditions. The pipeline starts in Colorado, goes through New Mexico and terminates at Seminole, Texas. We start out at 9000 feet elevation with pressures varying from 1100 to 1500 - 1700 psig range. We handle liquid at 1100 - 1200 psig at 90 - 110F. The elevation eliminates the need of pump equipment. We actually use pressured injection from Bravo Dome. We have deliveries at Plains with receipts and deliveries at Denver City and Seminole. We have pressures of 1900 - 2250 at 50F - 80F liquid phase on the southern end and 1100 - 1200 psig - 90 - 110F dense phase (30lbs./cubic feet) on the northern portion of the system. We use turbine meters with densitometers following normal liquid pipeline techniques including pipe provers. Even in the 30 - 55 dense phase we treat this as normal "liquid pipeline measurement". At Sheep Mountain we calibrate the densitometers on both sides of the critical temperature (i.e. 60 - 70F at 2000 psig and 90 - 110F at

1100 psig). We don't worry about them operating correctly across the critical point. We feel we have established good data from the densitometers using a piconmeter for testing that is assumed to be accurate. Checking density tables in the same range of operation we find differences of as much as 10 - 20%. The new NBS data is just as bad on the other side of the densitometers.

We have fed the data back to NBS for their database but we believe the use of PVT is in bad shape, so we have chosen mass measurement using the following equation.

Pounds Mass = Turbine Volume x Meter Factor x Density

If necessary we convert from mass to volume based on our contract requirements. A typical meter station will have multiple meter runs with strainers, straightening vanes, turbine meter, densitometer, control valve, bypass connections for prover, small volume prover (for whole station). The control valve controls pressure with a flow override to prevent over ranging the turbine. The accuracy of the density is determined by a calibration standard and field tests of performance is determined by a picnometer test. The picnometer must be carefully controlled to the same temperature and pressure as the densitometer. We install thermometers at the densitometer and downstream of the picnometer, pressure is taken downstream of the picnometer also. Sampling must be at a slow enough rate so velocity head change won't cause an erroneous pressure. These precautions are of vital importance with CO_2 because of its sensitivity to small changes in pressure or temperature making such large changes in density. We make sure there are no leaks in the entire system. By using a proper technique we repeat out checks to within .01- equipment is shaded (no direct sun). The weighting system for the picnometer must be accurate with certified weights (special). The densitometers should be stable (not all makes are). Provers should also be stable so that once calibrated they should remain in calibration. Some units we have checked have shifted from 1 to 2% month to month (one unit now works OK). A major consideration is how much maintenance is required. The turbine meter accuracy and mechanical condition must be checked. We collect material on the blades and dirt in the bearings (extra drag). Be careful not to over range which can be done in pressuring up or blowing down - we have bent blades while doing this.

This was indicated by a factor shift, but still gave repeatability with large proof curve shift. You must design and operate your system to establish a repeatable meter factor. We use a rimmed type turbine meter but showed a 1% proof curve non-linearity. The manufacturer was consulted and they suggested a lighter rotor that gave a better turn down range. Tell your manufacturer you want a proof curve that is flat on your product. This may require a special rotor. Changes in operating conditions has differing effects on the same meter. They change with density changes. When you use a meter, prove at each operating condition as they change. The curves on the meters show a different set of data and changes in meter factors with rate of flow. We use a small volume prover for meter factor determinations. In the comparison of prover volume and meter volume it is critical that pressures and temperatures be accurately determined. We have lots of problems with densitometers, meters and provers (particularly seal problems) that still need to be identified and corrected. However, we do have one prover that has operated eight months without trouble.

M. L. WILLIAMS - AMOCO PRODUCTION COMPANY
AMOCO'S OUTLOOK ON MEASURING CO_2 IN THE BRAVO SYSTEM
(Note: Tape was faint and difficult to hear)

Amoco can't add much to what has previously been said since we are basically only now beginning to look seriously at the problems. We have no field experience to speak of and will spend most of this discussion on standards. What experience we have had is with pure CO2 without impurities, (Rest of tape was inaudible).

ROBERT ROSS - AMERADA HESS CORPORATION
PLANT STARTUP AND TROUBLE SHOOTING

Our system includes a back pressure regulator, an overhead hoist for prover disassembly. To seal the inside cylinder of this old style prover we have tried several modifications but this one shows a seal, wipe ring, the piston is 2-3/4 inches wide. We have tried many different elastomers and if this problem is solved the provers will work fine. We run a leak test to check the piston sealing and have found a lot of problems. The elastomers must have wear resistance since the service is pretty dirty. The worst combination we have tried is teflon working on a chrome-plated unit. We found that we had to reduce the finish to 16 micro-inches in the measurement portion of the barrel and 32 micro-inches outside of the measurement volume where the piston operates. We have tried virgin teflon, 85% teflon and 15% glass, and other elastomers. We will get further into this later. The alignment of the piston is very critical and difficult to obtain. The seals between the hydraulic system and the CO2 is also a point of critical concern. The large flange (3500 lbs. weight) would shift as we bolted it up and caused an alignment problem. A great deal of time was spent on this problem and resulted in a change in design and a special procedure. The basic mechanical engineering problems had to be solved first. The fit-ups had to be changed to get and maintain alignment. Assembly aids had to be developed to simplify the problem including an external hydraulic system to cycle the piston without pressurizing the unit. We pulled a vacuum between the seals to check their leakage. If the seals were checked with pressure they were blown out. A torque wrench is used to torque the bolts on the large flange so it would maintain alignment. When you blow down a 3200 psig CO2 line you form dry ice at - 110F. as well as forming ice on the outside of the prover when the unit is supercooled. The piston should not be moved while ice or dry ice is inside the unit. Time should be taken to allow them to dissipate.

We have tried super lube (silicone) on the seals, but CO2 will leach out the oily carrier and leave a dry white powder without lubricating qualities. CO2 will also cause problems with plug valve lubricants. One prover showed a bad honing job and the chromplating was uneven. Watch this closely when accepting a new prover. You can't be too careful when embarking on unknown paths. We didn't know how "smooth" smooth had to be or how tight a seal had to be to seal off. We found out the CO2 sealing is entirely different than sealing natural gas or water. However, we did find out that whatever seals nitrogen will usually work on CO2 (molecular size problem). So do all your test with nitrogen. Use a hydraulic oil in that system that is compatible with CO2 and the seals chosen. Some elastomers used in seals will react with various oils used; it is best to settle on one single oil that is used in your whole system. We have tried many different seal materials including fluorocarbons with 85% teflon and 15% coraphite. This seal had a problem when we left the differential pressure on the seal after a leakage test or when not in service. Once we recognized the source of the problem and kept the seal pressure balanced we eliminated the trouble and improved the life of the seals. We use an M & J valve for our by-pass valve and have had elastomer problems with the seals. This valve used a spring loaded slab seal and teflon seal. The chrome plating in the valve was damaged by trash and dirt in the valve and this caused a leak. We have changed a number of slabs. This is a strainer used in the CO2 service (dry 5 lbs./MMCF water dew point) and it shows corrosion on all parts even with the dry conditions. Anodizing got rid of this problem. The meter tube also is corroded. This may have come from the initial hydrostatic test of the system with water containing bacteria that produce "sulfate" and the system was not properly cleaned. This bacteria will damage even stainless steel. We have found only K-monel is safe from damage. Several large pipelines have found this problem with the bacteria including damage to stainless steel.

Sulfate producing bacteria will create corrosion that is separate from the problems of carbolic acid (formed from the CO_2) and sulfurous acid (formed from H_2S). Cases have been found where the sulfate producing bacteria can operate in rain water collected in equipment or pipelines during construction. These bacteria don't come from the CO_2 or the H_2S but have to already be present. 99.7% pure CO_2 lines have shown these problems. We have found lubricating oil inside our lines and metering stations which comes from our compressors operating at 4200 psig discharge. They flood these compressors, and the excess oil will collect in the meter tubes and meters which will create flow pattern problems. It gets on the plate and seal rings. Here is a seal ring coated with oil that has collected dirt. Our lines also have triethylene glycol at a rate of 1 gal/million cubic feet of through-put and our lines are handling 120 million cubic feet (120 gallons/day of glycol). Where does this go? We don't know, but by analysis of the collections on the metering system, we find them to be compressor lube oil.

On the Brooks prover we have a poppet valve that uses hydraulic oil to operate. This unit is uni-directional and you can calibrate it on both sides of the piston. However, you must use the same calibrated volume side with the data collected to be sure your meter test is using the right base volume.

We have bent turbine meter blades and we find they will not repeat a calibration. In addition, the curve will shift up or down and will change the turndown ratio. The bending isn't coming from trash in the line but from meter over range during pressuring up and blowing down. We have tested the Texas nuclear densitometer.

The elastomers used in down hole operations have also been a problem. In addition, to the CO_2 we have salt water, and H_2S some times present. Our Production Department has tried "critic" rubber, butyl rubber, chlorohydrin (HTO)M, EPDM rubber, fluorocarbon elastometer, natural rubbers, nitriterrubber, peroxide cured butyl nitrite, silicone rubbers, florosilicone rubbers, urethane, "ethylene-propane", propylene, copolymers among others.

We found we need the following information: tensile strength, elongation, burnell hardness, durometer hardness, service temperature, abrasive resistance, compression set, and how they react with the hydrocarbons present. For CO_2 and H_2S service we have found EPDM United 62, 85 durometer hardness has performed best. It can handle the explosive decompression from 2200 psig to atmosphere in a blow-down situation. During pressuring up it will swell and stretch. This material may solve some of your problems, but not all. If you find one that will solve all of the problems, let me know. The problems become more severe as we have wider variations in operating conditions of temperature and pressure. Question: Is lubrication a problem with turbine meters and what lubricants are used? Answer: No, we have not had any lubrication problems and there are Daniel turbines in the whole system. We have one Brooks on test and it has had no lubrication problem. We have had problems with dirt, but these show erratic pattern. We take them out and clean the deposits on the blades and in the bearing area and they straighten out. This doesn't happen very frequently. We have a system where we have an orifice checking a series of turbine meters and they don't check too well. Its not a problem of the different kinds of meters so much as the definition of the fluid densities. If things are done right we might get a balance to 5%. On our pipeline we have turbines on one end and orifices on the other. But our main concern at present is the liquid carry over problem, but we think we about have this solved. On our orifice installations we get deposits and we have less of this problem on our turbines since they are proved. This is with the prover-turbine combination. Without proving the turbine and the orifice both have problems. If you are not handling pure CO_2, the Fpv data is not good and both meters have problems. The choice of a meter orifice or turbine – is not so much one is more "accurate" than the other, but of operating them to minimize the problems. Based on experiences of companies to date, some choose one and others choose another.

COMMENT FROM M. L. WILLIAMS - AMOCO
(Note: Hard to hear)

We are using orifices because of familiarity but we have had enough experience to know whether they are best or not. (then M. L. explained the new gas standards)

ROBERT ROSS (CONT'D)

We are pleased that more information is being shared at this meeting. We've heard from the Cortez, Esky, Bravo and two others. We have heard of the turbines used with small provers on pipelines and orifices at wellheads and all kinds of calculation problems with compressibility a major problem. Basically, we have learned that no one answer will handle all measurement problems and that all aspects need some improvement. The small prover of Waugh has had a number of problems based on its design which uses a uni-direction piston, double chronometry, photo-optics, or fiber optics to sense displacer position, waterdraw calibration for certified volume and microprocessors for calculations. The maintenance experience of trouble shooting the prover, including the piston and its seals, the alignment problem, the by-pass valve and others that we have run into we have explained on experiences. We encourage additional conferences such as this as we have further experiences to share.