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REPORT ON DESIGN, CONSTRUCTION AND TESTING OF CO_2 BREAKOUT SYSTEM FOR GEOTHERMAL BRINES

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DISCLAIMER

SUMMARY

A skid mounted test facility has been built for determining conditions at which CO_2 flashes from geothermal brines. The system has been checked and operated at one geothermal plant. It performed as designed.

The equipment is designed to operate at temperatures and pressures typical of wells near Heber, California. (Nominally 180°C and 300-500 psig). It has heat exchangers which can cool the brine to less than 70°C. (The cooling water is recirculated after being cooled by a forced air heat exchanger). Breakout pressures can be determined for any temperature between 70°C and wellhead temperature.

An adjustable orifice provides final control on pressure required to initiate flashing. The orifice is at the bottom of a sight glass. A light beam shines through the sight glass and focuses on a photoelectric cell. The presence of bubbles scatters light and decreases the output of the cell. Results using the cell were more reproducible than those using the naked eye.

Results from one test show a smooth curve over the temperature range 75°C to 165°C. Agreement between the experimental values and calculated ones is discussed.

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INTRODUCTION

Commercial development of producing electricity from geothermal energy depends on solving scaling and corrosion problems. One important scaling species is calcium carbonate (calcite). It forms when carbon dioxide is released from the brine and the brine becomes supersaturated in carbonate. Keeping CO_2 in solution requires pump energy and ultimately increases the cost of geothermal power. Knowing conditions (temperature and pressure) for gas breakout will define pressures which must be maintained to prevent flashing.

Although the thermodynamics of calcite formation is fairly well understood, no reliable methods exist for predicting when flashing and resulting precipitation will occur in geothermal brines. Pumping costs to keep all the CO_2 in solution are not trivial. Generally pressures are kept some "safe limit" above what is thought necessary to prevent breakout. If actual breakout conditions were known, pumping costs could be held to a minimum and still provide a non-scaling plant.

EQUIPMENT DESCRIPTION AND OPERATION

The equipment is mounted on three skids. One contains the actual breakout equipment. A second contains recording instrumentation. The third supports an air-cooled heat exchanger for cooling circulating cooling water. The entire system is designed to be easily transportable and operable at remote locations. The only additional item required is a power supply to run the cooler and instrumentation. Portable generators are to be used at actual well sites.

A flow diagram for the equipment is shown in Figure 1. Detailed test procedures are included in the appendix.

During operation brine flows through an inlet heat exchanger (and/or by-pass) into an adjustable orifice/sight glass assembly, to a gas collection chamber, then on to an exit heat exchanger. Brine flow is controlled using valve V-4 at the exit of the gas collection chamber. Brine temperature at the sight glass is varied by changing the by-pass rate of hot inlet brine around the first heat exchanger. Valves V-2 and V-6 are used. The adjustable orifice, sight glass assembly is the producer and detector of CO_2 breakout from the brine. For any given temperature of the brine, pressure is dropped across the needle valve until bubbles of CO_2 are detected in the sight glass. The bubbles are detected by eye and also by a light source with a photoelectric cell.

Temperatures are measured at points shown using certified type K thermocouples. Pressures are measured with calibrated pressure transducers. All temperature and pressure readings are sent to a data logging system. The data logger paper tape output serves as the permanent record.

The recorder trace from the photoelectric cell is used as an operational guide to be sure the same bubbling conditions are selected at each temperature/pressure point. Other strip chart recorders monitor

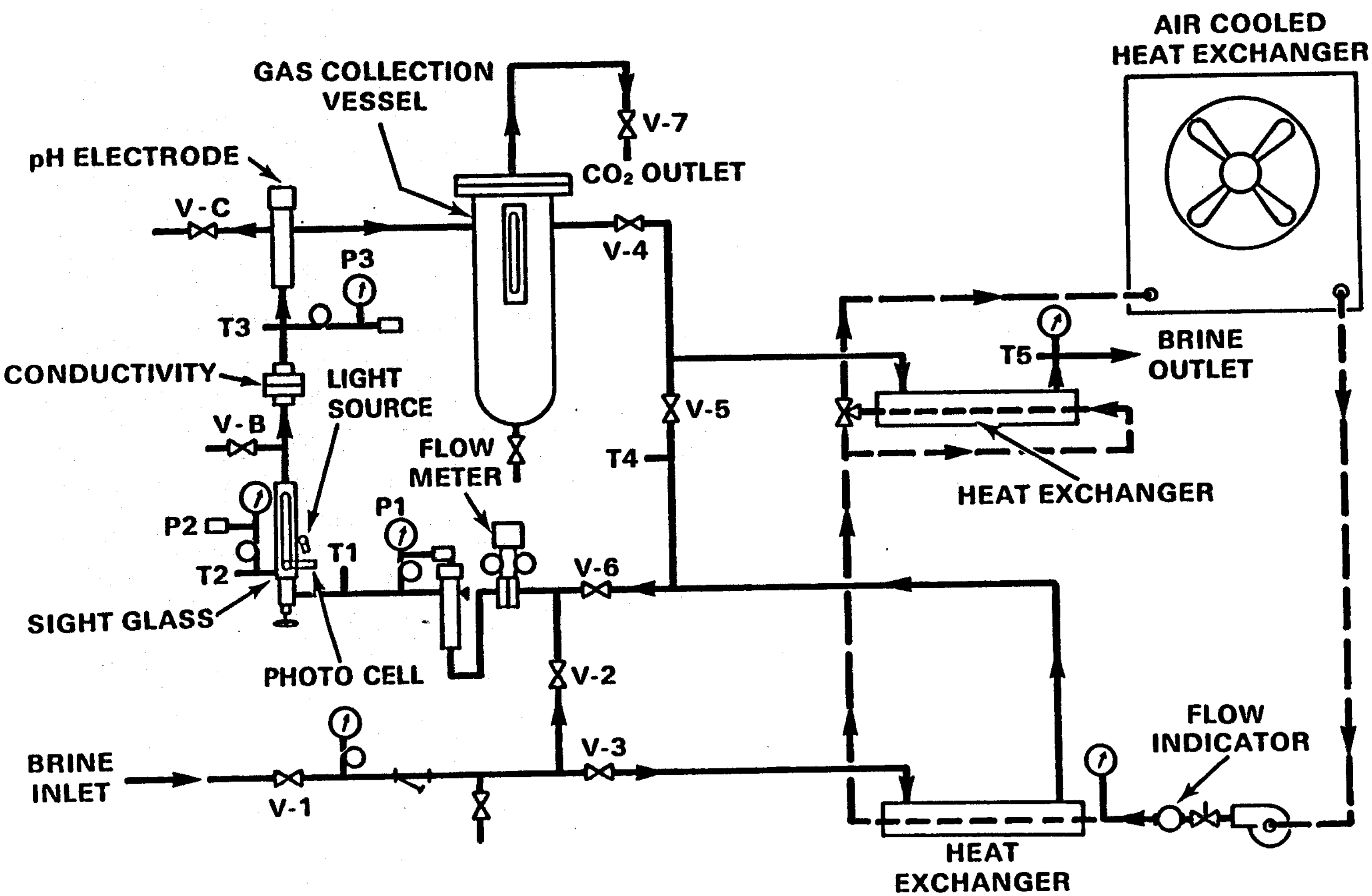

Figure 1. CO_2 Breakout Test System.

temperature and pressure just before and just after flashing. These recorders serve as operational guides only. One additional recorder monitors pressure drop across an orifice. This is the flow indicator and provides the operator visual indication of his desired control point.

EXPERIMENTAL RESULTS

Meaningful results can be achieved only when the brine to this test stand is unflashed. Henced any wells being tested must be pumped.

Two tests have been completed on the system. The purpose of the first test was to verify that all the equipment and instrumentation was operational. Pressure transducers were calibrated against a Hiese guage which was checked in a standards laboratory just before the tests. Thermocouples were accompanied by calibration certificates from the vendor. A certified turbine flow meter was used to calibrate the orifice.

Actual attempts to get breakout information were only partially successful. The point of incipient breakout was determined by eye and thus became somewhat subjective. Data was a bit scattered and discrepancies were not resolved immediately.

A second test was run later after a photoelectric cell was installed on the sight glass. This light detection set-up proved more reliable than the eye. After one break-out point was established visually, it was simple to come back to exactly the same condition at other temperatures and pressures.

The tests were done at the inlet to a geothermal power plant rather than a single well. The sampled stream was a composite of four different wells. This location was chosen only because power and tools were convenient.

Results from t second test are shown in Figure 2. The smooth curve indicates the ta are probably consistent. The same curve shows pressure tempe ture data for water as a reference point. Also shown are calculated urves. One calculation uses Henry's law constants for CO_2 solubility n pure water. It simply treats all of the CO_2 in solution as H_2 $_3$. Disassociation reactions are ignored. So are effects of ion strength.

The second cal lated curve is from a sophisticated chemical equilibrium computer code ich was developed specifically for complex solubility calculations. he code's acronym is CHMTMP, and it was developed internally at ttelle. This code considers several disassociation reactions for $_2$ in solution. It also accounts for mineral precipitates w ch could consume CO_2. The data base for the code includes 8 gas , 187 minerals, and 200 aqueous species. It uses a Gibbs free ene y minimization to calculate concentrations at equilibrium. e data base was current in 1981 so it's predictions are considered as curate as present data and calculational techniques will allow. One li tation for geothermal applications is that no hydrocarbon ga s are considered. They are known to exist in geothermal brines.

Comparison of eoretical and calculated values shows there is still a need to run ex riments. The agreement between CHMTMP and experiment at 77°C is artifi al. The code used this as a reference point to set the chemistry of t brine. Deviations between the code and experiment at higher tempera res cannot be completely explained. Experimentally we had to get to wer pressures than the code predicted. Part of the explanation mi t be kinetic effects which might not allow immediate bubble formati at equilibrium conditions.

Figure 3 provi s more information on the experimental vs. computed data. The CHM P TOT P line is the total equilibrium pressure in the system includi water's vapor pressure. The CO_2 P line is partial pressure of CO_2 only. The implication here is that gas bubbles which do form at high temperatures contain significant amounts of water vapor. They are not pure carbon dioxide.

CO_2 BREAKOUT CONDITIONS

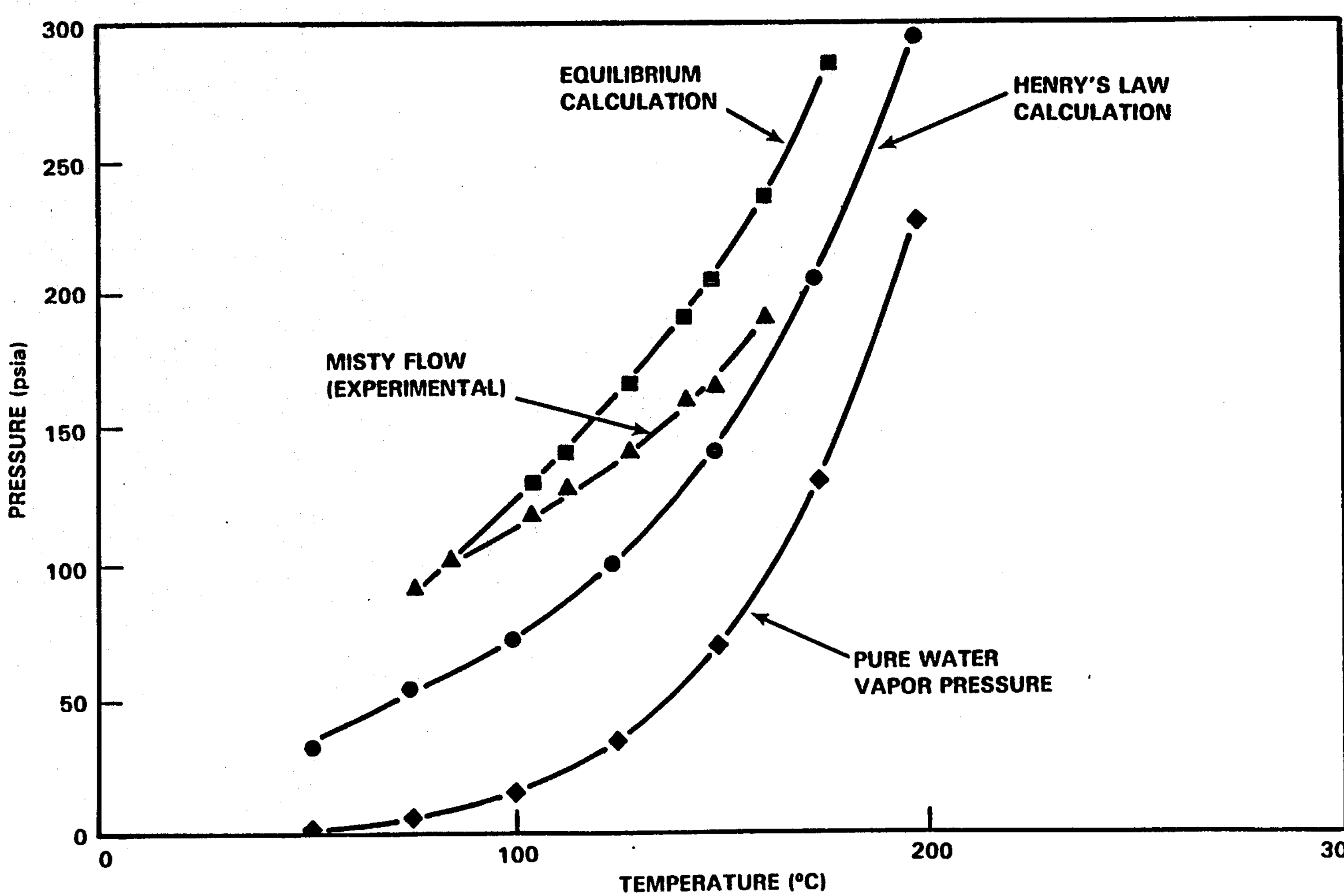

Figure 2. Experimental vs. Calculated Breakout.

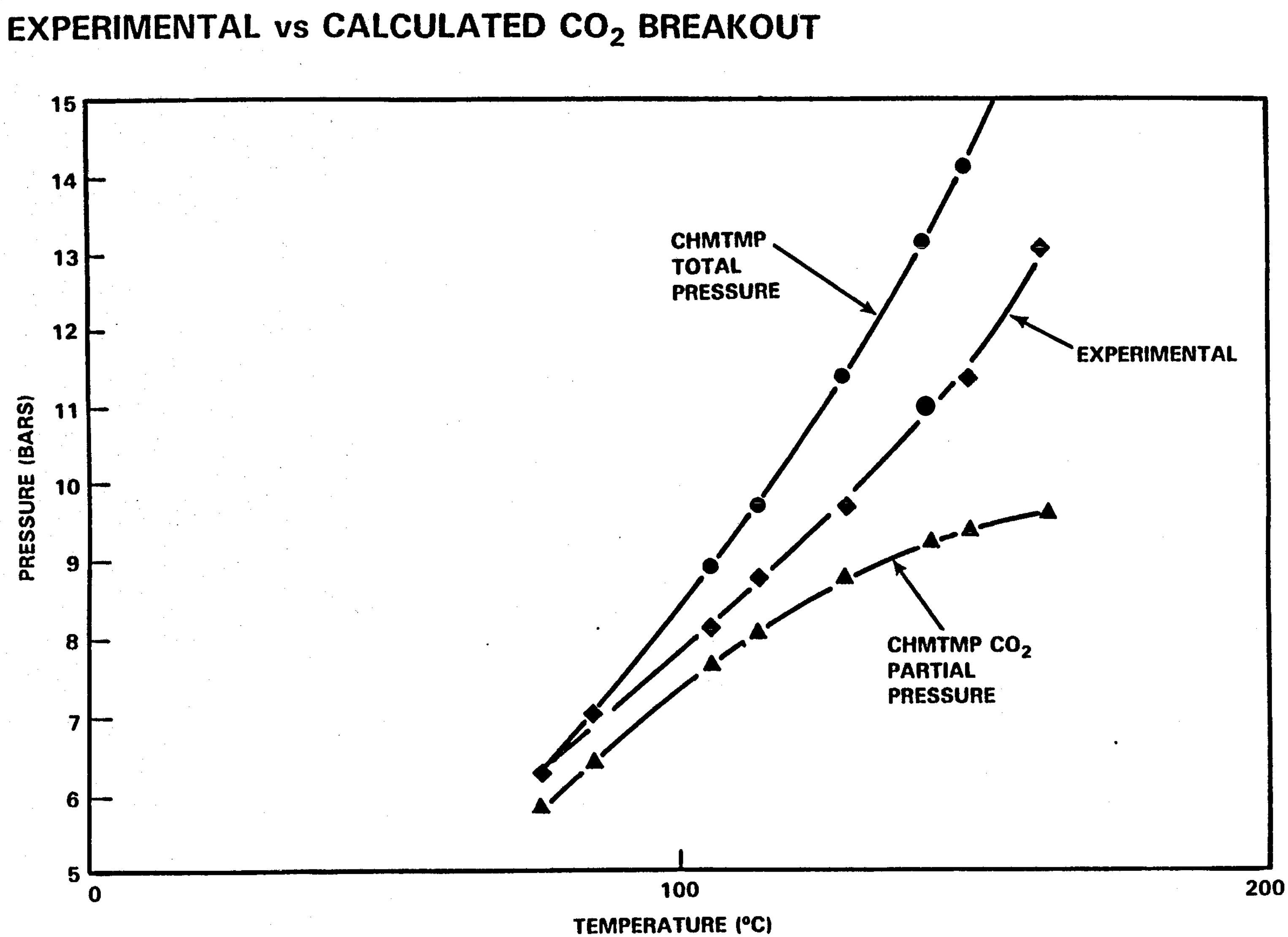

Figure 3. Equilibrium vs. Experimental Values.

APPENDIX

A. Test Procedure For Determing CO_2 Breakout Conditions in Geothermal Brines.

TEST PROCEDURE FOR DETERMINING CO_2 BREAKOUT CONDITIONS IN GEOTHERMAL BRINES

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REF. TITLE: CO_2 Breakout Procedure

APPROVED: ______________
DATE: ______________

OBJECTIVE

The objective of this test procedure is to determine conditions for carbon dioxide breakout in geothermal brines. A pressure-temperature curve is developed which is characteristic of the particular well being tested. The information generated identifies operating conditions which must be maintained to prevent carbon dioxide breakout in a geothermal plant using the tested brine.

Secondary information which may be determined is the change in pH associated with gas breakout. Also the gas phase can be sampled when CO_2 does break out. The sample can be analyzed later for gas composition. (Specifically CO_2 partial pressure is an important piece of information). Ultimately the data generated from these tests could serve as valuable input to models for predicting temperatures and pressures for gas breakout knowing only the brine chemistry.

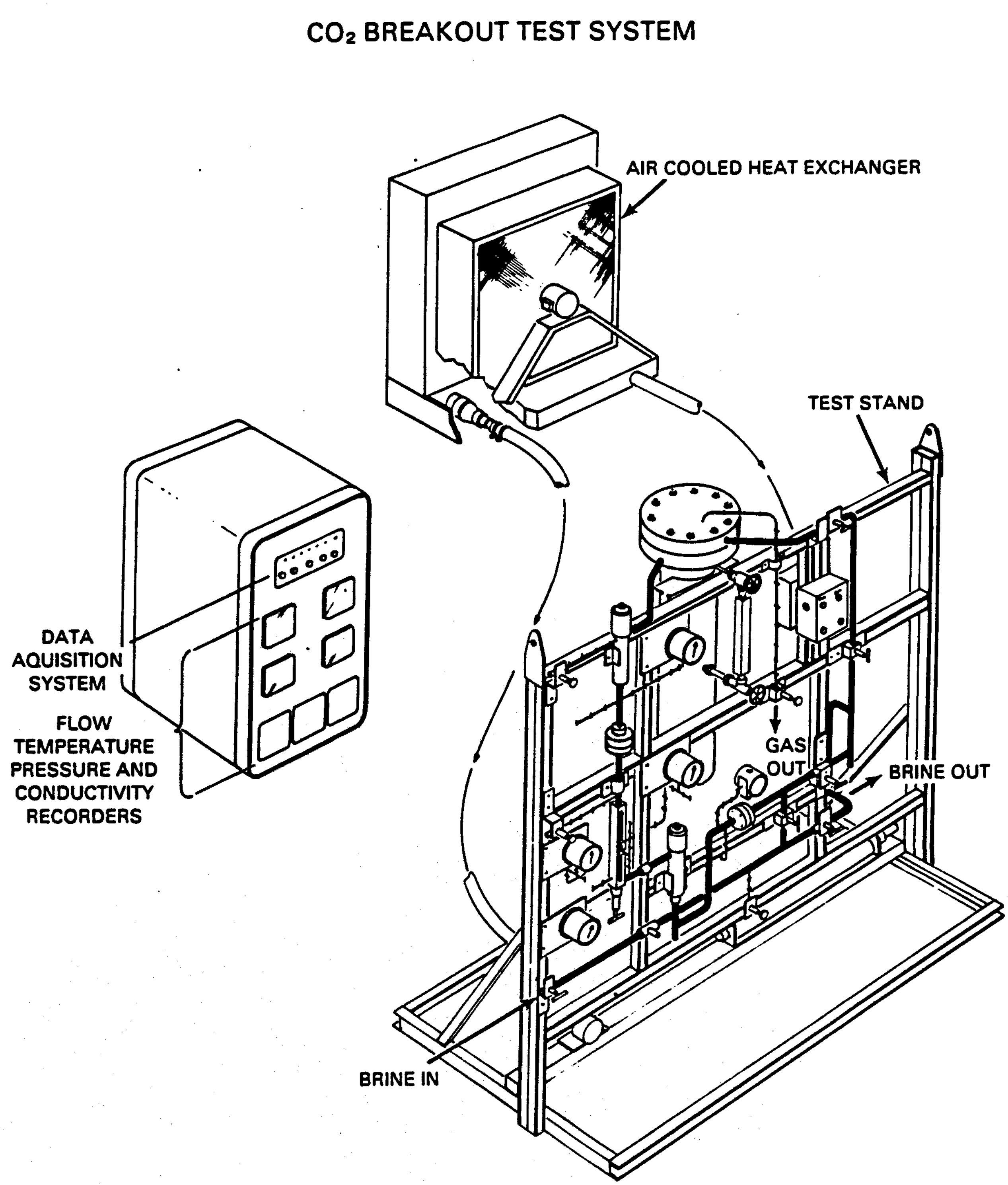
EQUIPMENT DESCRIPTION

The equipment is shown isometrically in Figure 1 and schematically in Figure 2. Brine from a flowing well normally passes through a heat exchanger before flowing through an adjustable orifice. The adjustable orifice is located just below the inlet to the sight glass. The sight glass provides visual verification of the presence of bubbles any time CO_2 is breaking out from the brine. The brine then passes to an expansion chamber where any gas which is released can be separated from the brine. The gas flow can be measured using a totalizing meter. Samples can be taken to determine composition of the gas phase. Brine is cooled to about 130°F in a second heat exchanger before leaving the test stand.

The equipment is designed to operate without a source of cooling water although cool water could be used if available. The heat exchanger system will cool a nominal 3 gpm of brine from 360°F down to 160°F. Temperature, pressure and flow measurements are tied to a data logger for continuous recording of those variables. Also, slots are available in the data logger for instruments which might measure pH before and after the orifice, and conductivity just after the sight glass. The conductivity meter is sensitive to gas bubbles and can provide continuous record of the brine condition with respect to gas evolution provided bubbling is vigorous enough to be detected. The continuous strip chart temperature and pressure recorders are secondary devices to aid operators in adjusting and controlling the system.

A part not shown is a photoelectric cell at the adjustable orifice. A light beam passing through the sight glass is focused on this cell. Output from the cell is continuously recorded on a strip chart recorder. This visual trace provides an accurate reference for the CO_2 breakout point as temperature and pressure are changed.

Figure 1. Equipment Modules.



CO_2 BREAKOUT TEST SYSTEM

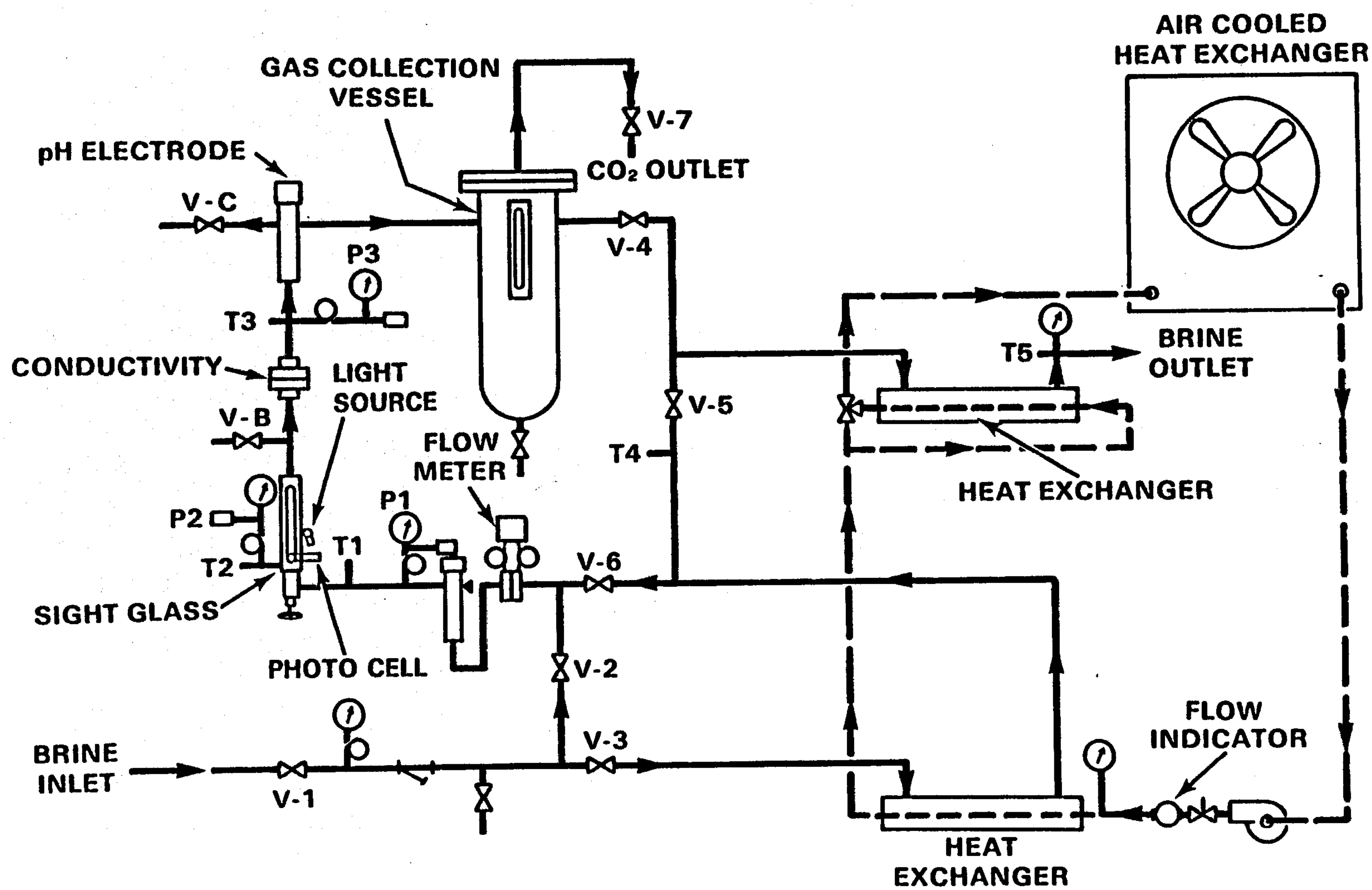


Figure 2. Equipment Flow Diagram.

OPERATION

PHILOSOPHY

Several ways exist to change temperature pressure relationships of brine in an operating geothermal power plant. The test equipment can simulate three of them.

1. Change in downhole or booster pump pressure but with negligible change in temperature.

2. Change in hydrocarbon flow under constant brine flow conditions.

3. Gradually plugging heat exchangers.

Regardless of the cause of a change in temperature and/or pressure of the brine, there should be a unique temperature for any given pressure at which the brine will flash. Theoretically how one reaches that temperature should not matter. The mode of operation is chosen to be the procedure which gives the most accurate results in a reasonable amount of time.

The final product of the tests at any well is a curve similar to Figure 3 showing the pressure/temperature relationship for that well. Deviations from pure water will be of interest on both ends of the curve. Uncertainties can be determined by identifying specific points using two different methods.

BRINE CO_2 BREAKOUT CONDITIONS

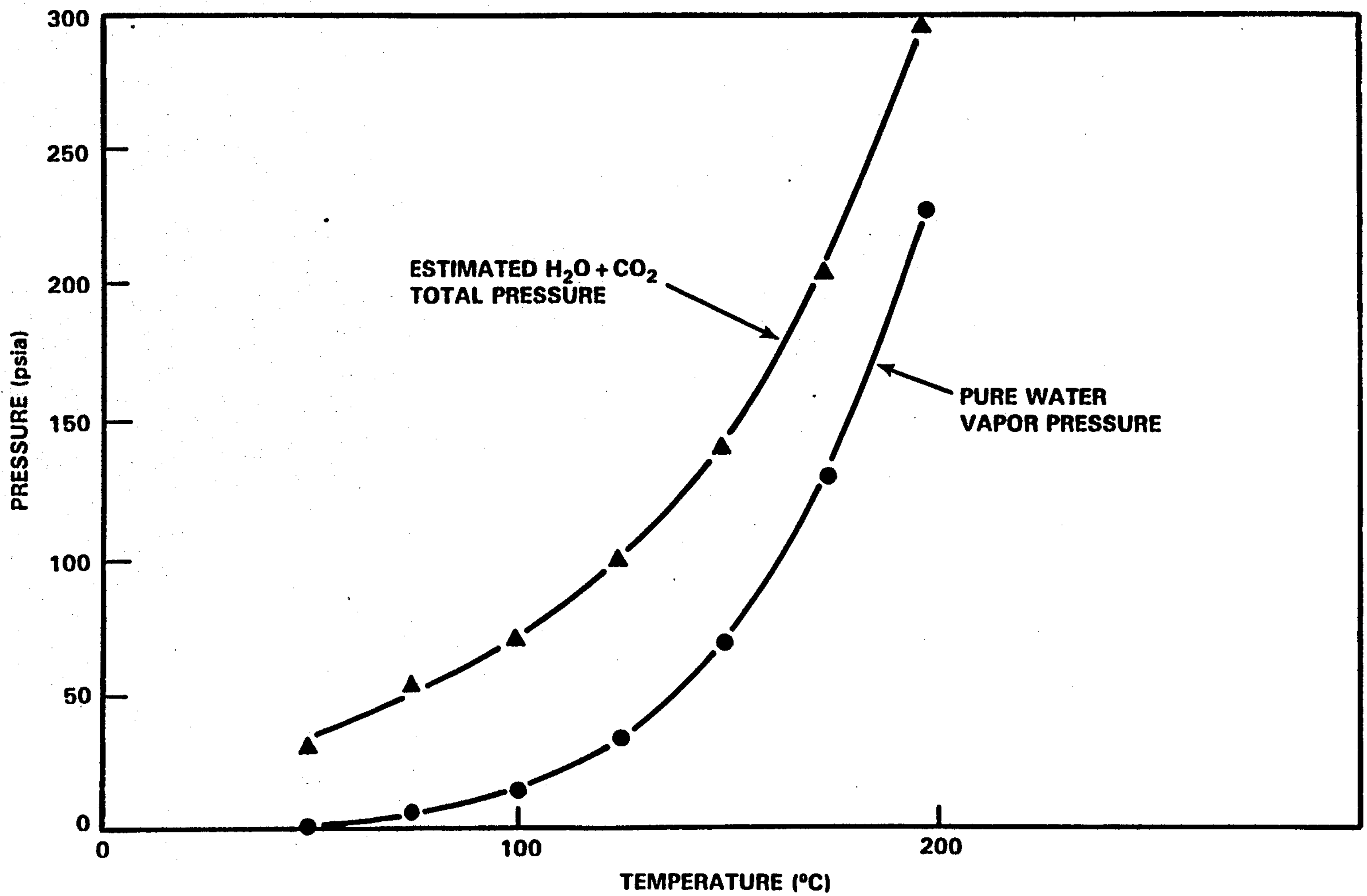


Figure 3. CO_2 Breakout Curve "Typical".

PROCEDURE

The procedure is solely for determining temperature and pressure conditions at which CO_2 releases from a brine. No detailed steps for gas collection and sampling have been tested using this equipment.

General

The actual point of incipient CO_2 breakout is determined visually by watching for bubbles in the sight glass. The photoelectric cell complements visual determinations. In some cases the cell is more reliable than the eye.

Equipment Set-up

Generally the hardware, cooling fan, and electronics arrive on site in three separate crates. They must be uncrated and connected together for testing. A source of 110 VAC power must be available. Electrical connections between the test stand and the hardware are all through a side port and then to a terminal strip in the rear of the instrument panel. All connections are well labeled. The fan requires single phase 220 VAC power. It should be located away from and blowing perpendicular to the instrument panel. This is recommended to keep dust and dirt out of the electronics. Flexible hoses are supplied to connect the cooling fan to the test stand for cooling water circulation.

The test stand is connected to the brine supply using carbon steel tubing. The inlet is at valve V-1. The brine discharge is to an atmospheric sump through heat exchanger 2. The discharge brine should be no hotter than 160°F.

Start-up

Check and fill the radiator loop with clean water. If empty the system will hold 15 gallons of water. Adding an anti-rust agent is recommended. Turn on the recirculation pump to be sure the system is full.

Verify that all the electronics is working. The data logger and recorder for the photocell are critical.

Start the fan. Relocation may be necessary if dust is a problem.

Close valves V-2, V-5, and V-7. Open valves V-3, V-6, and V-4. This assures that when brine flow is started, it will be cooled as much as possible, as soon as possible, in case there are leaks somewhere in the system.

Flow Characteristics at Breakout

At any given temperature, a unique pressure exists where CO_2 comes out of solution in a given brine. This CO_2 evolution is detected visually. Three regimes are noticed as the breakout pressure is approached and then passed beyond.

1. Wavy Flow: At the base of the needle valve on the adjustable orifice, waves similar to heat waves in the air will form. No distinct bubbles can be seen with the naked eye.

2. Misty Flow: The pressure here is still very close to that seen in wavy flow. The difference is that fine bubbles are noticed in the bottom of the sight glass. They almost all re-dissolve before reaching the top of the sight glass. This regime is taken as the point of incipient CO_2 breakout.

3. Bubbly Flow: Gas bubbles are generated at high frequency. They tend to agglomerate before reaching the top of the sight glass. This flow regime must be reached if sufficient gas is to be evolved for sampling and analysis.

Finding Low Temperature Points

In this region a small change in temperature does not change vapor pressure significantly. Consequently it is more accurate to fix a temperature, then adjust pressure until breakout occurs.

The procedure below assumes proper valve settings from the start-up procedure given previously.

a). Start brine flow slowly then adjust to about 3 gpm. The value selected should be maintained as closely as possibly throughout the test.

b). Select the desired temperature by varying the ratio of hot brine to cool brine (out of heat exchanger 1). The split is achieved using valves V-2 and V-6.

c). Approach the expected breakout pressure (using pure steam values if nothing better is available) by throttling on the brine discharge valve V-4.

d). Adjust to the misty flow regime using the needle valve orifice. The output from the photoelectric cell is the best indicator from one point to the next as to where this flow regime occurs. The eye has to determine the first point. This becomes the reference for the photo cell.

Finding High Temperature Points

In this region a small change in temperature results in a large pressure change. Hence it is best to select a pressure then vary the temperature until breakout occurs.

a). Adjust brine flow to 3 gpm and control as closely as possible to this value as temperature and pressure change.

b). Set the desired pressure by adjusting V-4 and the needle valve orifice.

c). Approach the expected breakout temperature by varying the ratio of hot brine to cool brine mixing in front of the sight glass. The ratio is adjusted using valves V-2 and V-6.

d). Adjust to the misty flow regime using the same procedure as in c) but pay particular attention to the total flow.

HELPFUL HINTS:

1. The "best" curve will require getting points about 25°F apart on the low temperature end and 15-20°F apart on the high end. In the middle a 20°F increment is small enough.

2. Each point should be identified by hand on the data logger tape and the recorder for the photocell. This simplifies resolving discrepancies later on.

3. All points should be plotted as soon as possible after the test so any discrepancies can be spotted early. Points can then be repeated as necessary.

4. For short duration tests, a turbine meter is useful for checking the brine flow rates.

Shut-Down Procedure

If the equipment is to be idle for more than 1-2 days, ALL water and ALL brine should be drained from the system. Several fittings must be loosened to be sure the system drains completely. Blowing compressed air through the system is recommended. After the water is drained, flushing the system with WD-40 is also good practice.

Over long idle periods, the equipment should be disassembled and re-packaged in its original crates. Prior to crating, all open pipes, tubes and hoses should be capped or plugged to keep the lines clean during storage.

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