CO_2 INJECTION WELL CONTROL AND MONITORING IN THE WILLARD UNIT A CASE STUDY

Ronald W. Trice

ARCO Oil & Gas Company

Once it was decided in 1984 to inject CO_2 in the Willard Unit (part of the Wasson Field at Denver City in West Texas), determination had to be made whether to automate the project and, if so, to what extent. Why the decision was made to fully automate the project and detailed descriptions of the automation system are the subjects of this paper.

The Willard Unit occupies approximately 25 square miles and consists of some 300+ oil wells producing from the San Andres zone and about 250 injection wells. The Unit has been in secondary recovery (water injection) since 1968 and has been experiencing a serious decline in oil production since production peaked at 32,000 BOPD in the mid-seventies. The decision to put the Unit into tertiary recovery (CO_2 injection) was made with the hope of extending the life of the Willard well into the next century by halting the production decline.

During secondary recovery, the reservoir condition stayed fairly constant so that manual control of individual well injection seemed adequate for most fields. However, tertiary recovery required accurate control over fluid volumes and bottom-hole pressures not only because of the expense of CO_2, but also because of the danger of exceeding fracture pressures and doing irreparable damage to the formation.

Due to the fact that the wells would be on a WAG (water alternated with gas) injection cycle, considerable research and testing was done to locate a meter that would meter both water and CO_2 volumes. The turbine type meter tested favorably, but had one major drawback: if the well was opened up too quickly after being out of service, the meter internals came apart from the meter body. The orifice meter also tested well, but was rejected due to problems with build-up of contaminants and warping of the plate when service personnel improperly put the well back in service. The meter that was picked was a modified orifice-type meter made by Taylor called the wedge meter. The wedge meter has a V-shaped replaceable wedge element that produces a differential pressure like an orifice when product flows through it. See figure 1. The obvious advantages over other meters tested are: no moving parts and ruggedness. It also has an 8 to 1 turn-down as opposed to the 4 to 1 turn-down of the orifice meter.

Several type valves were tested to be used as chokes. Some, like the multi-turn choke valves were immediately rejected because the high current required by the electric actuators was prohibitive. Others were rejected because of cost. It was found that very accurate control was possible with a modified ball valve.

Two types are being used: one has a V-slotted seat down-stream of the ball, the other has an incrementally slotted ball. See figure 2. The purpose in both cases is to obtain linear flow control from full-closed to full-open. An electric actuator was chosen that provided adequate torque while requiring minimal supply current.

Proper metallurgy and other materials were another prime concern. It was decided that 316 ss should be used everywhere that the CO_2 might come in contact with water due to the highly corrosive nature of the mixture. Therefore, the entire injection manifold (see figure 3) is stainless. The sensing cells of the electronic transmitters are Hastelloy and all rubber O-rings are special CO_2-approved material. In addition to valves separating the two fluids at the manifold inlet, positive blinding plates insure that the two fluids don't commingle in the manifold.

Automation vendors were asked to meet the following requirements:

The central computer for injection well monitoring and control would be duplicated in the new CO_2 recovery plant and would be able to replace the existing automatic well-testing and alarm monitoring system. The equipment at the 240 injection wells and the 9 test satellites would all be from the same manufacturer as the central computer.

The only vendor who met these requirements was Bailey Controls Co. of Cleveland, Ohio. The system is a DCS (distributed control system) built around Bailey's Network 90 architecture. Network-90 PCUs(process control units) are nodes on a continuous plant loop. Messages are generated based on exception reporting, so that communications rates in excess of 500 kilobaud are common. The configuration of the Bailey system in the Willard Unit is somewhat unique. See figure 4. There are nine remote plant loops each laid out around the nine test satellites with a small PCU at each injection well and a large PCU at the test satellite. At the test satellite PCU is a special module called a gateway that is connected via modem and cable to a companion gateway and modem that sits on the master plant loop. The gateway pairs automatically transfer information to and from the remote loops at the rate of two messages per second. Once information from the remote loops is on the master loop, it is available for use by the central processors for calculations and reports.

The PCUs at the injection manifold contain Bailey's Enhanced Controller Module which is basically a M68000 processor-based unit. This module is configured(programmed) in function codes which are linked together like building blocks. See figure 5. The control algorithm is written as in figure 6. As you can see, the prime concern is to maintain an injection rate as close to the desired rate without exceeding the maximum desired surface wellhead pressure.

In order to get proper rate measurement of CO_2 through the wedge meter (see figure 1), the proper specific gravity has to be calculated. This is accomplished by periodically sending the molecular weight of the CO_2 based on component analysis to the PCU for its density calculations. By condensing expansion tables for CO_2 down to a formula, a fairly accurate density is calculated from measured temperature and pressure. The formula used for calculating Z(expansion factor) is:

$$Z=0.21+(((P-1500)/250)*0.03)+(((T-40)/8)*0.004)$$

where: P=absolute pressure of the CO_2 in psi
T=temperature of the CO_2 in degrees Fahrenheit

This calculation is accurate from 1500-2000 psia and 40-80 degrees Fahrenheit. The density of the CO_2 is calculated using the following formula:

$$D=P*W_{CO_2}/(10.7315*(T+459.67)*Z)$$

where: D=density in pounds mass per cubic foot of CO_2
P=absolute pressure of the CO_2 in psi
W_{CO_2}=molecular weight of CO_2
T=temperature of the CO_2 in degrees Fahrenheit
Z=expansion factor of the CO_2 calculated above

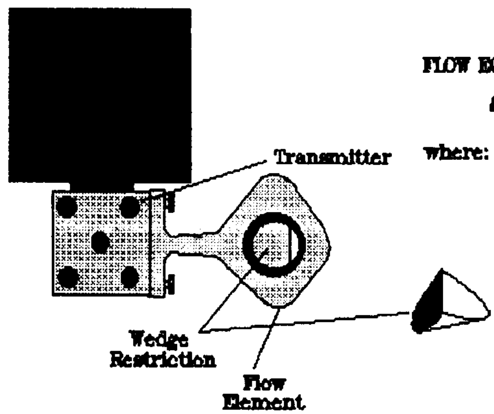
Once the density is calculated, all that has to be done to convert it to a liquid specific gravity is to divide it by the density of water (62.4 lbs/ft^3). Thus, the specific gravity is:

$$SG=D/62.4$$

All rate calculation and totalization at the injection PCU is done in barrel units (42 gallon barrels) at the request of production personnel. Once this information is transferred to the master loop, these units are converted to pounds mass and standard cubic feet for allocation and equipment surveillance.

Another very important task done by the Willard Unit automation system is control and monitoring of the purchased CO_2. CO_2 is supplied to the injection system from four sources: Bravo Dome pipeline, Cortez pipeline, Sheep Mountain pipeline, and processed CO_2 from the Willard Unit CO_2 recovery plant. A large Bailey PCU monitors and controls these meter runs to maintain smooth and constant CO_2 rates to the field.

The large PCUs at the test satellites are primarily responsible for monitoring fluids and gases entering the station from the producing wells. In addition, the equipment controls the automatic sequencing of wells into test separators and maintains test results to be transferred to the master loop for further computation and report generation.



FLOW EQUATION:

$$gpm = 5.663\ Kd^2 \sqrt{\frac{h}{g}}$$

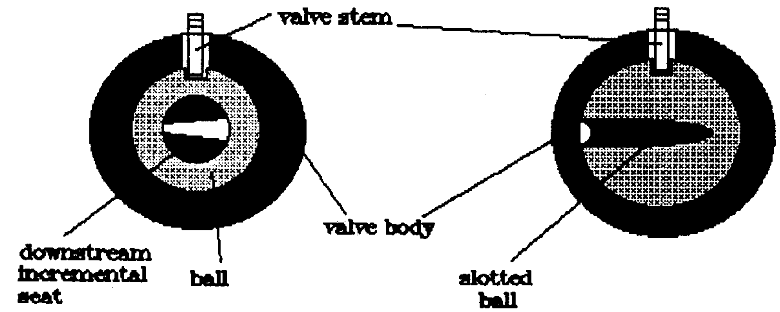
where: gpm = gallons/minute

Kd^2 = .122 for 20% wedge opening
.211 for 30% wedge opening
.305 for 40% wedge opening
.440 for 50% wedge opening

h = DP in inches of water

g = specific gravity of fluid

Figure 1



Ball Valve with V-slotted seat

Ball Valve with Slotted Ball

Figure 2

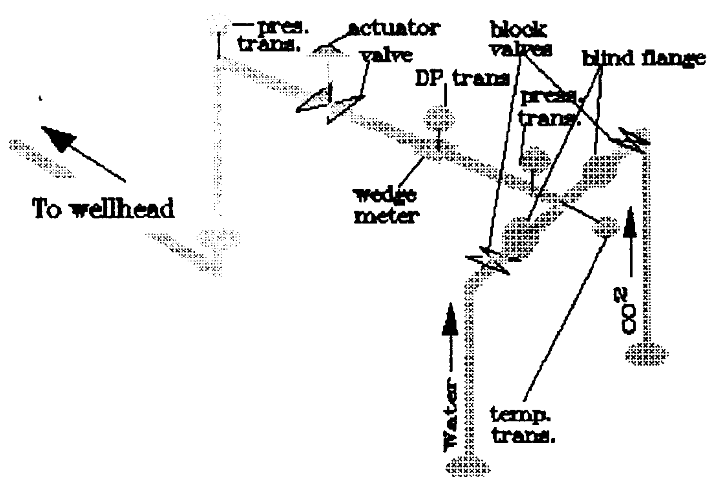


Figure 3

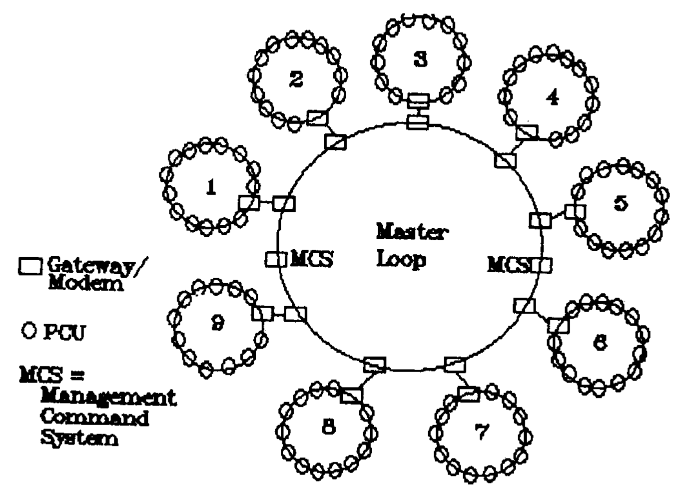


Figure 4

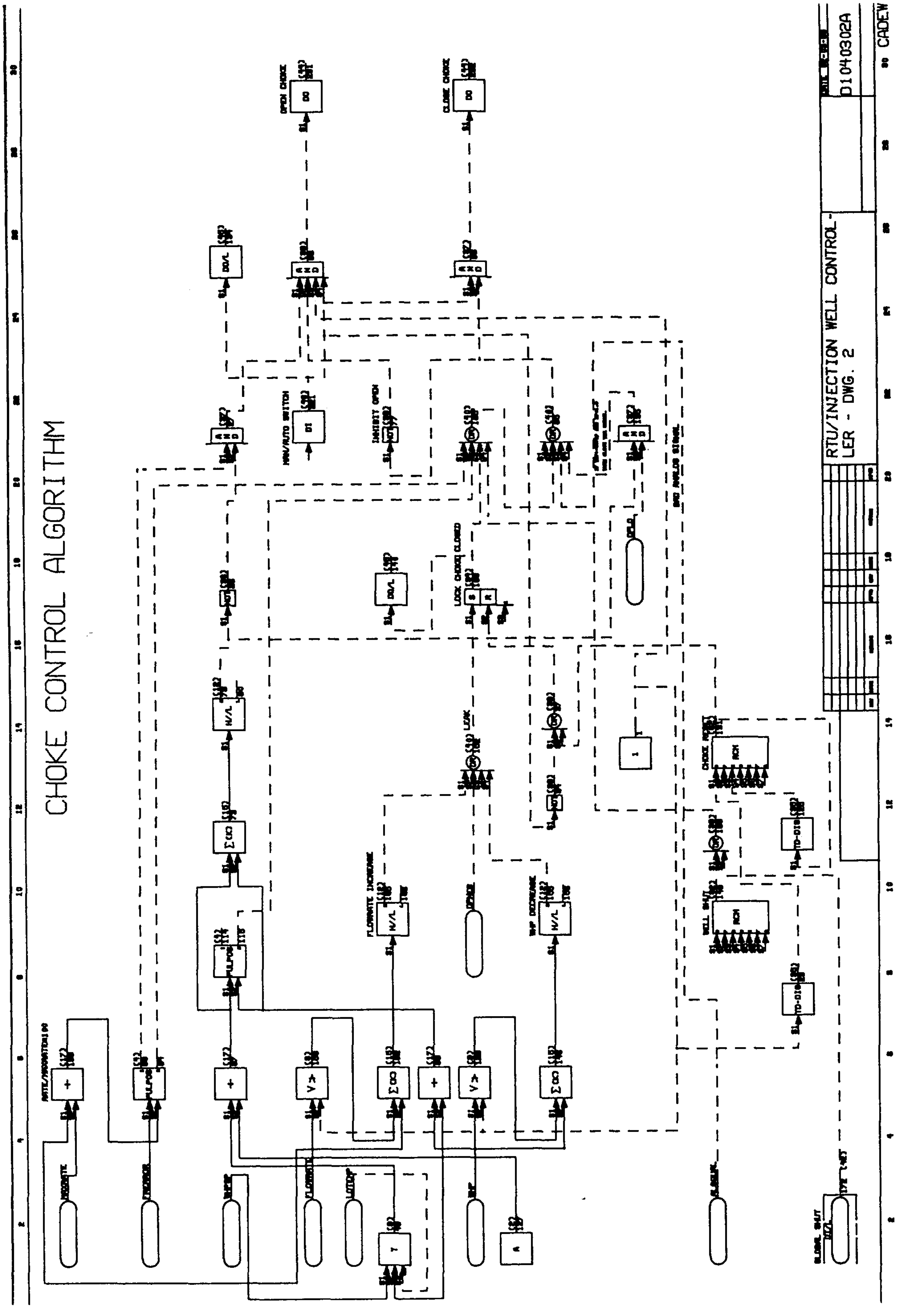

CHOKE CONTROL ALGORITHM
RTU/INJECTION WELL CONTROL-
LER - DWG. 2
D1040302A
CADEW

Figure 5

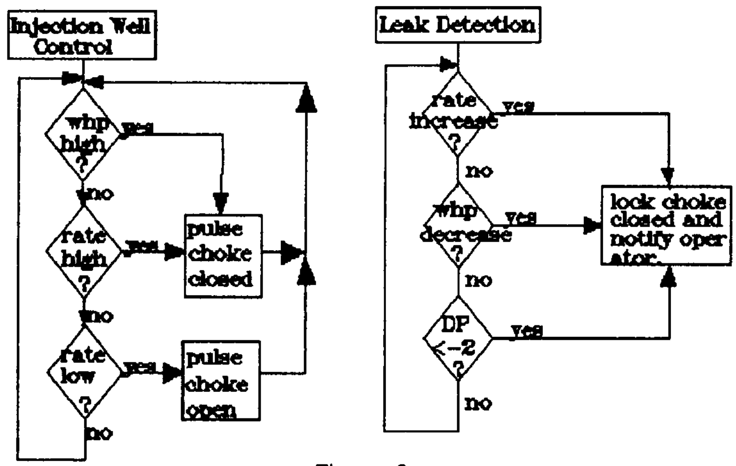

Injection Well Control
whp high ?
yes
no
rate high ?
yes
pulse choke closed
no
rate low ?
yes
pulse choke open
no
Leak Detection
rate increase ?
yes
no
whp decrease ?
yes
lock choke closed and notify operator.
no
DP <-2 ?
yes
no

Figure 6