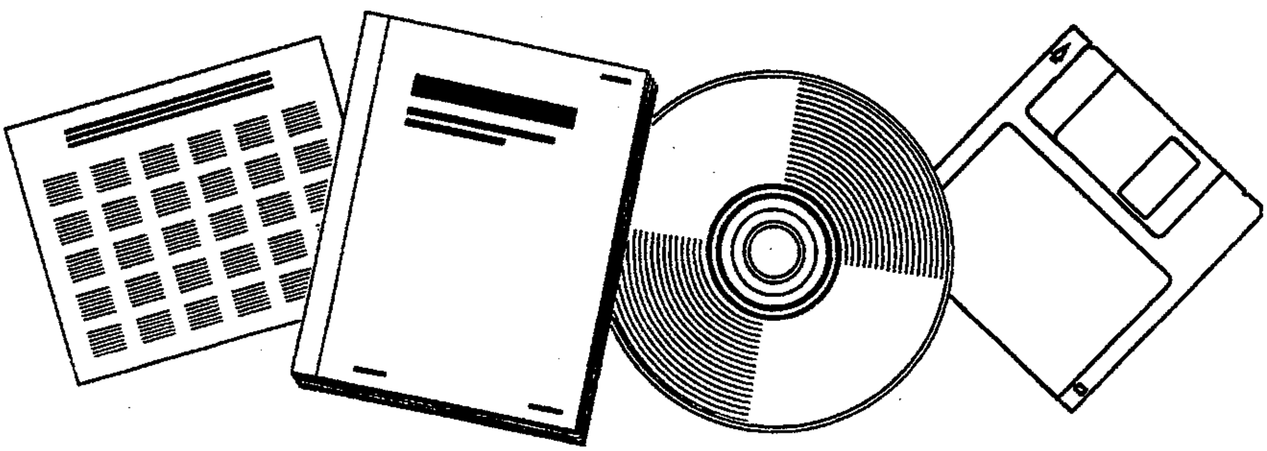
DE83008233

CONDUCTIVITY PROBE AND DATA ACQUISITION FOR A LIQUEFACTION COLD MODEL

DEPARTMENT OF ENERGY, PITTSBURGH, PA.
PITTSBURGH ENERGY TECHNOLOGY CENTER

1981



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

DOE/NBM--3008233

DE83 008233

CONDUCTIVITY PROBE AND DATA ACQUISITION FOR A LIQUEFACTION COLD MODEL

W. Fuchs , D. Smith
Pittsburgh Energy Technology Center
U. S. Department of Energy
P.O.Box 10940
Pittsburgh, Pa. 15236

Abstract

A device has been developed to measure local bubble size and velocity of the gas-phase in a three-phase slurry bubble column operated at coal liquefaction flow conditions. An in situ electrical conductivity twin probe (0.3-cm gap) detects the difference in conductivity of the gas and slurry phases. The analog signal from each probe is rapidly digitized and stored on a waveform recorder and subsequently transmitted and analyzed on a minicomputer. Measured bubble length and velocity are computed from the measured response time interval between probes and the dwell time of a bubble on each probe. A probabilistic model is used to derive actual bubble sizes and velocities.

Introduction

Slurry bubble columns are typically used as coal liquefaction reactors in which high throughputs, good slurry mixing, and high heat transfer coefficients are desirable. Recent published work by Satterfield and Huff (1980) has drawn attention to the importance of gas absorption resistance of Fischer-Tropsch reactions occurring in a three-phase slurry reactor. Thus, global rates of reaction will be influenced by the gas/liquid surface area, gas void fraction, bubble size, and gas absorption coefficients. Previous investigations of gas liquid surface area [Akita and Yoshida (1974), Quicker and Deckwer (1981)] have largely employed photographic techniques to obtain relevant parameters such as bubble size and bubble size distribution as well as estimations of the gas/liquid surface area. This method of measuring bubble size is limited to short distances from the wall, and resolution of the bubbles is further diminished in the presence of solids. Ueyama et al. (1980) measured bubbles in a 0.6-m-ID bubble column and found that a large bubble size gradient occurs in the radial direction from the center to the wall. The bubbles near the center of the column were found to be a factor of 2 to 8 times greater than the bubble size near the wall. This observation demonstrates the necessity of measuring bubbles over the cross section of the column in order to obtain an average bubble size.

Another important parameter, local gas void fraction, has been measured by several investigators [Neal and Bankoff (1963), Hills (1974)], and the various techniques used to study local void fraction have been reviewed by Hewitt (1972), Serizawa et al. (1975), and Jones and Delhaye (1976). Buchholz et al. (1981) recently reviewed, among other devices, the use of twin-electrode conductivity probes for the determination of bubble size parameters. The use of twin-conductivity probes for measuring properties of bubbles is a relatively new technique [Serizawa et al. (1975), Buchholz and

Schugerl (1979)]. This type of detector is employed in our present investigation of gas-phase characteristics in a slurry bubble column operated at coal liquefaction flow conditions. An integral data acquisition system is also described. The gas phase characteristics that are measured by the conductivity probes include bubble length, velocity, and frequency, in addition to the gas void fraction.

Experimental

A schematic diagram of the bubble column apparatus is shown in Figure 1. The bubble column is a transparent plastic cylinder having an inside diameter of 10.8 cm and a length of 194 cm. A single bubble cap distributor located at the bottom of the column is used to introduce the slurry and gas phases. Several ports are located along the axis of the column to allow insertion of the probe as well as slurry sampling valves and differential pressure gages.

Probe System

A depiction of the conductivity probe inserted into the slurry bubble column is given in Figure 2. The twin-electrode conductivity probe consists of two teflon coated wires with a diameter of 0.13 mm (0.005"). The teflon coating serves as a good moisture-repellent surface as well as an electrical insulator. This probe characteristic is essential to obtain rapid response of the bubble shedding water from the probe. The chromel wire has proven to be a good compromise between strength and electrical conductivity in a slurry environment. The pair of wires are threaded through the tubing, and a Conax fitting with teflon seals is fitted over the tubing. The ends of the tube are sealed with epoxy to hold the wires in place and provide a waterproof seal. One of the insulated wires extending from the epoxy seal is then bent in a j-shape such that the tip of the wire is perpendicular to the stainless steel tubing. In a similar manner, the other wire is bent approximately 1 mm past the bend in the first wire and terminated approximately 3 mm past the end of the first wire. The radial gap between wires avoids a liquid film buildup as a result of capillary attraction, and the vertical gap serves as a fixed reference for bubble travel after striking the upstream probe. The chromel wires are exposed at the tips of each wire with a scalpel to insure a minimal exposed area. The radial placement of the probe is accomplished during the operation of the bubble column by loosening the Conax fitting and moving the probe to the desired position with the aid of a calibrated ruler and a reference point located outside of the column.

The probe circuit consists of a power supply, probe, waveform recorder, junction box, and double pole - double throw switch. The power supply (HARRISON 2102A) is a variable DC supply nominally operated at 5 volts. Each electrode of the probe is in parallel with the power supply and waveform recorder. The waveform recorder (Biomation 2805 M) measures and stores the electrical conductivity signals over a known time interval, and subsequently the stored information can be transferred to a computer, visual display, or chart. A depiction of the probe circuit and data acquisition system is given in Figure 3.

A junction box is used to select any one of three probes installed in the slurry bubble column. A double pole - double throw switch is used to reverse current occasionally to dispose of any charge that may be acquired on the probe tip.

Data Collection System

The waveform recorder, or digitizer, is an analog-to-digital converter with a solid-state memory that stores the digital equivalent of an analog electric signal. The model that was used in our test facility, a BIOMATION model 2805M, provides for the simultaneous recording of two channels with sampling frequencies of up to 5 MHz; this means that each channel can be read and digitized every 200 ns. The solid-state memory provides space for 2048 numbers for each channel, with a resolution of 1 part in 256.

The trigger mechanism allows for delayed recording as well as pretriggering. Figure 4 demonstrates the difference between these two modes. The pretrigger feature, together with an adjustable trigger level control, permits the definition of a precise recording window with respect to a given or a detected trigger event. The trigger signal can be taken from either channel or can be supplied externally. In our application, a peak signal from the first channel was used, i.e., the signal caused by the probe that sees the bubble in the column first.

The contents of the memory, representing the recorded traces, are displayed on a CRT monitor. In addition, the collected information is transmitted to a computer for analysis via a digital output connection. This transmission is accomplished in asynchronous fashion; each number is transmitted on an 8-bit parallel line after a handshake signal has been established. The transfer rate is controlled by the computer; in our case it is approximately 150 data points per second. The selection of the sample speed and the arming of the trigger mechanism can be achieved manually or remotely by the computer. The interface with the computer consists of 27 lines. Of those lines, 12 are output lines, i.e., they send data or status information to the computer: 8 lines for data transmission, one line each for remote time select mode, recording status, digital output mode, and word ready flag. Fifteen (15) lines are used to send instructions to the waveform recorder: one line to enable the remote control of the instrument in general, one line to enable the remote control of the sampling speed, 7 lines for the selection of the sampling speed, one line for remote arming, 3 lines for the channel selection, one line to enable digital output, and one line for requesting a new data word. The diagram in Figure 5 illustrates the handshaking sequence.

For a typical run, a series of scans under identical conditions are taken in order to obtain a reasonably large statistical sample. The sampling interval for most tests is 0.5 or 1.0 ms per point. Figure 6 shows a plot of the data generated with one scan.

Results and Discussion

The signal amplitude or intensity is obtained as a function of time from the probe measurements and can be related to the bubble characteristics. A computer program has been developed to read and interpret the data so that bubble velocity, bubble size, and gas void fraction are derived. In order to interpret the conductivity probe signals, the following computations are made.

A threshold signal intensity that is slightly above the minimum baseline intensity is assigned to each recording at a level corresponding to 5 percent of maximum peak height. All signal intensities below the threshold value represent the conductive (liquid) phase, and all intensities above the threshold represent the gas phase. The dwell time, τ , of a bubble corresponds to the duration of time in which the probe is immersed in the bubble and can be calculated from the time interval in which the signal amplitude is greater than the threshold intensity. The lag time, Δt , between a pair of signals corresponding to the passage of a bubble is computed from the time interval during which the centroid of a pierced bubble travels from the upstream to the downstream probe. Let us indicate the coordinates associated with the downstream and upstream probes with the suffixes 1 and 2, respectively, and let us define the time, t, at which the signal intensity exceeds the threshold intensity as the instant at which a bubble is pierced by one of the two probes; then the following expression is obtained for the lag time.

$$\Delta t = (t_2 - t_1) + \frac{1}{2}(\tau_2 - \tau_1) \tag{1}$$

From Equation 1, the lag time, Δt, approaches the time interval for a bubble to be pierced by each probe as the dwell time of a bubble on each probe approaches the same value. The effect of taking the centroid of the pierced bubble as the reference frame for the computation of lag time is to average small deviations in dwell time due to the deflection or nonvertical travel of the bubble, and due to the offset of the top probe with respect to the bottom probe. Figure 7 shows the relationship of the probe signal as a function of time and the measured dwell and lag time.

The matching of a signal pair representing a bubble passing through both probes requires several conditions to be satisfied. An error may result from the fact that a bubble pierced by the downstream probe is not always preceded by a bubble pierced by the upstream probe. A discussion of the scenarios for such an occurrence has been given by Serizawa et al. (1975). In one case, a bubble penetrated by the upstream probe may be deflected and not strike the downstream probe. In another case, a bubble pierced by the upstream probe may not be deflected; but before it can reach the downstream probe, another bubble that missed the upstream probe touches the downstream probe. In addition to the cases mentioned above, a slight deflection of a bubble striking the upstream probe may result in a different dwell time of the bubble on the downstream probe. Any combinations of the conditions mentioned above can occur simultaneously.

The ascending velocity, U_b, and length, L_b , of each bubble passing vertically upward through the column can now be calculated from the lag time, the dwell time, and the vertical gap (h) between the twin probes.

$$U_b = h/\Delta t \tag{2}$$

$$L_b = h\tau/\Delta t \tag{3}$$

In order to avoid improper matching of a signal pair, the following constraints are placed on the matching process. A minimum velocity and a maximum velocity corresponding to the smallest and largest bubble observed in the bubble column are assigned to each recording. The minimum bubble velocity is assigned the value of 10 cm/s, which corresponds to a bubble size less than 1.6 mm (1/16 inch) as calculated by Stokes Law.

$$V_{min} = \frac{gD^2}{18\nu_\ell} \tag{4}$$

The maximum bubble velocity is calculated from the relationship given by Knicklin (1962) for the slugging flow regime.

$$V_{max} = 1.2\,(U_g + U_\ell) + 0.35\,(gD_t)^{1/2} \tag{5}$$

The acceptable velocities obtained from the probe measurements are considered to be within the limits of Equations 4 and 5. A further restriction on obtaining a signal pair is given by the similarity of the dwell time of a bubble on each probe. If the dwell time differs by more than 10 percent from each probe, then the bubble is considered to be deflected and is ignored in the analysis of bubble size and velocity.

The gas void fraction can be calculated from the ratio of the total time the signal intensity is above the threshold intensity to the total sampling time.

$$\epsilon_g = T_g/T_s \tag{6}$$

Average bubble velocities are calculated as suggested by Ueyama et al. (1980).

$$\overline{U}_b = \frac{1}{n}\sum_{i=1}^{n} U_{bi} \tag{7}$$

The standard deviation of the bubble velocity spectrum is given as

$$\sigma = \left[\frac{1}{n}\sum_{i=1}^{n}(\bar{U}_b - U_{bi})^2\right]^{1/2} \qquad (8)$$

A typical data set that is analyzed for the gas phase characteristics consists of at least 20 matched signal pairs for a given run condition. These data sets are obtained for 8 radial positions from the center of the column to the wall. The minimum sample population to obtain statistically significant parameters for the gas-phase characteristics is being investigated. The interpretation of bubble size from measured bubble length is being developed from a probabilistic model given by Tsutsui and Miyauchi (1980).

Conclusions

A conductivity probe and data acquisition system have been successfully developed to measure gas-phase characteristics in a slurry bubble column model operated at coal liquefaction flow conditions. The response time of the probe signal is adequate to observe the probe piercing the bubble and to establish a lag time corresponding to the gap between the twin probes. Further calibration of the probe will be made to determine the smallest detectable bubble.

Nomenclature

D = diameter
g = gravitational acceleration
h = vertical distance between twin probes
L = measured bubble length
n = number of bubble signals that are matched
t = time at which probe pierces bubble
T = total time interval
U = superficial velocity
V = rise velocity

Greek Symbols

Δt = lag time
ϵ = void fraction
σ = standard deviation of bubble velocity spectrum
τ = dwell time
ν = kinematic viscosity

Subscripts

b = bubble
g = gas
l = liquid
max = maximum
min = minimum
s = total sample
t = tube

Superscripts

= average

Disclaimer

Reference in this report to any specific commercial product, process, or service is to facilitate understanding and does not necessarily imply its endorsement or favoring by the United States Department of Energy.

References

1. Akita, K. and Yoshida, F., "Bubble Size, Interfacial Area, and Liqud-Phase Mass Transfer Coefficient in Bubble Columns," AIChE J., Vol. 9, No. 4, 490-494, 1963.

2. Buchholz, R., Zakrzewski, W., and Schugerl, K., "Techniques for Determining Properties of Bubbles in Bubble Columns," Int. Chem. Eng., Vol. 21, No. 2, 180-187, 1981.

3. Hewitt, G.F., "The Role of Experiments in Two-Phase Systems with Particular Reference to Measurement Techniques," Progress in Heat and Mass Transfer, Edited by Hestroni, G., Sideman, S., and Hartnett, J.P., Vol. 6, 295-343, 1972, Pergamon, England.

4. Jones, O.C., Delhaye, J.-M., "Transient and Statistical Measurement Techniques for Two-Phase Flows: A Critical Review," Int. J. Multiphase Flow, Vol. 3, 89-116, 1976.

5. Neal, L.G., and Bankoff, S.G., "A High Resolution Resistivity Probe for Determination of Local Void Properties in Gas-Liquid Flow," AIChE J., Vol. 9, No. 4, 490-494, 1963.

6. Nicklin, D.J., Wilkes, J.O., Davidson, J.F., "Two-Phase Flow in Vertical Tubes," Trans. Inst. Chem. Engrs., Vol. 40, 61-68, 1962

7. Quicker, G., and Deckwer, W.D., "Gas Holdup and Interfacial Area in Aerated Hydrocarbons," Ger. Chem. Eng., Vol. 4, 363-370, 1981.

8. Satterfield, C.N., and Huff, G.A. "Effects of Mass Transfer on Fischer-Tropsch Synthesis in Slurry Reactors," Chem. Eng. Sci., Vol. 35, 195-202, 1980.

9. Serizawa, A., Kataoka, I., Michiyoshi, I., "Turbulence Structure of Air-Water Bubbly Flow - I. Measuring Techniques," Int. J. Multiphase Flow, Vol. 2, 221-233, 1975.

10. Tsutsui, T., and Miyauchi, T., "Fluidity of a Fluidized Catalyst Bed and Its Effect on the Behavior of the Bubbles," Int. Chem. Eng., Vol. 20, No. 3, 386-393, 1980.

11. Ueyama, K., Morooka, S., Koide, K., Kaji, H., Miyauchi, T., "Behavior of Gas Bubbles in Bubble Columns," Ind. Eng. Chem., Process Des. Dev., Vol. 19, 592-599, 1980.

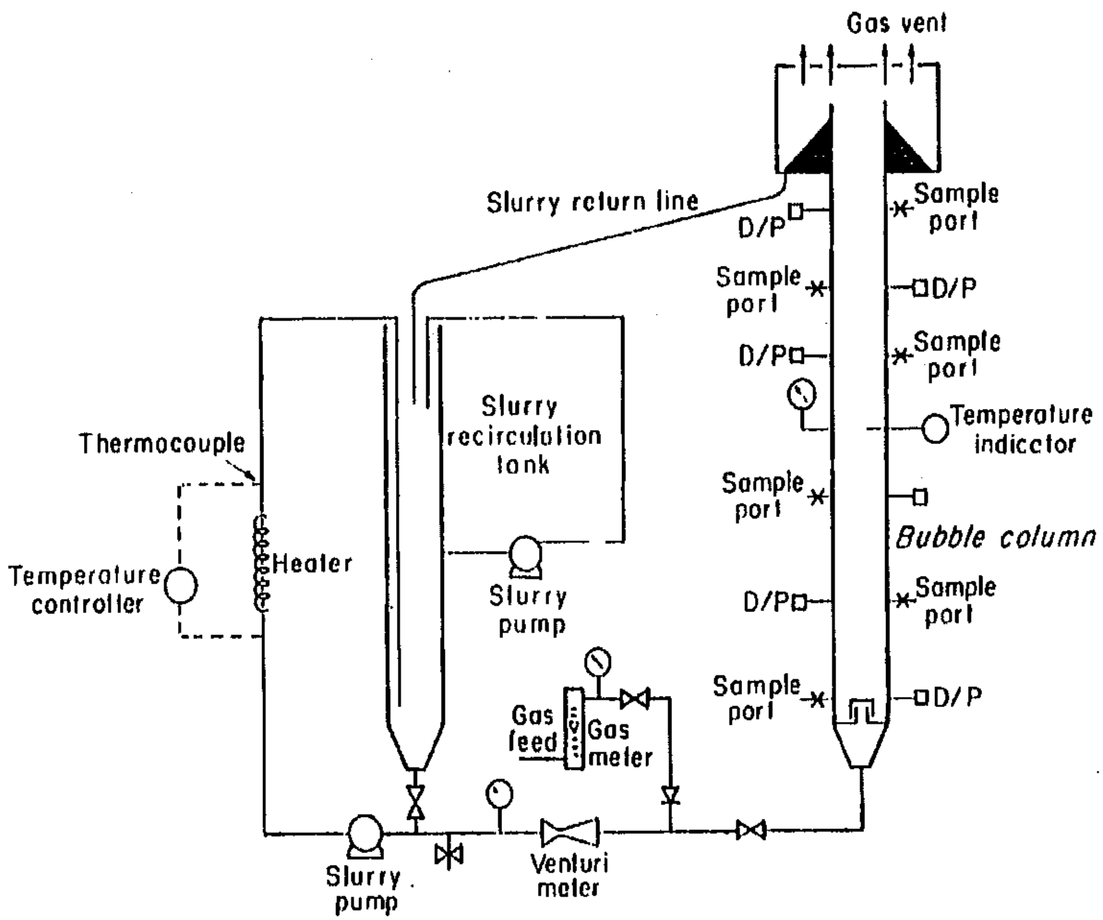


Figure I- 10.8 cm ID slurry bubble column apparatus

1-13-81 L-18107

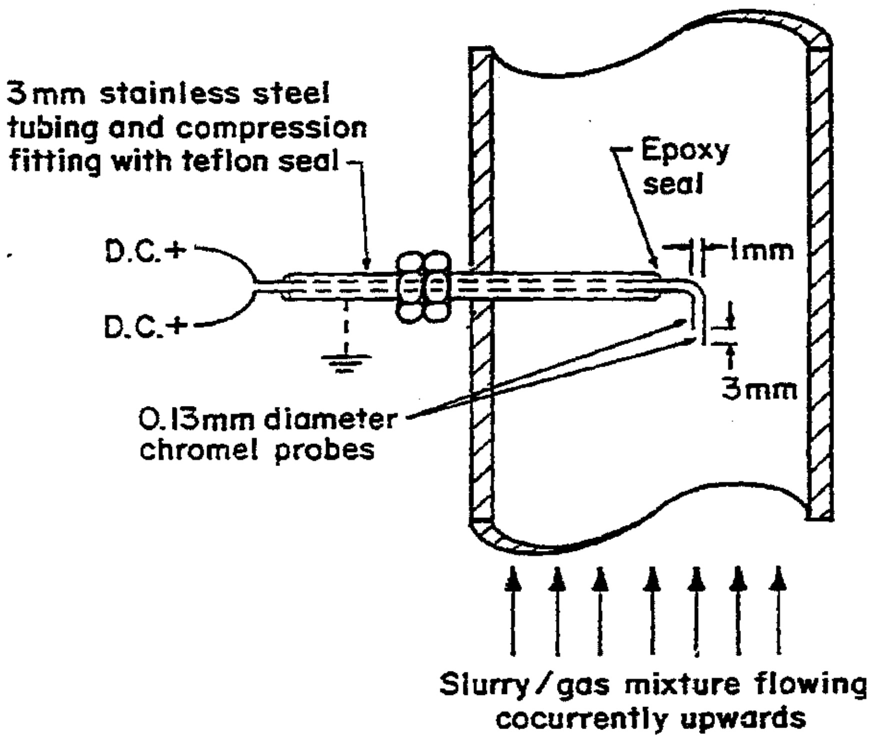


Figure 2 - Probe configuration for conductivity measurements in 10.8 cm I.D. slurry bubble column apparatus.

BSI/1115

9

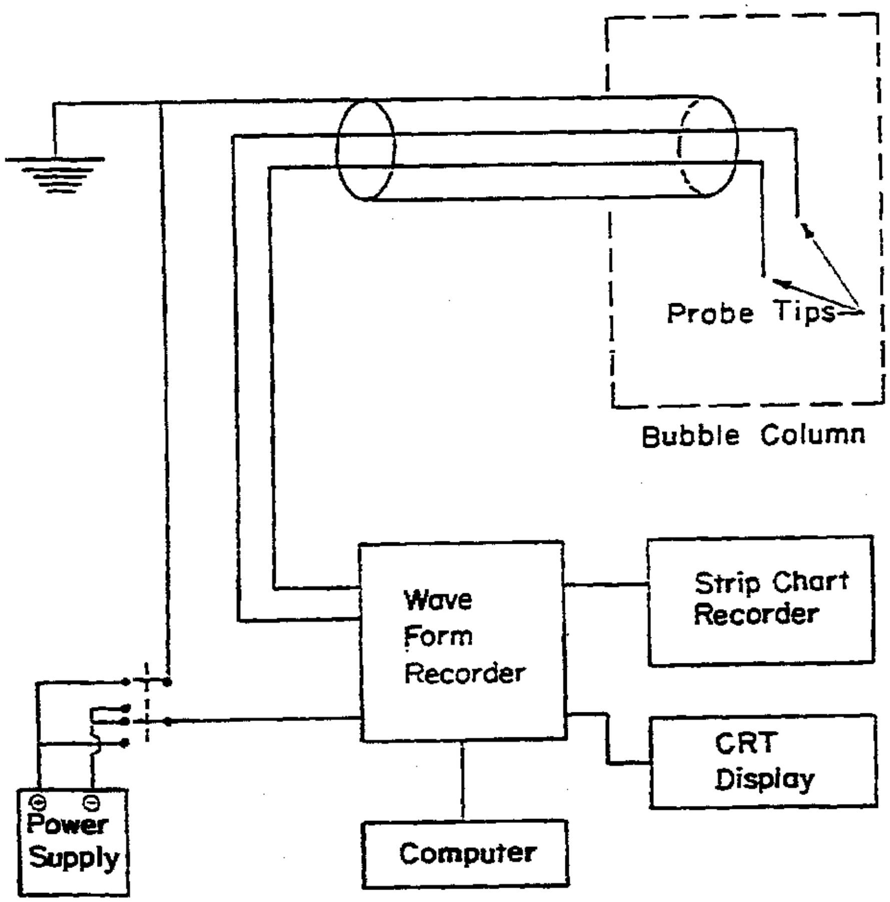


Figure-3 Two point electrical conductivity probe circuit and data acquisition system.

L-82753

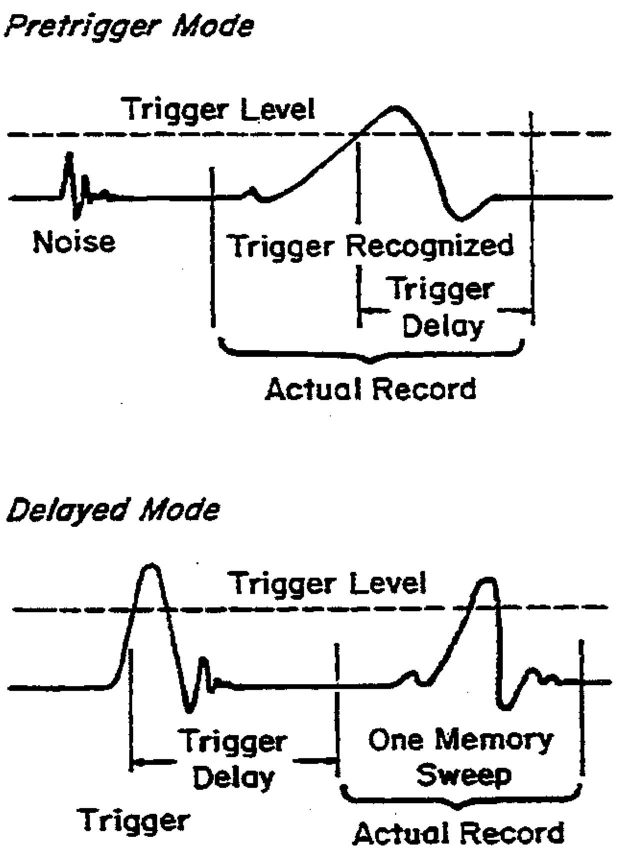


Figure 4 - Scanning modes of digital waveform recorder.

BSI/1160

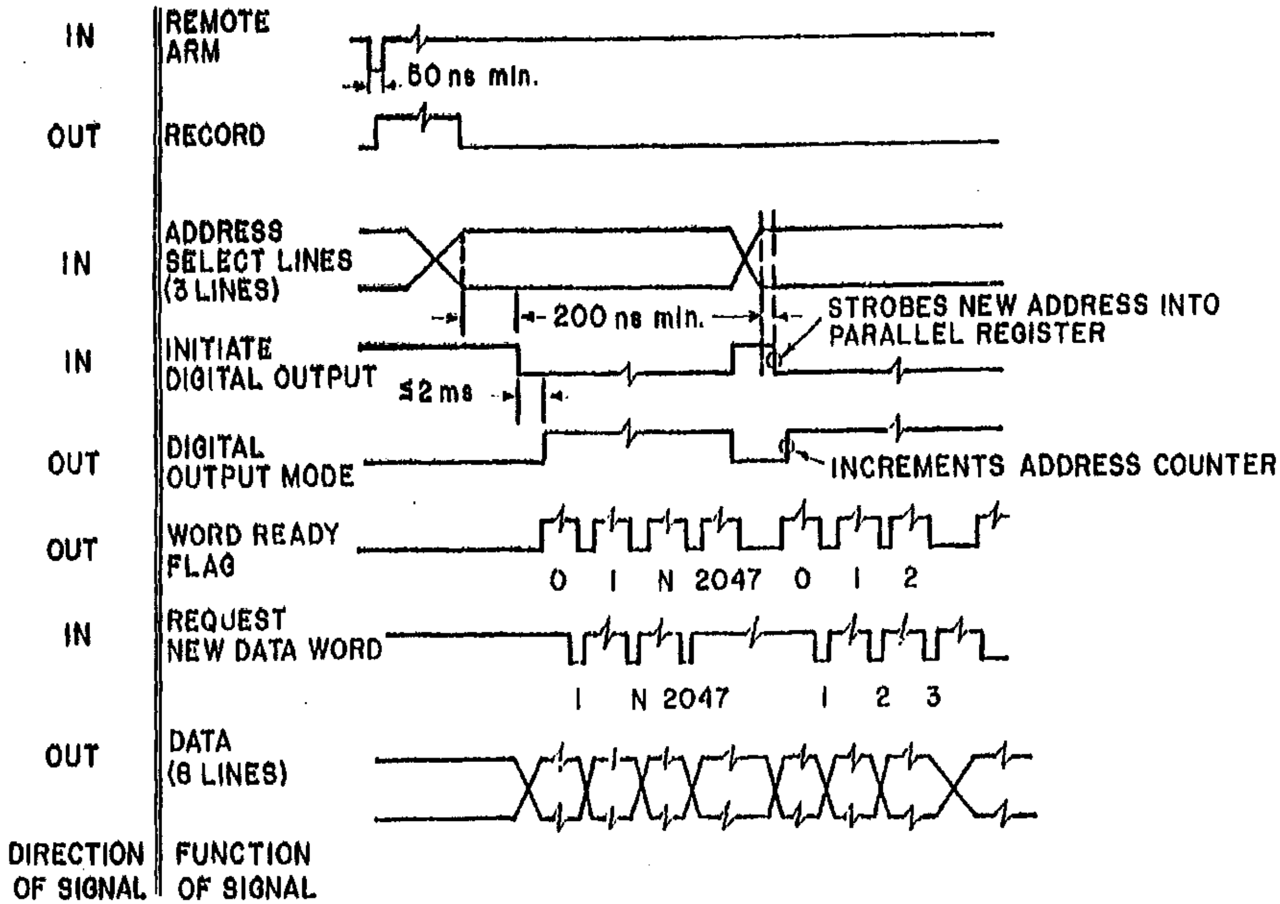


Figure 5 - Digital Interface timing diagram for biomation 2805 m.

BSP1161

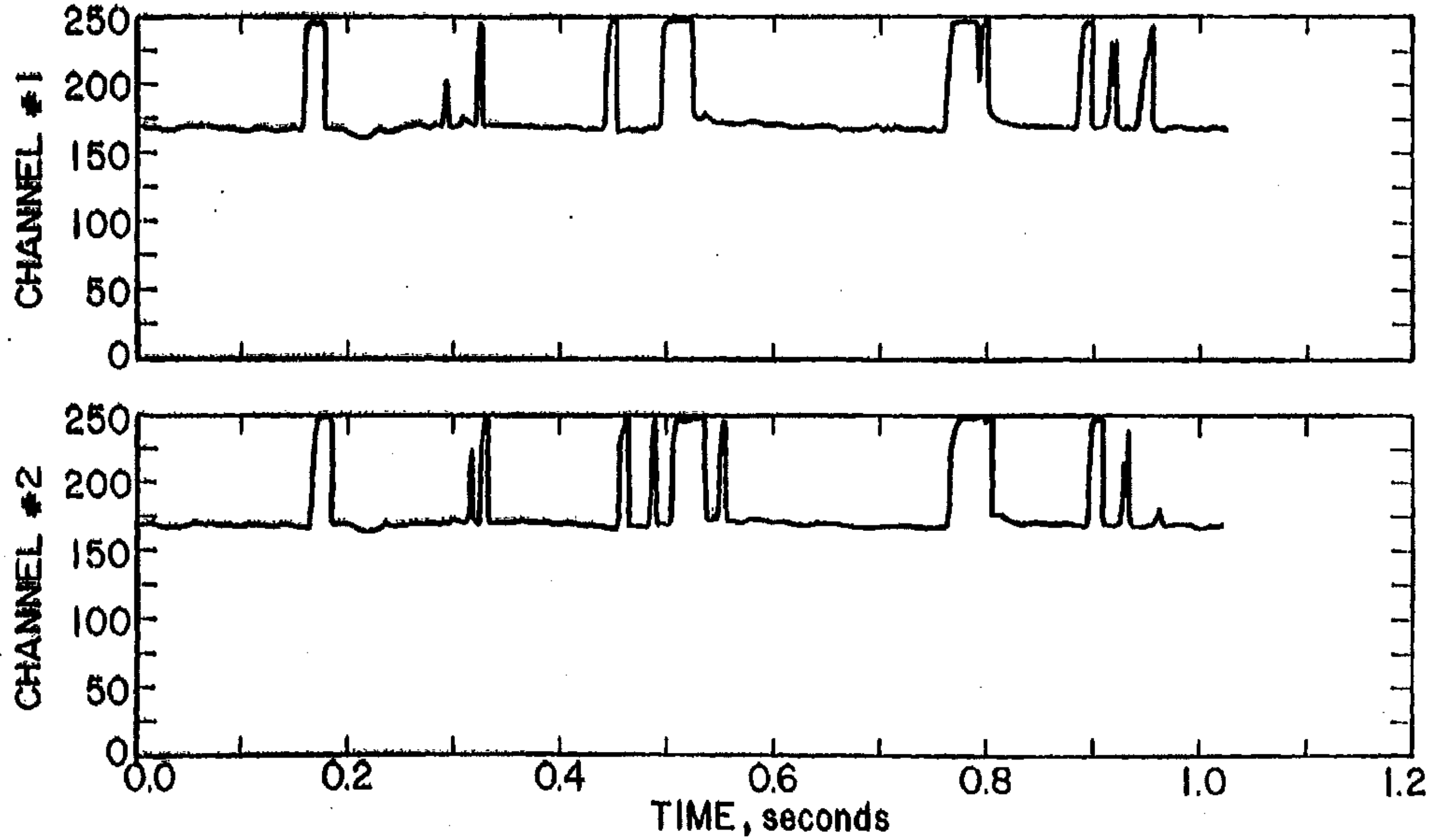
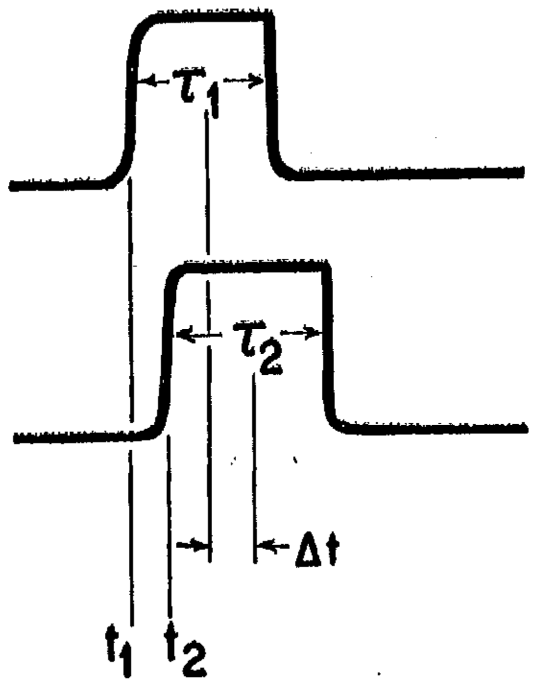


Figure 6 - Biomation data from 19 Mar-82 08:26:24
File: [117.2] PC025. Dat;5

USI/1102



Dwell Time : τ_1, τ_2

Lag Time : Δt

$$\Delta t = (t_2 - t_1) + \frac{1}{2}(\tau_2 - \tau_1)$$

Figure 7 - Relationship between probe signals and bubble dwell and lag time.

L-82738