DOE/PC/40797--T2

Study of Multiphase Flow Useful to Understanding Scaleup of Coal Liquefaction Reators

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Technical Progress Report

September 1, 1983 to November 30, 1983

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DISCLAIMER

MULTIPHASE FLOW
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I. HIGHLIGHTS

The objective of this work during the last few months was to determine the variation of bubble size along and across a bubble column type reactor and its effect on interfacial area when a non-Newtonian liquid is used. Air and CMC solutions flowing cocurrent up are studied in a 33 cm I.D. bubble column. Only the bubble and bubble-slug patterns are taken into consideration.

Gas holdup, bubble size and specific interfacial area studies were made in a 33cm inside diameter bubble column with air-carboxymethyl cellulose aqueous solution as the system. Experiments were performed with a fixed porous plate gas distributor by varying superficial gas velocity. The flow patterns of interest were bubble and bubble-slug patterns. Gas holdup data was obtained by the bed expansion method and bubble size distribution by taking photographs with a boroscope at different radial and axial positions.

Gas holdup decreased with carboxymethyl cellulose (CMC) concentration and exhibits a maximum with superficial gas velocity. This maximum also diminishes with CMC concentration.

Bubble size measured by the boroscope is smaller near the walls and reaches its maximum at R/2. The bubble size increases when either CMC concentration or superficial gas velocity is increased. There is no substantial variation of bubble size in the axial direction for the lower portion of the column. A maximum for total interfacial area was found for all the solutions with the exception of the higher concentrations. This maximum was found in the bubble-slug pattern near the transition from bubble to bubble-slug pattern. Operation under this condition is recommended.

II. OBJECTIVES AND SIGNIFICANCE

There are three major objectives for this proposed study. These objectives are basic to the understanding needed to develop a rationale for scale up in bubble columns. This understanding is the key to improving our scientific and technical knowledge of the fundamental process involved in complex two and three phase flows.

These objectives are:

1. to properly characterize two phase flow patterns in the region of interest that direct coal liquefaction reactors will be operated.
2. to characterize for viscous liquids, Newtonian and non-Newtonian, the flow pattern boundaries in the operating region of direct coal liquefaction reactors. The characterization would include both empirical and theoretical models.
3. to develop empirical expressions and models for the gas holdup in the flow regimes of interest. This objective would focus on non-Newtonian liquids that follow some elementary models for constitutive behavior.

The significance to the fossil energy program includes:

1. Flow pattern prediction will aid in the design and scaleup of coal liquefaction reactors.

III. EXPERIMENTAL

A. Procedure

All the experiments were conducted with no liquid flow. The experiment started by filling the column with a specific CMC solution. In this case solutions from 0.25 to 2.0% in weight, which were prepared using CMC from Sigma Chemical Co. and distilled deionized water with a maximum of 10 ppm as equivalent sodium chloride.

Then, the air control valve was opened and the air pressure regulator set to approximately 50 psig. The air flow rate was adjusted to a desired value and the system was allowed to equilibrate for about 5 min. At this moment the air flow rate, air temperature and pressue at the distributor were noted. The borescope was set inside the column at 141 cm above the distributor and 2.5cm from the wall and approximately 18 pictures taken with the focus distance set 2mm from the tipof the borescope. Photographs were also taken with the boroscope located at 5cm, 7.5cm, 12.5cm and in the center line of the column. In earlier experiments, the horescope was switched to the lowest axial position to see the variation in the bubbles size. Photographs of a ruler with 0.5 mm divisions were taken at the same focal distance as that set in the borescope in order to have a pattern of comparison for the bubbles size.

The temperature of the liquid was also observed.

The height of the bubbled bed was taken and then the magnetic valve in the air line closed and the air disengagement (22) monitored at 5sec intervals after the valve was closed. Samples of the solution were drawn at the beginning and the end of the experiment in order to evaluate physical properties as viscosity, surface tension and density.

The density was measured with a hydrometer. The flow curve of the solution was determined with a viscometer Haake RV-12, and the surface tension with a Fisher autotensiomat.

For every solution, experiments with 8 different air flow rates were conducted. The same procedure was repeated for the different solutions investigated.

B. Experimental errors

The fluctuation in the air rotameter readings were negligible. But for high velocities and/or high CMC concentrations there were fluctuations in the bubbled bed height giving a corresponding error in average gas holdup of 7%.

C. Calculations of desired parameters

The total gas holdup is calculated using the following equation:

$$EG = \frac{Hb - Hl}{Hb} \tag{48}$$

Where Hl represents the height of the liquid bed and Hb is the height of the bubbled bed.

The bubble gas rising velocity is calculated by:

$$Vb = \frac{\Delta EG}{\Delta t} \tag{49}$$

Where the ratio $\Delta EG/\Delta t$ is found as the slope in figures 11 to 15.

The interfacial area for unimodal distribution is found with:

$$a = 6\ EG/dVs \tag{31}$$

Where dVs represents the mean Sauter diameter.

For a bimodal distribution the equation changes to

$$a = \frac{6\,EG1}{dVs} + 6\,\frac{EG2}{db}\,\frac{V2}{V1}$$

Where db represents the equivalent diameter of the large bubble and V2/V1 the ratio of gas bubbles rising velocities with subindex 2 for the large bubble.

IV. DISCUSSION OF RESULTS

Gas Holdup :

Holdup showed a maximum with superficial gas velocity for the porous plate distributor. This maximum is shifted to lower gas velocities as CMC concentration is increased. However, for high CMC concentrations this maximum was obtained at the superficial Gas velocity of 1 cm/s. Also, the maximum in holdup tends to vanish with increasing CMC concentration

The holdup for different CMC concentrations at the same gas velocity is always lower for the higher polymer concentration in the bubble-slug pattern.

Gas disengagement :

From figures (11 to 15) for gas disengagement it is important to remark that the higher the gas velocity, the steeper the slope for disengagement(from 0 to 6 sec). This means that the gas leaves the bubble column faster and the average size of the bubbles present in the column is bigger at higher gas velocities. Also,it is interesting to realize that a constant slope throughout the gas disengagement for a specific velocity and a specific CMC concentration, represents a uniform bubble size. The holdup was found to be a maximum in this particular case as was expected.

Franz et al (18); have found higher values for gas holdup, even using perforated plates. Differences are especially at high gas velocities with about 40% variation in most of the cases.

Using a sintered plate with 0.2mm pore diameter, Deckwer et al (11) found a maximum in holdup at the same gas velocities as this study, i.e., VG =1 cm/s. The value of holdup is always lower than that found in my experiments. For example using a 1.5% CMC solution they found EG =0.04 as the maximum while in this study the maximum is 0.12. Similar differences were found by comparing my results with results from Buchholz et al (6) using a Cr-Ni stainless steel porous plate with 17.5 um as the mean pore diameter. Both experiments (5,11) were carried out in 14cm diameter bubble columns and low superficial liquid velocities which does not affect the holdup greatly (56).

In general, gas holdup values obtained from my experiments are very close to those of Schumpe and Deckwer(56). Their results , results from Buchholz et al (6) and my experiments exhibit similar curves for holdup vs. superficial gas velocity as far as CMC concentration is concerned.

Bubble Size and Interfacial Area:

Figures 16 to 25 show the radial variation for bubble size at different gas velocities and CMC

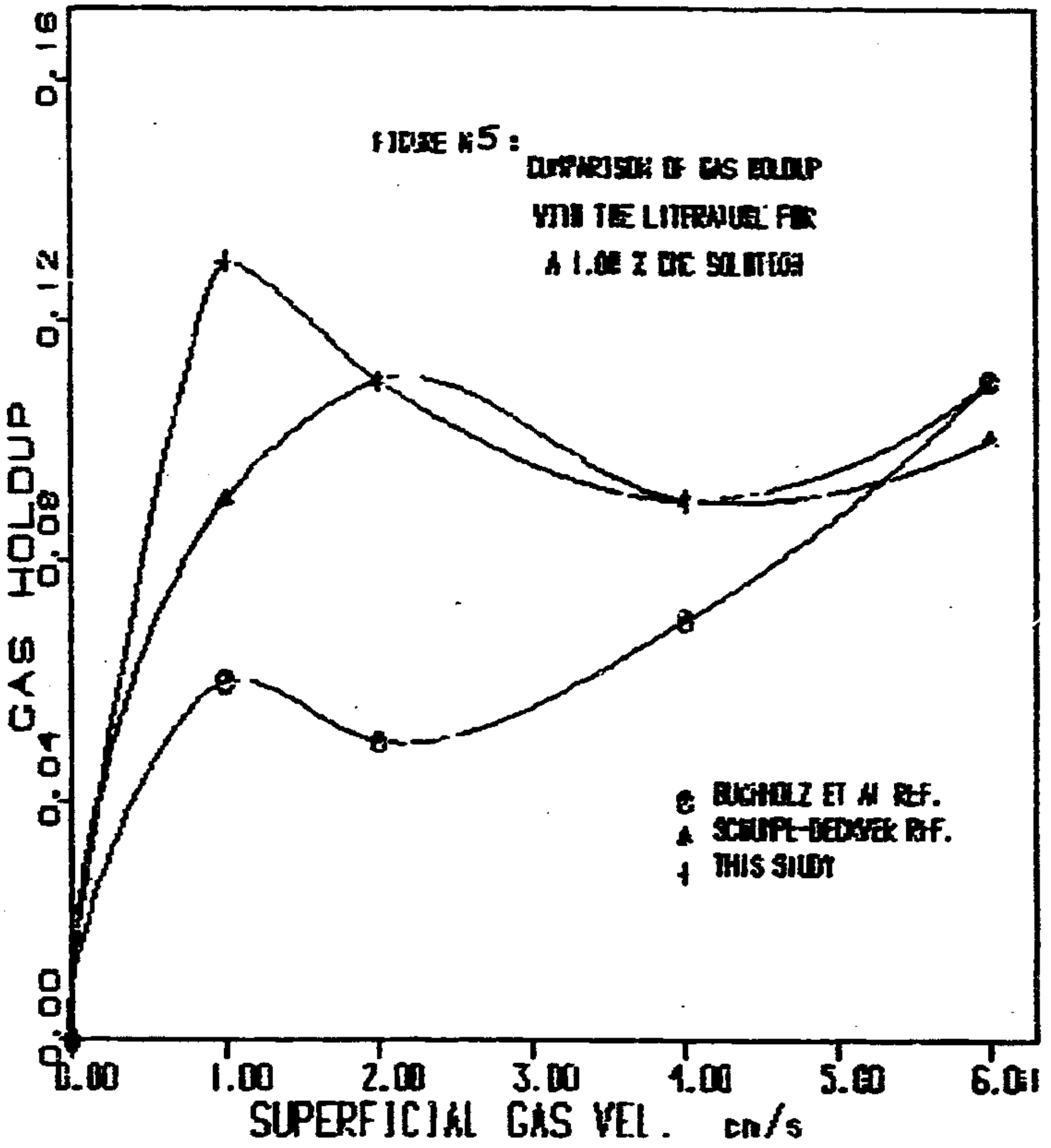

FIGURE N5 : COMPARISON OF GAS HOLDUP WITH THE LITERATURE FOR A 1.0 % CMC SOLUTION concentrations. In general, the bubble size is smaller near the wall and has its peak approximately at R/2. For the same gas velocity the bubble size increases with CMC concentration as can be seen from figures 29 to 33. However, at high CMC concentrations, the data is scattered and no specific behavior can be interpreted. Nevertheless, for a 1.00% CMC solution, mean Sauter diameter values are very close to those from Franz et al (18).

Bubble size did not vary significantly at different axial positions in the lower portion of the column. Two positions one at 62cm and another at 141cm from the distributor where tested and approximately the same bubble size was found. However, no other higher axial position was investigated although it was evident that at high throughputs coalescence takes an important roll.

For low CMC concentrations the formation of large bubbles starts at relatively high superficial gas velocities (figure 26). However, with highly concentrated solutions big bubbles are evolved with gas velocities as low as 1cm/s, which represents the absence of a well defined homogeneous flow.

At low gas velocities, for all the CMC solutions excluding 2.0%, a maximum in specific interfacial area was found. This maximum is achieved at a superficial gas velocity of 1cm/s for intermediate concentrated solutions (figures 8,9) and at relatively higher gas velocities for the more diluted solutions (figures 6,7). This maximum diminishes with increasing CMC concentration and its

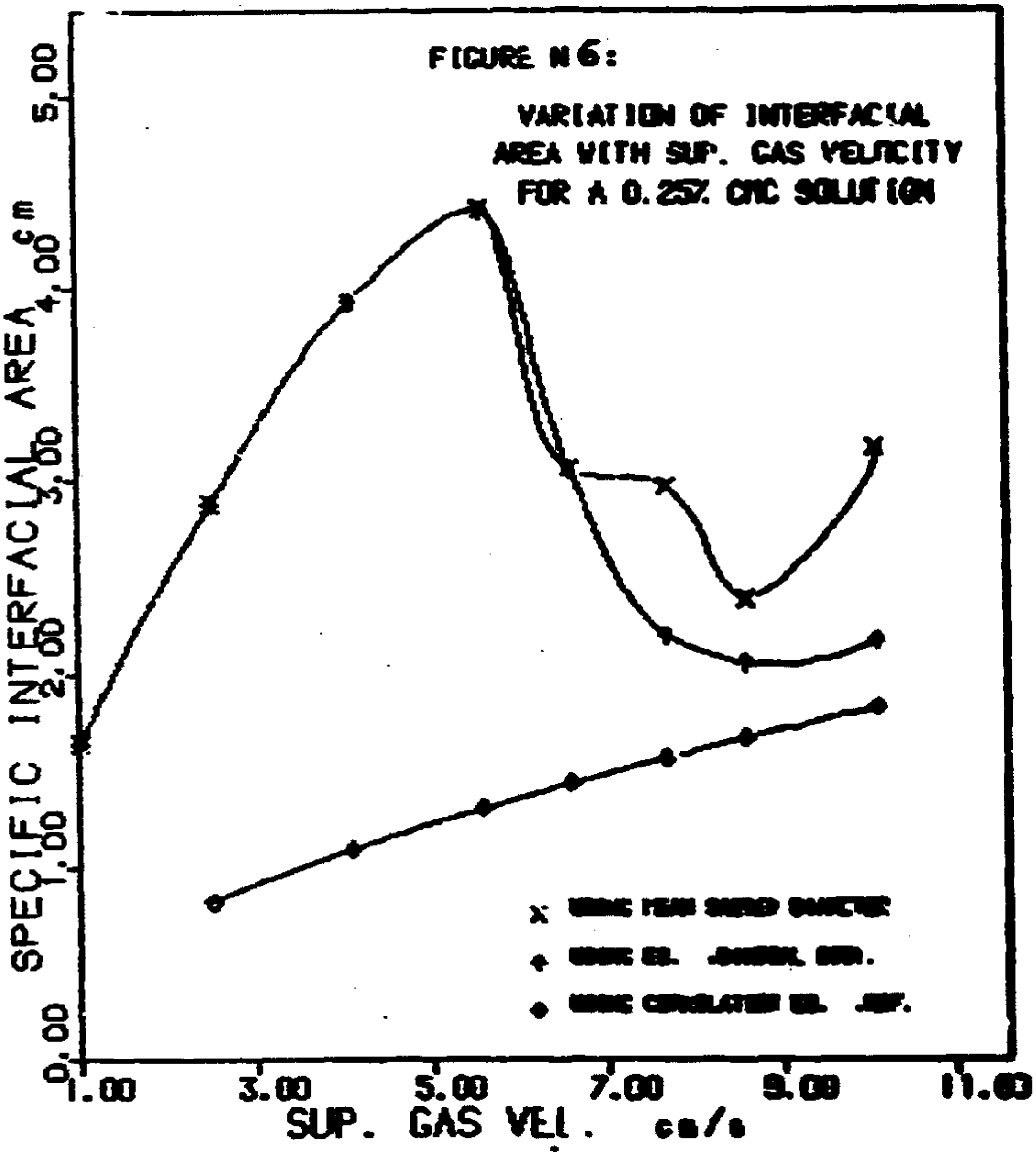

FIGURE N6:

VARIATION OF INTERFACIAL AREA WITH SUP. GAS VELOCITY FOR A 0.25% CMC SOLUTION

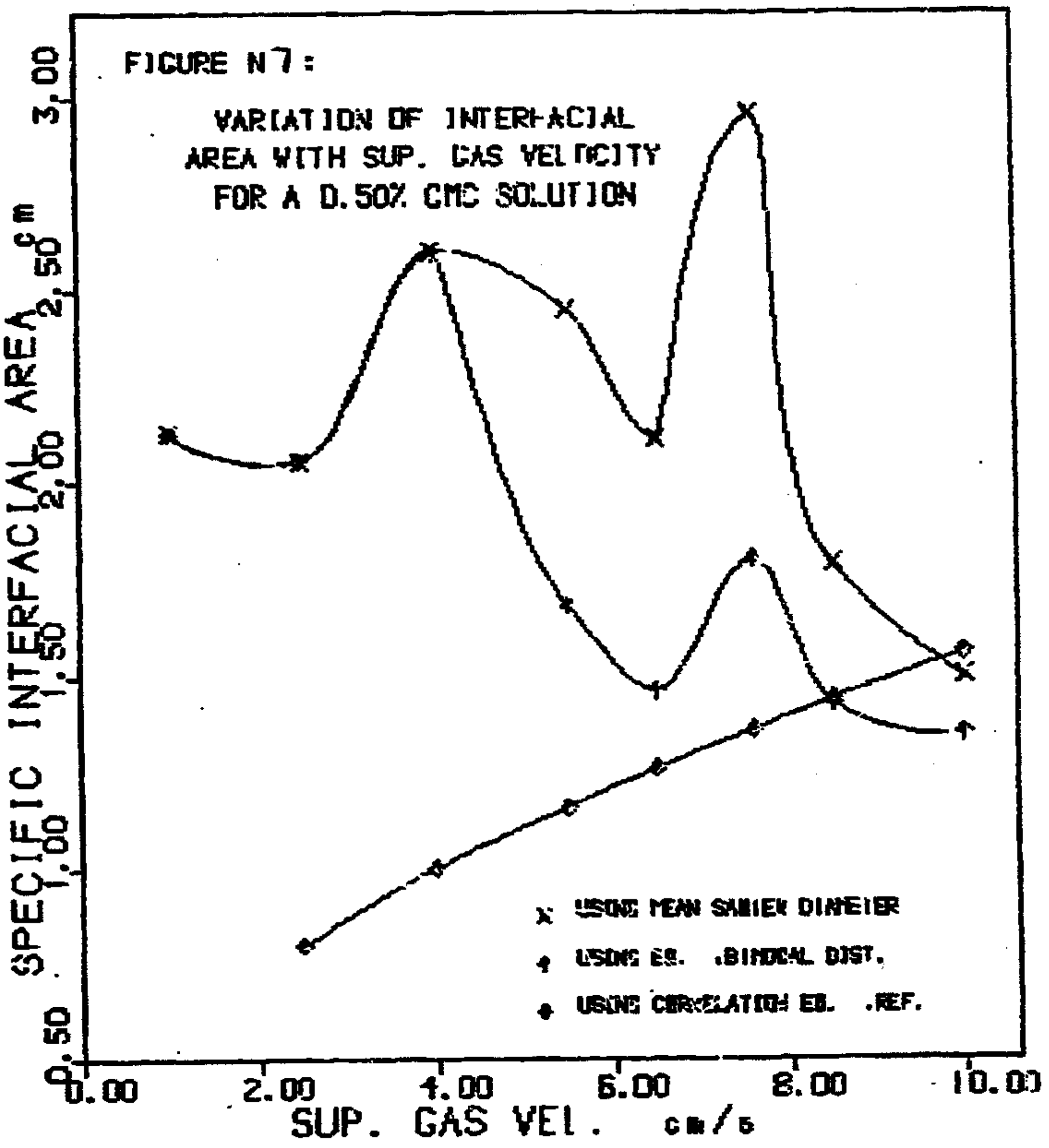

FIGURE N7:

VARIATION OF INTERFACIAL AREA WITH SUP. GAS VELOCITY FOR A 0.50% CMC SOLUTION

variation is directly related to gas holdup variation as expected. For the lowest maximum, 1.5% CMC solution, a fivefold gas flow is required to achieve the same interfacial area at higher throughputs (figure 9), which demonstrates the convenience of the homogeneous flow.

Interfacial area is calculated over the entire gas velocity range taking into account unimodal and bimodal distributions, figures 6 to 10 show both of them. In both cases at low gas velocities for diluted solutions the interfacial area is calculated only with homogeneous Sauter diameter because of the absence of big bubbles. Obviously, the specific interfacial area calculated using bimodal distribution is lower than the one calculated assuming unimodal distribution and the main reason is the use of a lower value for the equivalent diameter in the latter. At high superficial gas velocities interfacial area calculated using bimodal distribution is more reliable.

Comparing results for specific interfacial area with the correlation from Schumpe and Deckwer (56) agreement is found at low and high superficial gas velocities for only highly concentrated CMC solutions whereas, for diluted solutions the agreement is at high superficial gas velocities as can be seen from figures 6 to 10. The specific interfacial area calculated from this correlation is always lower than interfacial area from this study.

The main difference in specific interfacial area between this study and Schumpe and Deckwer (56) is at low superficial gas velocities and diluted solutions, conditions

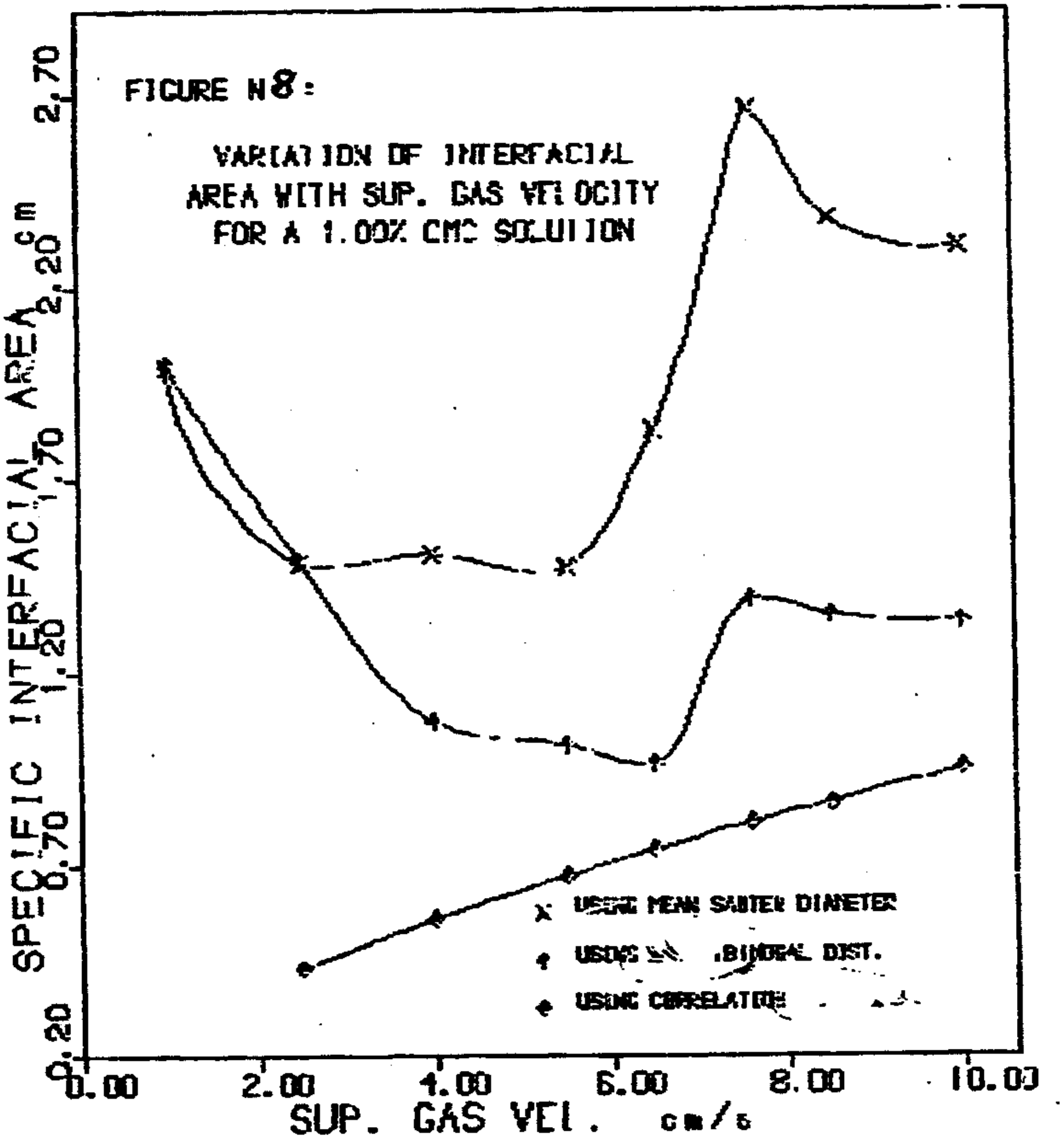

FIGURE N8:

VARIATION OF INTERFACIAL AREA WITH SUP. GAS VELOCITY FOR A 1.00% CMC SOLUTION

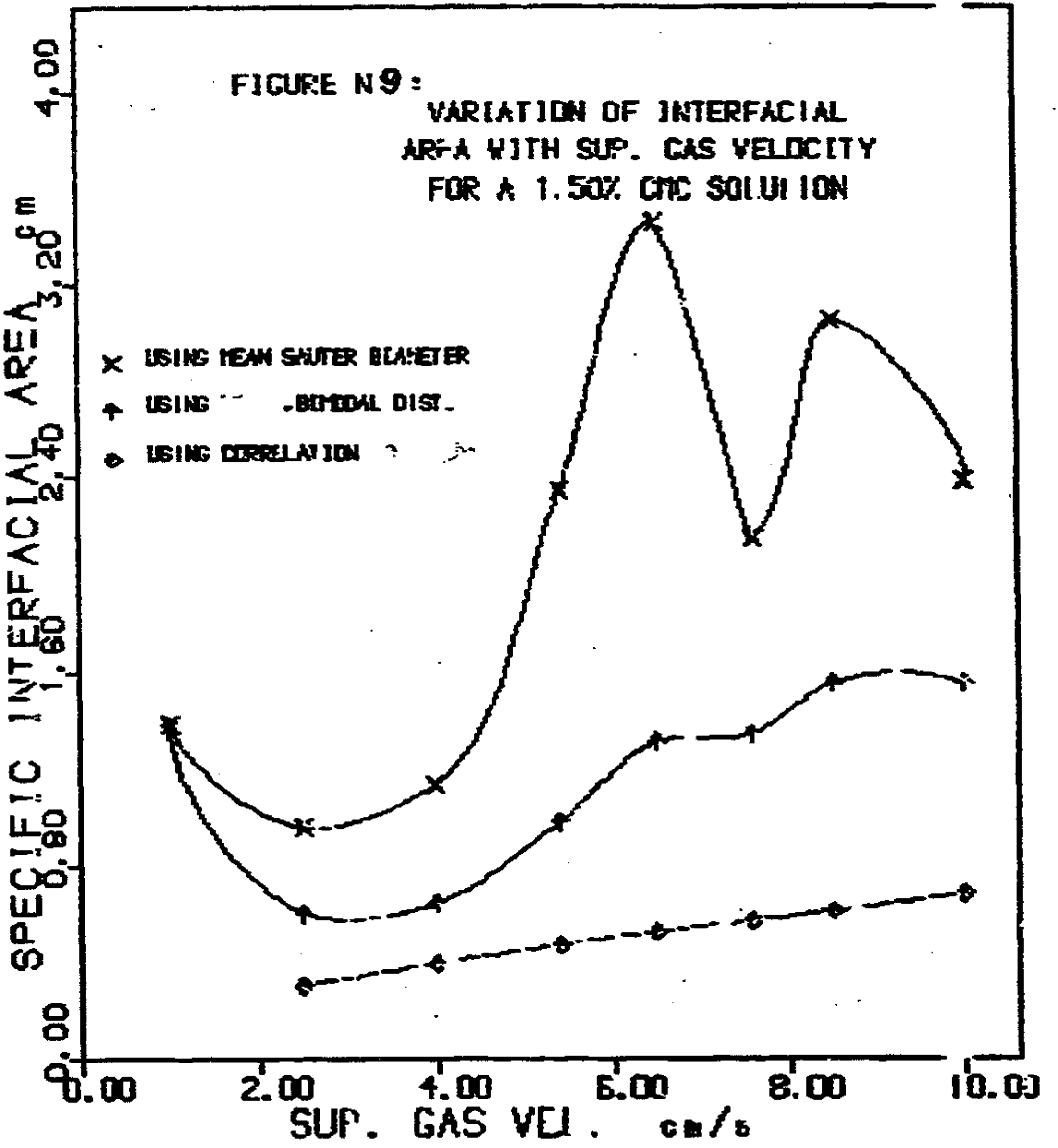

FIGURE N9: VARIATION OF INTERFACIAL AREA WITH SUP. GAS VELOCITY FOR A 1.50% CMC SOLUTION

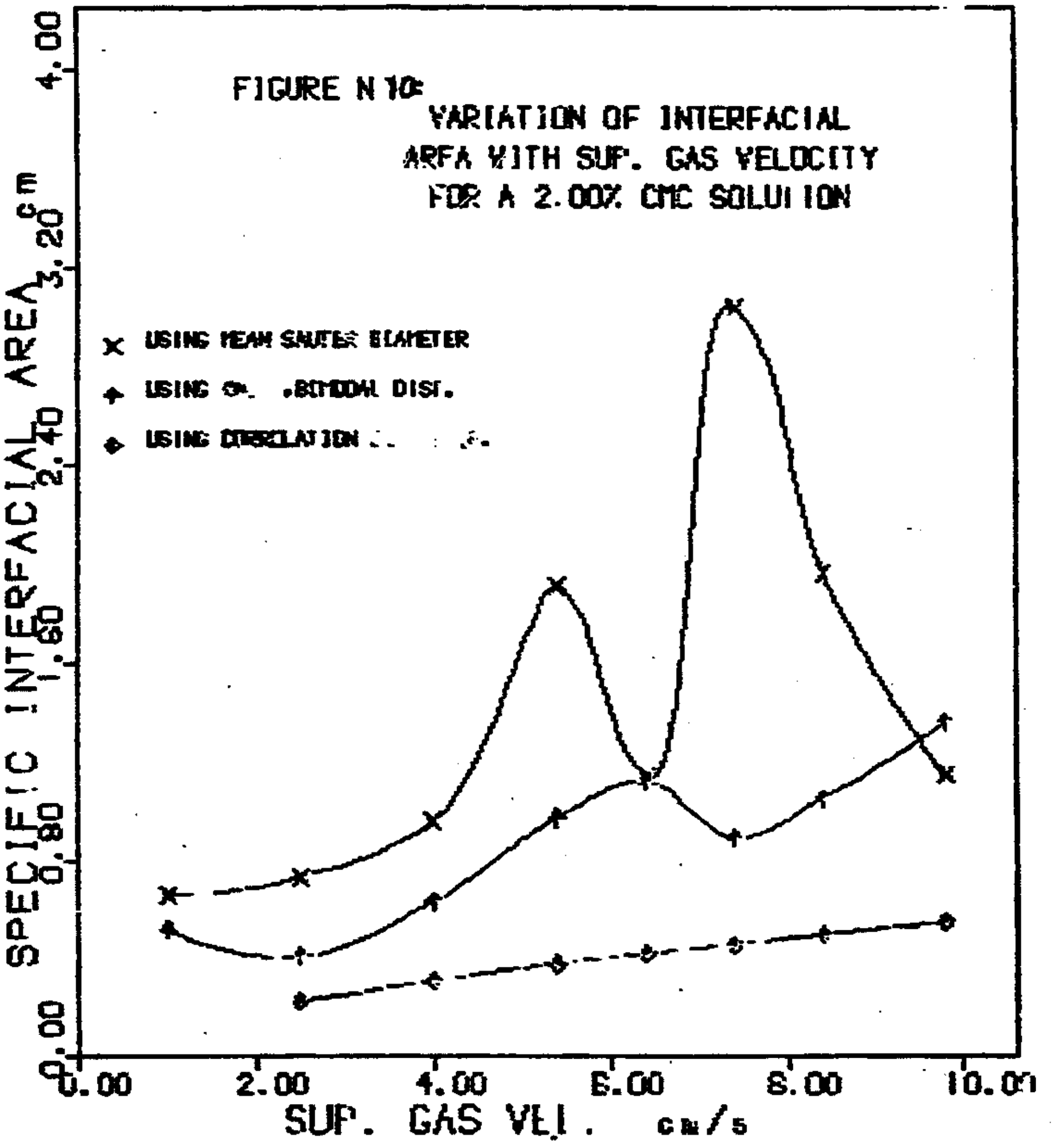
FIGURE N 10: VARIATION OF INTERFACIAL AREA WITH SUP. GAS VELOCITY FOR A 2.00% CMC SOLUTION

in which interfacial area presents a maximum. This difference can be explained by the fact that these investigators correlated data found with different distributors and mostly perforated plates. Thus their generalized correlation is principally for perforated plates.

For a 1.5% CMC solution using sintered plate Schumpe and Deckwer (56) found approximately 0.64 cm^{-1} as the maximum for interfacial area using the chemical method (13), coinciding with a superficial gas velocity of 1cm/s. For the same conditions, the interfacial area is 1.4 cm^{-1} in this study. However, if gas holdup found by Schumpe and Deckwer (56) at those conditions and mean Sauter diameter found in this study are used, an interfacial area of 0.48 cm^{-1} results. Then, differences in gas holdup values are the main argument as far as interfacial area results is concerned. It is also important to remark that the difference in bubble column diameter (Schumpe-Deckwer 14cm, this study 33cm) could make any comparison wrong because of the coalescence effect in smaller diameters as well as the differences in the average pore diameter in the porous plate.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES

Bubble size and specific interfacial area studies were made in a 33cm diameter bubble column for the carboxymethyl cellulose (CMC) aqueous solution -air system using a 70 um porous plate gas distributor. The bubble column was operated in Bubble and Bubble-Slug flow patterns. The Bubble to Bubble-Slug transition occurred within superficial gas velocities of 1 to 5 cm/s depending upon the CMC concentration. The transition at higher superficial gas velocity occurred for the most diluted solution.

Gas holdup decreased with CMC concentration and exhibited a maximum at the Bubble to Bubble-Slug transition zone. The maximum diminishes with CMC concentration. Actually, this maximum appears to vanish for highly concentrated solutions. Results for gas holdup are in fair agreement with those from Schumpe and Deckwer (56) but having large differences for the maximum values.

Small bubble size was found to be smaller near the wall and bigger at R/2 in the column and it always increased with superficial gas velocity or CMC concentration. Finding bubble size distributions at high superficial gas velocities and/or highly concentrated CMC solutions was not succesful due to some limitations in the photographic equipment in determining the larger bubble sizes. Therefore, results for specific interfacial area are not accurate under those conditions.

For low and moderate CMC concentrations it is recommended to work near the bubble to bubble-slug transition where the specific interfacial area exhibits a maximum. This maximum diminishes with CMC concentration and eventually vanishes at highly concentrated solutions.

The method for evaluation of specific interfacial area taking into account bimodal distribution presented in this study is more accurate than methods taking into consideration only a mean bubble diameter (6, 13, 17, 55) even if this average is calculated from accurate bubble size distributions as in Buchholz et al (6).

RECOMMENDATIONS FOR FURTHER STUDIES

Bubble columns have many applications in two and three phase flow. The effect of fluid properties and the nature of the gas distributor on flow pattern and interfacial area are important for the design and scale up of bubble column reactors. In the present work the effect of pseudoplastic properties in specific interfacial area using a porous plate was studied. Further work is recommended using other types of gas distributors and different methods for characterization of interfacial area in order to have a source of comparison. The use of a combination of borescope pictures and photographs from outside the column at high gas throughputs is also recommended. The objective of the borescope can be enlarged with the use of a telex adaptor (from Olympus Co.), experiments using this device are also suggested.

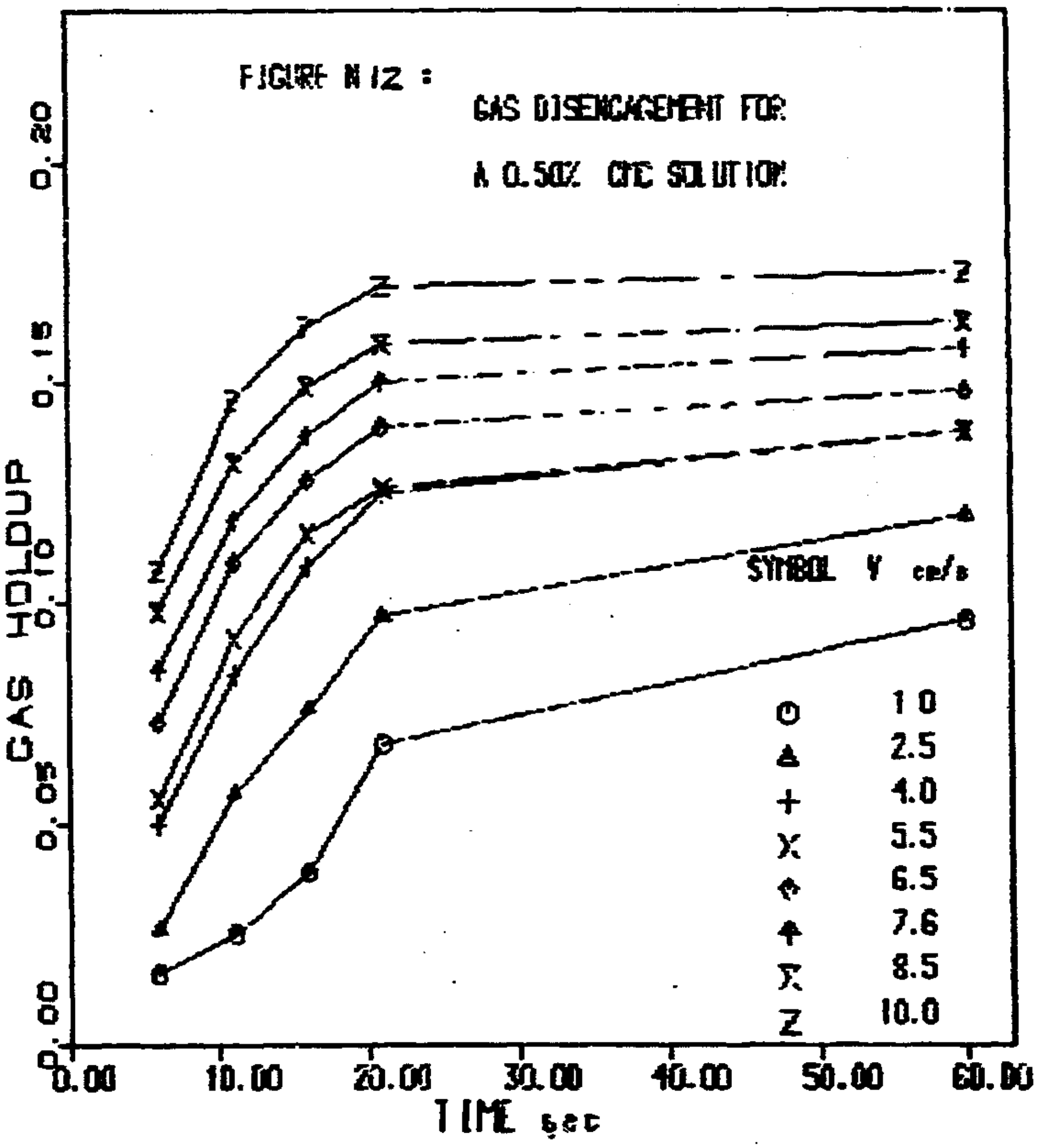

FIGURE N 12 : GAS DISENGAGEMENT FOR A 0.50% CMC SOLUTION

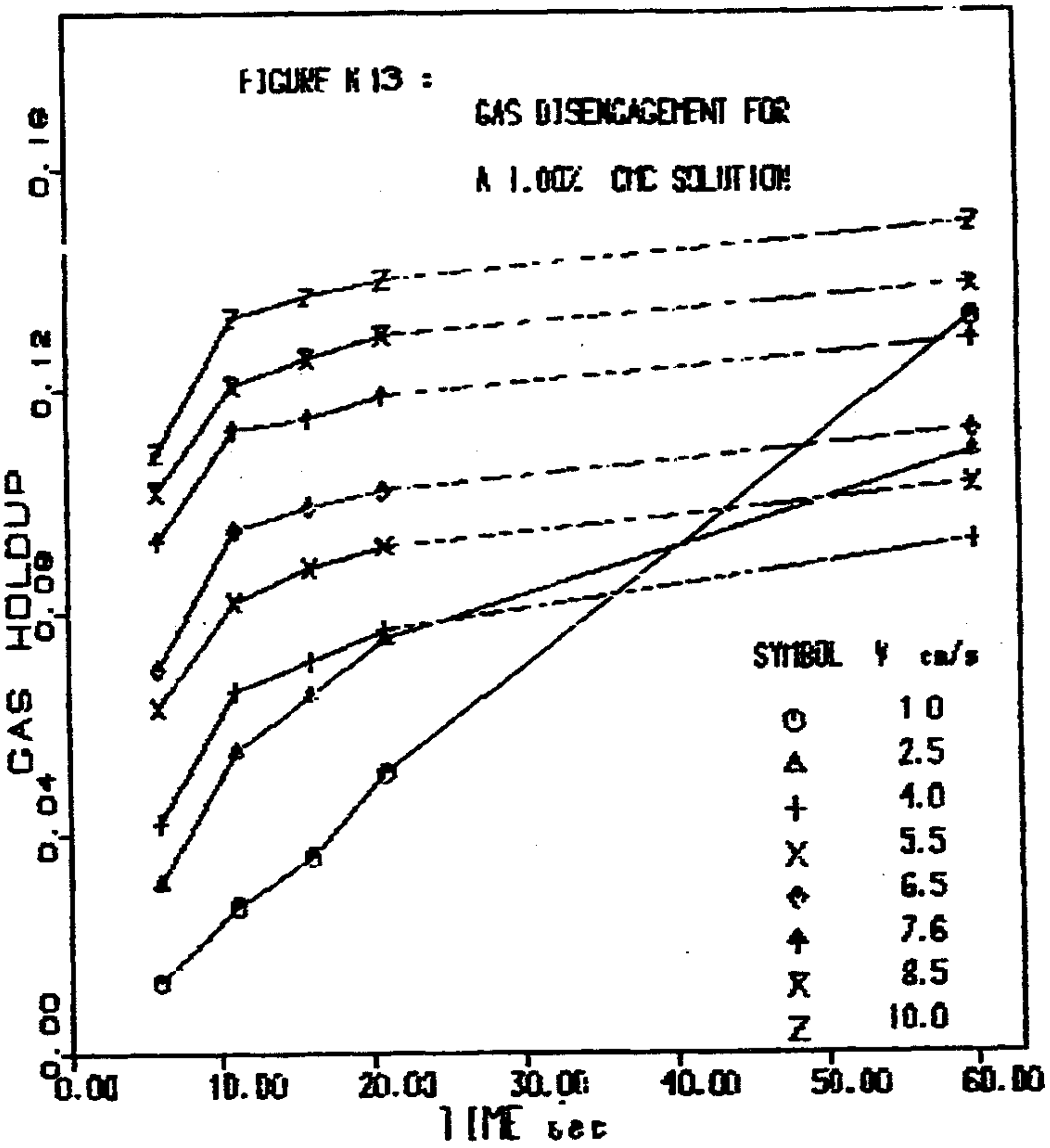

FIGURE K13 : GAS DISENGAGEMENT FOR A 1.00% CMC SOLUTION

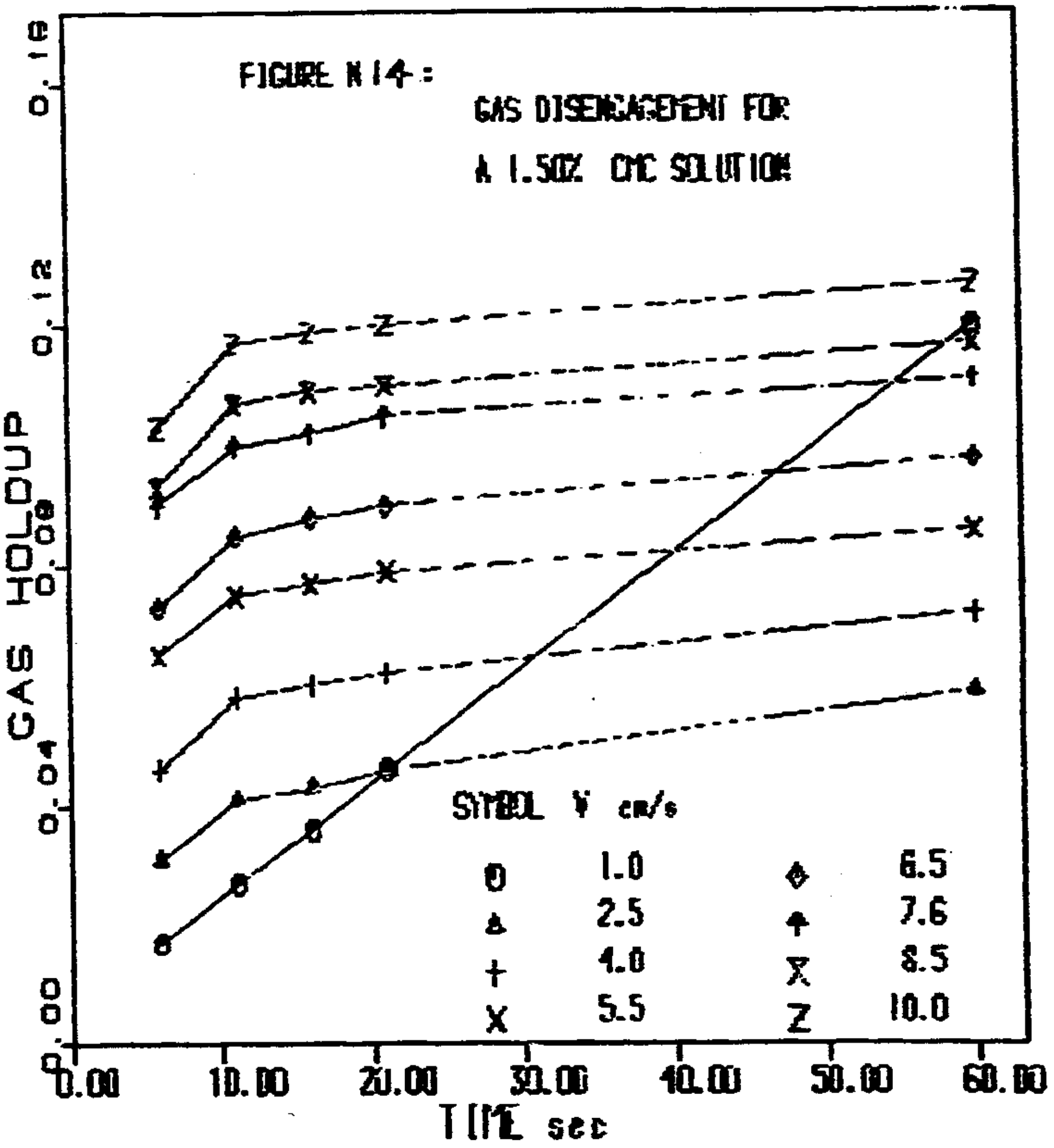
FIGURE N 14 : GAS DISENGAGEMENT FOR A 1.50% CMC SOLUTION

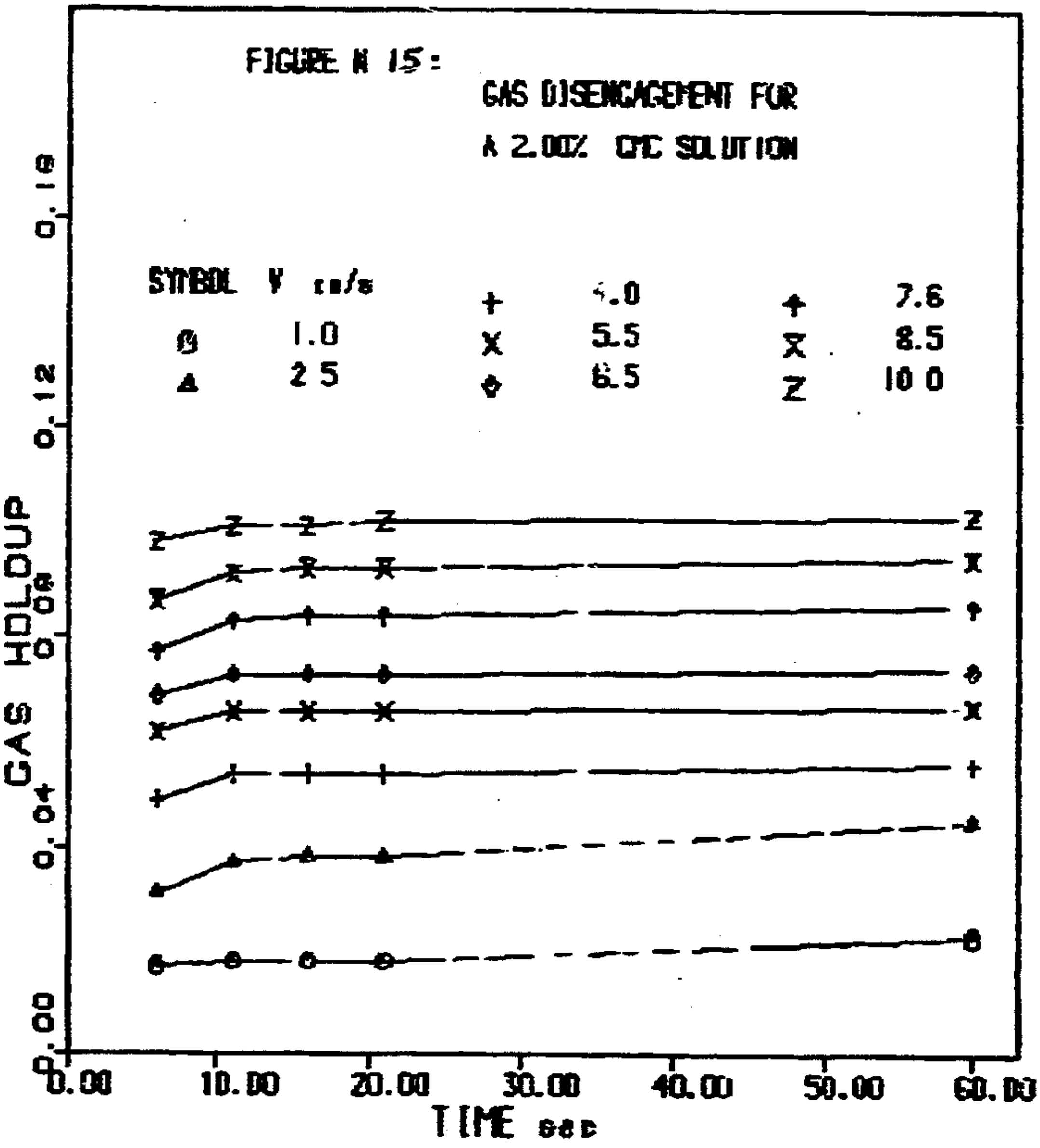

FIGURE N 15: GAS DISENGAGEMENT FOR A 2.00% CMC SOLUTION

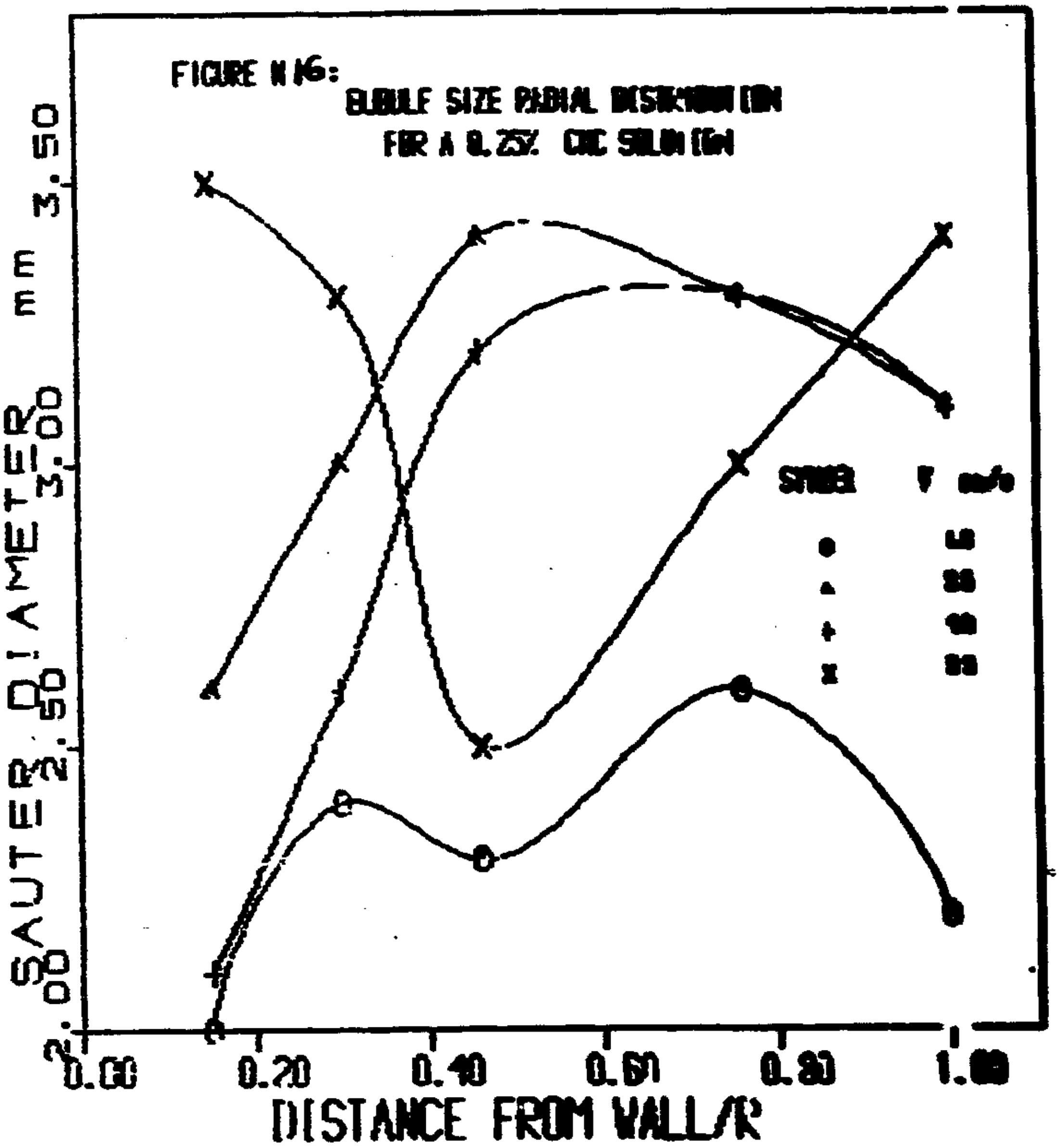

FIGURE N 16: BUBBLE SIZE RADIAL DISTRIBUTION FOR A 0.25% CMC SOLUTION

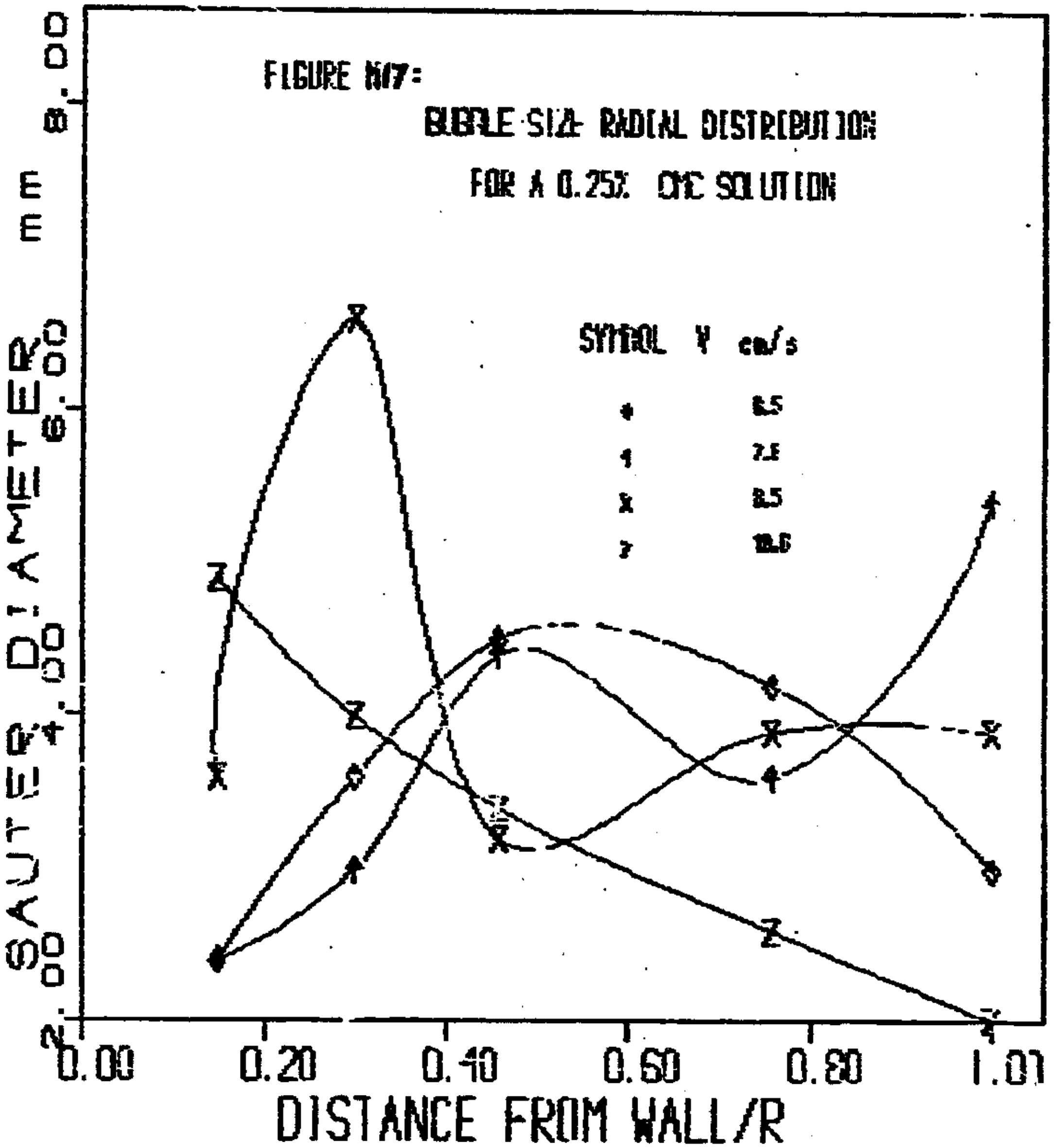

FIGURE N/7:

BUBBLE SIZE RADIAL DISTRIBUTION

FOR A 0.25% CMC SOLUTION

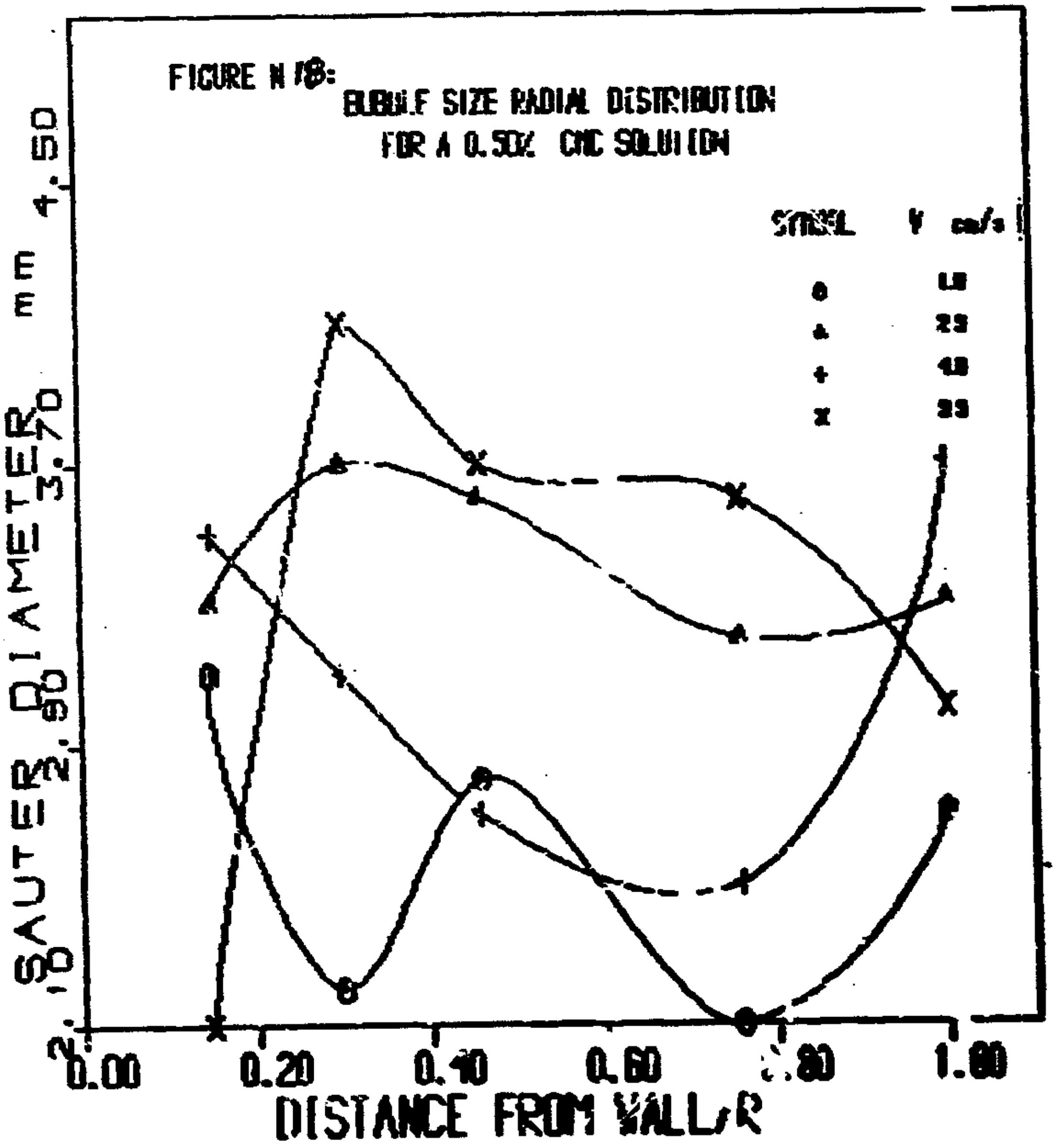

FIGURE N°18: BUBBLE SIZE RADIAL DISTRIBUTION FOR A 0.50% CMC SOLUTION

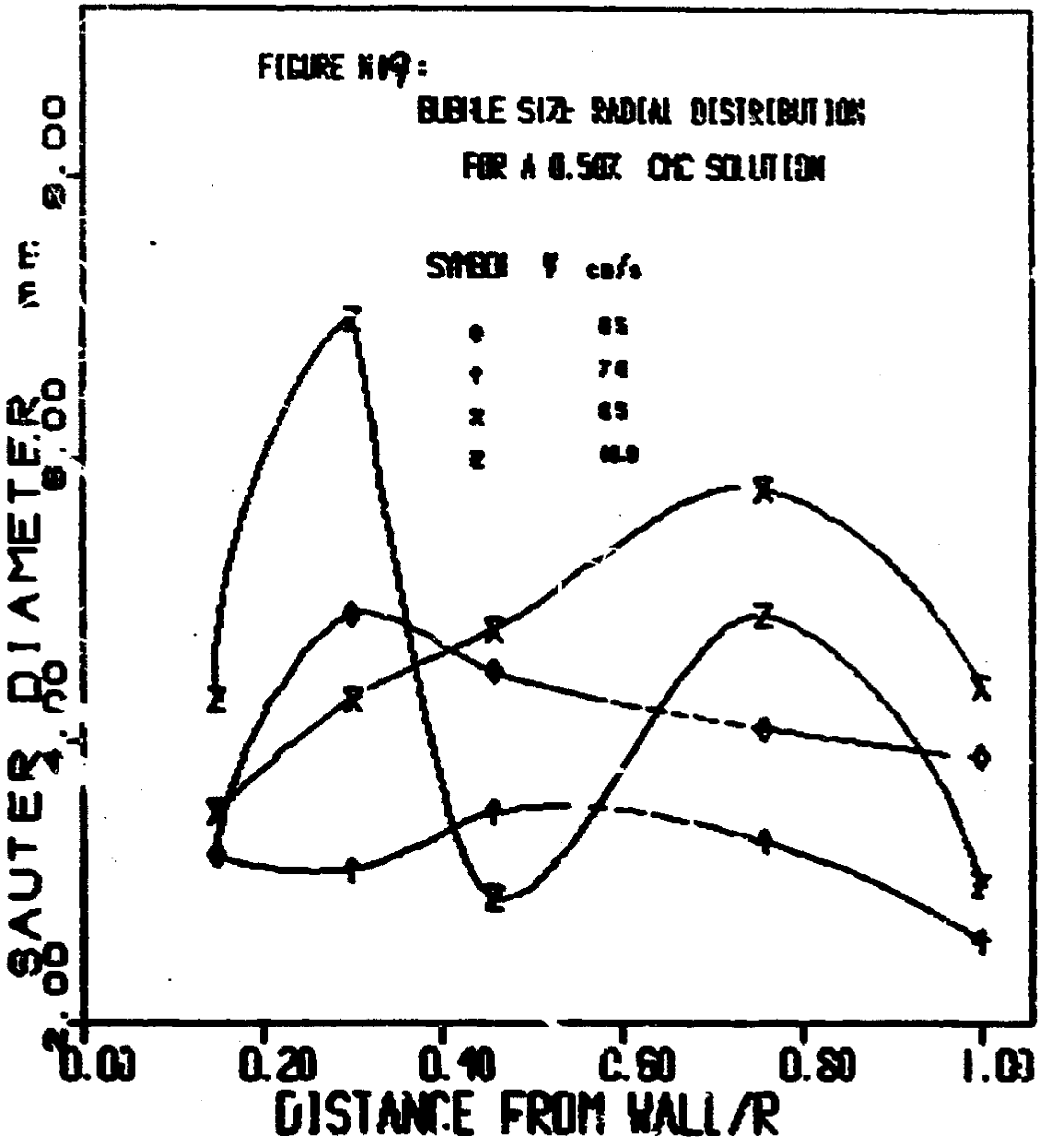
FIGURE N°9:
BUBBLE SIZE: RADIAL DISTRIBUTION
FOR A 0.50% CMC SOLUTION
SYMBOL V cm/s
● 65
↑ 74
x 85
z 10.0
SAUTER DIAMETER mm
2.00
4.00
6.00
8.00
0.00
0.20
0.40
0.60
0.80
1.00
DISTANCE FROM WALL/R

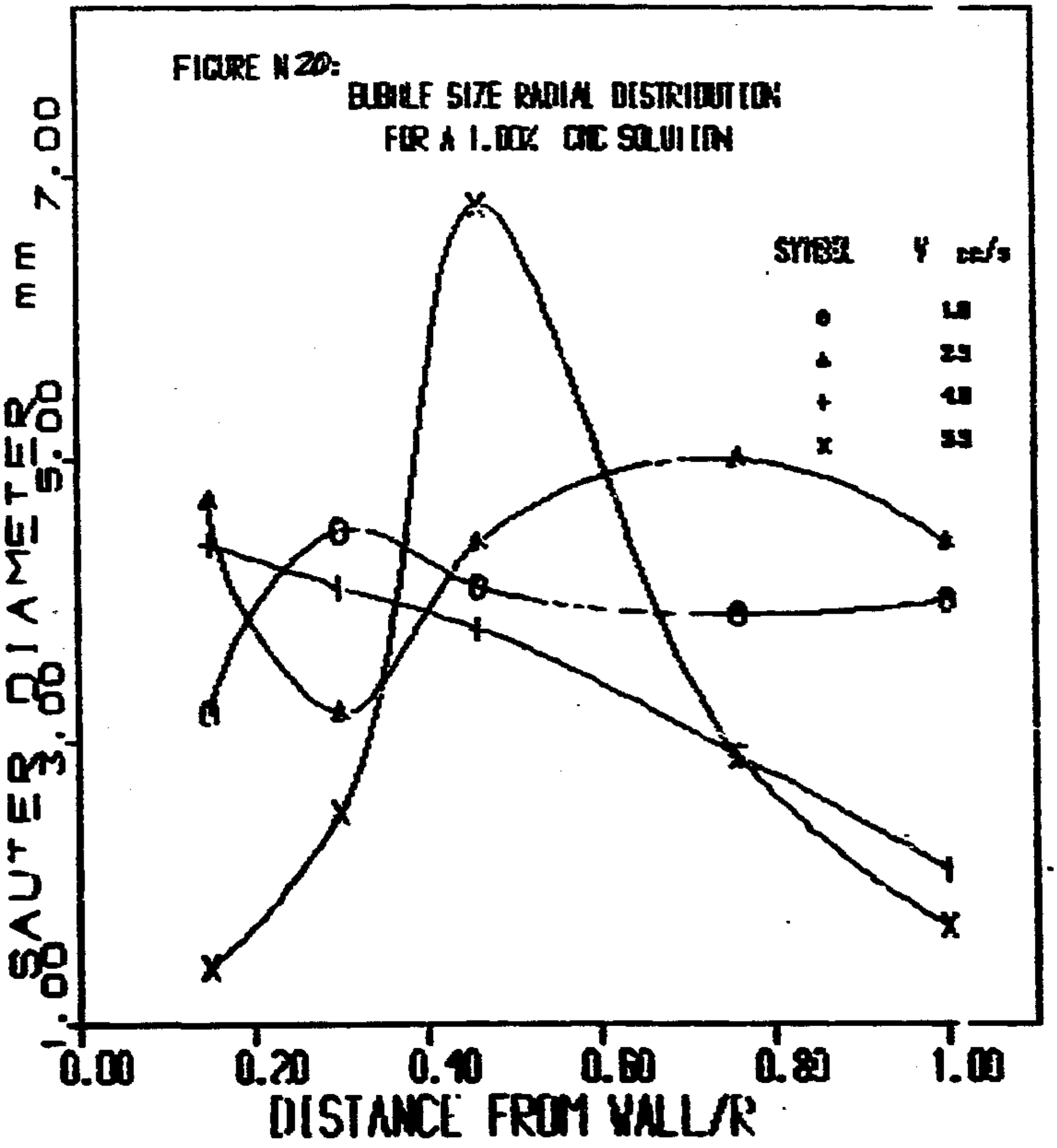
FIGURE N 20: BUBBLE SIZE RADIAL DISTRIBUTION FOR A 1.00% CMC SOLUTION

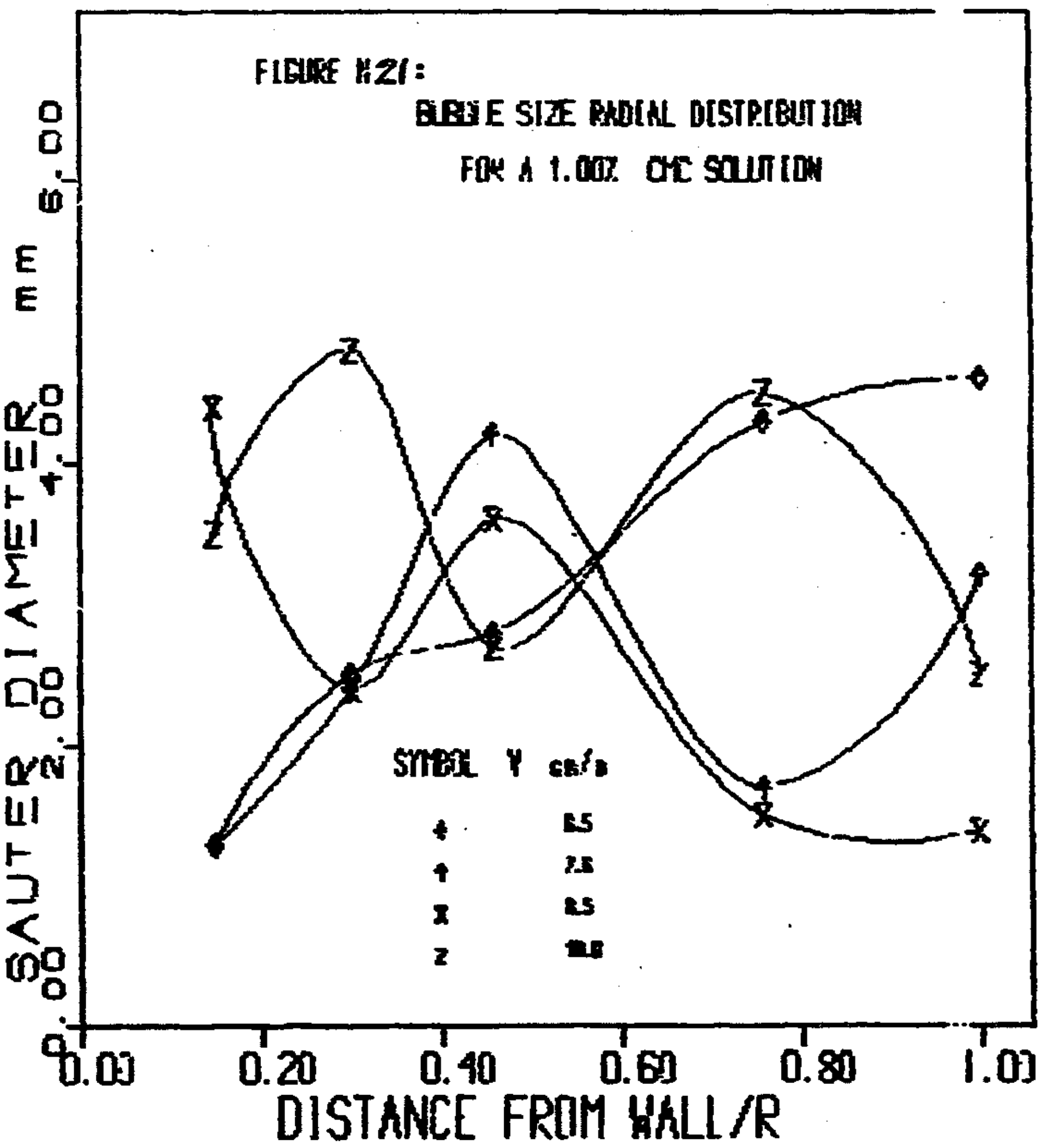

FIGURE N21:
BUBBLE SIZE RADIAL DISTRIBUTION
FOR A 1.00% CMC SOLUTION

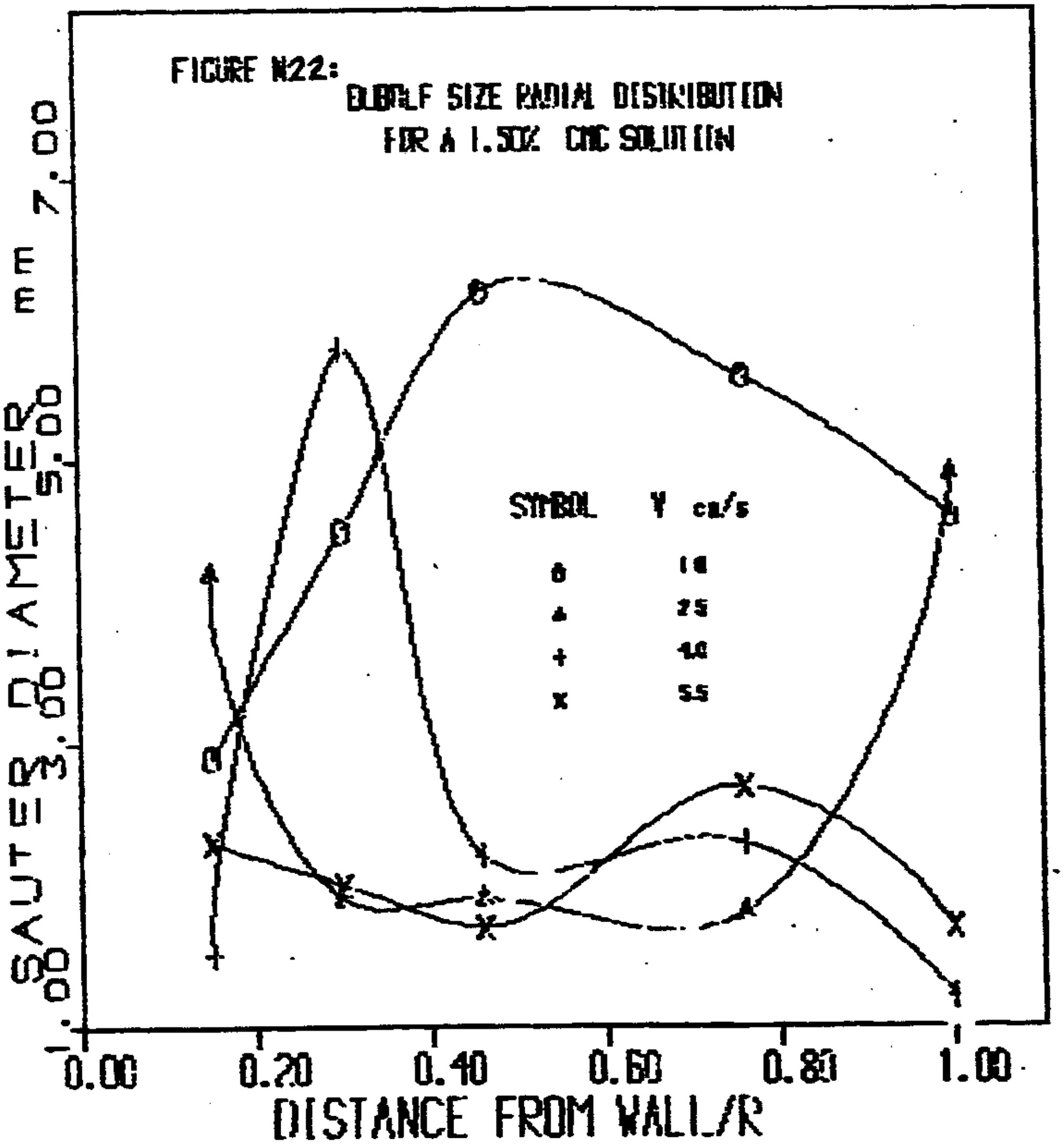

FIGURE N22: BUBBLE SIZE RADIAL DISTRIBUTION FOR A 1.50% CMC SOLUTION

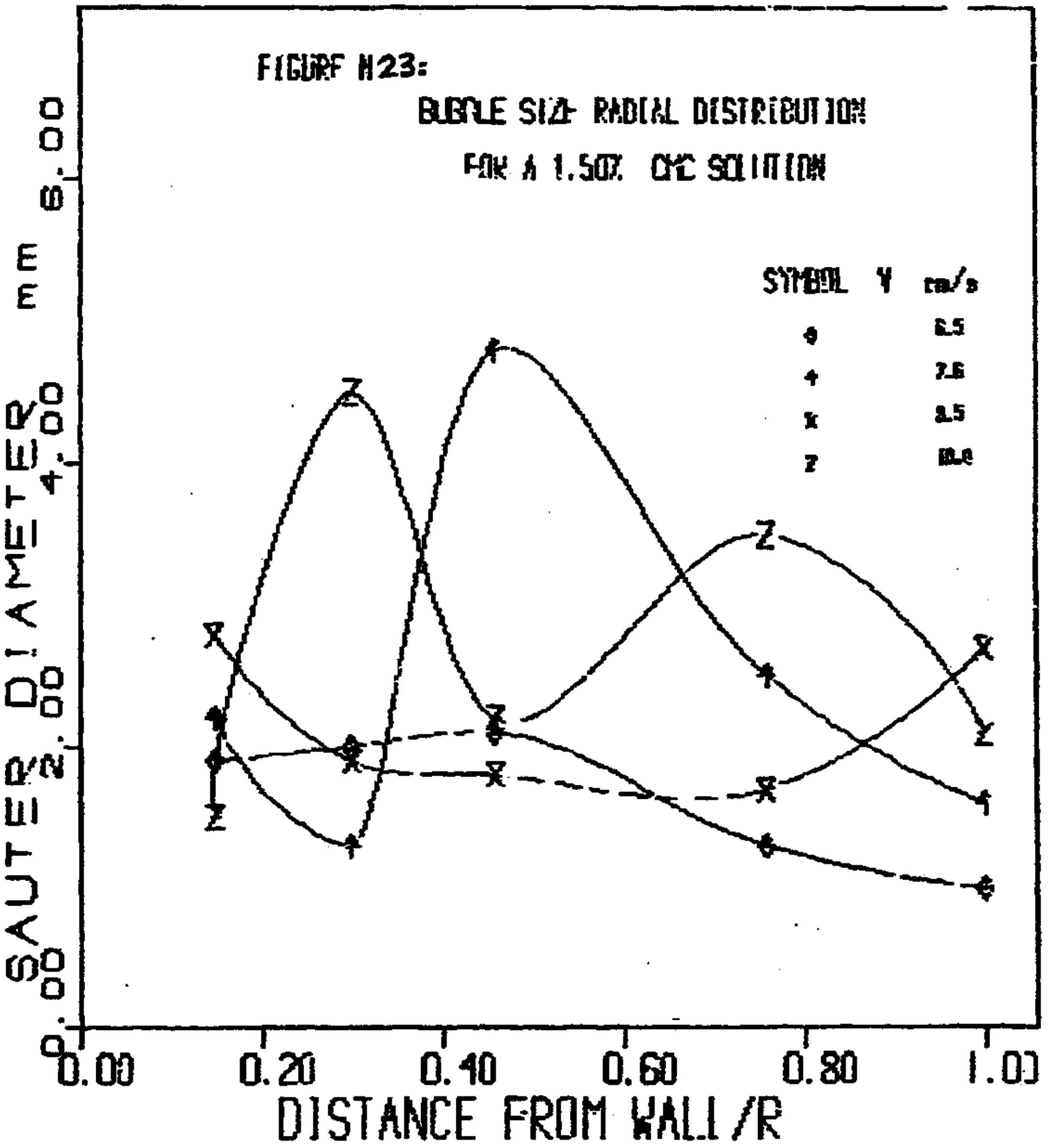

FIGURE N23: BUBBLE SIZE RADIAL DISTRIBUTION FOR A 1.50% CMC SOLUTION

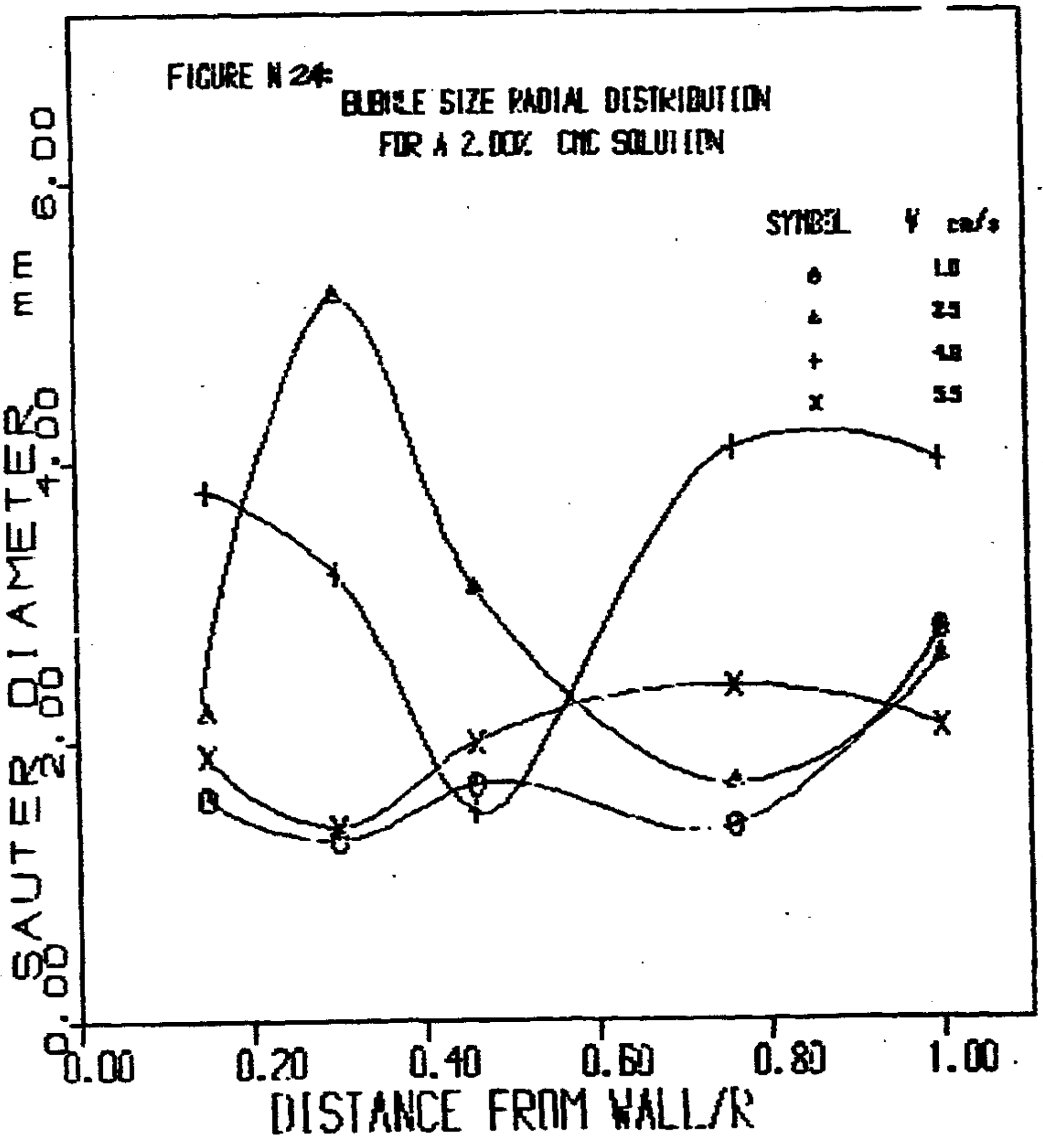

FIGURE N 24: BUBBLE SIZE RADIAL DISTRIBUTION FOR A 2.00% CMC SOLUTION

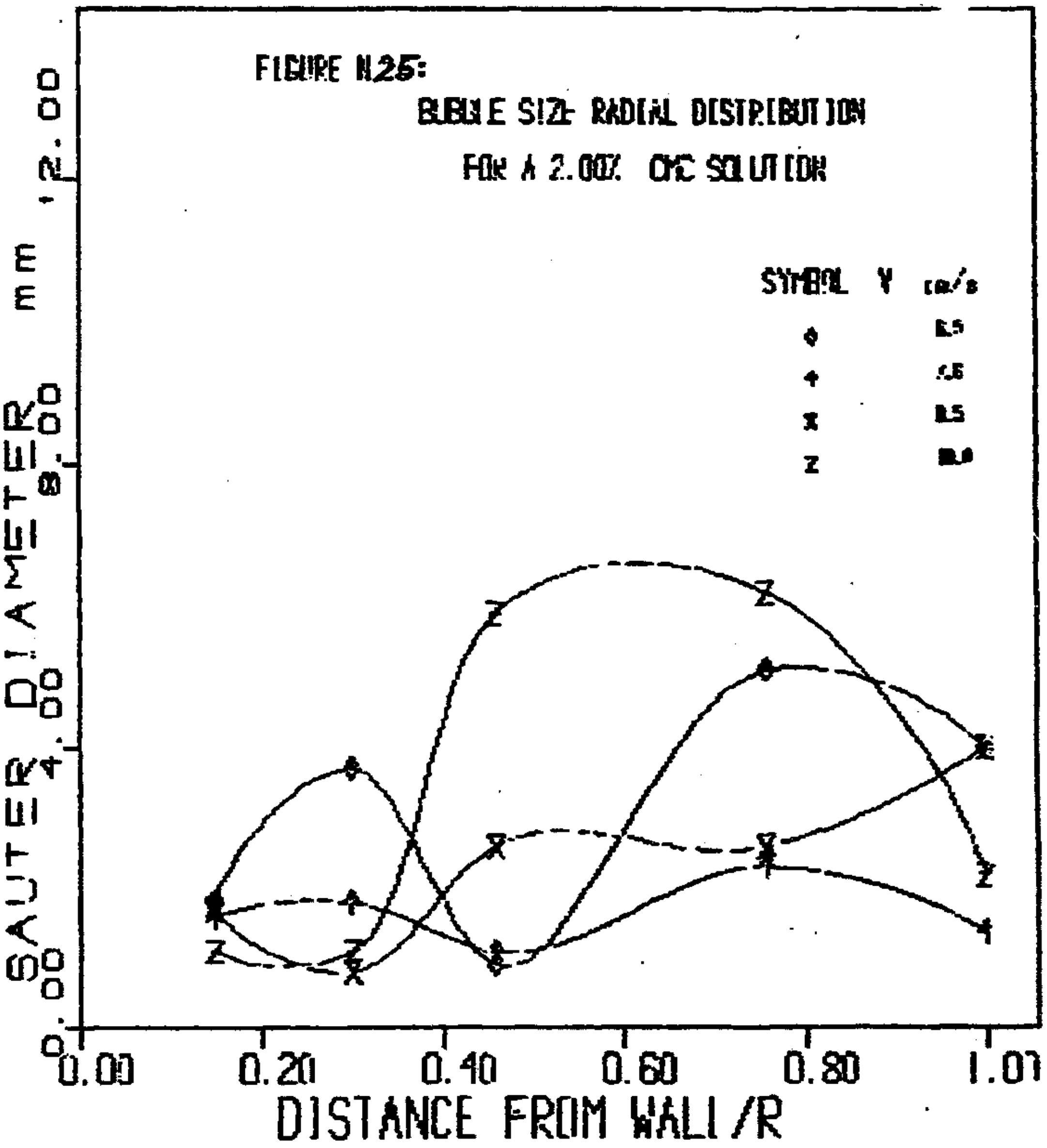

FIGURE N.25:
BUBBLE SIZE RADIAL DISTRIBUTION
FOR A 2.00% CMC SOLUTION

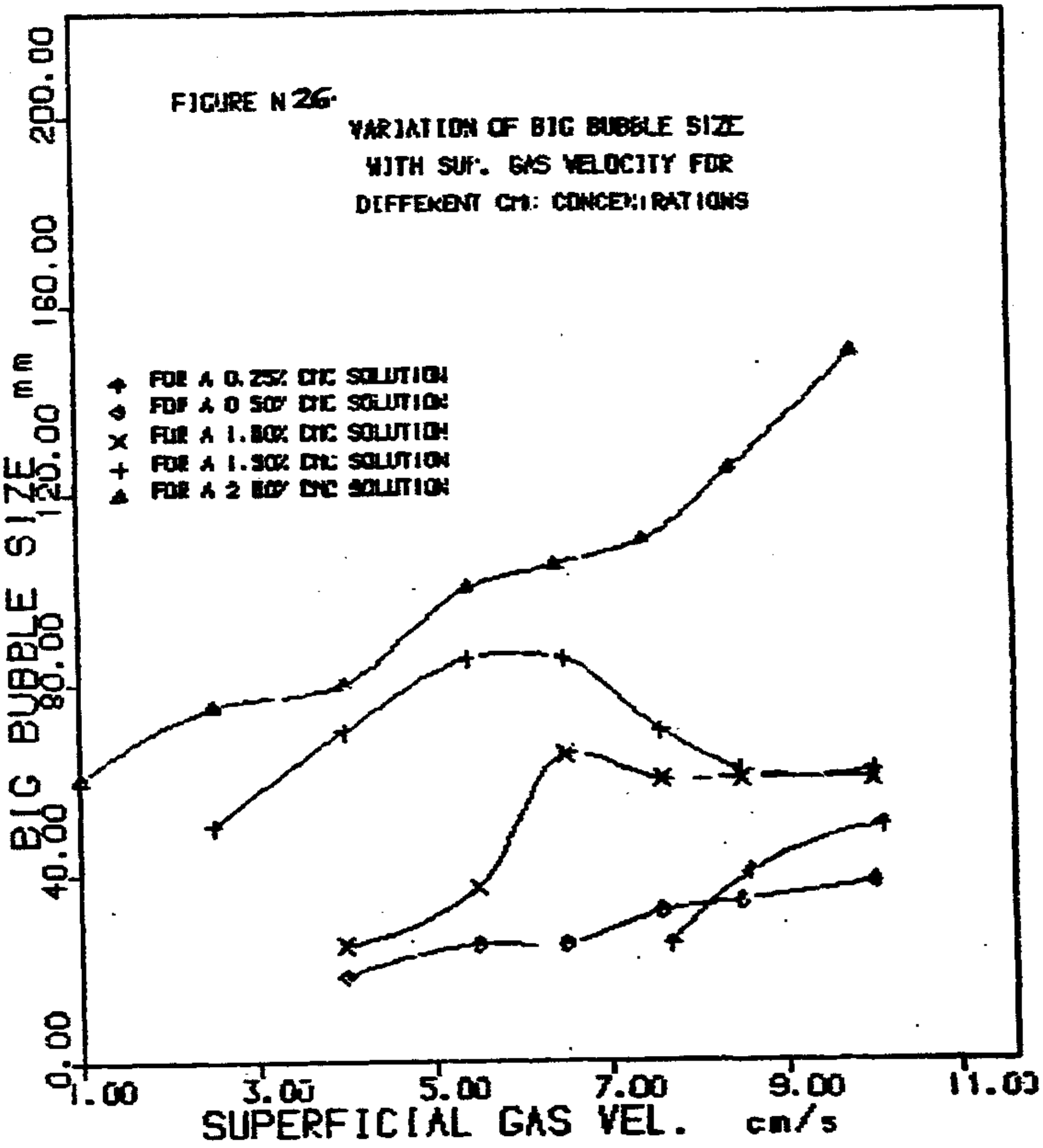

FIGURE N 26

VARIATION OF BIG BUBBLE SIZE
WITH SUP. GAS VELOCITY FOR
DIFFERENT CMC CONCENTRATIONS

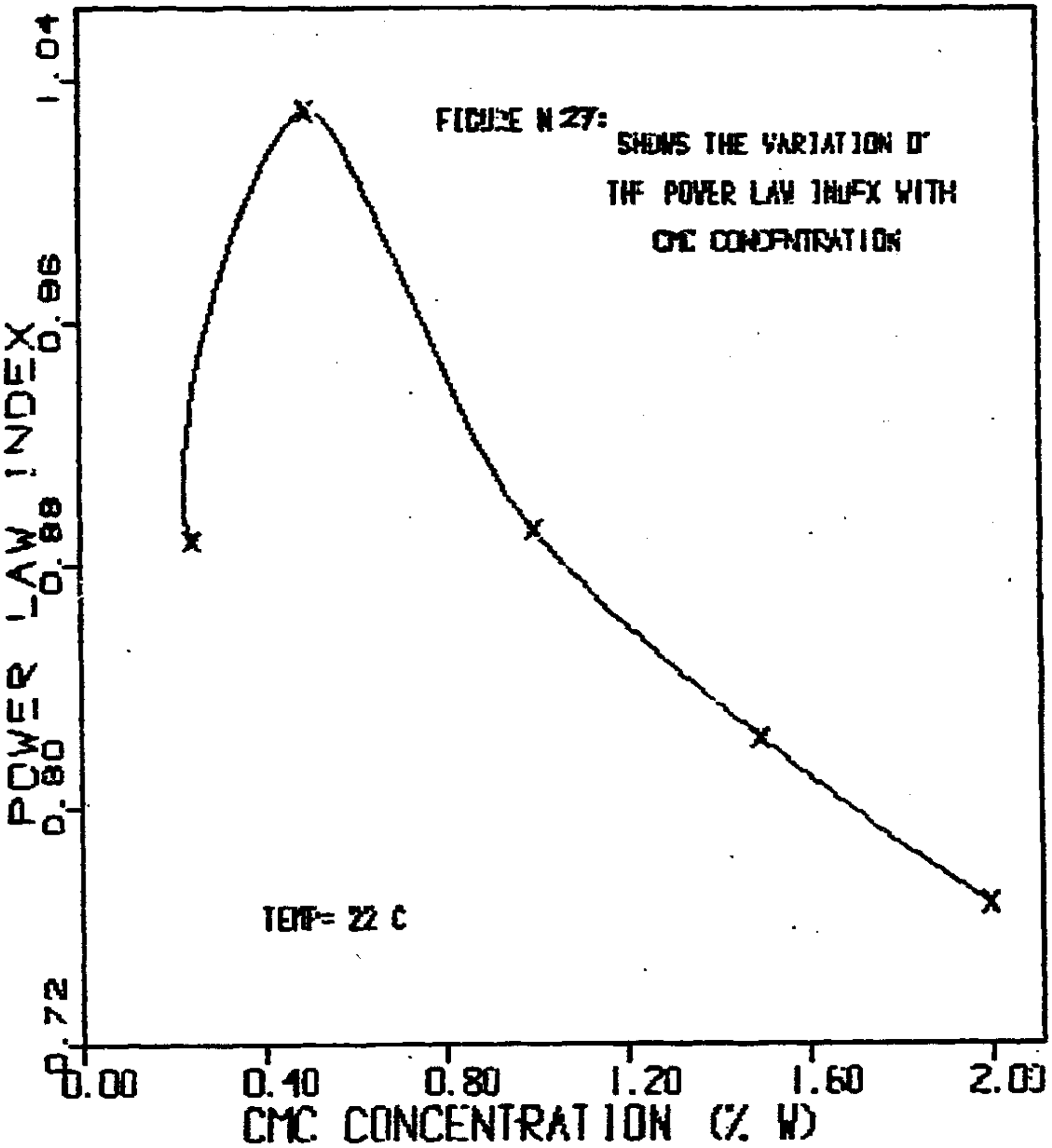
FIGURE N 27: SHOWS THE VARIATION OF THE POWER LAW INDEX WITH CMC CONCENTRATION

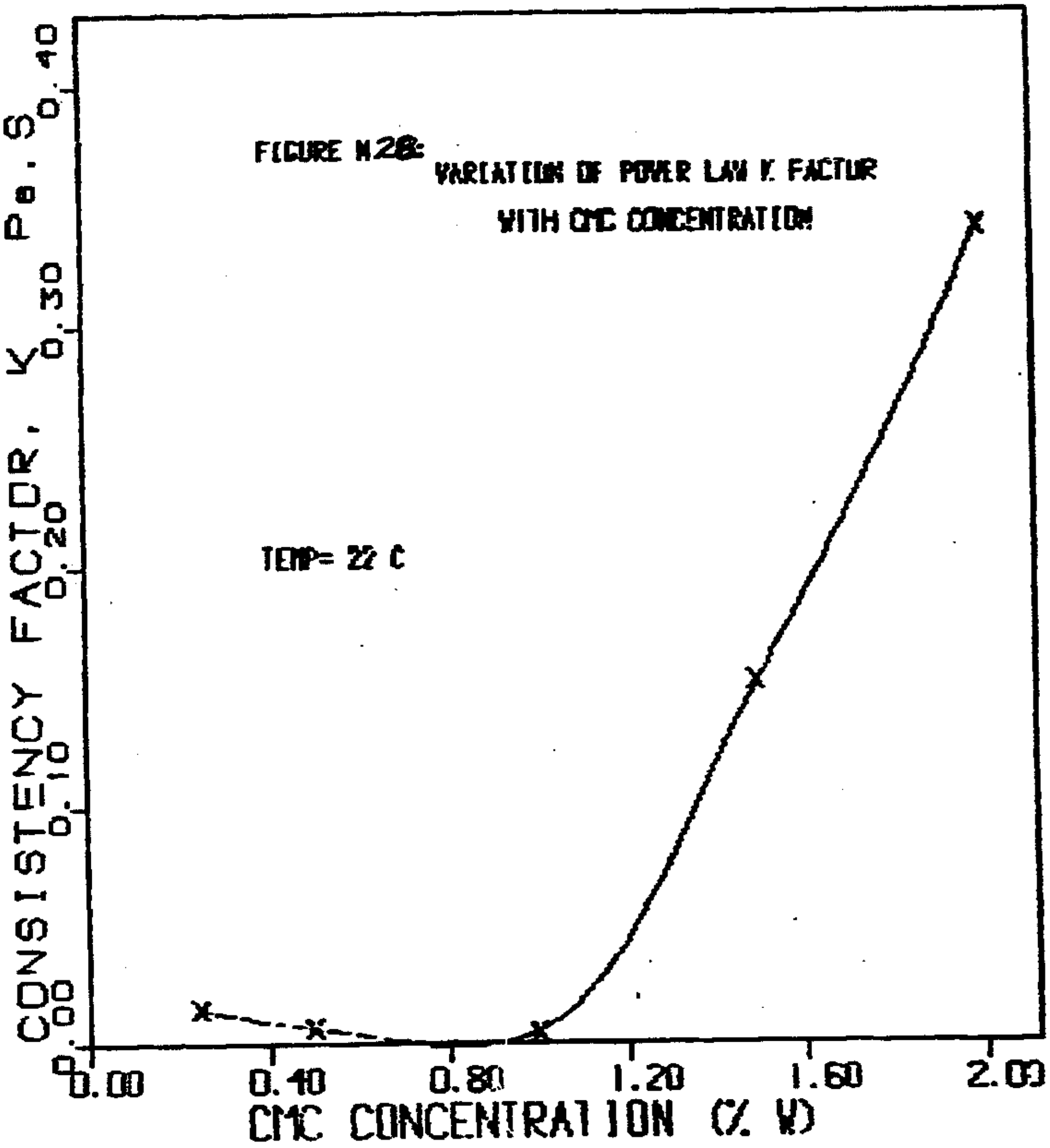

FIGURE N28: VARIATION OF POWER LAW K FACTOR WITH CMC CONCENTRATION

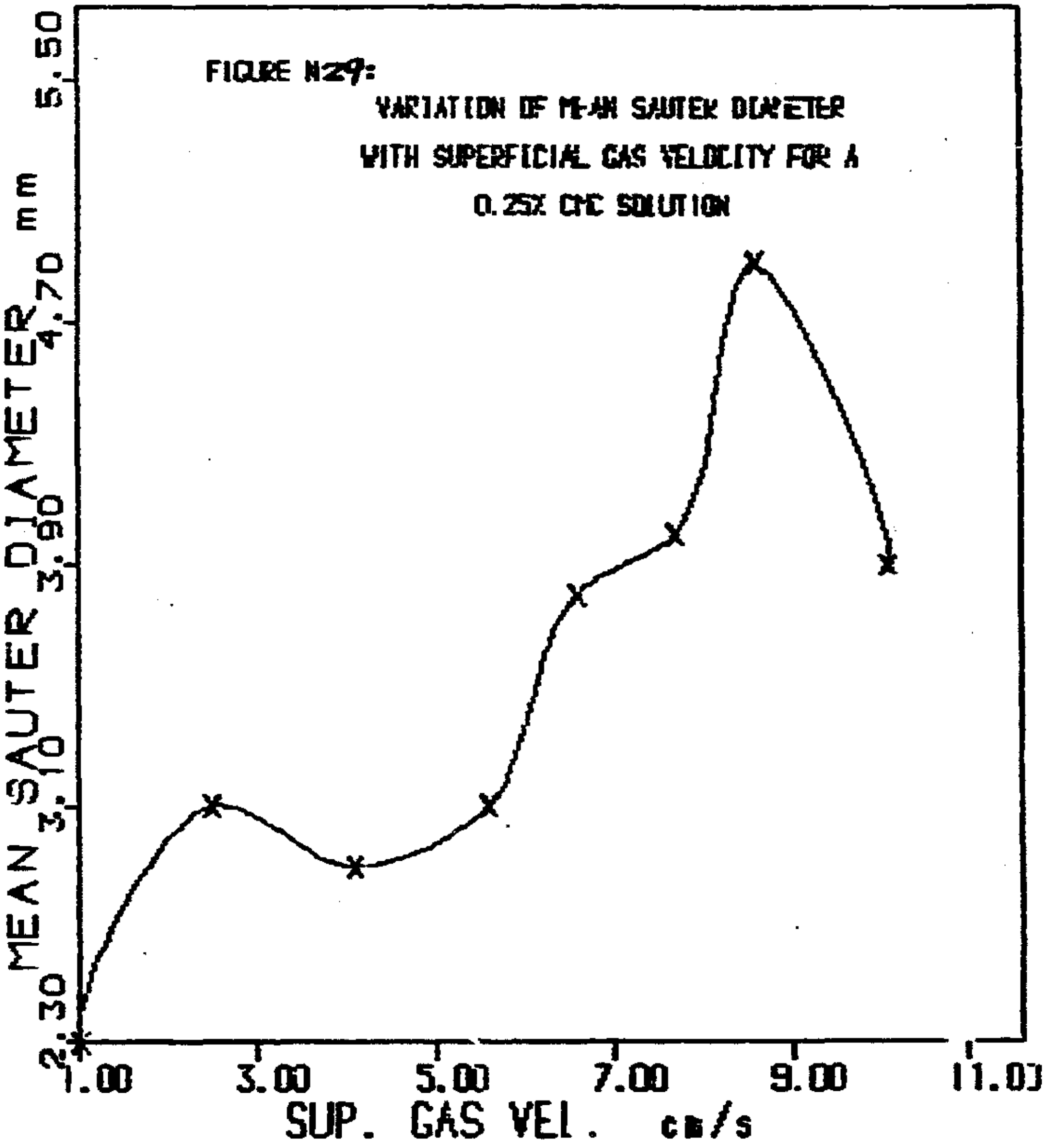

FIGURE N29: VARIATION OF MEAN SAUTER DIAMETER WITH SUPERFICIAL GAS VELOCITY FOR A 0.25% CMC SOLUTION

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