

VACUUM DEGASIFICATION OF WATER

A Thesis

Presented to

The Faculty of the Graduate School
University of Missouri - Columbia

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by

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December 1979

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VACUUM DEGASIFICATION OF WATER

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Master of Science

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December 1979

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VACUUM DEGASIFICATION OF WATER

A procedure for design of a water vacuum degasifier is presented for removing oxygen, carbon dioxide, nitrogen, and argon from water from 35 to 90 F. This procedure is based on gas solubilities following Henry's law and diffusivities following the Stokes-Einstein equation. Column mass transfer is described in terms of the number and height of overall liquid transfer units, N_{OL} and H_{OL} . A computer performance program is presented.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. Truman S. Storvick for his guidance and insight in the development of this work, and to Mr. Lester C. Webb for his willingness and support for this work to be performed.

Appreciation is also due to Black & Veatch Consulting Engineers for the use of their computing facilities and library resources.

A great deal of credit belongs to Priscilla, my wife, for her expressions of love and encouragement in assisting this work.

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CHAPTER I

INTRODUCTION

The design of vacuum degasification equipment in demineralization systems for boiler feedwater treatment was studied. The dissolved gases requiring removal were oxygen and carbon dioxide. The vacuum degasifier equipment consisted of a packed column having one or more stages and a vacuum source.

The design of a vacuum degasifier was based upon the water flow rate, temperature, concentrations of dissolved gases and solids, and the required effluent gas concentrations. The design variables were the column diameter, number of stages, type and height of packing, and the stage pressure and evacuation rate.

Henry's law was used to model gas solubilities. Correlations for the solubilities of argon, carbon dioxide, nitrogen, and oxygen by Weiss (51, 52) were used. The correlations were compared with experimental data. Carbon dioxide solubility was corrected for ionization. Dalton's law and Raoult's law were also used to model gas-liquid behavior.

The mass transfer performance of a stage was based on the liquid diffusivity of the gases and packing mass transfer characteristics. MASPAC packing and its published performance characteristics were used. The liquid diffusion coefficients

were assumed to follow the Stokes-Einstein equation. The Stokes-Einstein constant results for each gas were compared to experimental diffusion coefficient data.

A design procedure for equipment selection was developed. Correlations for Nash air ejector performance were developed for incorporation into the design equations. The procedure outlines the selection of column diameter, type of packing, the height of packing, and size of vacuum system in each stage. A design performance program was developed to evaluate degasifier designs.

CHAPTER II

VACUUM DEGASIFICATION

Vacuum degasification refers to the removal of dissolved gases from water by reducing their solubility with vacuum. This takes advantage of the decreased gas solubility at low pressure. Vacuum degasification is used as a water treatment process where dissolved gases would pose problems in the distribution and use of the water.

Vacuum degasification was first used to remove oxygen from water to prevent corrosion in water pipeline systems (38, 39, 1). Among its current applications vacuum degasification is used in ion exchange demineralizers to remove dissolved carbon dioxide and oxygen in treating feedwater for a boiler. It was this application to which this study was directed.

The purpose of vacuum degasification in this application is generally two-fold. The removal of carbon dioxide reduces the anion exchanger load which results in reductions in the size of the anion exchanger and in chemical consumption. The removal of oxygen prevents corrosion in the demineralized water piping to the boiler deaerator.

A typical vacuum degasifier column is shown schematically in fig. (II-1). This degasifier column has two stages

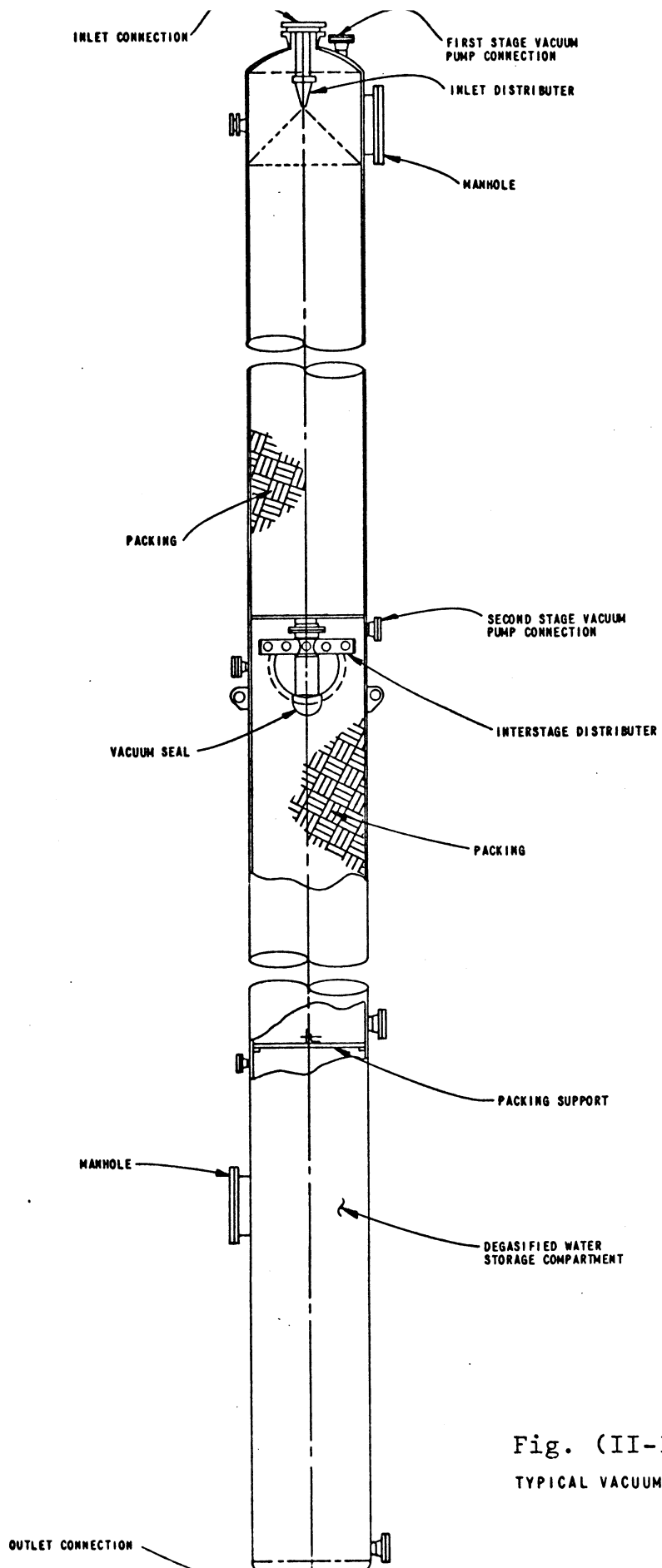


Fig. (II-1)
TYPICAL VACUUM DEGASIFIER

containing packing. Water enters the top and is distributed on and passes through the packing in each stage. An inter-stage water seal allows maintenance of different pressures while allowing the water to flow from the first to the second stage. Vacuum is drawn at the top of each stage. The vacuum source may be mechanical vacuum pumps, steam or air ejectors or a combination of these devices.

In this study the vacuum degasifier was located in a demineralization system, either following a primary cation exchanger when the primary anion exchanger contains strong base anion resin, as shown in fig. (II-2), or following a primary cation and anion exchanger pair when the primary anion contains weak base anion resin, as shown in fig. (II-3). In the first case the influent to the degasifier was deca-tionized. The cations in the raw water have been removed and replaced by hydrogen ions, resulting in an acidic water. The water, in the second case, was neutral, having been demineralized.

The typical design conditions considered were those shown on Table II-1. The leakage of ions from cation and anion exchangers was taken to be less than 20 milligrams per liter, sodium and chloride respectively, when the total dissolved solids of the raw water feed to the demineralizer was less than 600 milligrams per liter. General limits for oxygen and carbon dioxide were a maximum of 0.02 and 5.0 milligrams per liter respectively. Oxygen, nitrogen, and argon were assumed dissolved to their atmospheric saturated solubility at the given water temperature.

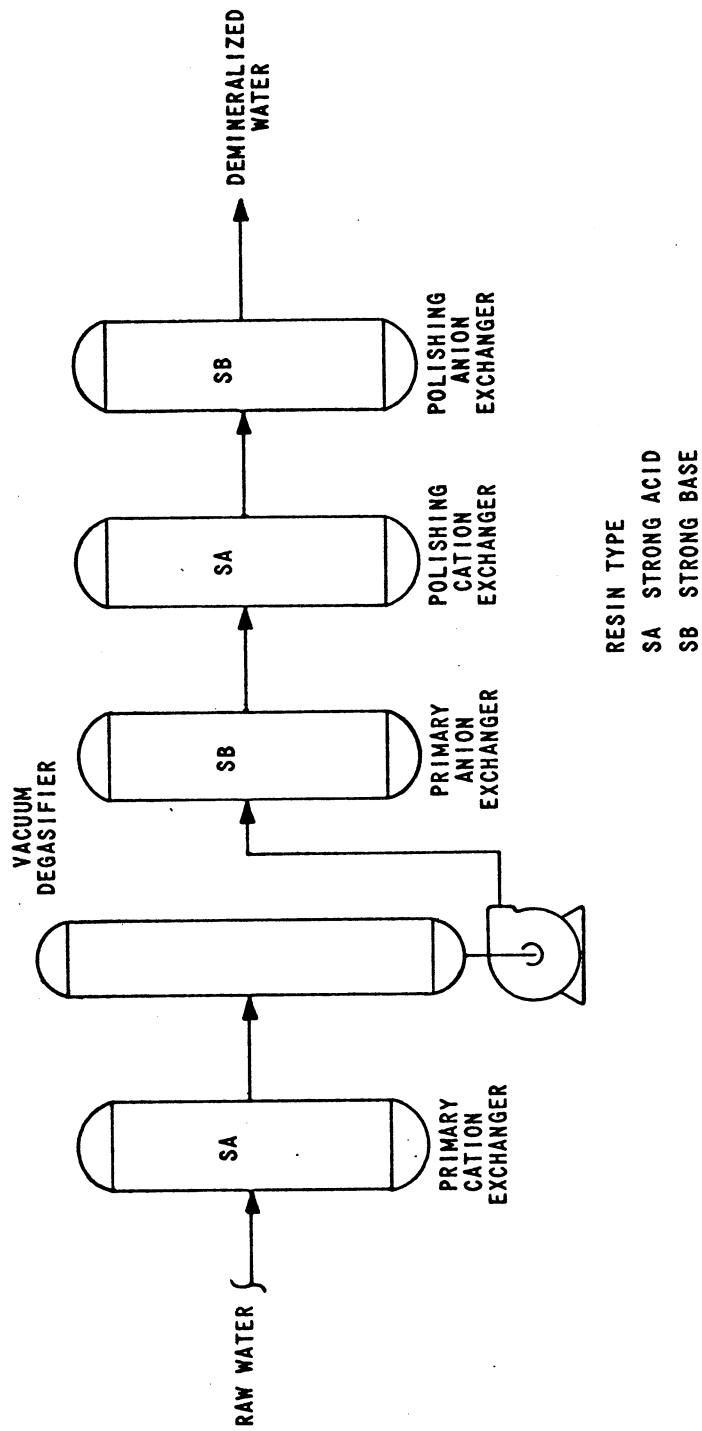


Fig. (II-2)

DEMINERALIZER ARRANGEMENT WITH DEGASIFIER
 FOLLOWING PRIMARY CATION EXCHANGER

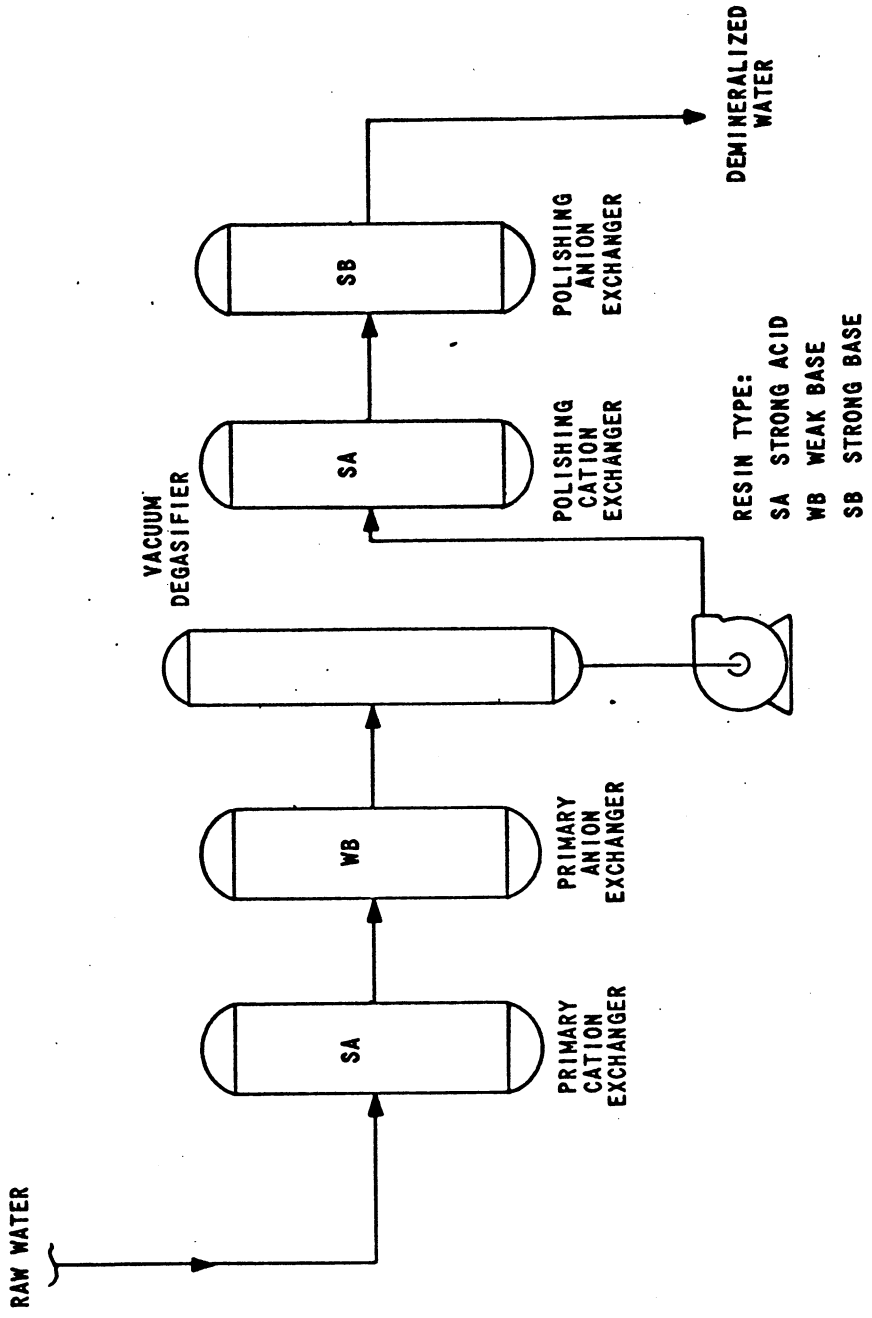


Fig. (II-3) DEMINERALIZER ARRANGEMENT WITH DEGASIFIER FOLLOWING PRIMARY EXCHANGERS

TABLE II-1

TYPICAL DEGASIFIER INLET WATER

ANALYSIS RANGES

	<u>Primary Cation Exchanger Effluent</u>	<u>Primary Anion Exchanger Effluent</u>
Na (mg/l as CaCO ₃)	0 - 20	0 - 20
Cl (mg/l as CaCO ₃)	0 - 170	0 - 20
CO ₂ (mg/l as CO ₂)	5 - 200	5 - 200
Oxygen (mg/l as O ₂)	0 - Saturated	0 - Saturated
pH	2.0 - 6.0	5.0 - 7.5
Temperature (F)	35 - 90	35 - 90

CHAPTER III

DESIGN CRITERIA

The design of a vacuum degasifier was based upon the water flow rate, water temperature, concentrations of dissolved gases and total dissolved solids in the incoming water, and the required effluent gas concentrations. The design parameters which were varied to accomplish the required degasification are the column diameter, the number of stages, the type and height of packing, and the size of the vacuum source. Temperature may also be adjusted to improve performance, although this work did not consider it as a design variable.

In a degasifier stage the pressure of the stage is reduced by the vacuum pump or ejector so that the solubilities of the dissolved gases are exceeded in the entering water. The gases diffuse to the liquid-gas interface and diffuse across the interface into the vapor phase where they are removed from the stage by the vacuum pump or ejector. The rate of transfer of these gases across the interface depends upon the interface area, the diffusivities of the gases, and the degree of supersaturation which exists in the stage. Thus, the packing type selection, height of packing and vacuum source size were based upon the mass transfer

characteristics of the packing and the solubilities and diffusivities of the dissolved gases. The diameter of the column is determined by the hydraulic performance of the packing media. The general design of the degasifier column followed the recommendations of Eckert (13), Leva (27), McCabe and Smith (29), and Treybal (46) with regard to packing size, liquid distribution, and redistribution.

Column Diameter

The degasifier column diameter determination does not follow general packed column design practice (55, 13, 27, 29, 46). Generally, packed column diameters are established by assuming operation at 50 to 75 percent of loading. The low gas flow rates in a degasifier column would allow the column diameter to be almost the same size as the inlet water piping. Thus, to provide the required interface area, packing heights would be excessive. The degasifier diameter was selected to be small enough to prevent channelling yet large enough to obtain a reasonable column height. This in practice is a cost optimization problem considering both the degasifier column and structural design. A flow of 25 gallons per minute per square foot flow through the degasifier was assumed in this study.

Gas Solubilities

The relationship of gas solubility to pressure most often used in design is Henry's law (25, 23, 2, 19, 30, 40, 5). Henry's law can be stated as "the mass of gas dissolved

in a given volume of solvent at constant temperature is proportional to the partial pressure of the gas with which it is in equilibrium" (16). Henry's law is generally followed by gases of low solubility as long as pressures are not too high or temperatures too low. Comparisons of the experimental Henry's law constants with Henry's law correlations derived from Weiss (51, 52) are shown in figs. (III-1) to (III-4). The correlations given by Weiss and correlation coefficients are shown on Table III-1.

The correlations by Weiss (51, 52) correct solubility with respect to salinity which is useful for sea water and brackish water degasification. This correction accounts for the "salting-out" effect in which the solubility of a gas decreases as salinity increases. In the demineralization systems studied, this effect was assumed to be negligible. Typically, the total dissolved solids would be under 600 milligrams per liter which, if taken as sodium chloride, would represent less than a one percent reduction in gas solubility.

Alternate Henry's law constant correlations for oxygen, nitrogen, and argon have been developed by Benson and Krause (3). Correlations of other authors are also reported and discussed by them. The derived correlations are possibly more consistent with theory, but the deviation from Weiss' correlation was not significant enough to affect the results of this work.

The experimental data for argon solubility reported by Estreicher, Winkler, Lannung (4), Klots and Benson (24),

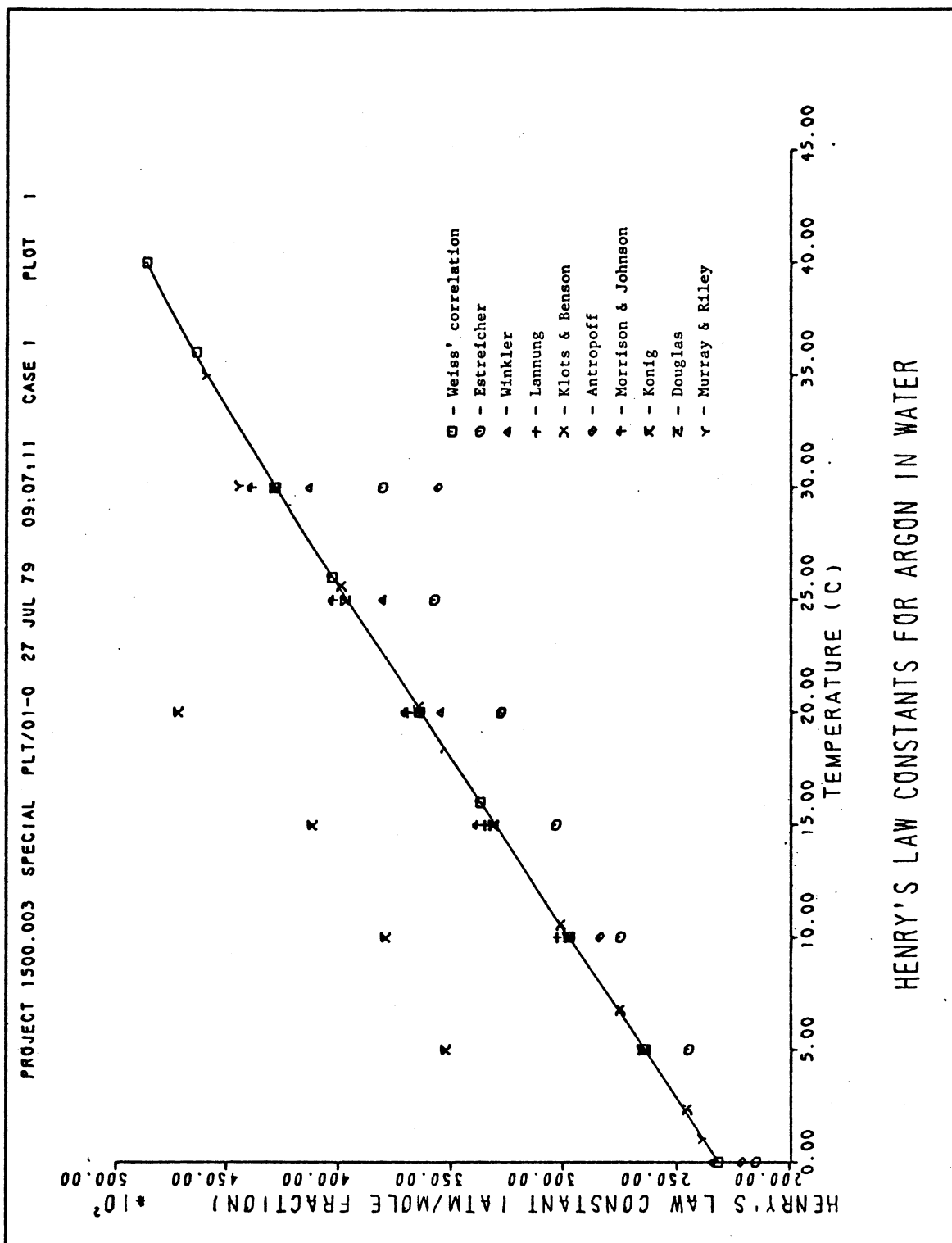


Fig. (III-1)

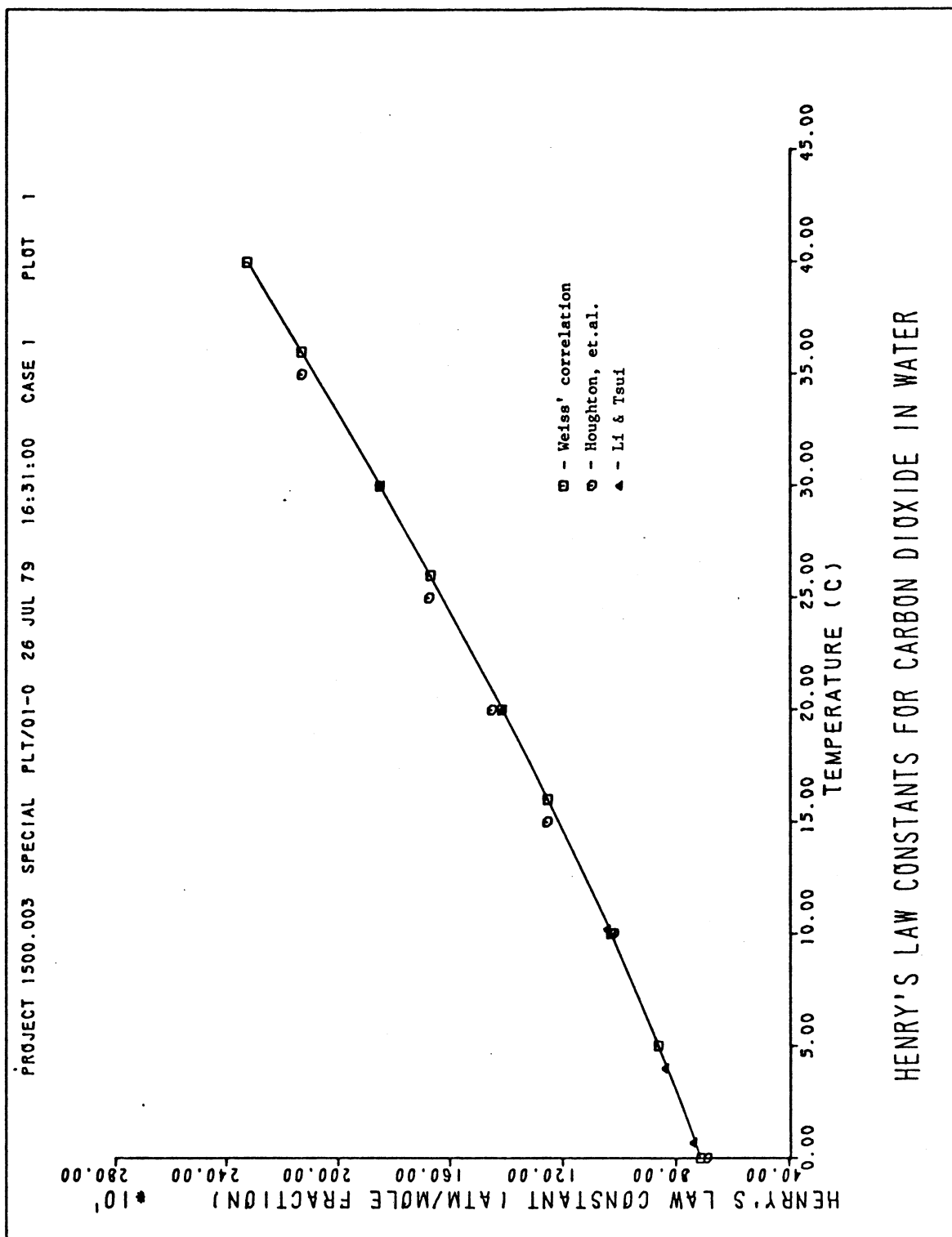


Fig. (III-2)

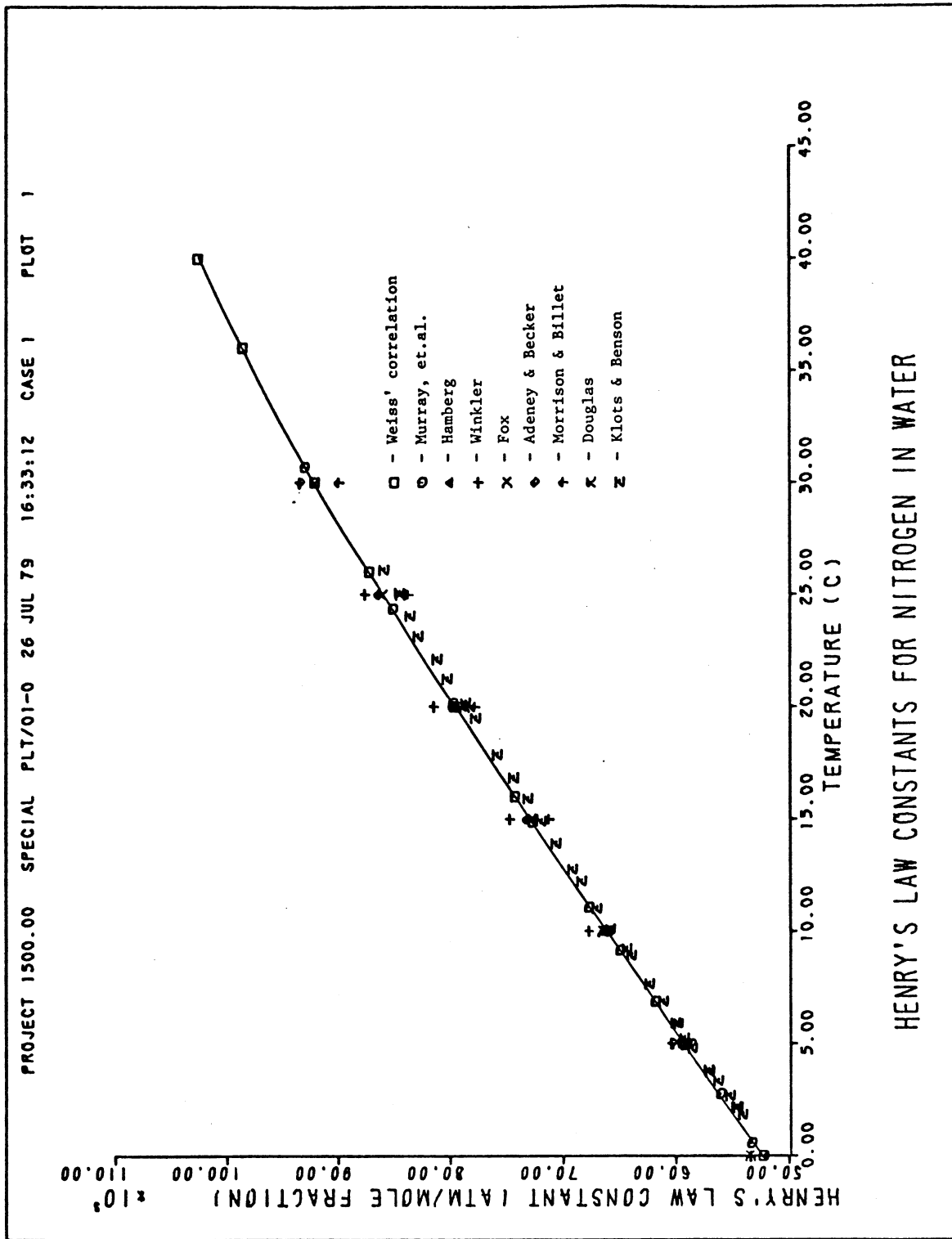


Fig. (III-3)

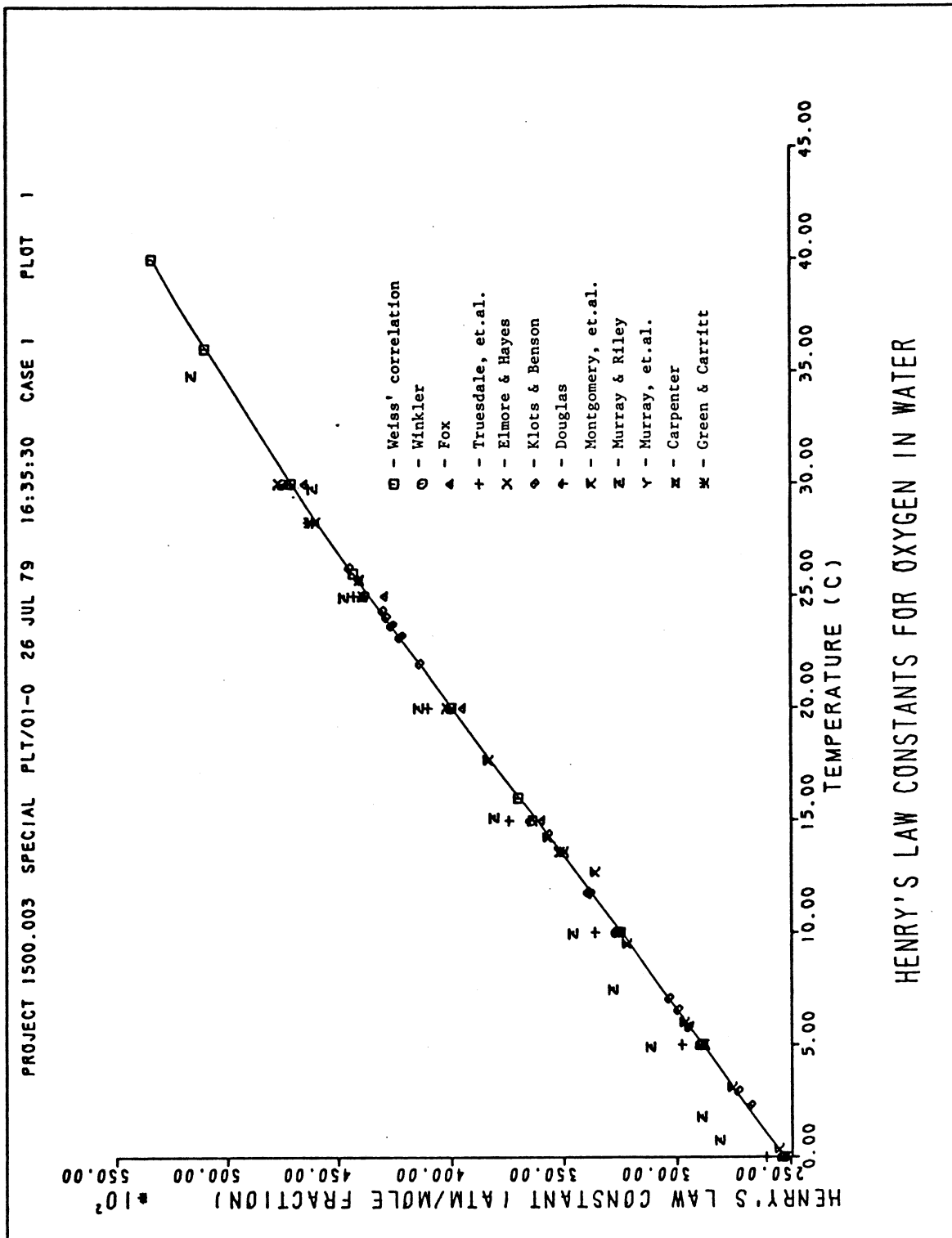


Fig. (III-4)

TABLE III-1

HENRY'S LAW CONSTANT CORRELATIONS

Equation form for argon, nitrogen and oxygen is:

$$\ln \beta = A_1 + A_2(100/T) + A_3 \ln(T/100) + S^{\circ}/\infty (B_1 + B_2(T/100) + B_3(T/100)^2)$$

where the A's and B's are constants, T is absolute temperature, S^o/∞ is salinity in grams per kilogram, and β is the Bunsen solubility coefficient (51).

<u>Gas</u>	<u>A₁</u>	<u>A₂</u>	<u>A₃</u>	<u>B₁</u>	<u>B₂</u>	<u>B₃</u>
N ₂	-59.6274	85.7661	24.3696	-0.051580	0.026329	-0.0037252
O ₂	-58.3877	85.8079	23.8439	-0.034892	0.015568	-0.0019387
Ar	-55.6578	82.0262	22.5929	-0.036267	0.016241	-0.0020144

Equation form for carbon dioxide is:

$$\ln K_o = A_1 + A_2(100/T) + A_3 \ln(T/100) + S^{\circ}/\infty (B_1 + B_2(T/100) + B_3(T/100)^2)$$

where K_o is the solubility coefficient in moles per liter atmosphere (52).

<u>Gas</u>	<u>A₁</u>	<u>A₂</u>	<u>A₃</u>	<u>B₁</u>	<u>B₂</u>	<u>B₃</u>
CO ₂	-58.0931	90.5069	22.2990	0.027766	-0.025888	0.0050578

Antropoff, Morrison and Johnstone, Konig, Douglas (11), and Murray and Riley (33) are shown in fig. (III-1). Close agreement is shown by most points with Weiss' correlation. The data of Konig appears to be high, while the data of Estreicher and Winkler appears to be low. There was no apparent reason found for these deviations.

The experimental data for carbon dioxide solubility reported by Houghton, McLean, and Ritchie (18); and Li and Tsui (28) are shown in fig. (III-2). Close agreement with Weiss' correlation is shown for all points.

The experimental data for nitrogen solubility reported by Winkler, Fox, Benson and Parker (4); Klots and Benson (24); Adeney and Becker; Morrison and Billet; Douglas (11); and Murray, Riley, and Wilson (35) are shown in fig. (III-3). Close agreement with Weiss' correlation is shown for all points.

The experimental data for oxygen solubility reported by Winkler; Fox; Truesdale, Downing and Lowden (47); Elmore and Hayes; Benson and Parker (4); Klots and Benson (24); Douglas (11); Montgomery, Thom, and Cockburn (32); and Murray and Riley (34) are shown in fig. (III-3). Close agreement is shown by most points with Weiss' correlation. The data of Truesdale, Downing and Lowden, and of Murray and Riley (34) appears to be high. The deviation in the values of Truesdale et al. have been attributed to systematic errors caused by loss of iodine by volatilization. No explanation is apparent for the deviation of Murray and Riley.

The solubility of carbon dioxide in a neutral or high pH water (pH greater than 6.5) is increased, because it ionizes. At low pH values, the solubility approaches that predicted by Henry's law. Weiss (52) suggested that the solubility be corrected by the ionization constant determined by Harned and Davis (17). The ionization constant was expressed by the following correlation:

$$\log_{10} K_{DI} = - 3404.71/T + 14.8435 - 0.032786T \quad (\text{III-1})$$

where K_{DI} is the ionization constant and T is the temperature in degrees Kelvin. Using the method described by King (22), carbon dioxide solubility may be corrected as follows:

$$x_{CO_2} = p_{CO_2}/H_{CO_2} (1 - K_{DI}/10^{-pH}) \quad (\text{III-2})$$

where x_{CO_2} is the concentration of carbon dioxide, p_{CO_2} is the partial pressure of carbon dioxide, and H_{CO_2} is the Henry's law constant.

At the low operating pressure of a vacuum degasifier the gases may be assumed to follow ideal gas behavior. Dalton's law of additive partial pressures may be assumed valid. Dalton's law states that the total pressure is the sum of the gas partial pressures (43) or:

$$P = \sum p_i = \sum \frac{n_i RT}{V} \quad (\text{III-3})$$

where P is the total pressure, and p_i is the individual gas component partial pressure.

When Henry's law is applicable to components in low concentrations, Raoult's law is valid for the component present at high concentrations. The liquid mole fraction of water in a degasification system is very nearly unity and, therefore, it can be assumed that water follows Raoult's law. Raoult's law is expressed as (43):

$$P_i = p_i' x_i \quad (\text{III-4})$$

where p_i' is the individual component vapor pressure and x_i is the component mole fraction. As the mole fraction of water approaches unity, the partial pressure of water may be assumed to be equal to the water vapor pressure. The vapor pressure of water has been correlated by Wexler and Greenspan (53) in the form:

$$p_{\text{H}_2\text{O}}' = 2.9522 \times 10^{-4} e^{\alpha} \quad (\text{III-5})$$

where

$$\alpha = E_0/T + E_1 + E_2(T) + B(\ln T)$$

with

$$E_0 = -7246.5822$$

$$E_1 = 77.641232$$

$$E_2 = 0.0057447142$$

$$B = -8.2470402$$

and T is the temperature in degrees Kelvin.

Mass Transfer

The mass transfer performance is determined by the gas concentrations and diffusivities, liquid flow rate, packing

type and depth, and the vapor flow rate and pressure as established by the vacuum system. The difference between the gas concentrations and solubilities as determined by the operating pressure is the driving force for mass transfer. The gas diffusivities, liquid and vapor flow rates, and type and depth of packing establish the mass transfer rate.

The overall and component mass balances for a single degasifier stage as represented by fig. (III-5) are:

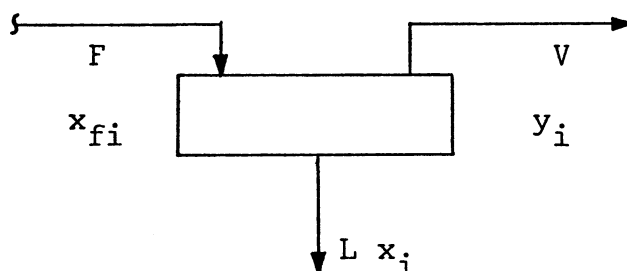


Fig. (III-5) Degasifier Stage

$$F = L + V \quad (\text{III-6})$$

and

$$Fx_{fi} = Lx_i + Vy_i \quad (\text{III-7})$$

where F and L are the entering and exiting liquid flow rates, x_{fi} and x_i are the entering and exiting component concentrations, V is the vapor flow rate, and y_i is the component vapor concentration.

From Henry's law for dissolved gas components in a liquid,

$$x_i^* = p_i/H_i \quad (\text{III-8})$$

where x_i^* is the component equilibrium concentration in a liquid. From Dalton's law for the gas components in a vapor,

$$y_i^* = p_i/P \quad (\text{III-9})$$

where y_i^* is the component equilibrium concentration in the gas. Eliminating p_i between Equations III-8 and III-9, the following may be derived:

$$y_i^* = H_i x_i^*/P. \quad (\text{III-10})$$

If the vapor is assumed to be in equilibrium with the liquid at the vapor-liquid interface, equation (III-10) may be substituted into equation (III-7) to yield:

$$F x_{fi} = L x_i + V H_i x_i^*/P \quad (\text{III-11})$$

Because the mass of gas removed with respect to the mass of liquid is small, the entering liquid flow may be assumed to be equal to the exiting liquid flow. Equation (III-11) may then be written as:

$$F x_{fi} = F x_i + V H_i x_i^*/P \quad (\text{III-12})$$

or by rearranging,

$$x_i^* = FP(x_{fi} - x_i)/VH_i \quad (\text{III-13})$$

The packing height (2) may be expressed as the product of the number of overall liquid mass transfer units (N_{OL}) times the height of an overall liquid mass transfer unit (H_{OL}) (7, 12), or:

$$z = (N_{OL})(H_{OL}). \quad (\text{III-14})$$

The number of overall mass transfer units is given by Foust et al. as (15):

$$N_{OL} = \ln((x_{fi} - x_i^*) / (x_i - x_i^*)) \quad (\text{III-15})$$

The height of a liquid mass transfer unit (H_L) has been correlated by Sherwood and Holloway (42) as:

$$H_L^O = \beta \left(\frac{L}{\mu_L}\right)^n (N_{ScL})^{0.5} \quad (\text{III-16})$$

where the quantities β and n are characteristics of the particular packing, μ_L is the liquid viscosity, L is the cross sectional area liquid flow rate, and N_{ScL} is the liquid phase Schmidt number. For MASPAC packing, figs. (III-6) and (III-7) show the quantity $\beta(L/\mu_L)^n$ or $H_L^O/(H_{ScL})^{0.5}$ as a function of cross sectional area liquid flow rate (5). The curves shown by these figures were fit to the following equations:

$$\ln(H_L^O/(N_{ScL})^{0.5}) = C_0 + C_1 \ln(L) \quad (\text{III-17})$$

where C_0 and C_1 are constants. The constants for MASPAC FN200 and FN90 are shown on Table III-2.

The liquid phase Schmidt number (N_{ScL}) may be expressed as:

$$N_{ScL} = \mu / \rho D_{AB} \quad (\text{III-18})$$

where μ is the liquid viscosity, ρ is the liquid density and D_{AB} is the liquid diffusion coefficient of the solute (A) in

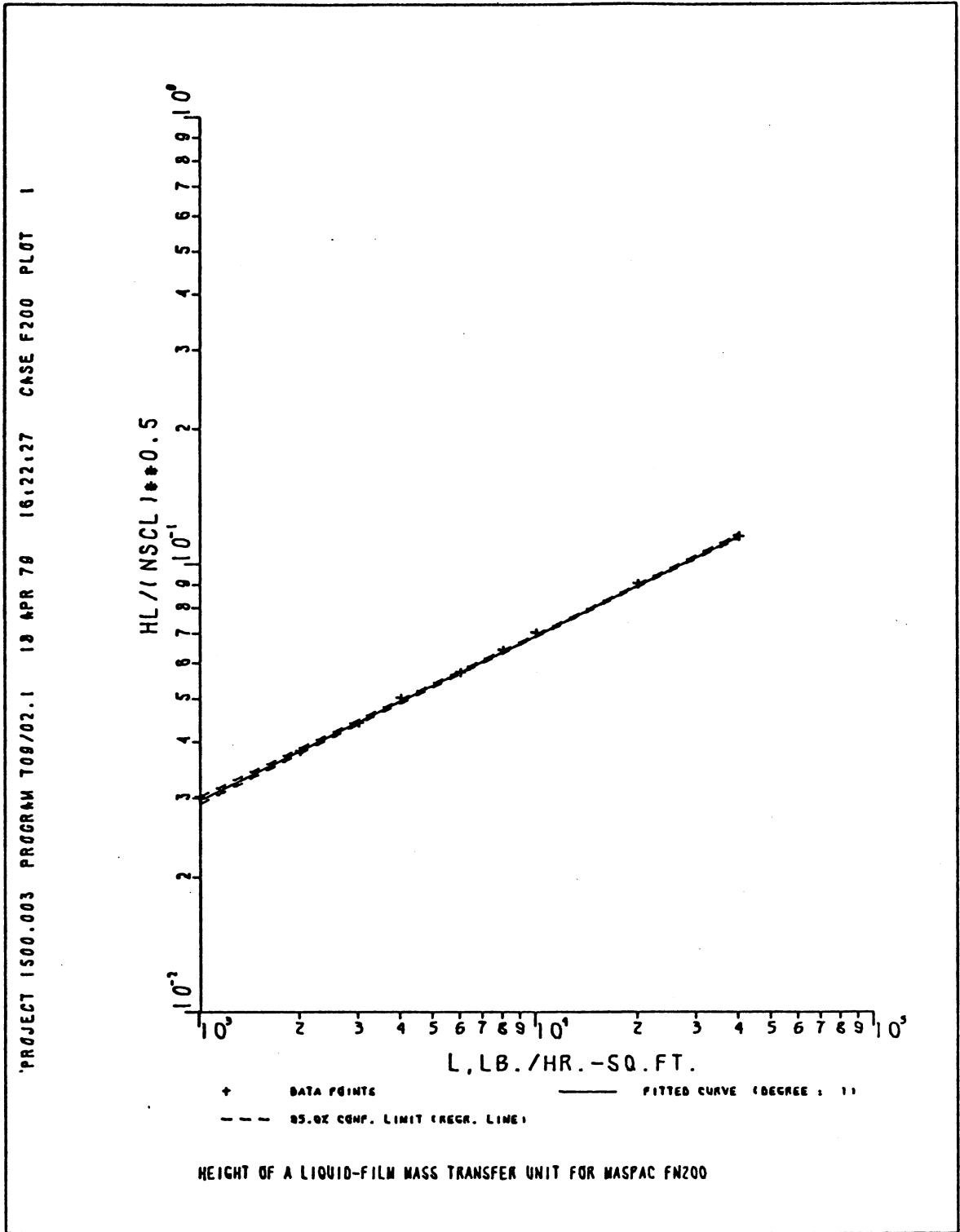


Fig. (III-6)

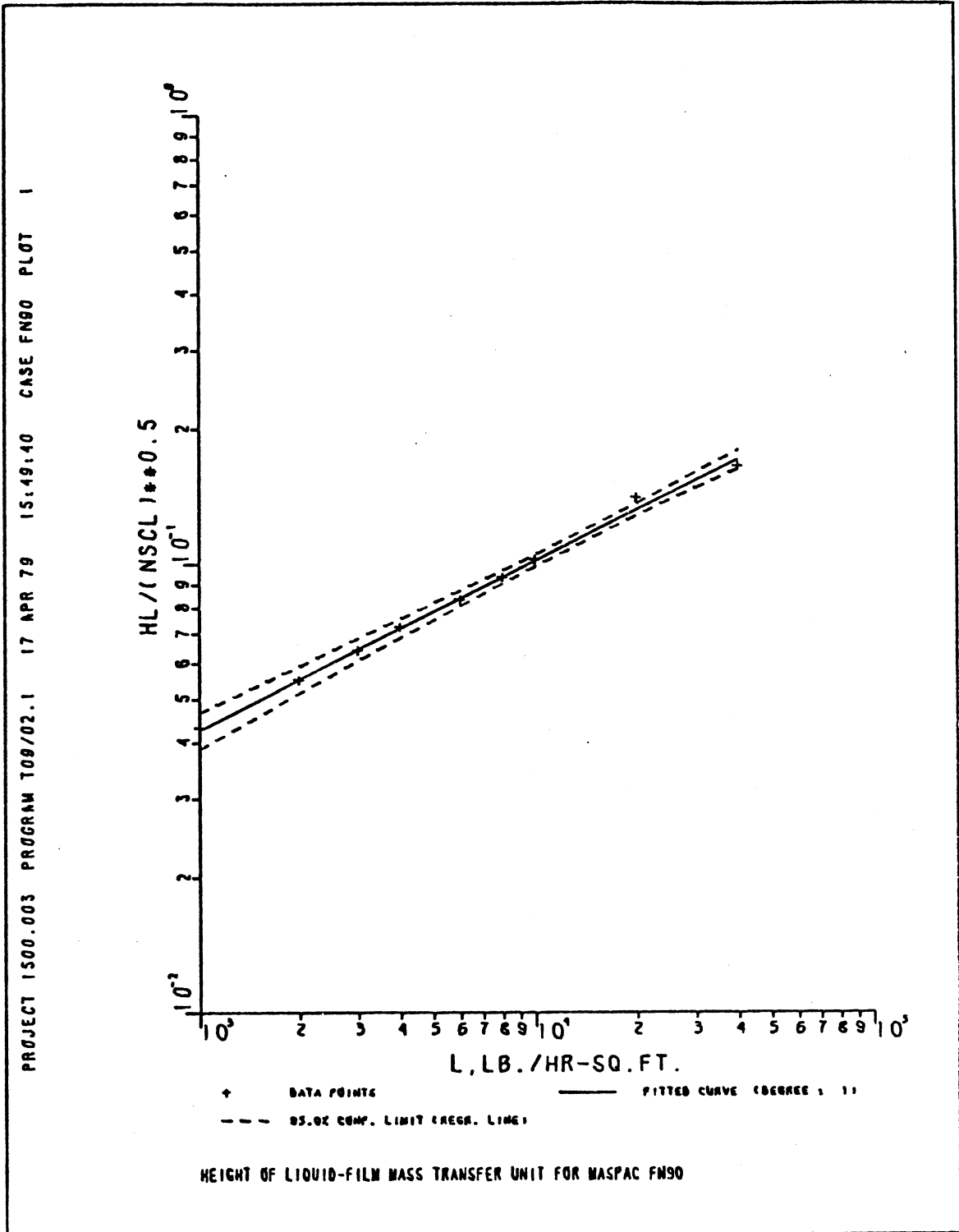


Fig. (III-7)

TABLE III-2

CONSTANTS FOR MASPAC PACKING

<u>Packing Type</u>	<u>C₀</u>	<u>C₁</u>
FN200	-6.05879348	0.36812290
FN90	-5.75738798	0.37688520

the solvent (B). The viscosity of water as a function of temperature is given from 0 to 20 degrees centigrade by Hardy and Cottingham (50) to be:

$$\begin{aligned} \text{Log } \mu = & (1301/(998.333 + 8.1855 (T-20) \\ & + 0.00585 (T-20)^2)) - 3.30233 \end{aligned} \quad (\text{III-19})$$

where μ is the water viscosity in poise and T is the temperature in degrees centigrade. From 20 to 100 degrees centigrade Swindell (50) expresses the water viscosity as:

$$\begin{aligned} \log \frac{\mu_T}{\mu_{20}} = & (1.3272(20-T) \\ & - 0.001053(T-20)^2)/(T-105) \end{aligned} \quad (\text{III-20})$$

where μ_T is the water viscosity at the water temperature, μ_{20} is the water viscosity at 20 degrees centigrade, and T is the temperature in degrees centigrade (50). Water density data by Kell (50) was fit to the following equation:

$$\rho = C_0 + C_1(T) + C_2(T)^2 + C_3(T)^3 \quad (\text{III-21})$$

where

$$\begin{aligned} C_0 &= 0.99988782 \\ C_1 &= 5.8558112 \times 10^{-5} \\ C_2 &= 8.0158925 \times 10^{-6} \\ C_3 &= 4.5214476 \times 10^{-8} \end{aligned}$$

T is the temperature in degrees centigrade and ρ is the density in grams per milliliter. A comparison of the density data with the correlation is shown in fig. (III-8).

Diffusion coefficient data for argon, carbon dioxide, and nitrogen were fit to the Stokes-Einstein equation, which is expressed as:

$$D_{AB} = K(T/\mu) \quad (\text{III-22})$$

where K is constant. St-Dennis and Fell (41) fit oxygen diffusion coefficients to the Stokes-Einstein equation. The values for K determined for each gas are shown on Table III-3. Comparisons of the Stokes-Einstein equation with diffusion coefficient data are shown on fig. (III-9) to (III-12). As shown on these figures, the data show some deviations from the correlation and inconsistencies with other data. No attempt was made to account for those deviations or inconsistencies. The argon data are those reported by Wise and Houghton (54), and Duda and Vrentas (12). The carbon dioxide data are those reported by Davidson and Cullen (9), Vivian and King (49), Ferrell and Himmelblau (14), Duda and Vrentas (12), Ng and Walkley (37), Unver and Himmelblau (48) Tang and Himmelblau (44), Thom et al. (45), and Malik and Hayduk (31). The data for nitrogen are those by Wise and Houghton (54), Ferrell and Himmelblau (14), and Ng and Walkley (37). The data for oxygen are those reported by Davidson and Cullen (9), Vivian and King (49), Wise and Houghton (54), Ferrell and Himmelblau (14), Krieger et al. (26), Duda and Vrentas (12), Ng and Walkley (37), Carlson (6), Jordan et al. (20), Jordan and Bauer (21), and Davis et al. (10).

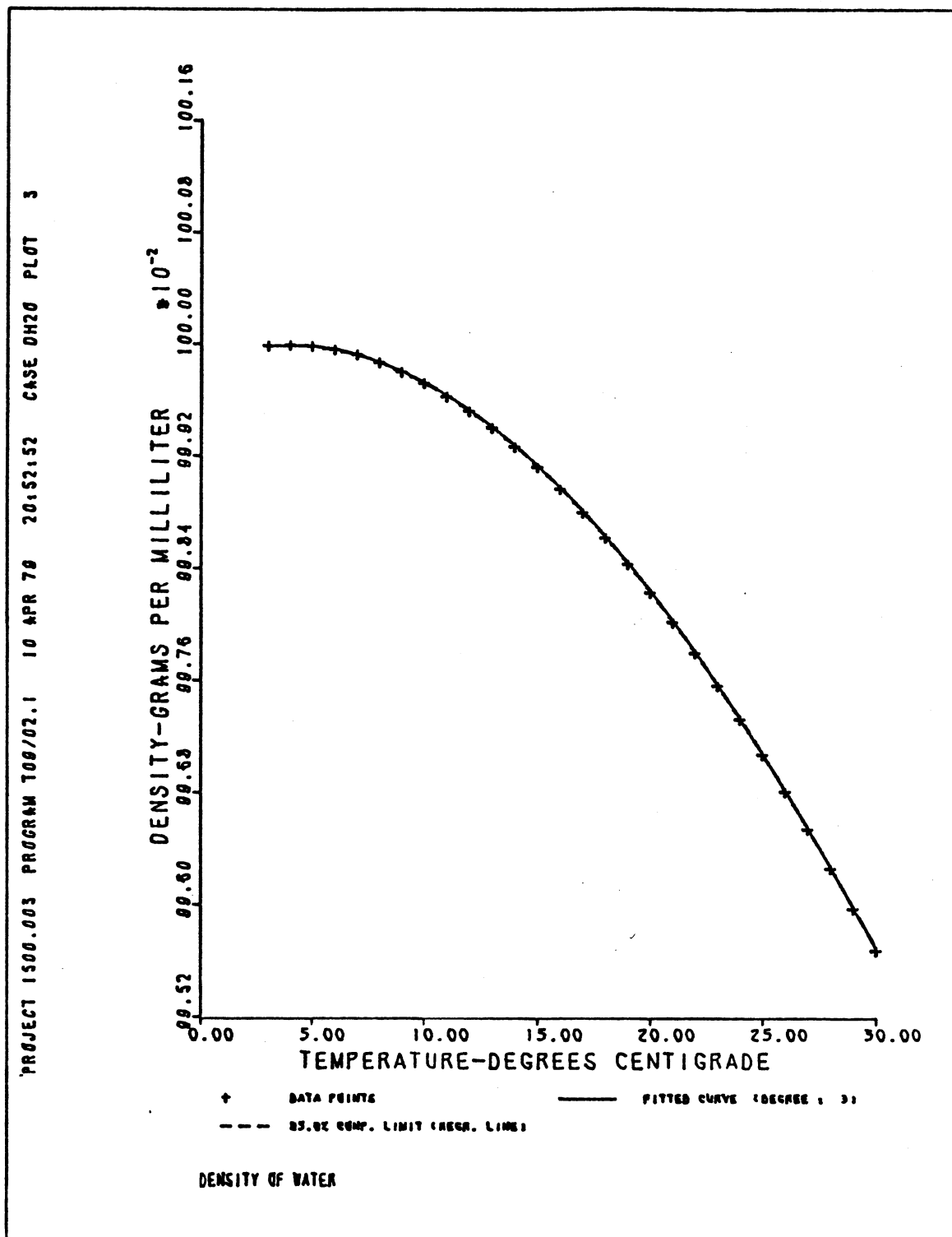


Fig. (III-8)

TABLE III-3

STOKES-EINSTEIN EQUATION CONSTANTS

<u>Gas</u>	<u>K</u> (gm cm/sec ² K)
Ar	6.72 x 10 ⁻¹⁰
CO ₂	5.76 x 10 ⁻¹⁰
N ₂	7.23 x 10 ⁻¹⁰
O ₂	6.92 x 10 ⁻¹⁰

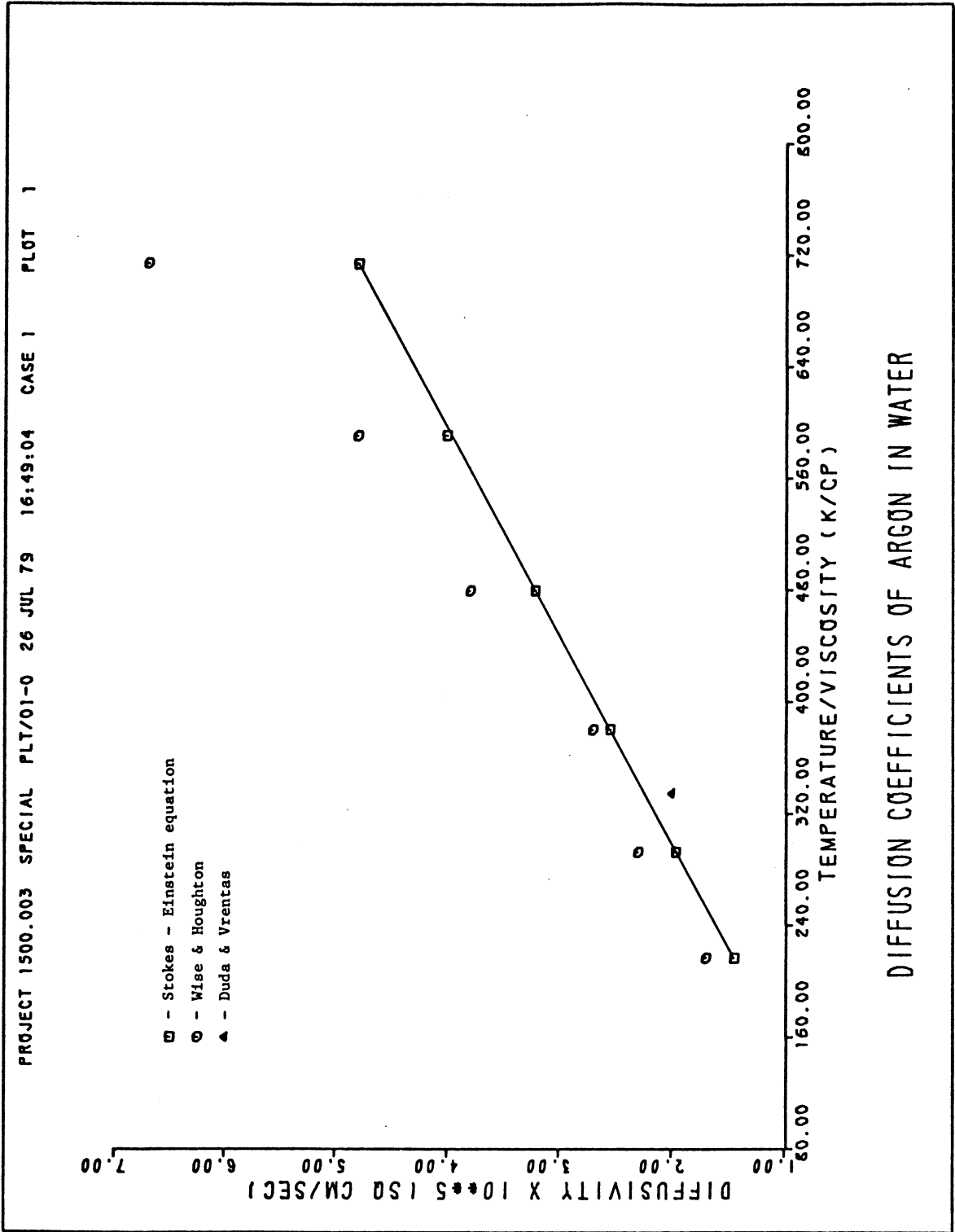


Fig. (III-9)

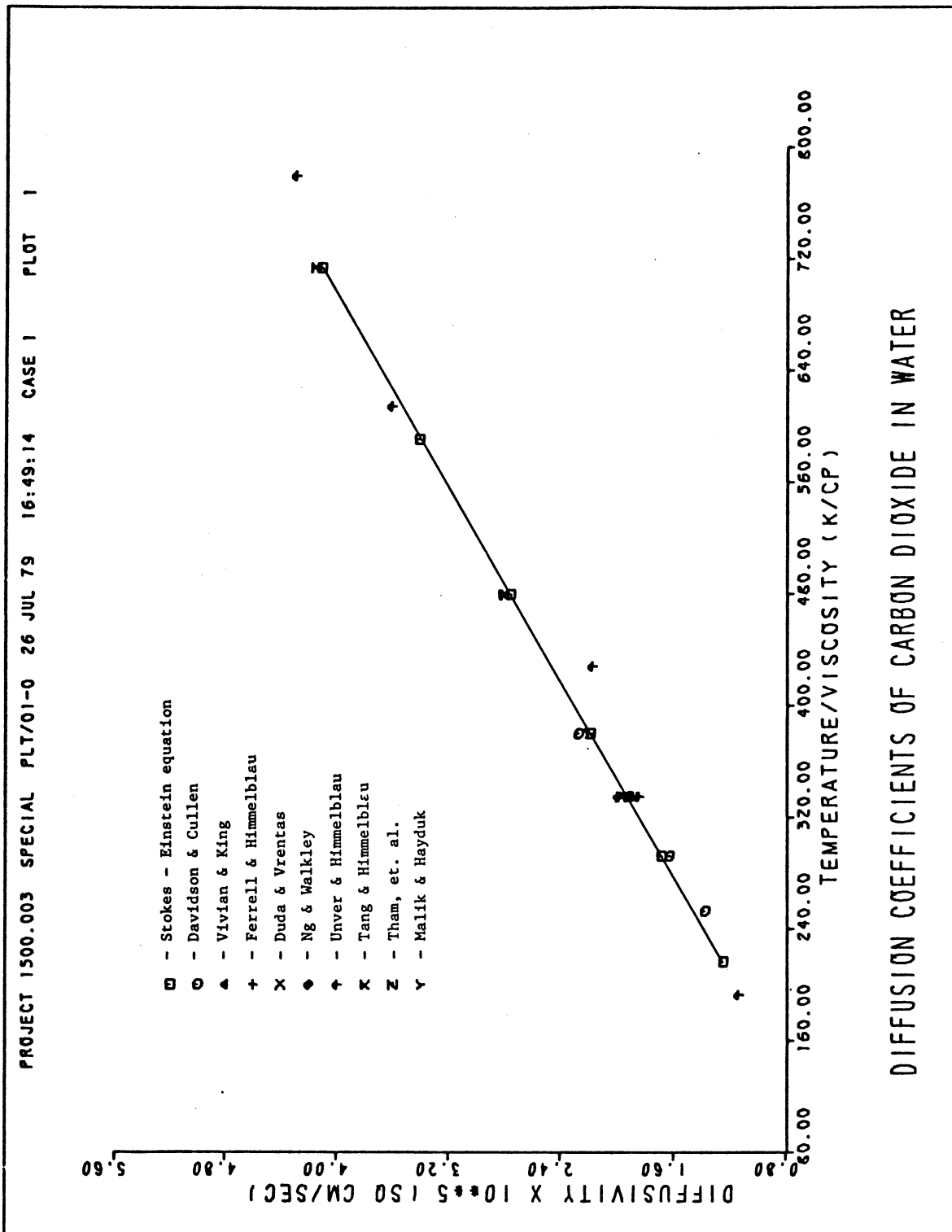


Fig. (III-10)

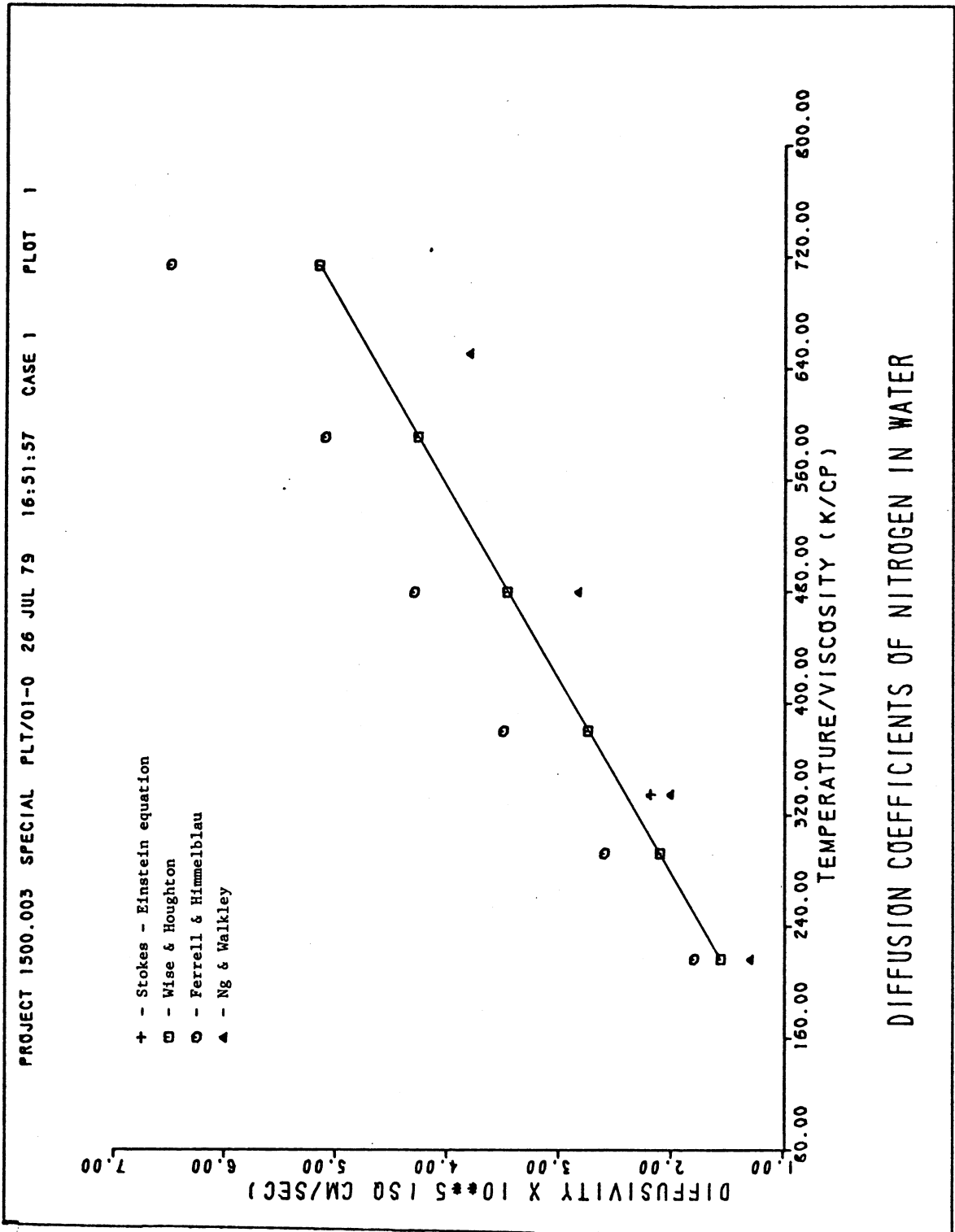


Fig. (III-11)

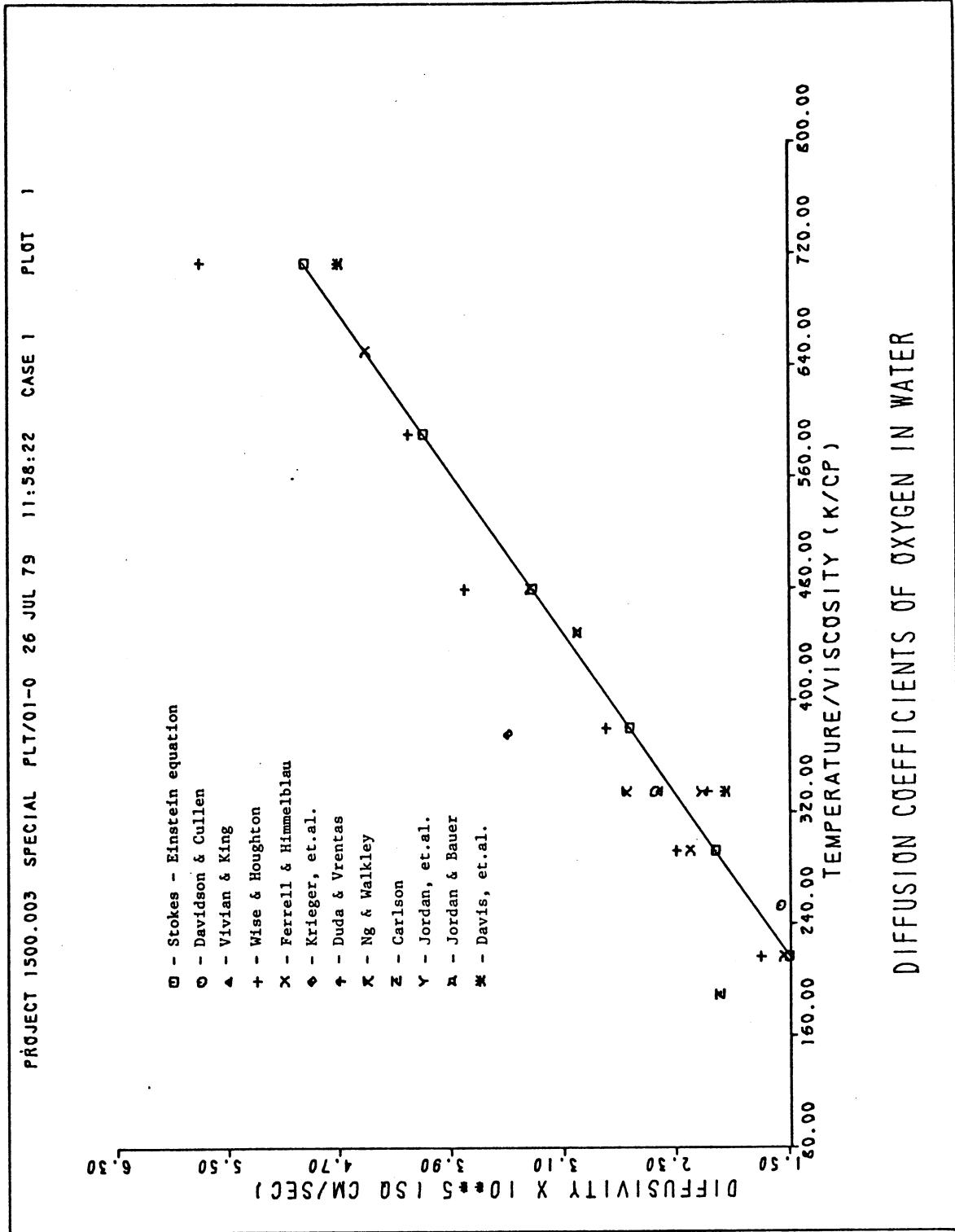


Fig. (III-12)

The height of an overall mass transfer unit (H_{OL}) is related to the height of a mass transfer unit (H_L) as follows:

$$H_{OL} = H_L + (L_m/mG_m)H_G \quad (\text{III-23})$$

where L_m and G_m are the molal mass velocities for liquid and gas, m is the slope of the operating line, and H_G is the height of a gas mass transfer unit. Generally, the term $(L_m/mG_m)H_G$ is negligible in comparison to H_L for vacuum degasifiers, as H_G is small and m is large, offsetting L_m being much greater than G_m . Thus, the height of an overall liquid mass transfer unit (H_{OL}) may be expressed as being equal to the height of a liquid mass transfer unit (H_L), or:

$$H_{OL} \approx H_L \quad (\text{III-24})$$

The value for H_L computed from equation (III-16) should be corrected for packing height. The correction for the packing height is:

$$H_L = H_L^O (z/3)^{0.15} \quad (\text{III-25})$$

for MASPAC packing, where H_L^O is the height of a liquid mass transfer unit derived by equation III-16. This follows the form outlined by Van Krevelin and Hoftijzer and modified by Cornell, Knapp, and Fair (8).

The number of overall liquid mass transfer units (N_{OL}) may be expressed by combining equations (III-14), (III-15), and (III-25) to yield:

$$N_{OL} = z / (H_L^O (z/3)^{0.15}) - \ln \frac{x_{fi} - x_i^*}{x_i - x_i^*} . \quad (\text{III-26})$$

or

$$e^{-z / (H_L^O (z/3)^{0.15})} = \frac{x_i - x_i^*}{x_{fi} - x_i^*} . \quad (\text{III-27})$$

This result may be combined with equation (III-13) to give:

$$\frac{x_i}{x_{fi}} = \frac{(1 - e^\alpha)(FP/VH_i) + e^\alpha}{(1 - e^\alpha)(FP/VH_i) + 1} \quad (\text{III-28})$$

where

$$\alpha = -z / (H_L^O (z/3)^{0.15}) .$$

Equation (III-28) represents the mass transfer performance model for each gas component in each degasifier stage. By applying Dalton's law, the total evacuation or vapor flow rate may be checked by adding up the component vapor flow rates. This equation must be solved by trial and error for each gas component dissolved in the feed water and must be evaluated for each stage.

CHAPTER IV

DESIGN PROCEDURE

The following procedure was used to size the degasifier column and vacuum system. It was assumed that the liquid flow rate, inlet and desired outlet gas concentrations, and temperature were known.

1) The degasifier column diameter was selected based upon the liquid flow rate assuming a molal mass velocity of 25 gallons per minute per square feet.

2) The size and type of packing was chosen consistent with the column diameter and liquid flow rate. The maximum recommended packing size to column diameter ratios for several packings are as follows (13, 5):

Rasching Rings	1:30
Berl Saddles	1:15
Intalox Saddles	1:15
Pall Rings	1:10 to 1:15
MASPAC	1:12.

3) The packing height and vacuum system capacity were computed using equation (III-28) and the desired outlet gas concentrations computed. The vacuum system selection was based on the air ejector performance curves shown on figs.

(IV-1) to (IV-5) (36). The performance curves were fit to the function:

$$\ln V = C_0 + C_1 \ln P + C_2 (\ln P)^2 + C_3 (\ln P)^3 \quad (\text{IV-1})$$

where V is the evacuation rate in actual cubic feet per minute and P is the pressure in inches of mercury. The constants for the air ejectors are given on Table IV-1.

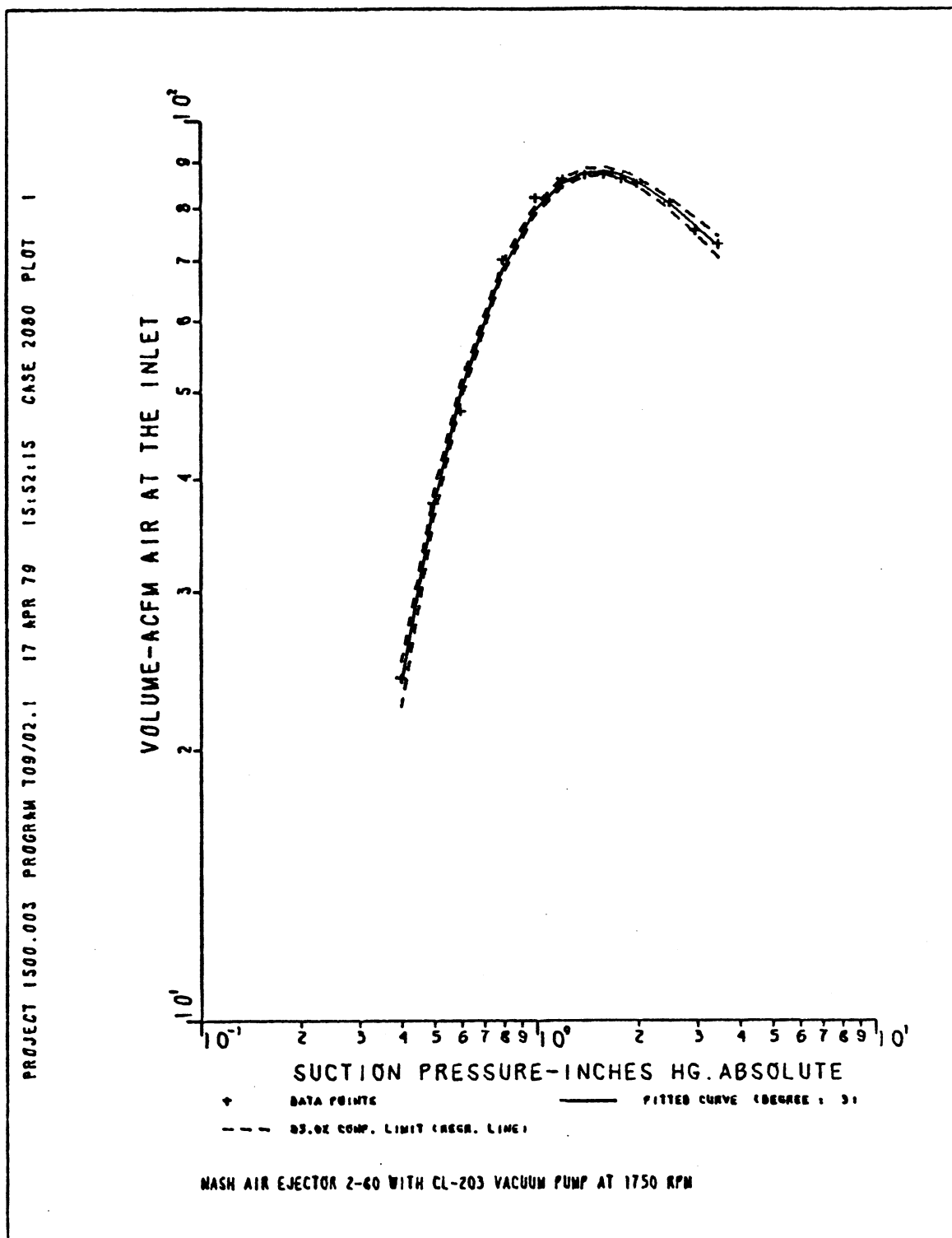


Fig. (IV-1)

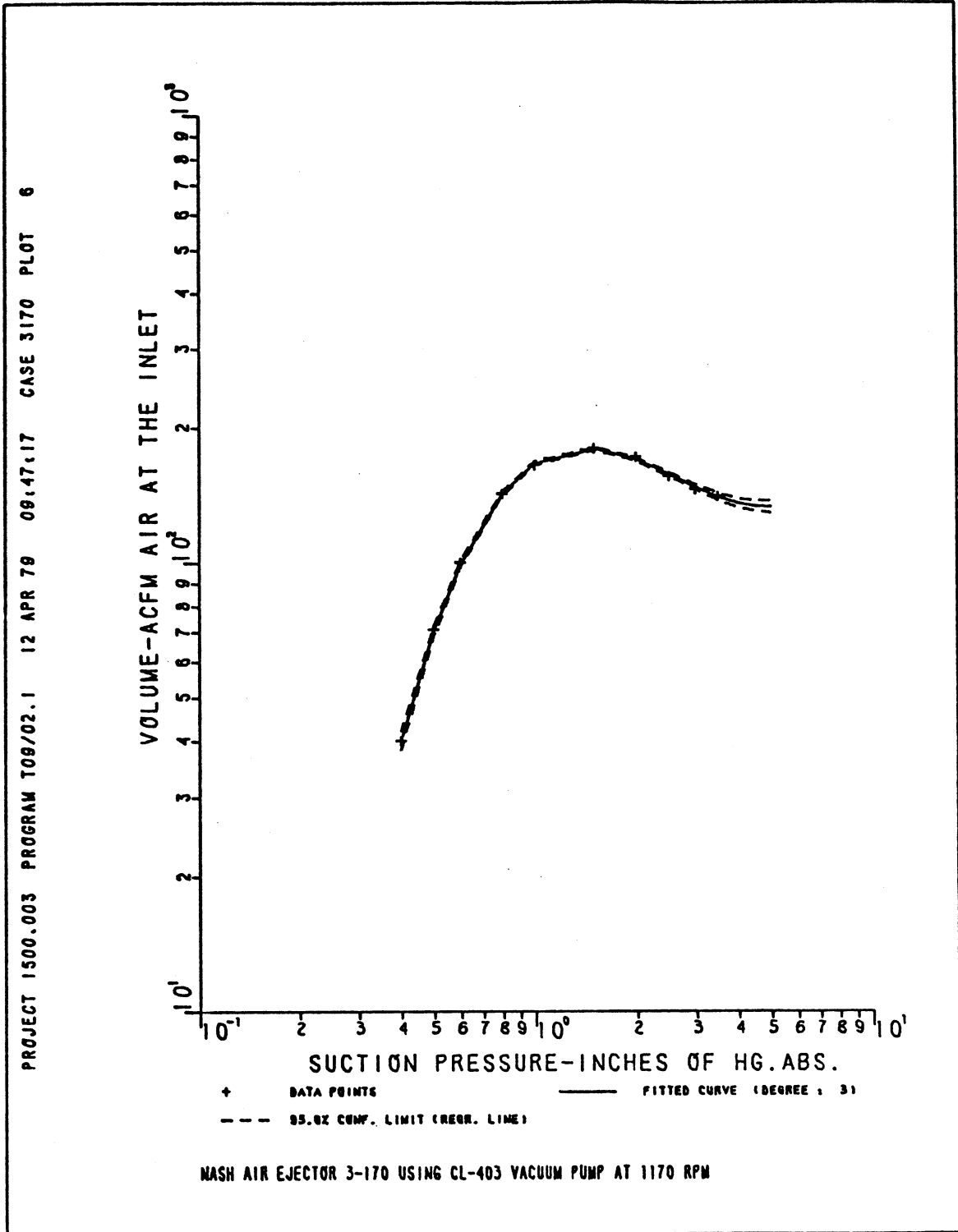


Fig. (IV-2)

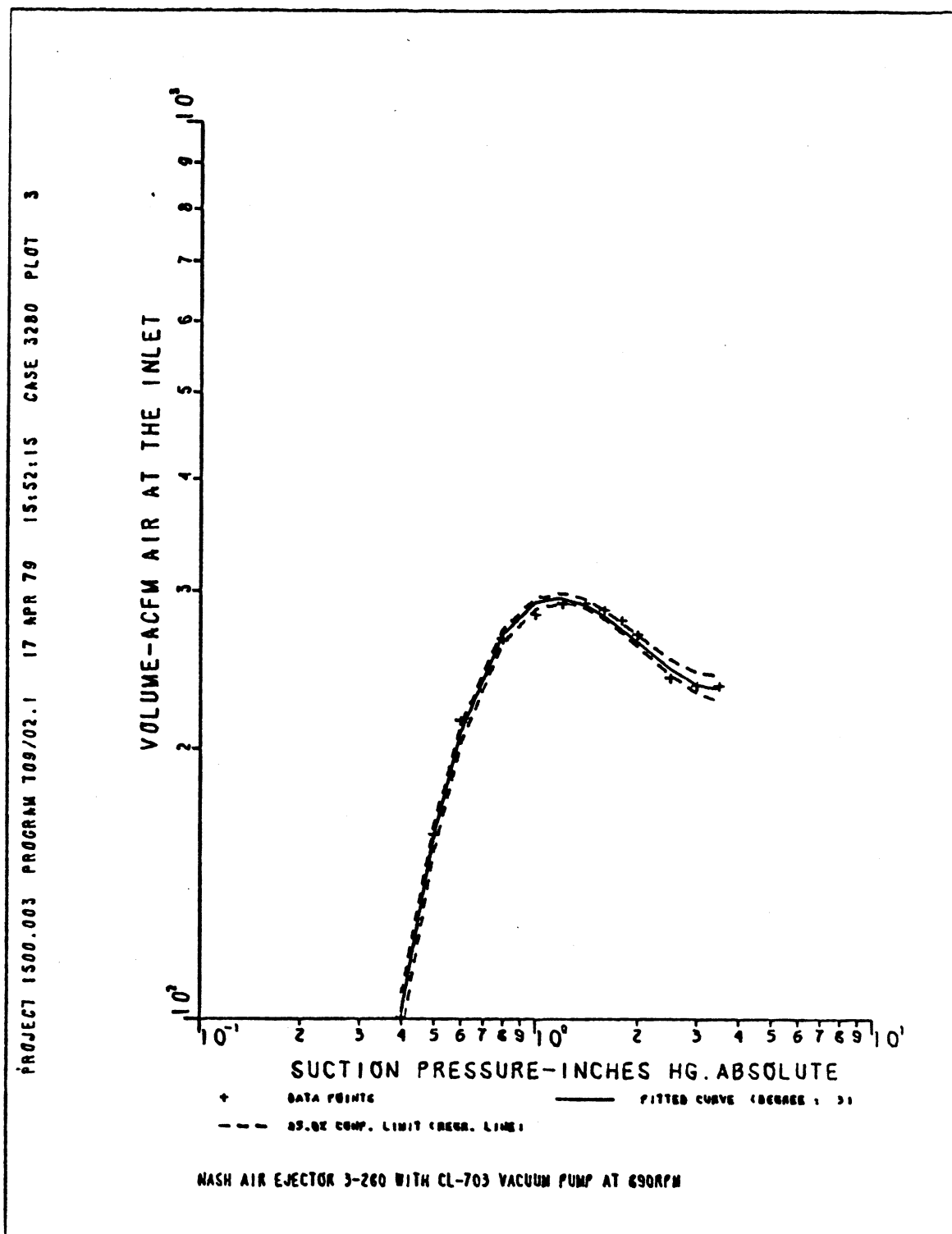


Fig. (IV-3)

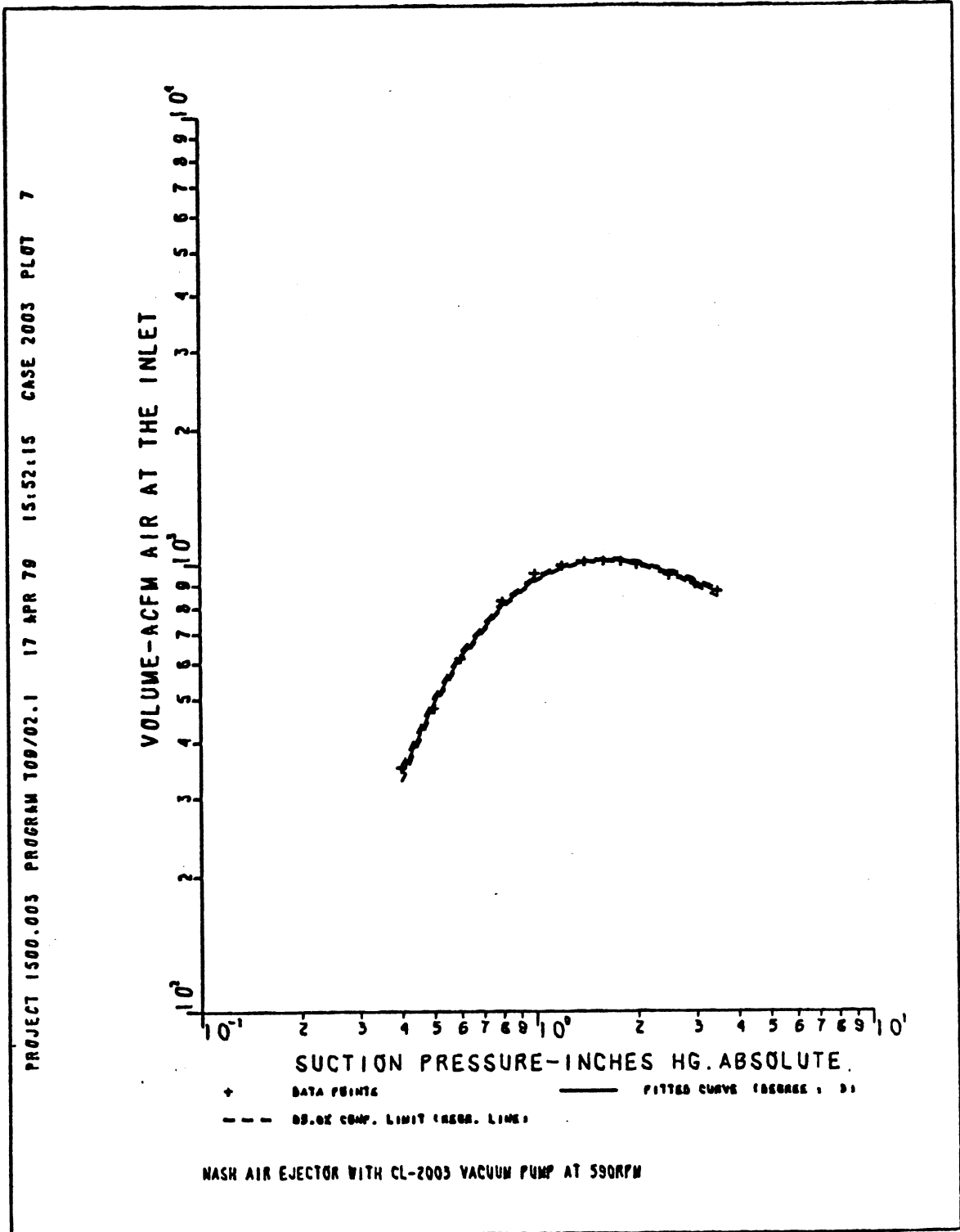


Fig. (IV-4)

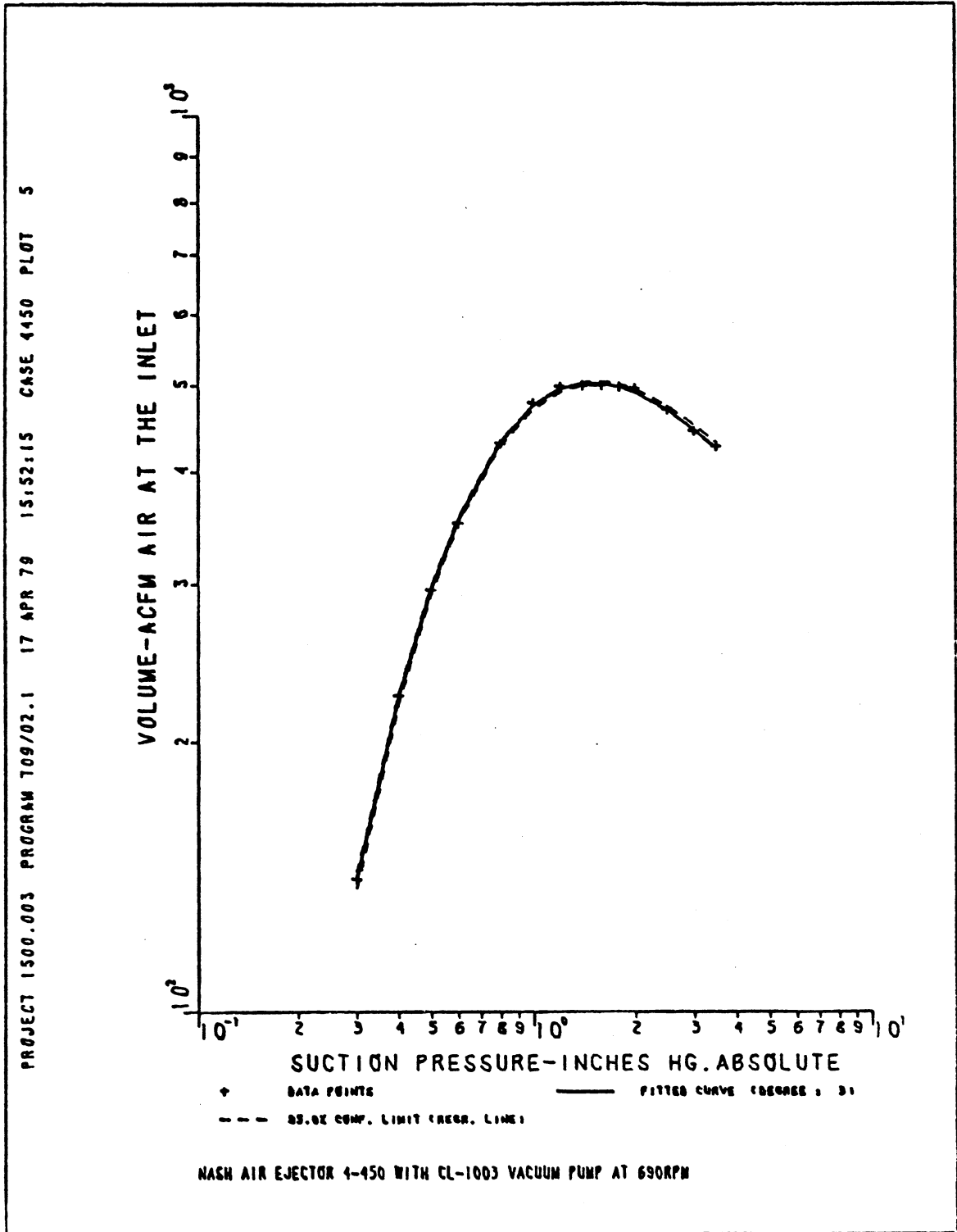


Fig. (IV-5)

TABLE IV-1

AIR EJECTOR FUNCTION CONSTANTS

<u>Air Ejector Model No.</u>	<u>C₀</u>	<u>C₁</u>	<u>C₂</u>	<u>C₃</u>
2.80	4.37780480	0.49571115	-0.71514278	0.20616891
3-170	5.11801154	0.48624600	-0.88448594	0.30729692
3-280	5.67209302	0.19574653	-0.72743787	0.34458044
4-450	6.16024028	0.31855519	-0.45069421	0.10348750
CL-2003	6.83084125	0.44517675	-0.57762709	0.13724532

CHAPTER V

DESIGN PROGRAM

A design performance program was developed to evaluate degasifier designs. A flowchart of this program is shown on fig. (V-1). A listing of the program is included as Appendix A. Example designs were run and are included as Appendix B.

The program requires the following input data:

- . number of stages,
- . vacuum system type of each stage,
- . temperature,
- . liquid flow rate,
- . inlet dissolved gas concentrations,
- . packing height of each stage,
- . column diameter, and
- . packing type.

The program results output are the pressure, evacuation rate, and outlet gas compositions of each stage of the degasifier.

APPENDIX A
COMPUTER PROGRAM LISTING

00100	C	1*	C	00000
00100	C	2*	C	00000
00100	C	3*	C	00000
00100	C	4*	C	00000
00100	C	5*	C	00000
00100	C	6*	C	00000
00100	C	7*	C	00000
00100	C	8*	C	00000
00100	C	9*	C	00000
00100	C	10*	C	00000
00100	C	11*	C	00000
00100	C	12*	C	00000
00101	C	13*	C	00000
00103	C	14*	C	00001
00104	C	15*	C	00001
00104	C	16*	C	00001
00104	C	17*	C	00001
00104	C	18*	C	00001
00104	C	19*	C	00001
00105	C	20*	C	00001
00105	C	21*	C	00001
00113	C	22*	C	00001
00113	C	23*	C	00001
00113	C	24*	C	00001
00113	C	25*	C	00001
00113	C	26*	C	00001
00113	C	27*	C	00001
00120	C	28*	C	00001
00125	C	29*	C	00001
00132	C	30*	C	00001
00135	C	31*	C	00001
00135	C	32*	C	00001
00135	C	33*	C	00001
00143	C	34*	C	00001
00146	C	35*	C	00001
00146	C	36*	C	00007
00146	C	37*	C	00007
00146	C	38*	C	00007
00146	C	39*	C	00007
00146	C	40*	C	00007
00146	C	41*	C	00007
00147	C	42*	C	00007
00155	C	43*	C	00024
00155	C	44*	C	00024
00156	C	45*	C	00024
00161	C	46*	C	00032
00161	C	47*	C	00032
00162	C	48*	C	00032
00165	C	49*	C	00040
00165	C	50*	C	00040
00165	C	51*	C	00040
00165	C	52*	C	00040
00165	C	53*	C	00040
00165	C	54*	C	00040
00165	C	55*	C	00040
00166	C	56*	C	00050
00171	C	57*	C	00050
00171	C	58*	C	00050
00172	C	59*	C	00050

VACUUM DEGASIFIER PERFORMANCE PROGRAM

C THIS PROGRAM MAY BE USED TO EVALUATE THE PERFORMANCE OF A VACUUM
 C DEGASIFIER HAVING UP TO THREE STAGES AND REMOVING ANY OR ALL OF
 C THE FOLLOWING GASES: ARGON,CARBON DIOXIDE,NITROGEN,AND OXYGEN AT
 C TEMPERATURES FROM 0 C(32 F) TO 32 C(90 F) USING AN AIR EJECTOR ON
 C EACH STAGE.

C REAL L,LM,LA,MH,MHA,KI
 C INTEGER EJECT,PACK
 C DIMENSION X(4,4),Z(4,4),MH(4,4),DL(4),HL(4),VJEC(4),VM(4),P(4),
 C 1VSY(4),D(4,4),XM(4,4),VY(4,4),Y(4,4),VNC(4),SNSC(4),EJECT(4),
 C 2GAS(4),TVAC(4),SPACK(2),SVACC(5)
 C DENSITY CORRELATION COEFFICIENTS
 C DATA D0,D1,D2,D3,D4/,99987017,,-66494608E-4,,-88324560E-5,
 C 1.81965782E-7,,-55683796E-9/
 C WATER VAPOR PRESSURE CORRELATION COEFFICIENTS
 C DATA B,E0,E1,E2/,8.2470402,-7246.5822,77.641232,-.0057447142/
 C DIFFUSION COEFFICIENTS OF GAS IN WATER AT 25 C.
 C DL(1)=OXYGEN
 C DL(2)=CARBON DIOXIDE
 C DL(3)=NITROGEN
 C DL(4)=ARGON

C DATA DL(1),DL(2),DL(3),DL(4)/2.32E-5,1.93E-5,2.42E-5,2.25E-5/
 C DATA GAS(1),GAS(2),GAS(3),GAS(4)/2H02,3HCO2,2HN2,2HAR/
 C DATA SPACK(1),SPACK(2)/4HFN90,5HFN200/
 C DATA SVACC(1),SVACC(2),SVACC(3),SVACC(4),SVACC(5)/6HCL2003,4H2-80,
 C 15H3-170,5H3-280,5H4-450/
 C ENTER NUMBER OF STAGES (MAXIMUM OF 3)
 C READ (5,500) N
 C 500 FORMAT (I1)
 C ENTER AIR EJECTOR DESIGNATION FOR EACH STAGE
 C *280* FOR NASH AIR EJECTOR 2-80 WITH CL-203 VACUUM PUMP
 C *3170* FOR NASH AIR EJECTOR 3-170 WITH CL-403 VACUUM PUMP
 C *3280* FOR NASH AIR EJECTOR 3-280 WITH CL-703 VACUUM PUMP
 C *4450* FOR NASH AIR EJECTOR 4-450 WITH CL-1003 VACUUM PUMP
 C *2003* FOR NASH AIR EJECTOR WITH CL-2003 VACUUM PUMP
 C READ (5,501) (EJECT(J),J=1,N)

C 501 FORMAT (2I5)
 C ENTER TEMPERATURE IN DEGREES FAHRENHEIT
 C READ (5,502) T
 C 502 FORMAT (F10.4)
 C ENTER LIQUID FLOW RATE IN GALLONS PER MINUTE
 C READ (5,503) L
 C 503 FORMAT (F10.4)
 C ENTER INLET DISSOLVED GAS CONCENTRATIONS IN MILLIGRAMS PER
 C LITER. ENTER *-1* IF SATURATED
 C X(1,1)=OXYGEN CONCENTRATION
 C X(1,2)=CARBON DIOXIDE CONCENTRATION
 C X(1,3)=NITROGEN CONCENTRATION
 C X(1,4)=ARGON CONCENTRATION
 C READ (5,504) (X(1,I),I=1,4)

C 504 FORMAT (4F10.4)
 C ENTER PACKING HEIGHT OF EACH STAGE IN FEET
 C READ (5,505) (Z(J),J=1,N)

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00200 60* 505 FORMAT (F10.4)
00200 61* C ENTER DIAMETER OF DEGASIFIER COLUMN IN FEET
00201 62* READ (5,506) DIA
00204 63* 506 FORMAT (F10.4)
00204 64* C ENTER PACKING DESIGNATION
00204 65* C *200* FOR MASPAC FN200 PACKING
00204 66* C *90* FOR MASPAC FN90 PACKING
00205 67* READ (5,507) PACK
00210 68* 507 FORMAT (I4)
00210 69* C ENTER PH, IF INFLUENT IS FROM A CATION EXCHANGER
00210 70* C *-1* FOR NEUTRAL WATER
00211 71* READ (5,508) PH
00214 72* 508 FORMAT (F10.4)
00214 73* C TEMPERATURE CONVERSIONS (RANKINE,CENTIGRADE,AND KELVIN)
00215 74* TR=T+460
00216 75* TC=(T-32)/1.8
00217 76* TK=TC+273
00217 77* C DENSITY CALCULATIONS (GM/ML AND GM/CC)
00220 78* RH01=D0+D1*TC+D2*TC**2+D3*TC**3+D4*TC**4
00221 79* RH02=.999972*RH01
00221 80* C VISCOSITY OF WATER CALCULATION (CP)
00222 81* IF (TC.GT.20) GO TO 50
00224 82* VIS=10**((1301/(998.333+8.1855*(TC-20))+0.0058*(TC-20)**2)-3.30233)
00224 83* 1*100
00225 84* GO TO 51
00226 85* 50 VIS=1.002+10**((1.3272*(20-TC)--001053*(TC-20)**2)/(TC+1055))
00226 86* C VAPOR PRESSURE OF WATER CALCULATION (IN. OF HG.)
00227 87* 51 VP=EXP(E0/TK+E1+E2*TK+B*ALOG(TK))*2.9522E-4
00227 88* C LIQUID RATE CALCULATIONS (LBMOLE/HR AND LB/HR-SQ FT)
00230 89* LM=L*RH01+27.792533
00231 90* LA=L*RH01*159.38103/(DIA/2)**2
00231 91* C CALCULATION OF HENRY'S LAW CONSTANTS (ATM/MOLE FRACTION) AND
00231 92* C SATURATION CONCENTRATIONS (MG/L)
00232 93* AA=ALOG(TK/100)
00232 94* AB=100/TK
00233 95* BA=EXP(-58.3877+85.8079*AB+23.8439*AA)
00234 96* MH(1,1)=1244.0656*RH01/BA+1
00236 97* AC=-58.0931+90.5069*AB+22.294*AA
00237 98* BB=EXP(AC)
00240 99* MHA=55.506*RH01/BB
00241 100* CA=-3404.71/TK+14.8435-0.032786*TK
00242 101* KI=10.0*CA
00243 102* BC=EXP(-59.6274+85.7661*AB+24.3696*AA)
00244 103* MH(1,2)=1244.0656*RH01/BC+1
00245 104* BD=EXP(-55.6578+82.0262*AB+22.5929*AA)
00246 105* MH(1,4)=1244.0656*RH01/BB+1
00247 106* IF (X(1,1).GE.0) GO TO 201
00251 107* X(1,1)=-.21/MH(1,1)*1776200
00252 108* PHC=-1.0
00253 109* 201 IF (X(1,2).GE.0) GO TO 190
00255 110* PH=7.0
00256 111* 180 MH(1,2)=MHA/(1+KI/10**(-PH))
00257 112* X(1,2)=0.0003/MH(1,2)*2442900
00260 113* PHC=-ALOG10((KI*X(1,2)*RH01*2.2742E-5)**0.5)
00261 114* DIFF=PH-PHC
00262 115* IF (ABS(DIF).LT.0.1) GO TO 202
00264 116* PH=PHC
00265 117* GO TO 180
00266 118* 190 IF (PH.GE.0) GO TO 170
00270 119* PH=-ALOG10((KI*X(1,2)*RH01*2.2742E-5)**0.5)

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00271 120* PHC=1.0
00272 121* 170 MH(1,2)=MHA/(1+KI/10**(-PH))
00273 122* 202 IF (X(1,3).GE.0) GO TO 203
00274 123* X(1,3)=-.78/MH(1,3)*1555000
00275 124* 203 IF (X(1,4).GE.0) GO TO 204
00276 125* X(1,4)=-.0093/MH(1,4)*2217100
00300 126* C CALCULATING RATIO OF HEIGHT OF TRANSFER UNIT OVER THE SQUARE ROOT OF
00300 127* C LIQUID SCHMIDT NUMBER
00300 128* 204 IF (PACK.EQ.200) GO TO 210
00301 129* HNSC=EXP(-5.7573898*.37688520*ALOG(LA))
00304 130* TPACK=SPACK(1)
00305 131* GO TO 211
00306 132* 210 HNSC=EXP(-6.05879348*.36812290*ALOG(LA))
00307 133* TPACK=SPACK(2)
00307 134* C SCHMIDT NUMBER AND HEIGHT OF TRANSFER UNIT CALCULATION
00310 135* 211 DO 212 I=1,4
00313 136* SNSC(I)=(VIS**2/(DL(I)*TK*RH02))*3.3468)**0.5
00314 137* HL(I)=HNSC*SNSC(I)
00315 138* 212 CONTINUE
00317 139* XM(1,1)=X(1,1)/1776200
00320 140* XM(1,2)=X(1,2)/2442900
00321 141* XM(1,3)=X(1,3)/1555000
00322 142* XM(1,4)=X(1,4)/2217100
00322 143* C STAGE PERFORMANCE CALCULATIONS
00323 144* DO 30 J=1,N
00323 145* C ASSIGNMENT OF VACUUM SOURCE PERFORMANCE COEFFICIENTS
00326 146* IF (EJECT(J).EQ.280) GO TO 100
00330 147* IF (EJECT(J).EQ.3170) GO TO 101
00332 148* IF (EJECT(J).EQ.3280) GO TO 102
00334 149* IF (EJECT(J).EQ.4450) GO TO 103
00336 150* CO=6.8384125
00337 151* C1=0.44577675
00340 152* C2=-0.57762709
00341 153* C3=0.13724532
00342 154* TVAC(J)=SVAC(1)
00343 155* GO TO 200
00344 156* 100 CO=4.37780480
00345 157* C1=0.49571115
00346 158* C2=-0.71514278
00347 159* C3=0.20616891
00350 160* TVAC(J)=SVAC(2)
00351 161* GO TO 200
00352 162* 101 CO=5.11801154
00353 163* C1=0.48624600
00354 164* C2=-0.88448594
00355 165* C3=0.30729692
00356 166* TVAC(J)=SVAC(3)
00357 167* GO TO 200
00360 168* 102 CO=5.67209302
00361 169* C1=0.19574653
00362 170* C2=-0.72743787
00363 171* C3=0.34458044
00364 172* TVAC(J)=SVAC(4)
00365 173* GO TO 200
00366 174* 103 CO=6.16024028
00367 175* C1=0.31855519
00370 176* C2=-0.45069421
00371 177* C3=0.10348750
00372 178* TVAC(J)=SVAC(5)
00372 179* C CALCULATION OF OUTLET GAS CONCENTRATIONS
000477 000477
000502 000502
000516 000516
000520 000520
000525 000525
000527 000527
000527 000527
000534 000534
000536 000536
000550 000550
000552 000552
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200 P(J)=1.0
DO 5 I=1,4
MH(J+1,I)=MH(J,I)
5 CONTINUE
1 P1=0.0
P2=3.5
VSY(J)=0
VJEC(J)=EXP(CO+CT*ALOG(P(J))+C2*(ALOG(P(J)))+2+C3*(ALOG(P(J))))
1**3)
VM(J)=P(J)*VJEC(J)+2.746/TR
DO 10 I=1,4
ENOL=EXP(-Z(J)/(HL(I)*(Z(J)/3)+0.15))
PROD=(1.0-ENOL)*LM+P(J)*0.03342/(VM(J)*MH(J,I))
D(J,I)=(PROD+ENOL)/(PROD+1)
X(J+1,I)=D(J,I)*X(J,I)
XM(J+1,I)=D(J,I)*XM(J,I)
VY(J,I)=LM*(XM(J,I)-XM(J+1,I))
VSY(J)=VY(J,I)+VSY(J)
10 CONTINUE
IF (PHC-1T.0) GO TO 6
PH=-ALOG10((KI*X(J+1,2)*RH01*2.2742E-5)+0.5)
MHC=MHA/(1+KI/10**(-PH))
DI F2=MHC-MH(J+1,2)
IF (ABS(DIF2).LT.25) GO TO 6
MH(J+1,2)=MHC
6 GO TO 1
DO 20 I=1,4
V(J,I)=VY(J,I)/VJEC(J)
20 CONTINUE
VNC(J)=(P(J)-VP)*VJEC(J)+2.746/TR
DEV1=(VSY(J)-VNC(J))*2/(VSY(J)+VNC(J))
IF (ABS(DEV1).LT.0.1) GO TO 30
VA=(VSY(J)+VNC(J))/2
2 AJEC=EXP(CO+CT*ALOG(P(J))+C2*(ALOG(P(J)))+2+C3*(ALOG(P(J))))**3)
VMA=(P(J)-VP)+AJEC*2.746/TR
DEV2=(VA-VMA)*2/(VA+VMA)
IF (ABS(DEV2).LT.0.01) GO TO 1
IF (VMA-6T.VA) GO TO 3
P1=P(J)
P(J)=(P(J)+P2)/2
6 GO TO 2
3 P2=P(J)
P(J)=(P(J)+P1)/2
6 GO TO 2
30 CONTINUE
C PRINT RESULTS
WRITE (6,799)
799 FORMAT (1H1)
WRITE (6,800)
800 FORMAT (20X,29HVACUUM DEGASIFIER PERFORMANCE)
WRITE (6,801)
801 FORMAT (1X)
WRITE (6,802)
802 FORMAT (1X,20HOPERATING CONDITIONS)
WRITE (6,803)
803 FORMAT (1X)
WRITE (6,804) L
804 FORMAT (6X,18HLIQUID FLOW RATE =,F10.3,3HGPR)
WRITE (6,805) T
805 FORMAT (6X,13HTEMPERATURE =,F10.3,2H F)

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00515	240*	WRITE (6,825) PH	001351
00520	241*	FORMAT (6X,4HPH =,F10.3)	001357
00521	242*	WRITE (6,806)	001357
00523	243*	FORMAT (6X,24HINLET GAS CONCENTRATIONS)	001364
00524	244*	WRITE (6,807) (GAS(I),X(1,I),I=1,4)	001364
00533	245*	FORMAT (11X,A4,1H=,F10.5,4HMG/L)	001400
00534	246*	WRITE (6,808)	001400
00536	247*	FORMAT (1X)	001405
00537	248*	WRITE (6,809)	001405
00541	249*	FORMAT (1X,24HVACUUM DEGASIFIER DESIGN)	001412
00542	250*	WRITE (6,810)	001412
00544	251*	FORMAT (1X)	001417
00545	252*	WRITE (6,811) DIA	001417
00550	253*	FORMAT (6X,17HCOLUMN DIAMETER =,F10.3,2HFT)	001425
00551	254*	WRITE (6,812) N	001425
00554	255*	FORMAT (6X,18HNUMBER OF STAGES =,I2)	001433
00555	256*	WRITE (6,813) TPACK	001433
00560	257*	FORMAT (6X,22HPACKING TYPE = MASPAC ,A5)	001441
00561	258*	WRITE (6,814)	001441
00563	259*	FORMAT (6X,13HPACKING DEPTH)	001446
00564	260*	WRITE (6,815) (J,Z(J),J=1,N)	001446
00573	261*	FORMAT (11X,6HSTAGE ,I2,2H =,F10.3,2HFT)	001463
00574	262*	WRITE (6,816)	001463
00576	263*	FORMAT (6X,11HVACUUM PUMP)	001470
00577	264*	WRITE (6,817) (J,TVAC(J),J=1,N)	001470
00606	265*	FORMAT (11X,6HSTAGE ,I2,20H = WASH AIR EJECTOR ,A6)	001505
00607	266*	WRITE (6,818)	001505
00611	267*	FORMAT (1X)	001516
00612	268*	DO 751 J=1,N	001516
00615	269*	WRITE (6,819) J	001516
00620	270*	FORMAT (1X,6HSTAGE ,I2,10H OPERATION)	001524
00621	271*	WRITE (6,824)	001524
00623	272*	FORMAT (1X)	001531
00624	273*	WRITE (6,820) VJEC(J)	001531
00627	274*	FORMAT (6X,17HEVACUATION RATE =,F10.3,4HACFM)	001537
00630	275*	WRITE (6,821) P(J)	001537
00633	276*	FORMAT (6X,16HSTAGE PRESSURE =,F10.5,10HIN. OF HG.)	001545
00634	277*	WRITE (6,822)	001545
00636	278*	FORMAT (6X,25HOUTLET GAS CONCENTRATIONS)	001552
00637	279*	WRITE (6,823) (GAS(I),X(J+1,I),I=1,4)	001552
00646	280*	FORMAT (11X,A15,3H = ,F10.6,4HMG/L)	001572
00647	281*	751 CONTINUE	001572
00651	282*	STOP	001576
00652	283*	END	001576

END OF COMPILATION: NO DIAGNOSTICS.

APPENDIX B
TYPICAL DESIGN CASES

TYPICAL DESIGN CASES

Example design cases were run to illustrate the effect of design variables upon the system design. In the first case, shown on Table B-1, the design was based upon the following data:

1. The inlet water flow rate was 650 gpm.
2. The system operating temperature was 45° F.
3. The inlet concentration of carbon dioxide dissolved in the water was 15.4 milligrams per liter. The other dissolved gas constituents were assumed to be present at their atmospheric solubility.
4. The degasifier was assumed to be located following the primary cation and anion exchangers and therefore the pH is only affected by the presence of dissolved carbon dioxide.
5. The vacuum degasifier design assumed a six foot diameter, two stage column with ten feet of MASPAC FN200 packing per stage. A NASH Model 3-170 air ejector was evacuating each stage.

The results indicated that this degasifier could be expected to meet the limit of 20 micrograms per liter oxygen, but would be somewhat marginal in achieving 5 milligrams per liter carbon dioxide.

TABLE B-1

VACUUM DEGASIFIER PERFORMANCE

Case 1

OPERATING CONDITIONS

LIQUID FLOW RATE = 650.000GPM

TEMPERATURE = 45.000 F

PH = 5.210

INLET GAS CONCENTRATIONS

O₂ = 12.25558MG/LCO₂ = 15.40000MG/LN₂ = 19.53593MG/L

AR = .98515MG/L

VACUUM DEGASIFIER DESIGN

COLUMN DIAMETER = 6.000FT

NUMBER OF STAGES = 2

PACKING TYPE = MASPAC FN200

PACKING DEPTH

STAGE 1 = 10.000FT

STAGE 2 = 10.000FT

VACUUM PUMP

STAGE 1 = NASH AIR EJECTOR 3-170

STAGE 2 = NASH AIR EJECTOR 3-170

STAGE 1 OPERATION

EVACUATION RATE = 148.617ACFM

STAGE PRESSURE = .83661IN. OF HG.

OUTLET GAS CONCENTRATIONS

O₂ = .629166MG/LCO₂ = 7.142911MG/LN₂ = .740317MG/L

AR = .061821MG/L

STAGE 2 OPERATION

EVACUATION RATE = 45.990ACFM

STAGE PRESSURE = .41976IN. OF HG.

OUTLET GAS CONCENTRATIONS

O₂ = .061781MG/LCO₂ = 5.214638MG/LN₂ = .045990MG/L

AR = .007904MG/L

@FIN

In Case 2 on Table B-2, the design condition are the same as in Case 1 except:

1. The inlet concentration of carbon dioxide was 162 milligrams per liter.
2. A NASH air ejector with a Model CL-2003 vacuum pump on each stage was used.

The results show satisfactory oxygen removal, but inadequate removal of carbon dioxide.

Case 3, on Table B-3, is the same as Case 2 except the degasifier was assumed to be located downstream of the primary cation exchanger receiving a decationized influent with a pH of 3.02. Carbon dioxide removed was only slightly improved by this change.

TABLE B-2

VACUUM DEGASIFIER PERFORMANCE

Case 2

OPERATING CONDITIONS

LIQUID FLOW RATE = 650.000GPM
 TEMPERATURE = 45.000 F
 PH = 5.115
 INLET GAS CONCENTRATIONS
 O2 = 12.25558MG/L
 CO2 = 162.00000MG/L
 N2 = 19.53593MG/L
 AR = .98515MG/L

VACUUM DEGASIFIER DESIGN

COLUMN DIAMETER = 6.000FT
 NUMBER OF STAGES = 2
 PACKING TYPE = MASPAC FN200
 PACKING DEPTH
 STAGE 1 = 10.000FT
 STAGE 2 = 10.000FT
 VACUUM PUMP
 STAGE 1 = NASH AIR EJECTOR CL2003
 STAGE 2 = NASH AIR EJECTOR CL2003

STAGE 1 OPERATION

EVACUATION RATE = 701.156ACFM
 STAGE PRESSURE = .66611IN. OF HG.
 OUTLET GAS CONCENTRATIONS
 O2 = .411843MG/L
 CO2 = 28.336331MG/L
 N2 = .567276MG/L
 AR = .036821MG/L

STAGE 2 OPERATION

EVACUATION RATE = 334.661ACFM
 STAGE PRESSURE = .39440IN. OF HG.
 OUTLET GAS CONCENTRATIONS
 O2 = .016019MG/L
 CO2 = 8.087854MG/L
 N2 = .017962MG/L
 AR = .001657MG/L

FIN

TABLE B-3

VACUUM DEGASIFIER PERFORMANCE

Case 3

OPERATING CONDITIONS

LIQUID FLOW RATE = 650.000GPM

TEMPERATURE = 45.000 F

PH = 3.020

INLET GAS CONCENTRATIONS

O2 = 12.25558MG/L

CO2 = 162.00000MG/L

N2 = 19.53593MG/L

AR = .98515MG/L

VACUUM DEGASIFIER DESIGN

COLUMN DIAMETER = 6.000FT

NUMBER OF STAGES = 2.

PACKING TYPE = MASPAC FN200

PACKING DEPTH

STAGE 1 = 10.000FT

STAGE 2 = 10.000FT

VACUUM PUMP

STAGE 1 = NASH AIR EJECTOR CL2003

STAGE 2 = NASH AIR EJECTOR CL2003

STAGE 1 OPERATION

EVACUATION RATE = 703.905ACFM

STAGE PRESSURE = .66877IN. OF HG.

OUTLET GAS CONCENTRATIONS

O2 = .411611MG/L

CO2 = 28.094636MG/L

N2 = .567092MG/L

AR = .036794MG/L

STAGE 2 OPERATION

EVACUATION RATE = 333.404ACFM

STAGE PRESSURE = .39361IN. OF HG.

OUTLET GAS CONCENTRATIONS

O2 = .016026MG/L

CO2 = 7.992206MG/L

N2 = .017967MG/L

AR = .001657MG/L

FIN

NOMENCLATURE

A_1, A_2, A_3	Constants used in gas solubility correlations of Weiss (51, 52).
B	Constants used in water vapor pressure correlation of Wexler and Greenspan (53).
B_1, B_2, B_3	Constants used in gas solubility correlations of Weiss (51, 52).
C_0, C_1, C_2, C_3	Constants used in packing height of a liquid transfer unit correlation, eq. (III-17), Constants used in water density correlation, eq. (III-21), and Constants used in air ejector performance correlation, eq. (IV-1).
D_{AB}	Liquid diffusion coefficient, (cm^2/sec).
E_0, E_1, E_2	Constants used in water vapor pressure correlation of Wexler and Greenspan (53).
F	Entering liquid flow rate, (gpm or lb mole/hr).
G_M	Gas molal mass velocity, (lb mole/hr-ft^2).
H_{CO_2}	Henry's law constant for carbon dioxide, (atm/mole fraction).
H_i	Henry's law constant for a gas, (atm/mole fraction).
H_G	Height of a gas mass transfer unit, (ft).
H_L	Height of a liquid mass transfer unit, (ft).
H_L°	Height of a liquid mass transfer unit computed by eq. (III-16), (ft).
H_{OL}	Height of an overall mass transfer unit, (ft).
K	Stokes-Einstein equation constant ($\text{gm cm/sec}^2 \text{ } ^{\circ}\text{K}$).

K_{DI}	Ionization constant.
K_O	Solubility coefficient, (moles/liter-atm).
L	Exiting liquid flow rate, (gpm or lb mole/hr).
L_M	Liquid molal mass velocity, (lb mole/hr-ft ²).
N_{OL}	Number of overall transfer units.
N_{ScL}	Liquid phase Schmidt number.
P	Stage pressure, (in. Hg.).
R	Ideal gas constant.
S^{oo}	Salinity, (gm/Kg).
T	Temperature, (°C, °K, or °F).
V	Vapor flow rate or evacuation rate, (lb mole/hr or acfm).
m	Slope of operating line.
n	Packing characteristic exponent in eq. (III-16).
n_i	Moles of gas.
\bar{p}_{CO_2}	Partial pressure of carbon dioxide, (in. Hg.).
p_i	Partial pressure of a gas, (in. Hg.).
$p_{H_2O}^*$	Vapor pressure of water, (in. Hg.).
p_i^*	Component vapor pressure, (in. Hg.).
x_{CO_2}	Liquid mole fraction of carbon dioxide.
x_i	Component liquid mole fraction.
x_i^*	Component liquid mole fraction in equilibrium.
x_{fi}	Entering component liquid mole fraction.
y_i	Component vapor mole fraction.

y_i^*	Component vapor mole fraction in equilibrium.
z	Height of packing, (ft).
β	Bunsen solubility coefficient, and Packing characteristic coefficient in eq. (III-16).
μ	Liquid viscosity, (cp).
ρ	Density, (gm/cm^3 or gm/ml).

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