NON-EQUILIBRIUM PARAMETRIC PUMPS FOR SEPARATING LIQUIDS OR GASES

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ABSTRACT

An experimental and theoretical study has been done of Non-Equilibrium parametric pumps. Mathematical models and computer programmes are developed for both thermal and heatless parametric pumps based on non-equilibrium conditions and linear isotherms. A mathematical study was done for thermal parametric pumps whereas both experimental and theoretical studies were made for a heatless parametric pump. The effect of different operating conditions has been investigated on the separation of $NaCl$-H_2O via a thermal parametric pump and He-CO_2 and He-C_3H_6 gas mixtures via a heatless parametric pump.

The experimental study of heatless parametric pumps was extended to the separation of ternary gas mixtures. The effect of different operating conditions on the separation has been emphasized. The results based on binary gas model have been compared with ternary experimental results.

The mathematical study of thermal parametric pumps shows that separation of mixtures may be predicted. It also helps in predicting the effect of different operating conditions, such as ϕ_B , half cycle time. Thus, mathematically optimum conditions can be found to attain a definite separation.

Similarly, a study of heatless parametric pumps shows that separation of gaseous mixtures is possible by this technique. The experimental studies shows that this technique is not only limited to binary mixtures but can be sucessfully applied to the multicomponent mixtures. The mathematically calculated results show the same effect as observed experimentally.

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Page No.

TABLE OF CONTENTS

Page No.

Appendices

(ii) Computer programmes for -

(iii) Figures and Tables

LIST OF FIGURES

SCOPE

Parametric pumping is a periodic separation technique which represents an alternative to the conventional adsorption process. This concept requires a solute/adsorbent system in which some controllable thermodynamic variable viz. temperature, pressure or pH affects the solute equilibrium distribution between the fluid and solid phases.

Parametric pumping has several advantage over conventional separation processes. In general, parametric cyclic technique is self generating. The operation is continuous. This technique increases the separating capacity for a given column. The capital investment for the process is relatively low for a given flow rates of products.

Parametric pumping technique can be categorized into two cases. In the first, solute and adsorbent(solid) are assumed to reach equilibrium instantaneously. The mass transfer coefficient between two phases is considered to be infinite. This is called ' Equilibrium parametric pumping.' In the second case which is closer to the real situation, the solute and solid do not reach eqilibrium. The mass transfer rate is dependent upon the overall driving force available and the mass transfer coefficient is finite. This is known as NON-EQUILIBRIUM pumping.

Further, periodic separation caused by variable temperature is known as Thermal Parametric Pumping,whereas separation obtained using pressure as a thermodynamic variable is called Heatless Parametric Pumping. In principle, Thermal Parametric Pumping consists of changing the operating column temperature and reversing the direction of flow during each half cycle. Two upflow and downflow half cycles constitute one cycle.During upflow or hot half cycle, solute is desorbed, while in reverse flow, cold half cycle solute is adsorbed. Thus, solute-rich and solute-lean products are obtained during respective half cycles.Thermal parametric pumps can be operated in batch, semicontinuously or continuously. On the other hand, heatless parametric pumping is based on changing of the total pressure during each half cycle, keeping the temperature of the system constant. During each half cycle, one column is maintained at high pressure and the other column at low pressure. At high pressure, solute is adsorbed and at low pressure , solute is desorbed, resulting in solute-lean product and solute-rich product from respective columns.

BACKGROUND

Many workers have studied parametric pumping in one of its specific forms. Thermal parametric pumping was conceived by Wilhelm about 1962. Separation of NaCl-H_2O liquid system using ion-exchange resins have been reported by Rice(1966), Wilhelm Rice and Bedelius(1966), Rolke(1967) and Wilhelm, Rice, Rolke and Sweed(1968). McAndrew(1967) studied recuperative thermal parametric pumping as applied to a gaseous methane-nitrogen system. Meyers(1968) showed the separation of equimolar feed of ethane and propane experimentally on a continuous flowrate basis. Meyers(1970) also developed a theoretical equilibrium plug flow model for the gaseous mixture separation.

Pigford, Baker and Blum(1969) also presented an equilibrium theory of the continuous parametric pumps. Sweed and Wilhelm(1969) computed the separation of Toluene-Heptane mixture using a numerical algorithm based on equilibrium operation and also determined the effect of displacement, cycle time, phase angle, and reservoir volume on separation. Chen and Hill(1971) investigated batch, semicontinuous, and continuous versions of the parametric pump in terms of an equilibrium theory. Patrick (1972) also showed the separation of the air-SO_2 mixture using a direct thermal mode and developed theoretical results based on instantaneous gas-solid equilibrium relationships. Patrick also studied the effect of the number of cycles,pumping cycle time and operating temperature range and level on the extent of separation over a wide range of operating conditions. Gregory(1974) made a quantitative comparision of conventional adsorption with parametric pumping for a non-equilibrium system with nonlinear isotherms.

Some workers have investigated the separation of gaseous mixtures via heatless parametric pumps. A brief review is given below:

Alexis(1967) made a comparative study of heatless parametric pumping with other separation processes in upgrading hydrogen. Alexis showed that heatless parametric pumping is the most economical for treating moderate amounts of hydrogen. Kadlec (1971) separated nitrogen and methane using pressure as the driving force in a single column similar to a thermal parametric pump. Kadlec also developed a mathematical model based upon the assumption of instantaneous equilibrium between the gas phase and the adsorbed gas. Kadlec(1972) investigated the problem of optimum feed rate and optimum cycle time for heatless parametric pumping based on instantaneous equilibrium theory.

A different approach has been used by Shendalman(1972) in studying the separation of He-CO_2 mixture via a heatless parametric pump. Shendalman developed a mathematical model considering instantaneous equilibrium theory. Shendalman (1972) extended his experimental and theoretical investigation for non-equilibrium conditions.

The present work has been divided into three parts. In the first part, a mathematical model has been developed for the non-equilibrium thermal parametric pump. In the second part an experimental study has been done for non-equilibrium heatless-parametric pumps for separating binary gas mixtures and also a mathematical model has been developed for the calculation of concentration profiles. In the third part, experimental study of heatless parametric pumps has been extended for the separation of ternary gas mixtures. The effect on the separation of different operating conditions such as half cycle time,operating pressure and purge ratio has been determined.

THEORY

Consider a differential element of thickness dx in the column. By material balance for the solute, one gets -

$$\epsilon \frac{\partial (cv)}{\partial x} + \rho_s (1-\epsilon) \frac{\partial w}{\partial t} + \epsilon \frac{\partial c}{\partial t} = 0 \quad . \qquad ----(1)$$

In the above equation the first term is due to bulk flow of fluid along the length of the column, the second and third terms are an accumulation in solid and fluid phases, respectively. Rearranging equation (1) -

$$v \frac{\partial c}{\partial x} + \frac{\partial c}{\partial t} = - \frac{(1-\epsilon)}{\epsilon} \rho_s \frac{\partial w}{\partial t} - c \frac{\partial v}{\partial x} \quad . \qquad ----(2)$$

Similarly, for the total mass balance,at steady state-

$$\epsilon \frac{\partial \rho}{\partial t} + \frac{\partial (\rho v)}{\partial x} + (1-\epsilon) \rho_s \frac{\partial w}{\partial t} = 0 \quad . \qquad ----(3)$$

$$\frac{\partial \rho}{\partial t} + \epsilon \rho \frac{\partial v}{\partial x} + \epsilon \, v \frac{\partial \rho}{\partial x} + (1-\epsilon) \rho_s \frac{\partial w}{\partial t} = 0 \quad . \qquad ----(4)$$

Equations (2) and (4) are based on the following assumptions -

(A) ASSUMPTIONS :

1. Only one component is adsorbed in the flowing fluid.
2. Plug flow.
3. Negligible axial diffusion.
4. Molar density of flowing fluid has been considered constant.

Validity of this assumption for two different cases is explained below -

a) In liquid phase, the solute concentration is very small compared to that of the solvent. Hence, change in the concentration of solute has a negligible effect on the molar density of the fluid.

b) In the gas phase, the solute gas concentration is very small and the density has been considered as that of the non adsorbing component helium only. If the pressure in the column is constant then the molar density of fluid will be constant.

5. Linear isotherms apply.

(B) Equations (2)and (4) are simplified further as below:

$$\frac{\partial \rho}{\partial t} = \frac{\partial \rho}{\partial x} = 0 \text{ , for constant density fluid.}$$

Equation (4) then changes to :

$$\frac{\partial v}{\partial x} = - \frac{(1-\epsilon)}{\epsilon} \frac{\rho_s}{\rho} \frac{\partial w}{\partial t} \quad . \qquad \text{----(5)}$$

Also, $\frac{\partial w}{\partial t} = f\ (c,w,v\ ) \quad .$ ----(6)

Equations (2),(5) and (6) are basic equations which are further used for generating characteristic equations. The steps are shown below :

$$c = f(x,t) \quad . \qquad \text{----(7)}$$

so, $dc = \frac{\partial c}{\partial x} dx + \frac{\partial c}{\partial t} dt \quad ,$

or $\frac{dc}{dx} = \frac{\partial c}{\partial x} + \frac{\partial c}{\partial t} \frac{dt}{dx} \quad .$ ----(8)

If $\frac{dt}{dx} = \frac{1}{v} \quad ,$

Equation (8) changes to :

$$v \frac{dc}{dx} = v \frac{\partial c}{\partial x} + \frac{\partial c}{\partial t} \quad . \qquad \text{----(9)}$$

According to the above condition, i.e., along a line of slope $= \frac{1}{v}$, the total derivative changes to the partial derivative. Similarly, $v = f(x,t)$,

so, $dv = \frac{\partial v}{\partial x} dx + \frac{\partial v}{\partial t} dt \quad ,$

or, $$\frac{dv}{dx} = \frac{\partial v}{\partial x} + \frac{\partial v}{\partial t}\frac{dt}{dx} \quad . \qquad \text{-----(10)}$$

If $\frac{dt}{dx} = 0$,

then $$\frac{dv}{dx} = \frac{\partial v}{\partial x} \quad . \qquad \text{-----(11)}$$

This shows that along t= a constant, the total derivative changes to partial derivative. In other words, in a t-x axis at a fixed time, velocity is a function of x alone, which can be solved using Euler's iterative method or Runge-Kutta method.

Similarly, $w = f(x,t)$,

$$dw = \frac{\partial w}{\partial x}dx + \frac{\partial w}{\partial t}dt \quad . \qquad \text{-----(12)}$$

$$\frac{dw}{dt} = \frac{\partial w}{\partial x}\frac{dx}{dt} + \frac{\partial w}{\partial t} \quad ,$$

If $\frac{dx}{dt} = 0$,

Then equation (12) changes to -

$$\frac{dw}{dt} = \frac{\partial w}{\partial t} \quad . \qquad \text{-----(13)}$$

Equation (13) shows that in a t-x axis, at a fixed distance in the column the solid concentration is a function of time only. Thus the solid phase concentration at any time can be solved using Euler's iterative method or Runge-Kutta method.

Combining equations (2),(5) and (6) with equations (9),(11) and (13)respectively, one obtains :

$$v\frac{dc}{dx} = -\left(\frac{1-\epsilon}{\epsilon}\right)\rho_s\frac{dw}{dt} - c\,\frac{dv}{dx} \quad . \qquad \text{-----(14)}$$

Along, $\frac{dt}{dx} = \frac{1}{v}$. -----(14-a)

$$\frac{dv}{dx} = -\frac{(1-\epsilon)}{\epsilon}\frac{\rho_s}{\rho}\frac{dw}{dt} \quad . \qquad \text{-----(15)}$$

Along, $$\frac{dt}{dx} = 0 \quad . \qquad \text{----(15-a)}$$

and, $$\frac{dw}{dt} = f(c,w,v) \quad . \qquad \text{----(16)}$$

Along, $$\frac{dx}{dt} = 0 \quad . \qquad \text{----(16-a)}$$

Equations (14) to (16-a) are used to generate concentration profiles for different parametric pumps. The application of the above equations in two types of pumps has been discussed separately.

(C)(i) THERMAL PARAMETRIC PUMPS

The following additional assumptions are used in simplifying equations (14) to (16-a) :

1. The concentration of the solute in the fluid mixture is very small. Hence, the velocity of fluid through the column is considered constant. Therefore, $v = v_0$,

2. The fluid phase driving force is controlling for the calculation of mass-transfer coefficients.

If $z = \frac{x}{v_0}$, then the above equations become -

$$\frac{dc}{dz} = -\left(\frac{1-\epsilon}{\epsilon}\right) \frac{\rho_s}{\rho} \frac{dw}{dt} \quad . \qquad \text{----(17)}$$

Along, $$\frac{dt}{dz} = 1 \quad . \qquad \text{----(17-a)}$$

$$\frac{dw}{dt} = \lambda \left(c - \frac{w}{M_T} \right) \quad . \qquad \text{----(18)}$$

Along, $$\frac{dz}{dt} = 0 \quad . \qquad \text{----(18-a)}$$

Where, $$\lambda = \alpha \, v_0^{1-\beta} \quad . \qquad \text{----(19)}$$

and, $$M_T = a - b\,T \quad . \qquad \text{----(20)}$$

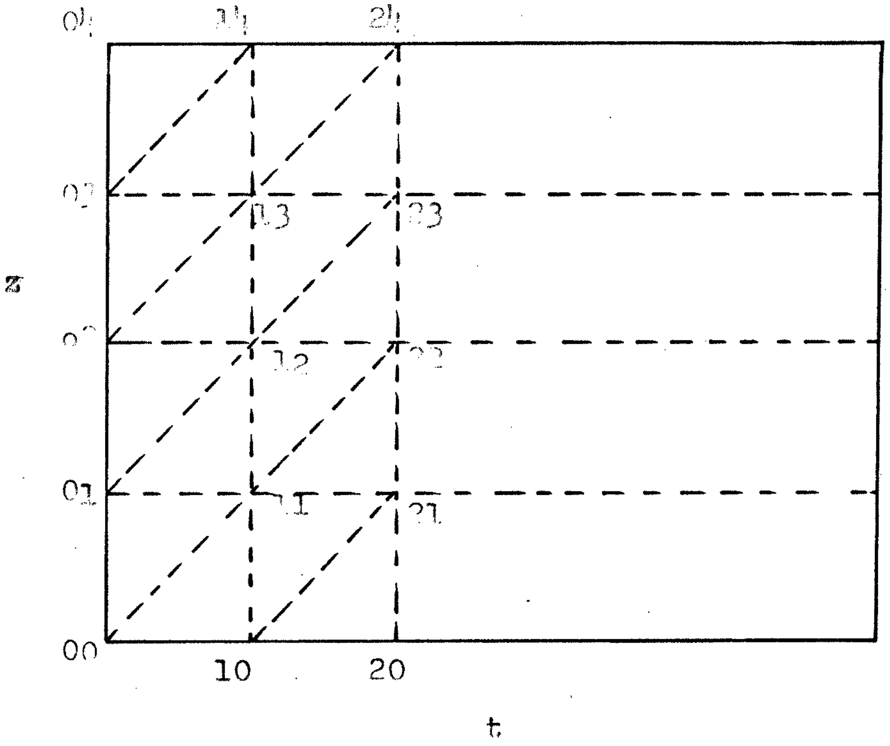


Figure 1

Network of Two Families of Characteristics as given by Sweed (1971) values of constants α, β, a and b are listed in Table-21. Equations (17) and (18) are solved in a t-z plane using Euler's iterative method as shown below :

In a t-z plane(Fig-1), the intersection of $t = z + k.\Delta t$ and $z = \ell . \Delta z$,i.e., point (k,ℓ) can be calculated using initial conditions along $z = \ell . \Delta z$ and $\frac{dt}{dz} = 1$. For example, if t is divided into k intervals and $\ell = NNZ$, then , considering $t = 1.\Delta t$, $c_{(1,1)}$ and $w_{(1,1)}$ can be calculated using points (0,0) and (0,1). The equations (17) to (20) can be written as below :

$$c_{(1,1)} = c_{(0,0)} - \left(\frac{1-\epsilon}{\epsilon}\right) \frac{\rho_s}{\rho} \lambda \int \left(c - \frac{w}{\bar{M}_T} \right) dz \quad . \qquad \text{----(21)}$$

$$w_{(1,1)} = w_{(0,1)} + \lambda \int \left(c - \frac{w}{\bar{M}_T} \right) dt \quad . \qquad \text{----(22)}$$

The first approximation for $c_{(1,1)}$ and $w_{(1,1)}$ will be :

$$c^1_{(1,1)} = c_{(0,0)} - \left(\frac{1-\epsilon}{\epsilon}\right) \frac{\rho_s}{\rho} \lambda \left(c_{(0,0)} - \frac{w_{(0,0)}}{M_T} \right) \Delta z \quad . \qquad \text{----(23)}$$

$$w^1_{(1,1)} = w_{(0,0)} + \lambda \left(c_{(0,1)} - \frac{w_{(0,1)}}{M_T} \right) \Delta z \quad . \qquad \text{----(24)}$$

A more exact result can be obtained by making use of a procedure analogous to the modified Euler's method used by Acrivos (1956) :

$$c^2_{(1,1)} = c_{(0,0)} - \left(\frac{1-\epsilon}{\epsilon}\right) \frac{\rho_s}{\rho} \lambda \frac{1}{2} \left(c^1_{(1,1)} - \frac{w^1_{(1,1)}}{M_T} + c_{(0,0)} - \frac{w_{(0,0)}}{M_T} \right) \Delta z \quad . \qquad \text{----(25)}$$

This iterative procedure is continued until the values of $C_{(1,1)}$

and $w_{(1,1)}$ converge. In identical manner $c_{(1,2)}$ and $w_{(1,2)}$; $c_{(1,3)}$ and $w_{(1,3)}$; $c_{(1,\ell)}$ and $w_{(1,\ell)}$ can be calculated. The whole procedure is repeated for $t = 2.\Delta t$; $3.\Delta t$; $k\Delta t$. Thus, values of c and w can be generated at (i,j) point, once values at (i-1,j-1) and (i-1,j) are known.

(C) (ii) HEATLESS PARAMETRIC PUMPS

Equations (14) to (16-a) are again simplified for a heatless parametric pump with the following additional assumptions :

1. The velocity of gaseous mixture is constant through the column bed.,i.e., $v = v_0$;
2. The gaseous mixture follows the simple ideal gas law. Hence, $c = \rho y$;
3. The solid phase driving force is controlling for the calculation of mass-transfer coefficients.

Hence,

$$v_0 \frac{d(\rho y)}{dx} = -\frac{(1-\epsilon)}{\epsilon} \rho_s \frac{dw}{dt} ,$$

or,

$$v_0\, y \frac{d\rho}{dx} + v_0 \rho \frac{dy}{dx} = -\frac{(1-\epsilon)}{\epsilon} \rho_s \frac{dw}{dt} . \qquad \text{----(27)}$$

Since, ρ is constant, $\frac{d\rho}{dx} = 0$, and equation (27) changes to :

$$v_0 \frac{dy}{dx} = -\frac{(1-\epsilon)}{\epsilon} \frac{\rho_s}{\rho} \frac{dw}{dt} . \qquad \text{----(28)}$$

Along,

$$\frac{dt}{dx} = \frac{1}{v_0} . \qquad \text{----(28-a)}$$

For the solid phase, concentration equations, (16) and (16-a) can be written as :

$$\frac{dw}{dt} = \lambda(\overset{*}{w} - w) . \qquad \text{----(29)}$$

and, $$\frac{dx}{dt} = 0 \quad . \qquad \text{----(29-a)}$$

where λ is mass transfer coefficient that has been defined in Appendix-I.

Also, $$\overset{*}{w} = M_P \left(\frac{P\ y}{R\ T}\right) \quad . \qquad \text{----(30)}$$

where the value of equilibrium constant M_P is assumed to be constant calculated at $P = 60$ psia from fig. - 2.

Let, $z = \frac{x}{v_0}$, equations (28) to (29-a) are transformed to the following form :

$$\frac{dy}{dz} = - \frac{\rho_s}{\rho} \frac{(1-\epsilon)}{\epsilon} \left(\frac{y\ P\ M_P}{R\ T} - w \right) \quad . \qquad \text{----(31)}$$

Along, $$\frac{dt}{dz} = 1 \quad . \qquad \text{----(31-a)}$$

$$\frac{dw}{dt} = \lambda \left(\frac{y\ P\ M_P}{R\ T} - w \right) \quad . \qquad \text{----(32)}$$

Along, $$\frac{dz}{dt} = 0 \quad . \qquad \text{----(32-a)}$$

Equations (31) and (32) are solved in a t-z plane using the Runge-Kutta method as discussed below .Consider in a t-z plane, two families of lines (31-a) and (32-a) such that the following conditions are satisfied :

$$\frac{dt}{dz} = 1 \quad \text{----I} \quad ,$$

and, $$z = \text{constant} \quad \text{----II} \ ,$$

A network of I and II characteristics can be represented by the following equations :

$$t = z + k\,\Delta t \quad ,$$

$$z = \ell \Delta z \quad ,$$

where Δt and Δz are arbitrary infinitesimal increments and k, ℓ

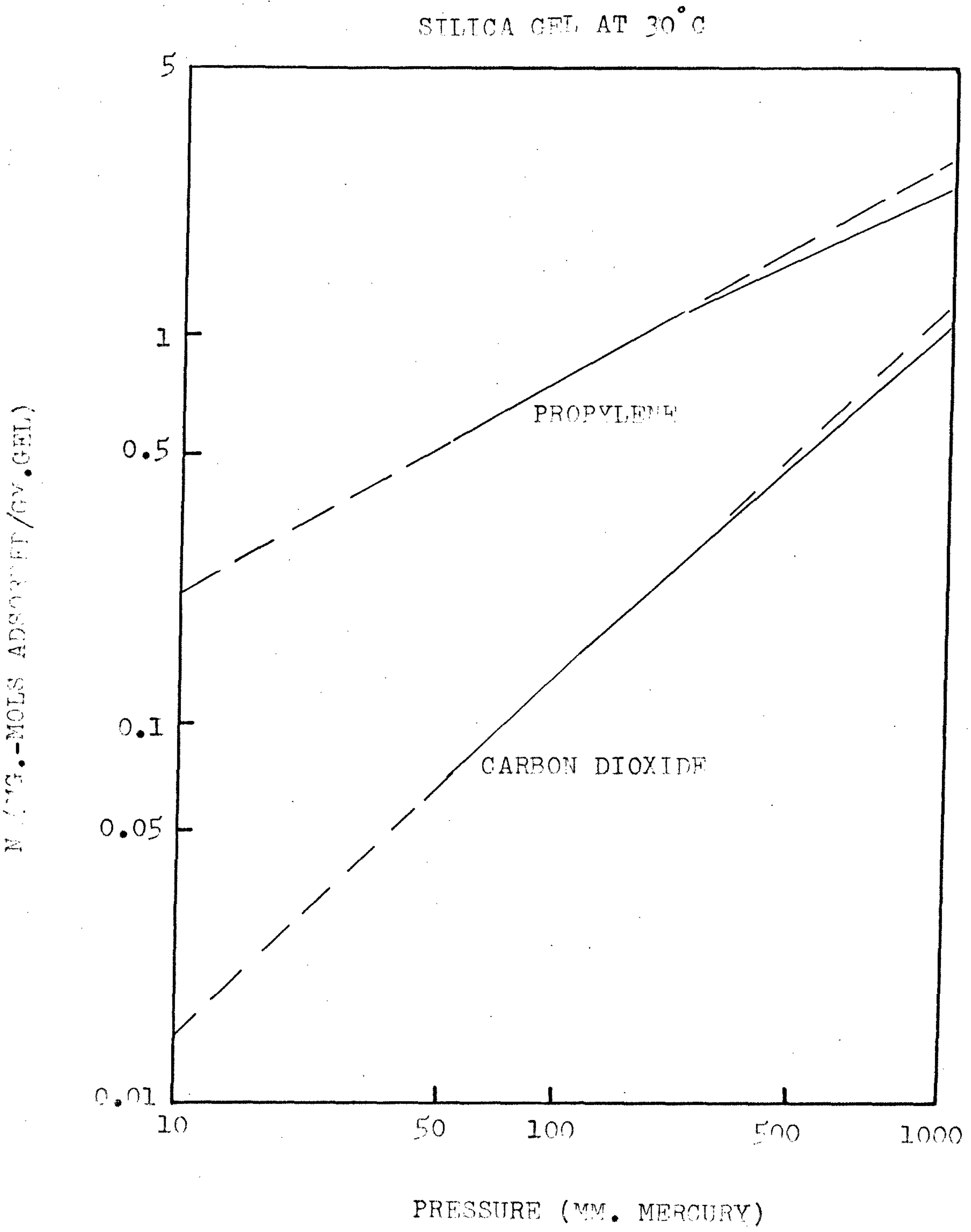

SILICA GEL AT 30°C
5
1
0.5
0.1
0.05
0.01
N (MG.-MOLS ADSORBED/GM.GEL)
PROPYLENE
CARBON DIOXIDE
10
50
100
500
1000
PRESSURE (MM. MERCURY)

Figure 2

are integers. The point of intersection of two characteristics can be denoted by the symbol (k,ℓ) and the values of y and w at these points will be denoted by $y_{(k,\ell)}$ and $w_{(k,\ell)}$ respectively. For example, (2,1) refers to the intersection of the two characteristics :

$$t = z + 2\,\Delta t \qquad \text{and} \qquad z = \Delta z \quad .$$

Evaluation of the quantities $y_{(1,1)}$ and $w_{(1,1)}$ proceeds in the following manner :

Equation (31) can be written as :

$$\frac{dy}{dz} = f(y,w) \quad ,$$

Using the Runge-Kutta method for Δz increment :

$$K_1 = f(\, y_{(0,0)} \,,\, w_{(0,0)} \,)\ \Delta z \quad ,$$

$$y^1_{(1,1)} = y_{(0,0)} + K_1/2 \quad ,$$

$$K_2 = f\,(\, y^1_{(1,1)} \,,\, w_{(0,0)} \,)\ \Delta z \quad ,$$

$$y^2_{(1,1)} = y_{(0,0)} + K_2\,/2 \quad ,$$

$$K_3 = f\,(\, y^2_{(1,1)} \,,\, w_{(0,0)} \,)\ \Delta z \quad ,$$

$$y^3_{(1,1)} = y_{(0,0)} + K_3/2 \quad ,$$

$$K_4 = f\,(\, y^3_{(1,1)} \,,\, w_{(0,0)} \,)\ \Delta z \quad ,$$

$$\Delta y = (\, K_1 + 2\,K_2 + 2\,K_3 + K_4 \,)\,/\,6 \quad ,$$

$$y_{(1,1)} = y_{(0,0)} + \Delta y \quad ,$$

For the calculation of $w_{(1,1)}$:

$$\frac{dw}{dt} = f(y,w) \quad , \quad \text{using the Runge-Kutta method :}$$

$$K_1' = f\,(\,y_{(0,1)}\,,\,w_{(0,1)}\,)\,\Delta t \quad ,$$

$$w^1_{(1,1)} = w_{(0,1)} + K_1'/2 \quad ,$$

$$K_2' = f\,(\,y_{(0,1)}\,,\,w^1_{(1,1)}\,)\,\Delta t \quad ,$$

$$w^2_{(1,1)} = w_{(0,1)} + K_2'/2 \quad ,$$

$$K_3' = f\,(\,y_{(0,1)}\,,\,w^2_{(1,1)}\,)\,\Delta t \quad ,$$

$$w^3_{(1,1)} = w_{(0,1)} + K_3'/2 \quad ,$$

$$K_4' = f\,(\,y_{(0,1)}\,,\,w^3_{(1,1)}\,)\,\Delta t \quad ,$$

$$\Delta w = (\,K_1' + 2\,K_2' + 2\,K_3' + K_4'\,)\,/\,6 \quad ,$$

$$w_{(1,1)} = w_{(0,1)} + \Delta w$$

Similarly, for $t = 1\,\Delta t$, $y_{(1,2)}$ and $w_{(1,2)}$; $y_{(1,3)}$ and $w_{(1,3)}$; $y_{(1,\ell)}$, $w_{(1,\ell)}$ can be estimated. The same procedure is repeated for $t = 2\,\Delta t$, $3\,\Delta t$, $k\,\Delta t$. Therefore, in general, $y_{(j,i)}$ and $w_{(j,i)}$ can be calculated once y and w are known at points (j-1,i-1) and (j-1,i) .

(D) CYCLIC OPERATION OF THERMAL PARAMETRIC PUMPS

A thermal parametric pump consists of one jacketed column with two reservoirs, each at one end. Feed is introduced at the top.(Fig.-3) After each half cycle the column temperature is changed , keeping the pressure constant. At the begining of cyclic operation the column is saturated at high temperature during the first half cycle. In general, one complete cycle can be divided into four parts as described herein :

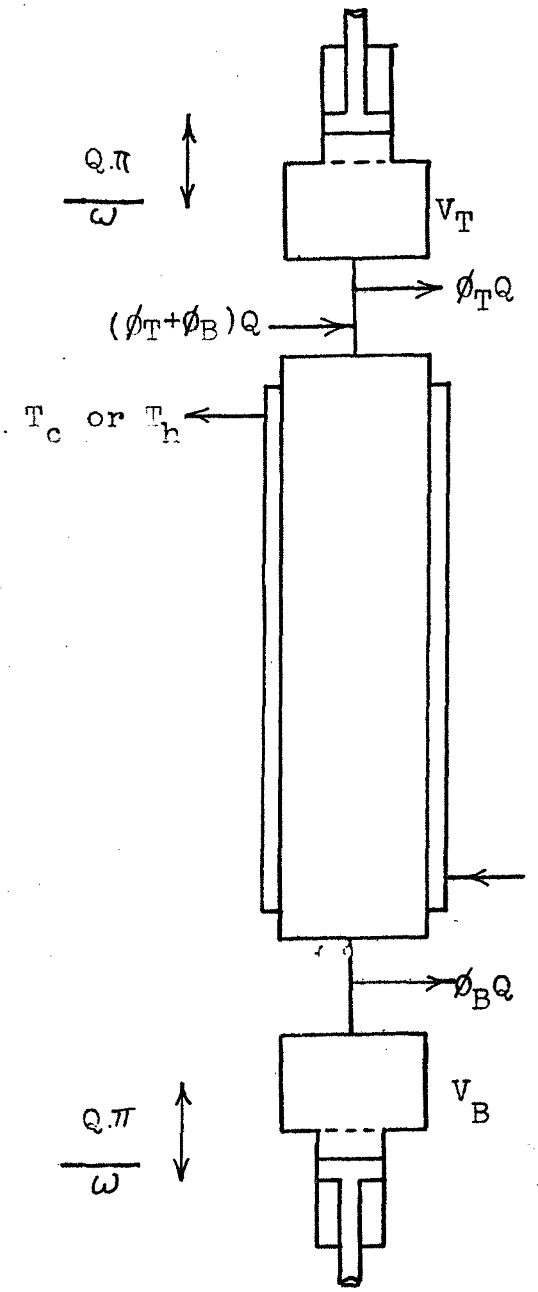


Figure 3

Continuous Thermal Parametric Pump

STEP 1 The direction of flow is upward and the column is maintained at a high temperature. Component A is desorbed; thus solute-enriched top product is obtained during this half cycle.

STEP 2 The temperature of the column changes from high temperature to low temperature and the direction of the flow is reversed.

STEP 3 The direction of flow is downward and the column is maintained at low temperature. Solute is adsorbed, resulting in a solute-lean product from the bottom end.

STEP 4 The temperature changes from high to low and the direction of flow changes from downward to upward. Steps 2 and 4 take place instantaneously and feed is introduced continuously at the top.

(E) COMPUTER CALCULATION FOR CYCLIC OPERATION (Fig. 4)

Total distance intervals = NNZ

STEP 1

$$v_1 = \frac{(1 - \phi_B)\, Q}{A \;\; TIME} \quad . \qquad \text{----(33)}$$

$$\Delta z1 = \Delta t1 = \frac{H}{v_1 \, NNZ} \quad . \qquad \text{----(34)}$$

Initial conditions :

(1) @ $z = 0$ for all $t \geqslant 0$

$c_{(k,0)} = \langle CBP1 \rangle_n$, where $\langle CBP1 \rangle_n$ can be obtained by material balance at the bottom reservoir.(Step 4)

For $n = 1$, $\langle CBP1 \rangle = c_0$,

Also integrating equation (18) :

$$w_{(k,0)} = w_{(k-1,0)} \; M_T - (M_T \, c_{(k,0)} - w_{(k-1,0)}) \exp(-\Delta t) \quad . \qquad \text{----(35)}$$

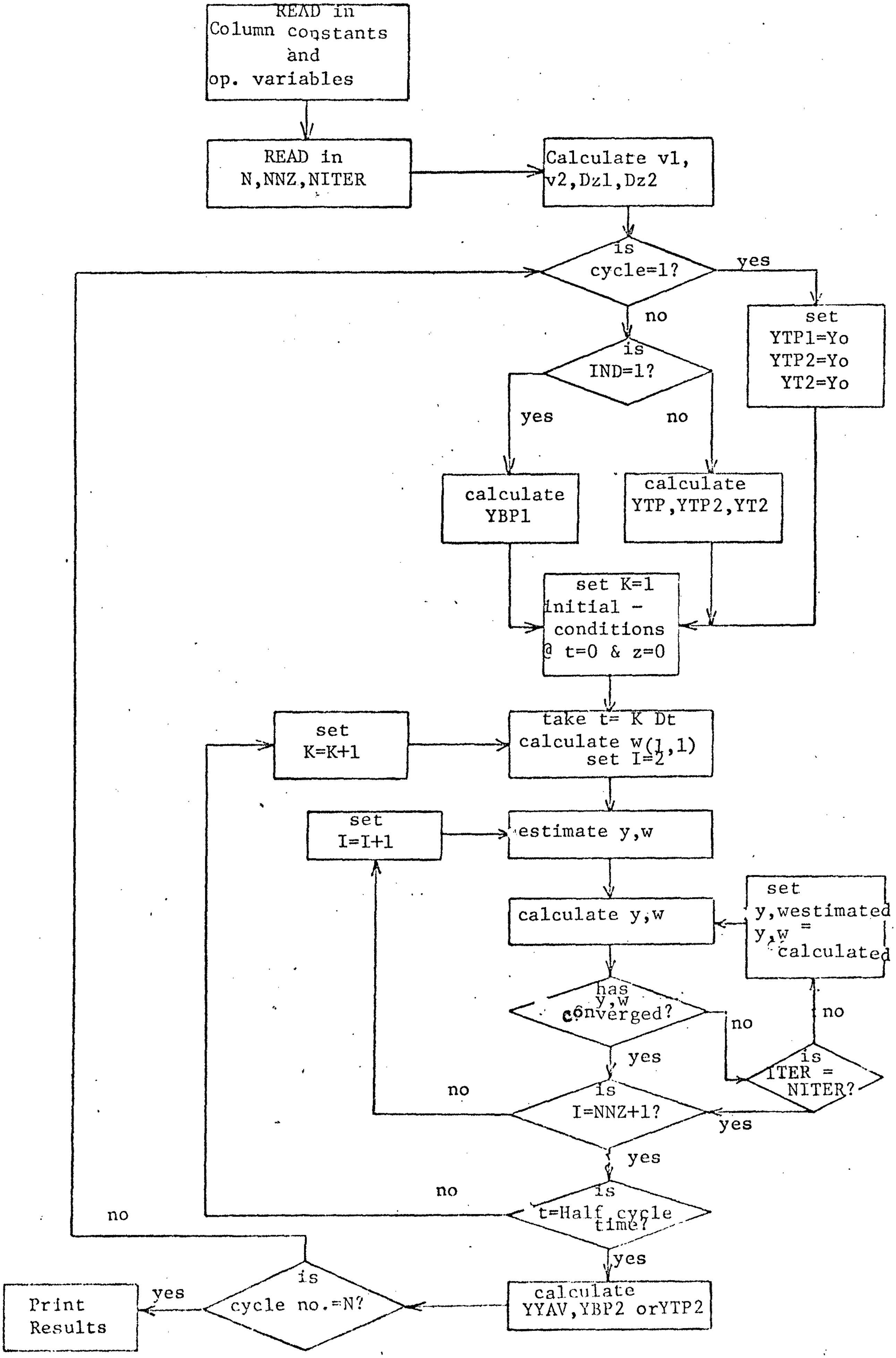


Figure 4: Block Diagram for Thermal Parametric Pumping

Where, $t = k\,\Delta t_1$,

For $n = 1$, $w_{(k-1,0)}$ = w values obtained at the end of $(n-1)^{th}$ cold half cycle.

(2) @ $t = 0$, $x \geqslant 0$

$$\left.\begin{array}{l} c_{(0,i)} \\ w_{(0,i)} \end{array}\right| = \text{ c , w values obtained at the end of } (n-1)^{th} \text{ cold half cycle.}$$

Using the method of characteristics concentration profiles are calculated for $t = \Delta t_1$; $2\,\Delta t_1$; $k\Delta t_1$ . . .

At the end of n^{th} high temperature half cycle :

$\langle CT1 \rangle$ = average of concentrations obtained at the end of column at $t = \Delta t_1$; $2\,\Delta t_1$; $k\Delta t_1$

STEP 2

For n^{th} downflow half cycle, by making material balance at the top reservoir :

$$\langle CTP2 \rangle_n = \frac{Q \langle CTP1 \rangle n + V_T \langle CTP2 \rangle n-1}{V_T + Q} \quad . \qquad \text{----(36)}$$

$$\langle CT2 \rangle = (\phi_T + \phi_B)\, c_0 + (1-\phi_T)\, \langle CTP2 \rangle_{n-1} \quad . \qquad \text{----(37)}$$

There is instantaneous temperature change in the column.

STEP 3

Column at the low temperature

$$v_2 = \frac{(1 + \phi_B)}{A \;\; TIME}\; Q \quad . \qquad \text{----(38)}$$

$$\Delta z2 = \Delta t2 = \frac{H}{v_2 \; NNZ} \quad . \qquad \text{----(39)}$$

This step is similar to the step 1. At the end of half cycle:

$\langle CBP2 \rangle$ = average of the concentration obtained at the end of $t = \Delta t2$; $2\ \Delta t2$; $k\Delta t\ 2$.

STEP 4

By material balance at the bottom reservoir

$$\langle CBP1 \rangle_{n+1} = \langle CBP2 \rangle_n \ Q + V_B \langle CBP1 \rangle_n \ . \qquad \text{----(40)}$$

During this step also, the solid and liquid phase concentrations stay at the value attained at the end of the n^{th} cold half cycle.

(F) CYCLIC OPERATION OF HEATLESS PARAMETRIC PUMPS

This technique uses two columns under operation. One column operates at high pressure and the other column operates at low pressure (Fig. 5). Before starting the cyclic operation, both columns are saturated with gas mixture by maintaining either both columns at the same pressure or both the columns at different pressures. In this work, both saturating conditions have been used. One complete cycle is divided into four steps as below: (See fig. 6)

STEP 1 High pressure feed flows through the column 1 , solute is adsorbed, resulting in a solute-lean top product. A portion of solute-lean product is purged to low pressure column 2. In column 2 , there is decrease in pressure, resulting in desorption of solute. Hence, solute-enriched bottom product is obtained at the end of column 2.

STEP 2 Column 2 is repressurized to high pressure (repressurization) while column 1 is brought to low pressure (blow-down). (Fig. 7)

STEP 3 Flow of feed is reversed from column 1 to column 2, now at high pressure.

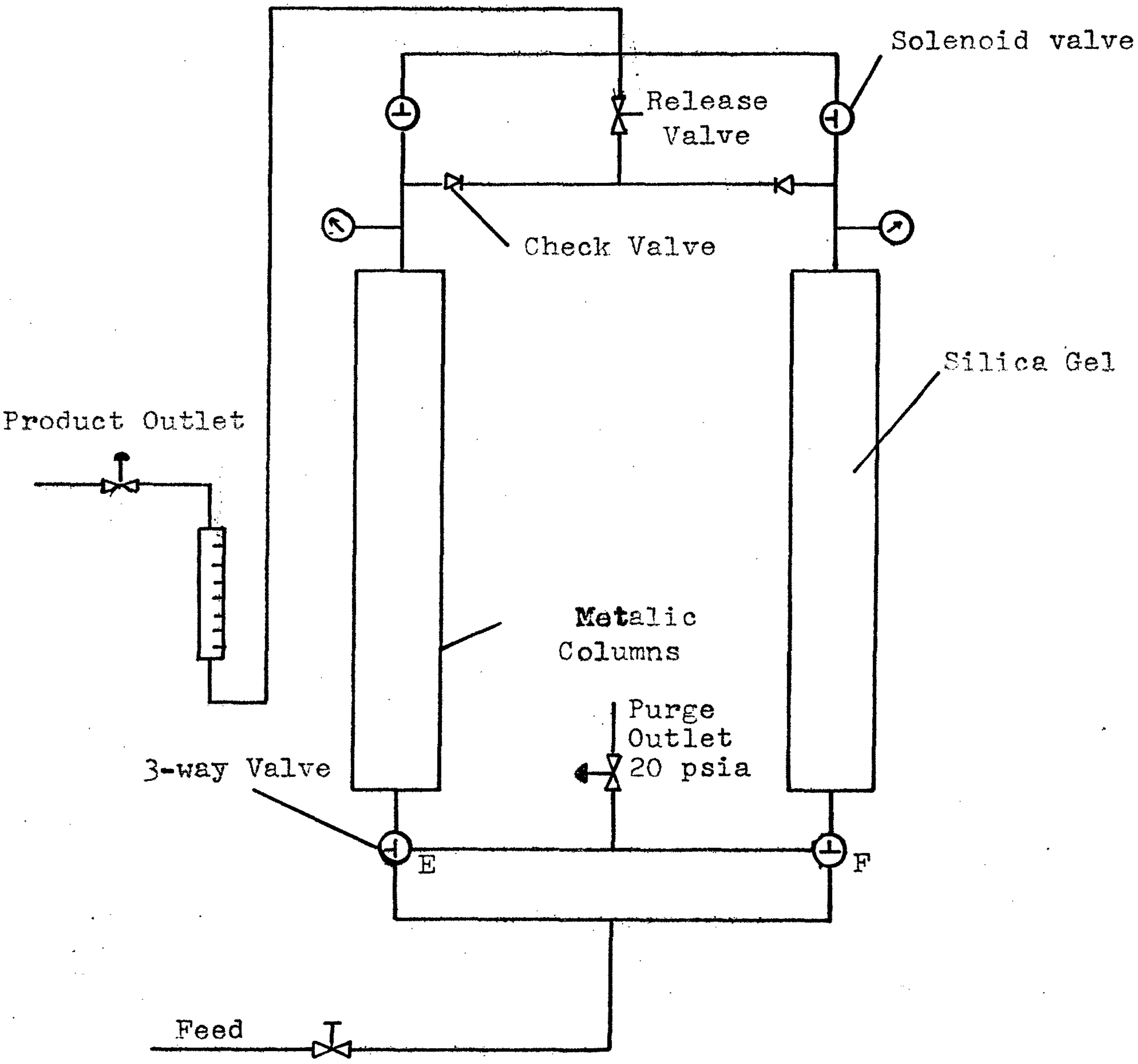


Figure 5

Schematic drawing of heatless Parametric Pump

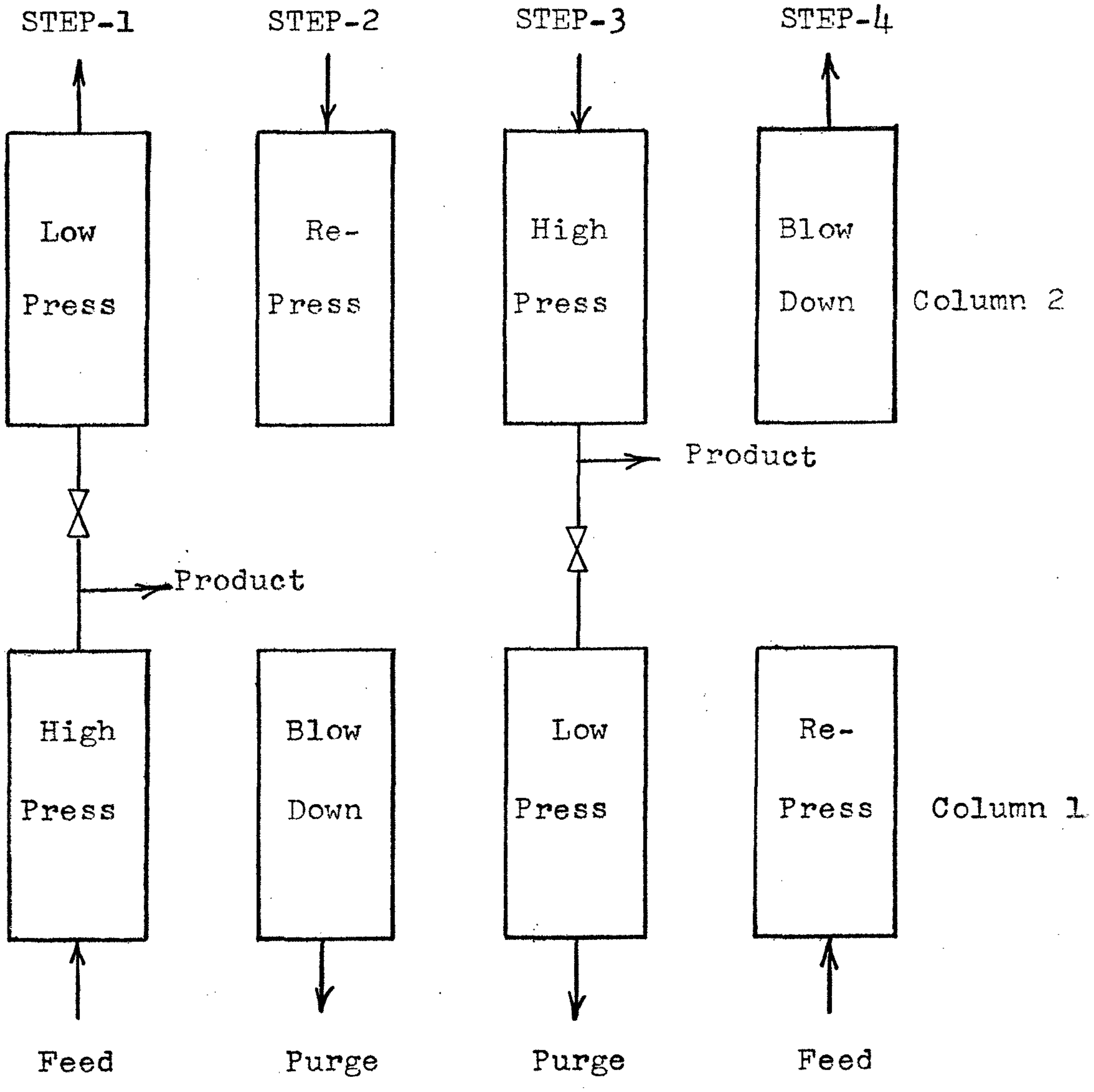


Figure 6

Stepwise Outline of Heatless Parametric Pumping

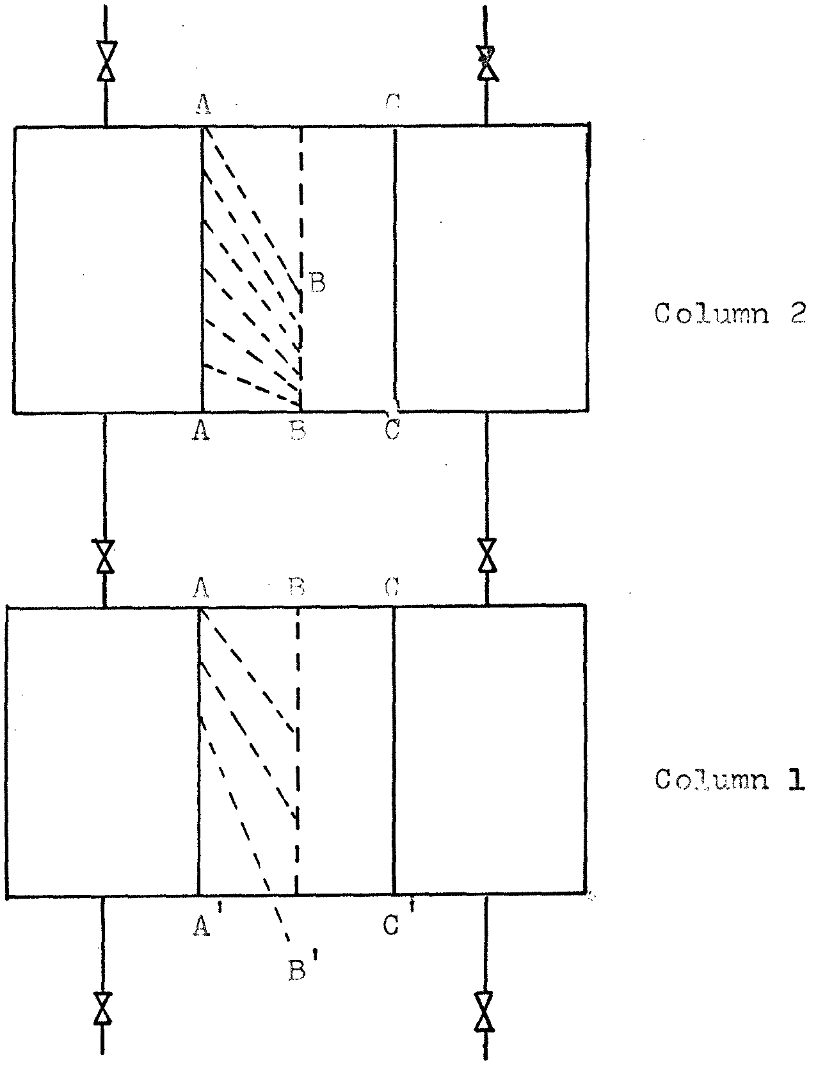


Figure 7

Repressurization and Depressurization of Columns

STEP 4 Column 1 is repressurized and column 2 is depressurized (Fig. 7) .

During steps 2 and 4, solid concentration is considered to be frozen while fluid concentration (in the bulk gas) changes according to the pressure difference. Also, in these steps , gas is fed at high pressure but no gas is removed from the pressurized column whereas gas is blown off from the low pressure column but no gas is fed into it. Steps 2 and 4 take place instantaneously.

(G) COMPUTER CALCULATION OF CYCLIC OPERATION (Fig. 8)

Let total number of intervals = NNZ

STEP 1 For high pressure column

$$\Delta z1 = \Delta t1 = \frac{H\ A}{NNZ\ Q} \quad . \qquad ----(41)$$

$$v_1 = \frac{Q}{A} \quad . \qquad ----(42)$$

For, n^{th} half cycle, initial conditions are :

(1) @ $z = 0$ $y_{(k,0)} = y_0$,

$w_{(k,0)} = f\ (w,y)$,

The solid phase concentration is calculated using Runge-Kutta method as below :

$$\frac{dw}{dt} = \lambda\ (\overset{*}{w} - w) \quad ,$$

Where, $$\overset{*}{w} = \frac{y_o\ P\ M_p}{R\ T} \quad ,$$

Now $$K_1 = (\overset{*}{w}_{(k,0)} - w_{(k-1,0)}) \ \Delta z1 \quad ,$$

$$w^{1}_{(k,0)} = w_{(k-1,0)} + K_1/2 \quad ,$$

$$K_2 = \lambda . (\overset{*}{w}_{(k,0)} - w^{1}_{(k,0)}) \quad \Delta z1 \quad ,$$

$$w^{2}_{(k,0)} = w_{(k-1,0)} + K_3/2 \quad ,$$

$$K_3 = \lambda . (\overset{*}{w}_{(k,0)} - w^{2}_{(k,0)}) \quad \Delta z1 \quad ,$$

$$w^{3}_{(k,0)} = w^{2}_{(k,0)} + K_3/2 \quad ,$$

$$K_4 = \lambda . (\overset{*}{w}_{(k,0)} - w^{3}_{(k,0)}) \quad \Delta z1 \quad ,$$

$$Dw = (K_1 + 2 K_2 + 2 K_3 + K_4)/6 \quad ,$$

$$w_{(k,0)} = w_{(k-1,0)} + Dw \quad .$$

For k = 1 , $w_{(k-1,0)}$ = w values obtained at the end of (n-1)th half cycle.

(2) @ t = 0 $y_{(0,i)}$, $w_{(0,i)}$ = y and w values obtained at the end of (n-1)th half cycle.

Using the method of characteristics, the concentration profile is calculated for t = Δt1 ; 2 Δt1 , k Δt1, until the half cycle time is complete. At the end of nth half cycle :

<YTP> = average of the concentrations obtained at the end of column during t = Δt1 , 2 Δt1, ...k Δt1.

For Low Pressure Column -

$$\Delta z2 = \Delta t2 = \frac{H . A}{NNZ . Q . Y} \quad . \qquad \text{----(43)}$$

$$v2 = \frac{Q . Y}{A} \quad . \qquad \text{----(44)}$$

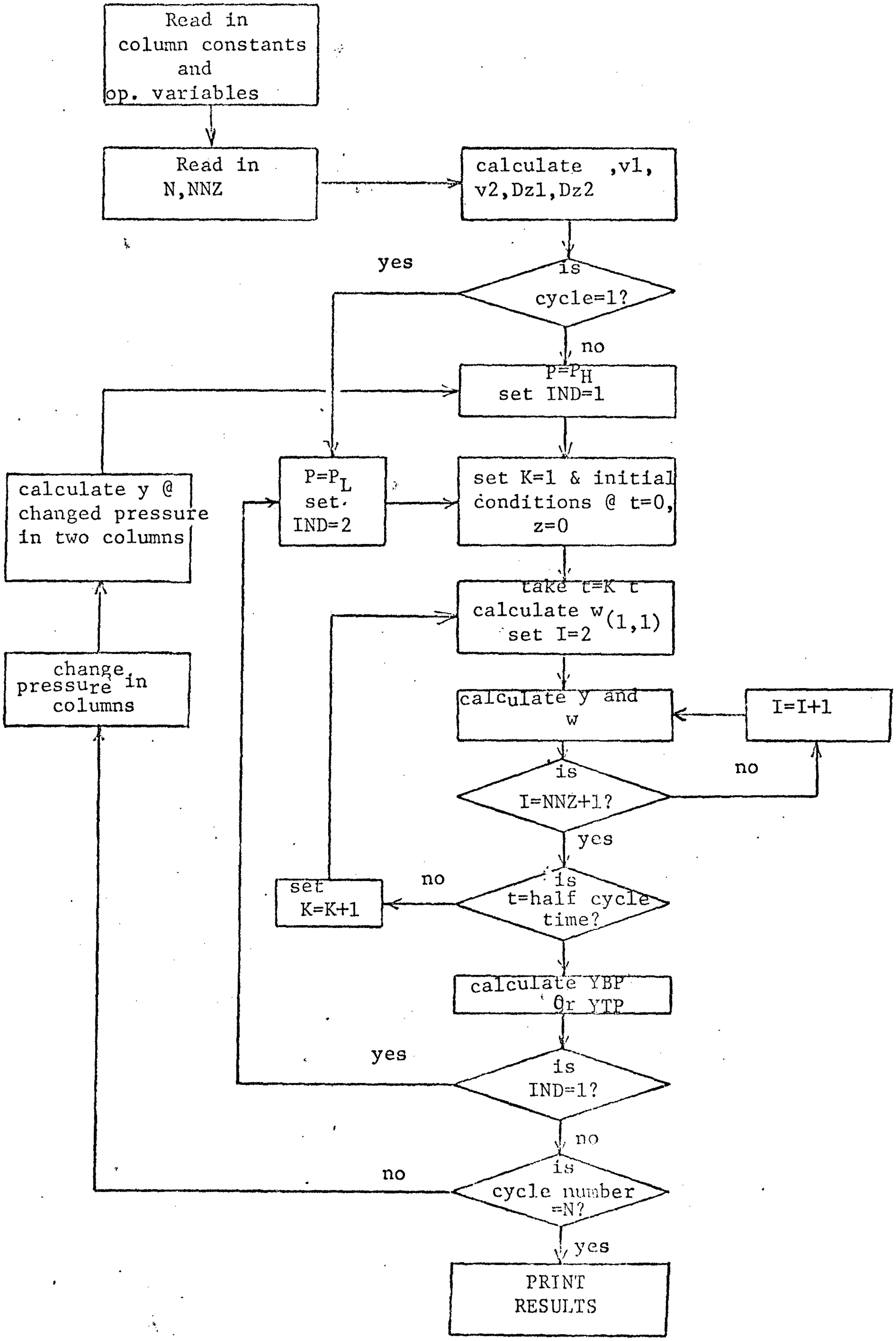


FIGURE 8 : Block Diagram for Heatless Parametric Pumping

Initial conditions :

(1) @ $z = 0$, $y_{(k,0)}$ = y values evaluated by interpolation of the values of $y_{(k,H)}$ obtained from high pressure column for n^{th} half cycle.

$w_{(k,0)}$ = w values calculated from Runge-Kutta method similar to the high pressure column calculation.

(2) @ $t = 0$

$y_{(0,i)}$, $w_{(0,i)}$ = y , w values obtained during $(n-1)^{th}$ half cycle.

Again using the method of characteristics, the concentration profiles are calculated. At the end of the half cycle :

<YBP> = average of the concentration obtained at the end of the column during $t = \Delta t2,\ 2\,\Delta t2,\ k\,\Delta t2$.

STEP 2 REPRESSURIZATION AND DEPRESSURIZATION OF COLUMNS

Before the start of $(n+1)^{th}$ half cycle , the column which was at low pressure during the n^{th} half cycle , is repressurized to high pressure. Also, the solid phase concentration remains frozen to the value attained at the end of the n^{th} half cycle, but, because of the change of pressure, the gas phase is compressed and is given by the simple ideal gas law :

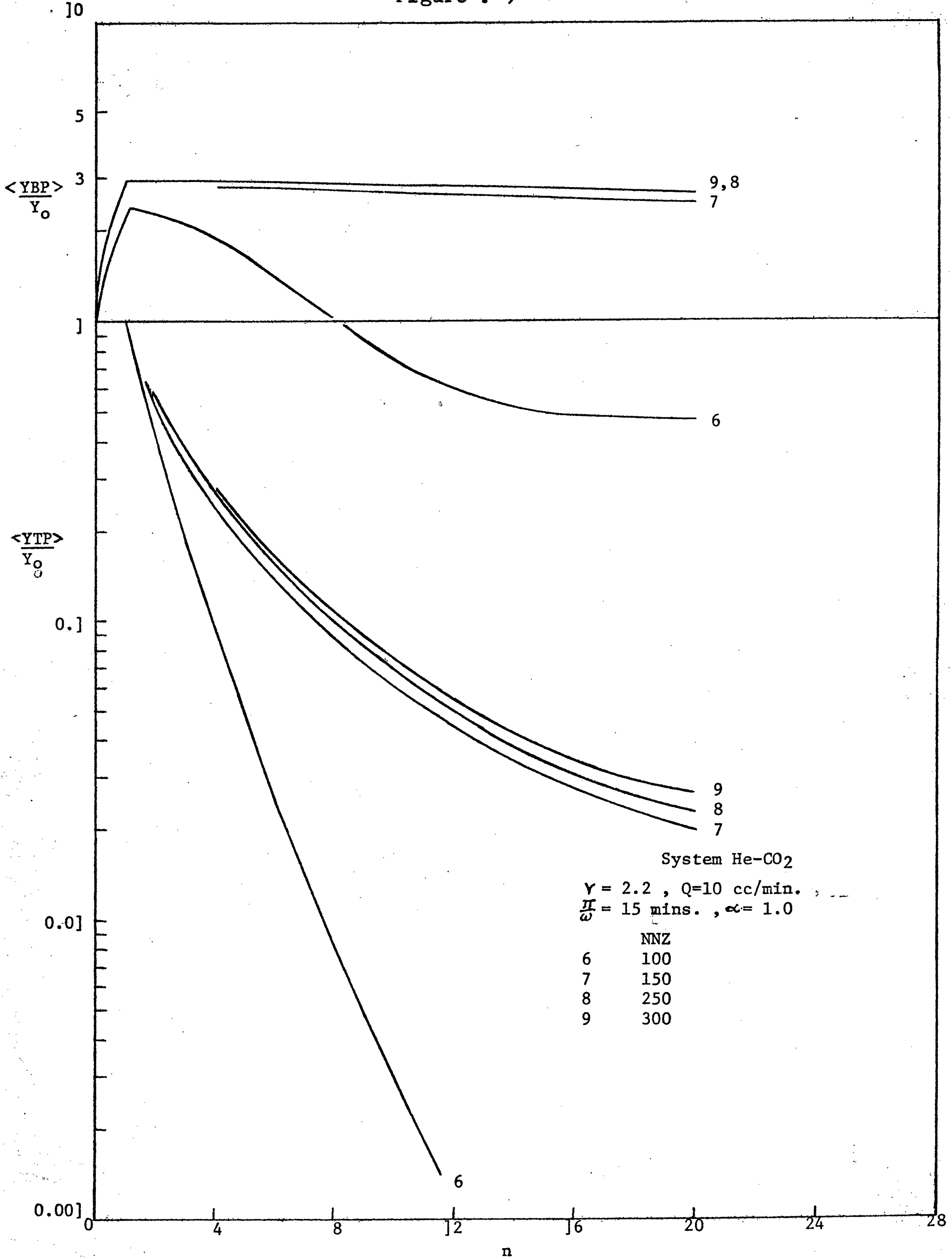
$$\ell_2 \; P_L = \ell_1 \; P_H \quad ,$$

$$\ell_1 = \ell_2 \; \frac{P_L}{P_H} \quad . \qquad \text{----(45)}$$

The void space formed by compression is filled by feed gas.(Fig. 7)

AA - position of the gas phase obtained at the end of the n^{th} cycle

Figure : 9


10
5
3
1
0.1
0.01
0.001
$\frac{\langle \underline{YBP} \rangle}{Y_o}$
$\frac{\langle \underline{YTP} \rangle}{Y_o}$
0
4
8
12
16
20
24
28
n
9,8
7
6
9
8
7
6
System He-CO_2
γ = 2.2 , Q=10 cc/min.
$\frac{\pi}{\omega}$ = 15 mins. , α = 1.0
NNZ
6 100
7 150
8 250
9 300

BB -position attained after the compression of gas phase.

CC - position of standard increments obtained by linear interpolation of position BB.

Similarly, the column which was at high pressure during the n^{th} half cycle is blown down to low pressure. Again the solid phase concentration remains frozen at the value obtained at the end of n^{th} half cycle, whereas fluid phase concentration is expanded according to the ideal gas law :

$$\ell_2 = \ell_1 \frac{P_H}{P_L} \quad . \qquad \text{----(46)}$$

In figure 7 :

AA' - position attained at the end of the n^{th} half cycle

BB' - position after compression

CC' - position obtained by linear interpolation of BB'

The calculations of steps 3 and 4 are similar to those of steps 1 and 2, respectively.

ADJUSTMENT OF OPTIMUM NUMBER OF INCREMENTS (NNZ)

In mathematical calculation, the selection of increments is important to achieve stability in concentration profiles. For the calculation of mass transfer coefficients in heatless parametric pumps, the following equation is used (Appendix - I)

$$\lambda = \alpha \left[\frac{D_P \, G}{\mu \, (1-\epsilon)} \right]^{-0.51} \frac{\left[\frac{\mu}{\rho D} \right]^{-2/3} G \, P}{M_g \, P \, \rho H \, \epsilon} \quad ,$$

Here, value of λ depends on the two constants α, β and on the operating conditions. The value of β has been selected equal to -0.51.

For the He-CO_2 system assume that $\alpha = 1.0$. Computer calculations are carried out for the concentration profiles taking NNZ= 100,150, 200,250. It was observed that NNZ $\geqslant$150 gives an almost stable concentration profile for top and bottom products (Fig. 9). Thus, for $\alpha = 1.0$, NNZ = 150 is the value to attain stability.

Similarly, for the He-C_3H_6 system :

$\alpha = 0.25$, NNZ = 150 for stability.

Other operating conditions are :

$\gamma = 2.2$, $Q = 10$ cc/min.

$\frac{\pi}{\omega} = 15$ mins., $y_0 = 1\%$ CO_2 or 1% C_3H_6 .

DISCUSSION OF RESULTS

In this work a mathematical model has been developed for the NaCl-H_2O system using a thermal parametric pump. Thirteen results have been mathematically calculated for different operating conditions and the effects of different operating conditions have been observed. In Table-1 different operating conditions for thirteen runs have been listed. A typical detailed display of concentration profiles is shown in Table-23 and Figure-10.

Both experimental and mathematical studies have been made for the separation of gaseous mixtures via a heatless parametric pump. Seventeen runs have been performed experimentally. Table-2 lists fifteen experimental runs with different systems and other operating conditions. Out of the fifteen runs listed, four runs are for the separation of the He-CO_2 mixture listed in Tables-4,5,6,7. Tables-4 and 5 give the calibration for peak height and pressure of CO_2 gas. Tables-6 and 7 present cyclic concentrations obtained after the each half cycle for CO_2 gas. In these tables concentration has been shown as the ratio of cyclic peak height and initial gas peak height.

It is shown in Appendix II that the peak height is proportional to y(concentration), so the peak height ratio is also the concentration ratio. Peak height ratio is plotted against half cycle time. Table-8 is calibration for He-C_3H_6 and Tables-9,10, 11,12 and 13 are cyclic concentrations for He-C_3H_6 separation. Table-14 is the calibration for ternary mixture He-CO_2-C_3H_6 and Tables 15 to 18 are for the cyclic separations. Tables-19 and 20 list degree of saturation of the bed with separation. Tables-21 and

22 list the operating conditions used in the mathematical models for two types of parametric pumps respectively. In Table-23, different operating conditions have been listed for the results calculated from the binary gas mathematical model. Table-24 presents a typical case in detail of the concentration profiles for the He-C_3H_6 mixture.

(A) THERMAL PARAMETRIC PUMPS -

Figure - 10 is the presentation of characteristics concentration front movement for the NaCl-H_2O system. It is obvious from the figure that the solute moves towards the upper end of the column with the change of cycle direction until the steady state is reached, finally, resulting in less solute at the bottom and more solute in the top product. Figures-11 and 12 show that the model developed predicts the separation of NaCl-H_2O and also compares the effect of different operating conditions on separation.

Figure-11 indicates the effect of ϕ_B with the ratio of bottom reservoir volume and the displacement with other conditions as- $\frac{\pi}{\omega}$ = 35 mins., c_0 = 0.1 M, $Q(\frac{\pi}{\omega})$ = 25 cc. It shows that with the decrease in ϕ_B from 0.16 to 0.04, fluid moves more from the bottom reservoir to the top reservoir through the column; this results in the increased mixing at the top reservoir and the better separation.

In separation, the rate of interphase mass transfer is dependent on the temperature, fluid velocity and cycle time. However, since velocity is inversely proportional to the cycle time for a given displacement, a study of cycle time alone includes implicitly the velocity effect. Figure-12 shows the top and bottom products concentration for different cycle time with ϕ_B = 0.04, $Q(\frac{\pi}{\omega})$= 25 cc.

and c_0=0.1 M. Increase in the cycle time from 25 mins. to 100 mins. results in better separation because more time is allowed for the transfer to occur between two phases.

An optimization study for the displacement volume is shown in figure-13. It is a plot of the steady state bottom product concentration vs. volumetric displacement for $\frac{\pi}{\omega}$=35 mins., ϕ_B=0.04, c_0=0.1M and gives the following important information:

For the above mentioned conditions the minimum concentration is 0.018M, for which the optimum value of displacement $Q(\frac{\pi}{\omega})$ is 5 cc. This curve is also helpful in determining the volumetric displacement required to obtain a desired bottom product concentration. For example, from figure-13 it can be shown that for obtaining 0.3 M bottom product ratio, the displacement $Q(\frac{\pi}{\omega})$ should be 26 cc, while all other operating conditions are fixed.

Experimental study for the NaCl-H_2O system has been done by Kim(25) and Rak(26).

(B) HEATLESS PARAMETRIC PUMPS

(i) Binary systems-

(a) Adjustment of 'α' value -

For the He-CO_2 system the concentration curve with α=1.0, β= -0.51 and NNZ=150 differs from the experimental results, figure-14. Therefore, different values of α have been tested to minimize the difference between the experimental and the computed results. A linear relation between α and NNZ has been used as shown below:

$$\frac{\alpha_1}{\alpha_2} = \frac{NNZ_1}{NNZ_2} = \text{constant} ,$$

if

$$\frac{\alpha_1}{\alpha_2} = \frac{NNZ_1}{NNZ_2} = 1.5 ,$$

and $\alpha_1 = 1.0$, $NNZ_1 = 150$,

then $\alpha_2 = 1.5$, $NNZ_2 = 225$.

This trial and error procedure is continued until two types of results are close; figure (14) shows the optimum value for the He-CO_2 system. Similarly, for the He-C_3H_6 system the optimum values of α and NNZ have been found. These values are tabulated as below ($\gamma = 2.2$, $\frac{\pi}{\omega} = 15$ mins. , $Q = 10.0$ cc/min.)

System	Optimum value of	
	α	NNZ
He-CO_2	4.0	600
He-C_3H_6	1.25	600

(b) Effect of different operating conditions -

The separation of binary gaseous mixtures He-CO_2 and He-C_3H_6 was observed experimentally, (Figures (17) and (19)). These two plots show clearly two curves for the bottom product. It is because both the columns were saturated at different pressures, i.e. , one column at 60 psia and the other at 20 psia initially. ($\gamma = 2.2$, $\frac{\pi}{\omega} = 15$ mins. and $Q = 10$ cc/min.). It is expected that these two curves will merge into one at steady state value. The same trend was observed with the computed results. Hence at this point it was decided that both the columns should be saturated at the same pressure, i.e. , at high initial pressure. Figures 19 and 20 are for the separation of He-C_3H_6 mixture with a new saturation pressure of 60 psia and the other operating conditions - $\gamma = 2.2$, $\frac{\pi}{\omega} = 15$ mins. and $Q = 10$ cc/min. These conditions result in only one curve for the bottom product.

Next, the effect of the purge ratio on the separation of He-C_3H_6 mixtures was studied experimentally. It was found that the decrease in the purge ratio or purge volume to the low pressure column increases separation of mixture while the other operating conditions are fixed at $\frac{\pi}{\omega} = 15$ mins., $y_o = 1\%$ C_3H_6 and $Q = 10$ cc/min. Also, for the same operating conditions, the mathematically calculated results are close to the experimental results. Hence the mathematical model is in agreement with the experimental results.

(ii) Ternary gas mixtures

Figures-22, 24 and 25 are for the experimental separation of gas mixture $He-CO_2-C_3H_6$ using a heatless parametric pump. These figures also represent the effect of different operating variables such as the purge ratio 'γ' and half cycle time $\frac{\pi}{\omega}$ on the separation. In figure - 23 it is observed that for the operating conditions $\gamma = 2.2$, $\frac{\pi}{\omega} = 15$ mins. and $Q = 10$ cc/min. after the 15th half cycle, both the top and the bottom product concentrations for CO_2 drops below the feed concentration. This indicates accumulation of incoming CO_2 in the bed. It is considered that this occurs because of the following reasons:

1. half cycle time is too large ,
2. there is some interaction during the absorption of the gases. This causes the CO_2 disappearance from both the top and the bottom products.

To justify the above reasons the bed was saturated with CO_2 and C_3H_6. Figure-23 is the saturation curve for CO_2 and C_3H_6 at 20 and 60 psia. From this figure for any gas,total amount absorbed is proportional to the area under the saturation curve. It was found that the net amount desorbed in changing the cycle from 60 psia to 20 psia is less for CO_2 than for C_3H_6. The numerical values are as given below:

Pressure	Amount adsorbed for	
psia	CO_2	C_3H_6
20	$\frac{2.084}{R\ T\rho_s}$	$\frac{3.605}{R\ T\rho_s}$
60	$\frac{4.200}{R\ T\rho_s}$	$\frac{11.98}{R\ T\rho_s}$

Net amount desorbed in changing the pressure from 60 psia to 20 psia, for $CO_2 = \frac{4.2 - 2.084}{R\ T\rho_s}$,

$$= \frac{2.116}{R\ T\rho_s} \text{ gm-moles /gm-solid} .$$

for, $C_3H_6 = \frac{11.98-3.605}{R\ T\rho_s}$,

$$= \frac{8.375}{R\ T\rho_s} \text{ gm-moles / gm-solid} .$$

Figure 23 shows less desorption of CO_2 than C_3H_6; hence, the half cycle time may affect the separation of CO_2 in a ternary system. Figures 24 and 25 ($\gamma = 1.0$ and 1.5 respectively and $\frac{\pi}{\omega} = 8$ mins., Q = 10 cc/min) support the reasoning for large half cycle time. Figures 24 and 25 also show the affect of purge ratio on the separation. As in the case of a binary mixture, a decrease in the purge ratio from 1.5 to 1.0 increases the separation.

The computed results based on the binary gas mixture model have been compared with the ternary experimental results. (Figures 22 and 25) The two results are quite close for the operating conditions Q= 10 cc/min, $\frac{\pi}{\omega} = 15$ mins., and $\gamma = 2.2$ (Figure 22). However, for run 13, the deviation between the calculated and experimental results are higher than expected. (Figure 25). Thus, the above comparision indicates that for ternary mixtures, the effect of interaction of gases on adsorption should be taken into account in the development of the mathematical model.

RECOMMENDATIONS

Further investigation in this field should be, determining the effect of different operating conditions such as feed flow rate, effect of half cycle time and purge ratio in more detail for both types of parametric pumps. For ternary or multicomponent system, a mathematical model can be developed similar to that for a binary system. In this mathematical model it would be important to consider the interaction of different gases in adsorption. Also, the experimental and mathematical studies of parametric pumping technique can be extended to the separation of different liquid and gaseous mixtures.

NOMENCLATURE

a - constant

A - cross sectional area of the column, cm^2

b - constant

c_0 - molal concentration of solute in feed, gmole/cc

$\overset{*}{c}$ - equilibrium molal concentration, gmoles/cc

CBP1 - bottom product concentration during upflow, gmole/cc

CTP1 - top product concentration during upflow, gmole/cc

CT1 - outlet concentration in upflow cycle, gmole/cc

CT2 - inlet concentration in downflow, gmole/cc

CTP2 - top product concentration during downflow, gmole/cc

CBP2 - bottom product concentration in downflow cycle, gmole/cc

D - diffusivity, cm^2/min.

D_P - average particle diameter for 12-28 mesh size,cm

G - gas mass flow rate, gm/cm^2/min.

H - height of the column, cm

j_D - j - factor for mass transfer , dimensionless

ℓ - length at any time, cm

M - molecular weight, gm/gmole

M_P - equilibrium coefficient for gas phase

M_T - equilibrium coefficient for liquid phase

NNZ - number of intervals

N - number of moles

P_C - critical pressure, atm.

Q - volumetric flow rate, cc/min.

$K_1, K_2, K_3, K_4, K_1', K_2', K_3', K_4'$ - constants in Runge-Kutta method

R - gas constant = 82.06 atm-cm^3/gmole/ K
t - time, min.
T - temperature, K
T_C - critical temperature, K
V - reservoir volume, cc
v, v_0 - velocity of fluid through the column, cm/min
w - solid phase concentration , gmole/gm of solid
x - linear distance, cm
y - mole fraction of solute, gmole/gmole
$z = x/v_0$, min
x - increment in x, cm
z - increment in z, min
t - increment in t, min
YTP - top product concentration, gmole/gmole
YBP - bottom product concentration, gmole/gmole

Greek letters-

β - ratio of reservoir volume to displcement, cc/cc

γ - purge ratio

ρ - density of bulk fluid, gmloe/cc

ρ_s - solid density, gm/cc

ϵ - voidage of bed

μ - viscosity, gm/ cm/ min

σ - collision diameter, cm

Ω - collision integral, dimensionless

λ - mass transfer coefficient for,heatless parametric pump, min^{-1}
for thermal parametric pump,
cm^3/gm of solid/min

Subscript-

$\langle\rangle$ - average

T - top product

B - bottom product

H - high pressure

L - low pressure

1 - hot cycle or upflow

2 - cold cycle or downflow

i, ℓ - z

j,k - time

n - cycle number

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APPENDICES

APPENDIX - I

Calculation of mass transfer coefficient for heatless parametric pumps

Othmer (13) has given an expression for the calculation of mass transfer coefficient as below -

$$j_D = \frac{P \quad \lambda}{G/M_g} \left[\frac{\mu}{\rho . D}\right]^{2/3} . \qquad ----(A)$$

where,

$$j_D = \alpha \left[\frac{D_P \quad G}{\mu \ (1-\epsilon)}\right]^{-0.51} . \qquad ----(B)$$

equations (A) and (B) are further simplified for 'λ' -

$$\lambda = \frac{\alpha \left[\frac{D_P . G}{\mu (1-\epsilon)}\right]^{-0.51} . \left[\frac{\mu}{\rho \ D}\right]^{-2/3} . G . P}{M_g \ P . \rho . H . \epsilon} \quad (\text{min}^{-1}) . \qquad ----(C)$$

Physical properties of gaseous mixture in the above equation have been considered as that of Helium only, because solute gas (CO_2 or C_3H_6) in the mixture is in very small amount (1 % only). Viscosity of Helium and diffusivity of of CO_2 and C_3H_6 in helium have been estimated using the expression given by Bird (3) .

- Calculation of Viscosity -

$$\mu = 2.6693 * 10^{-5} * \frac{M.T}{\sigma^2 \Omega_\mu} \qquad ----(D)$$

for Helium -

$\sigma = 2.576$, $\frac{\epsilon}{K} = 10.2$, $\Omega_\mu = 0.7005$

Also, $T = 25^\circ C = 298^\circ K$

$$\mu_{He} = \frac{2.6693 * 10^{-5} * 4 * 298}{(2.576)^2 * 0.7005} * 60$$

$$= 0.0018956$$

$$= 0.0019 \ gm / cm / min.$$

- Calculation of Diffusivity -

$$\frac{P \cdot D_{A-B}}{(P_{C-A} . P_{C-B})^{1/3} \cdot (T_{C-A} \cdot T_{C-B})^{5/12} \cdot \left[\frac{1}{M_A} + \frac{1}{M_B}\right]^{1/2}} = a \cdot \left[\frac{T}{\sqrt{T_{C-A} \cdot T_{C-B}}}\right]^b$$

	T_C (K)	P_C (atm.)	M
He	5.26	2.26	4.0
CO_2	304.2	72.9	44.0
C_3H_6	365.0	45.5	42.0

$a = 2.745 * 10^{-4}$, $b = 1.823$

(a) He - CO_2 system -

$$\left[P_{C-CO_2} \cdot P_{C-He}\right]^{1/3} = 5.39$$

$$\left[T_{C-CO_2} \cdot T_{C-He}\right]^{5/12} = 21.63$$

$$\sqrt{T_{C-CO_2} \cdot T_{C-He}} = 40.0$$

$$\frac{T}{\sqrt{T_{C-CO_2} \cdot T_{C-He}}} = 7.45$$

@ P = 4.0186 atm. (60 psia) -

$$D_{CO_2-He} = \frac{5.39 * 2.745 * 10^{-4} * 7.45^{1.823} * 21.63 * 0.5233}{4.0186}$$

or $D_{CO_2\text{-}He} = 0.1618 \text{ cm}^2/\text{sec.}$

$= 9.708 \text{ cm}^2/\text{min.}$

@ P = 2.721 atm. (40 psia)

$D_{CO_2\text{-}He} = 14.34 \text{ cm}^2/\text{min.}$

@ P = 1.36 atm. (20 psia)

$D_{CO_2\text{-}He} = 29.14 \text{ cm}^2/\text{min.}$

Similarly for He - C_3H_6 system -

@ P = 4.0186 atm. (60 psia)

$D_{C_3H_6\text{-}He} = 7.485 \text{ cm}^2/\text{min.}$

@ P = 2.721 atm. (40 psia)

$D_{C_3H_6\text{-}He} = 11.228 \text{ cm}^2/\text{min.}$

@ P = 1.36 atm. (20 psia)

$D_{C_3H_6\text{-}He} = 22.456 \text{ cm}^2/\text{min.}$

Apart from viscosity and diffusivity other properties are calculated as below -

Density -

$$\rho_H = \frac{P_H}{RT} \quad , \quad \rho_L = \frac{P_L}{RT}$$

Molecular weight -

He - CO_2 = 4.4

He - C_3H_6 = 4.4

Other parameters such as D_p, ϵ, H are given in table

APPENDIX II

Description of Apparatus -

The laboratory heatless continuous parametric pump, shown in fig. 5 , consists of two 3.175 cm * 3.0 m metallic columns packed with 12-28 mesh PA-400,grade-408 silica gel. Feed is introduced alternatively to both columns. Feed rate is controlled by two electric actuated three way solenoid valves, E and F. At the top end of each column one pressure gauge is installed to measure the pressure in the column. A part of the gas coming out from the column under feed is purged to other column via a solenoid valve and pressure relief valve. Two check valves are used to check the direction of flow. Top product from the column under feed is withdrawn through a rotameter. Flow rate of top and bottom products is maintained by measuring flow of a soap bubble in a burette. Concentration of top and bottom product is measured by a Model 810, reserch chromatograph.

Description of operation -

Initially two columns are saturated at the same pressure (high-pressure) or one column at high pressure and other column at low pressure. This is checked by measuring the product concentration. When product concentration is same as that of feed, the columns are considered to be saturated . After saturating the column, flow rate of top product and bottom product are adjusted to the operating values. After this, cyclic operation is started by actuating electronic solenoid valves.

During the half cycle, at different intervals concentration of top or bottom product is analyzed. This concentration is measured as peak height which is represented as concentration by following relation :

$$\frac{y}{y_0} = \frac{\text{Peak height for top or bottom product}}{\text{Peak height for feed}}$$

At the end of half cycle direction of feed is reversed by switch system. This procedure is repeated for each cycle. Peak height can be adjusted by changing attenuation of column. Peak height can also be changed to concentration using calibration curve and ideal gas law. For any sample peak height corresponding pressure can be obtained from calibration curve, this pressure can be changed to concentration units using ideal gas law -

$$c = \frac{n}{v} = \frac{P}{RT} \propto y$$

APPENDIX- III - A

Computer programme for thermal parametric pump

```
$JOB                RASTOGI
C ********************************************************************
C      ANIL RASTOGI ****ANIL RASTOGI ****ANIL RASTOGI *****
C      THIS PROGRAMME HAS BEEN MADE BY ANIL K. RASTOGI ,NEW JERSEY INSTITUTE
C      OF TECHNOLOGY
C      SUBSCRIPT 1  -FOR HOT CYCLE - UPFLOW
C      SUBSCRIPT  2  FOR COLD CYCLE  DOWNFLOW
C      X = SOLID CONCENTRATION
C      Y = LIQUID CONCENTRATION
C      N=NUMBER OF CYCLE
C      NNZ = NUMBER OF INTERVALS
C      NCASE = NUMBER OF CASES FO DIFFERNT VALUES OF PHI BOTTOM & PHI TOP
C      NTER = NUMBER OF ITERATIONS
C      AM & BM = CONSTANTS FOR EQUILIBRIUM COEFFICIENTS
C      H = HEIGHT OF THE COLUMN
C      TIME = HALF CYCLE TIME
C      YO = FEED CONCENTRATION
C      Q = RESERVOIR VOLUME
C      VT & VB = DEAD VOLUME FOR TOP & BOTTOM RESPECTIVELY
C      VOID = VOIDAGE OF THE PACKING
C      AK1 , AK2 , BK = CONSTANTS FOR MASS-TRANSFER COEFFICIENTS
C      DENS = DENSITY OF THE PACKING
C      ERR = ITERATION ERROR
C      A = CROSS-SECTIONAL AREA OF THE COLUMN
C      PHOT = PHI TOP
C      PHOB = PHI BOTTOM
C      IND = NUMBER TO CHARACTERIZE THE DIRECTION OF FLOW  UP OR DOWN
C      M= NUMBER OF ANY CYCLE , M(MAXIMUM) = N
C      V1 & V2 = FLUID VELOCITY THROUGH THE COLUMN
C      DT1 & DT2 = INCREMENT FOR TIME
C      YT1 = COLUMN TOP CONCENTRATION FOR HOT CYCLE
C      YTP1 = TOP PRODUCT CONCENTRATION FOR UPFLOW
C      YTP22 = CONCENTRATION OF TOP DEAD VOLUME
C      YTP2 = TOP PRODUCT CONCENTRATION
C      YT2 = INLET COLUMN CONCENTRATION
C      YBP22 = CONCENTRATION OF BOTTOM DEAD VOLUME
C      YBP2 = BOTTOM PRODUCT CONCENTRATION FOR DOWNFLOW
C      YBP1 = COLUMN INLET CONCENTRATION FOR HOT CYCLE-UPFLOW
C      XT = INITIAL SOLID CONCENTRATION AT THE COLUMN INLET
C      XXS & YYS = ESTIMATED VALUES AT ANY POINT
C      NTR = NUMBER OF ITERATIONS USED
C      K = NUMBER OF INCREMENT TAKEN HORIZONTALLY
C      TT = TIME AT ANY INCREMENT,TT(MAXIMUM) = TIME
C      X2 & Y2 = INITIAL SOLID & LIQUID CONCENTRATION ALONG HEIGHT OF THE COLUMN
C      XX & YY = SOLID & LIQUID CONCENTRATION ALONG HEIGHT OF THE COLUMN
C              FOR ANY INCREMENT TAKEN HORIZONTALLY
C      XX2 & YY2 = INITIALSOLID & LIQUID CONCENTRATION ALONG THE HEIGHT
C      OF THE COLUMN    FOR  SUBROUTINE
C      YHIS PROGRAMME CALCULATES CONCENTRATION PROFILE FOR THERMAL PARAMETRIC
C      PUMP USING MODIFIED ITERATIVE EULERS METHOD
C ********************************************************************
C      MAIN PROGRAMME
C ********************************************************************
       DIMENSION PHOT(10),PHOB(10),X2(100),YTP2(100),Y2(100),YBP2(100)
      1,XX2(100),YY2(100),XX(100),YY(100),XT(100),XXS(100),YYS(100)
      2,NTR(100)
       READ 10,N,NNZ,NCASE,NITER
 10    FORMAT(4I10)
```

```
      READ 16,AM,BM
   16 FORMAT(4E20.5)
      READ 15,H,TIME,YO,Q,VT,VB,TEMP1,TEMP2,VOID,AK2,BK,AK1,DENS,ERR,A
   15 FORMAT( 8F10.4)
      READ 20,(PHOT(I),PHOB(I),I=1,NCASE)
   20 FORMAT(2F10.4)
      DO 600 I=1,NCASE
      V1=(1.-PHOB(I))*Q/(A*VOID*TIME)
      V2=(1.+PHOB(I))*Q/(A*VOID*TIME)
      DT1=H/(NNZ*V1)
      DT2=H/(NNZ*V2)
      NZ=NNZ+1
      YT1=YO
      DO 30 J=1,NZ
      Y2(J)=YO
   30 X2(J)=YO*(AM-BM*TEMP1)
      M=1
      IF(M-1)31,31,32
   31 YTP22=YO
      GO TO 33
   32 YTP22=YTP2(M-1)
   33 YTP1=((PHOT(I)+PHOB(I))*YO+(1.-PHOB(I))*YT1)/(1.+PHOT(I))
      IND=2
      YTP2(M)=(Q*YTP1+VT*YTP22)/(VT+Q)
      YT2=((PHOT(I)+PHOB(I))*YO+(1.-PHOT(I))*YTP2(M))/(1.+PHOB(I))
      YIN=YT2
C
      CALL XYCAL(VOID,DENS,AK1,AK2,BK,AM,BM,TEMP1,TEMP2,V1,V2,IND,DT1,
     1DT2,NITER,X2,Y2,YIN,TIME,NZ,XX,YY,YB,XX2,YY2,M,ERR)
      YBP2(M)=YB
      IF(M-N)50,500,500
   50 IF(M-1)51,51,52
   51 YBP22=YO
      GO TO 53
   52 YBP22=YBPI
   53 YBP1=(Q*YBP2(M)+VB*YBP22)/(Q+VB)
      M=M+1
      YIN=YBPI
      DO 60 L=1,NZ
      LL=L-1
      X2(L)=XX(NZ-LL)
   60 Y2(L)=YY(NZ-LL)
      IND=1
C
      CALL XYCAL(VOID,DENS,AKI,AK2,BK,AM,BM,TEMP1,TEMP2,V1,V2,IND,DT1,
     1DT2,NITER,X2,Y2,YIN,TIME,NZ,XX,YY,YT1,XX2,YY2,M,ERR)
      DO 70 L=1,NZ
      LL=L-I
      X2(L)=XX(NZ-LL)
   70 Y2(L)=YY(NZ-LL)
      GO TO 32
  500 PRINT 510,(M,YTP2(M),YBP2(M),M=1,N)
  510 FORMAT('-',18X,'M',12X,'YTP2',16X,'YBP2'//(10X,I10,2E20.5))
  600 CONTINUE
      STOP
      END
C
C
```

```
      SUBROUTINE  XYCAL(VOID,DENS,AK1,AK2,BK,AM,BM,TEMP1,TEMP2,V1,V2,
     1IND,DT1,DT2,NITER,X2,Y2,YIN,TIME,NZ,XX,YY,YYAV,XX2,YY2,M,ERR)
C ******************************************************************
C     THIS SUBROUTINE USES TRIAL AND ERROR METHOD FOR THE CALCULATION OF
C     LIQUID AND SOLID PHASE CONCENTRATIONS
C ******************************************************************
C
      DIMENSION X2(100),Y2(100),XX(100),YY(100),XT(100),YYS(100),XXS(100
     1),XX2(100),YY2(100),NTR(100)
      SUM=0
      IF((-1)**IND)20,10,10
10    CK=AK2*V2**BK
      CM=AM-BM*TEMP2
      DT=DT2
      T=TEMP2
      GO TO 30
20    CK=AK1*V1**BK
      CM=AM-BM*TEMP1
      DT=DT1
      T=TEMP1
30    CNST=-(1.-VOID)*DENS*CK/VOID
      XT(1)=X2(1)
      DO 22 L=1,NZ
      XX2(L)=X2(L)
22    YY2(L)=Y2(L)
      K=1
155   CNK=K
      TT=DT*CNK
      YY(1)=YIN
      XT(K+1)=CM*YY(1)-(CM*YIN-XT(1))*EXP(-CK*TT/CM)
      XX(1)=XT(K+1)
      I=2
C
85    ITER=1
      NTR(1)=1
      YYS(I)=YY(I-1)+CNST*DT*(YY(I-1)-XX(I-1)/CM)
      XXS(I)=XX2(I)+CK*DT*(YY2(I)-XX2(I)/CM)
100   YY(I)=YY(I-1)+(DT/2.)*CNST*(YYS(I)-XXS(I)/CM+YY(I-1)-XX(I-1)/CM)
      XX(I)=XX2(I)+(CK*DT/2.)*(YYS(I)-XXS(I)/CM+YY2(I)-XX2(I)/CM)
      DEVY=(YY(I)-YYS(I))/YYS(I)
      IF(ABS(DEVY)-ERR)50,50,60
50    DEVX=(XX(I)-XXS(I))/XXS(I)
      IF(ABS(DEVX)-ERR)70,70,60
60    IF(ITER-NITER)80,70,70
80    YYS(I)=YY(I)
      XXS(I)=XX(I)
      ITER=ITER+1
      GO TO 100
70    NTR(I)=ITER
      IF(I-NZ)81,90,90
81    I=I+1
      GO TO 85
C
90    SUM=SUM+YY(NZ)
      IF(TT-TIME)150,200,200
150   DO 151 L=1,NZ
      YY2(L)=YY(L)
151   XX2(L)=XX(L)
```

```
              K=K+1
              GO TO 155
      200     TOTK=K
              YYAV=SUM/TOTK
              PRINT 525
      525     FORMAT('-')
              PRINT 95,M,IND,TT
      95      FORMAT('0',18X,'M',18X,'IND',15X,'TT'/(2I20,F20.3))
              PRINT 98
      98      FORMAT('-',18X,'I',12X,'YY',20X,'XX',23X,'NTR')
              DO 97 I=1,NZ,1
      97      PRINT 96,I,YY(I),XX(I),NTR(I)
      96      FORMAT(I20,2F20.5,I20)
              PRINT 210,YYAV
      210     FORMAT('-',20X,'YYAV'/10X,E20.5)
              RETURN
              END
      C

      $ENTRY
```

```
                   M                  IND               TT
                   1                    2           37.067


                   I            YY                      XX                       NTR
                   1       0.10000E-03             0.16384E-03                    1
                   2       0.96375E-04             0.15780E-03                    3
                   3       0.92913E-04             0.15264E-03                    3
                   4       0.89685E-04             0.14826E-03                    3
                   5       0.86734E-04             0.14457E-03                    3
                   6       0.84075E-04             0.14148E-03                    3
                   7       0.81710E-04             0.13889E-03                    3
                   8       0.79627E-04             0.13674E-03                    3
                   9       0.77609E-04             0.13496E-03                    3
                  10       0.76234E-04             0.13348E-03                    3
                  11       0.74879E-04             0.13226E-03                    3
                  12       0.73719E-04             0.13125E-03                    3
                  13       0.72731E-04             0.13043E-03                    3
                  14       0.71893E-04             0.12975E-03                    3
                  15       0.71187E-04             0.12920E-03                    3
                  16       0.70591E-04             0.12874E-03                    2
                  17       0.70093E-04             0.12837E-03                    2
                  18       0.69676E-04             0.12807E-03                    2
                  19       0.69329E-04             0.12783E-03                    2
                  20       0.69041E-04             0.12763E-03                    2
                  21       0.68803E-04             0.12747E-03                    2
                  22       0.68606E-04             0.12734E-03                    2
                  23       0.68443E-04             0.12723E-03                    2
                  24       0.68309E-04             0.12715E-03                    2
                  25       0.68199E-04             0.12708E-03                    2
                  26       0.68109E-04             0.12702E-03                    2
                  27       0.68035E-04             0.12698E-03                    2
                  28       0.67976E-04             0.12694E-03                    1
```

APPENDIX - III - B

Computer programme for heatless parametric pump

```
$JOB               RASTOGI
C ******************************************************************
C ***ANIL RASTOGI ***ANIL RASTOGI ***ANIL RASTOGI *******
C      THIS PROGRAMME IS MADE BY ANIL K. RASTOGI , NEW JERSEY INSTITUTE OF
C      TECHNOLOGY
C      THIS PROGRAMME IS FOR THE CALCULATION OF CONCENTRATION PROFILE
C      FOR THE HEATLESS PARAMETRIC PUMPING , USING RUNGE KUTTA METHOD
C      NOMENCLATURE FOR THE PROGRAMME
C      SUBSCRIPT 1-FOR  HIGH PRESSURE COLUMN
C      SUBSCRIPT 2 - FOR LOW PRESSURE COLUMN
C      N - NUMBER OF CYCLES
C      NNZ - NUMBER OF HEIGHT INTERVALS
C      NCASE - NUMBER OF CASES FOR DIFFERENT PURGE RATIO
C      H - HEIGHT OF COLUMN
C      TEMP - OPERATING OF COLUMN
C      TIME - HALF CYCLE TIME
C      VOID - VOIDAGE OF THE BED
C      A - CROSS SECTIONAL AREA OF THE COLUMN
C      Q - VOLUMETRIC FLOW RATE TO THE COLUMN
C      YO - INITIAL CONCENTRATION OF THE FEED
C      PH- HIGH PRESSURE , PL - LOW PRESSURE
C      PURG(I) - PURGE RATIO
C      M - CYCLE NUMBER AT ANY TIME
C      R - GAS CONSTANT
C      DENS - DENSITY OF SOLID
C      AK - EQUILIBRIUM CONSTANT
C      DP - PACKING PARTICLE DIAMETER
C      VISC - VISCOSITY OF GAS (HELIUM )
C      DIFFH,DIFFL - DIFFUSIVITY AT HIGH PRESSURE AND LOW PRESSURE
C      ALPHA , BETA - CONSTANTS FOR CALCULATION OF MASS-TRANSFER COEFFICIENTS
C      AMAV - AVERAGE MOLECULAR WEIGHT OF THE GAS
C      DH , DL - DENSITY OF GAS AT HIGH AND LOW PRESSURE RESPECTIVELY
C      VO1 , VO2 - VELOCITY FOR HIGH AND LOW PRESSURE COLUMNS
C      DZ1 , DZ2 -INCREMENTS IN Z FOR HIGH AND LOW PRESSURE COLUMNS
C      DT - LINEAR INCREMENT IN HEIGHT
C      Y - GAS PHASE CONCENTRATION , W - SOLID PHASE CONCENTRATION
C      YY , WW - GAS AND SOLID PHASE CONCENTARATION OBTAINED AT THE END
C      OF HALF CYCLE
C       YYT - COLUMN INLET CONCENTRATION
C      YP - PRODUCT CONCENTRATION
C      CKG - MASS TRANSFER COEFFICIENT
C ******************************************************************
C      MAIN PROGRAMME
C ******************************************************************
       DIMENSION YMH(50),YML(50)
       DIMENSION PURG(10),W1(800),Y1(800),W2(800),Y2(800),YIN(800),WIN(80
      10)
       DIMENSION YTT(800),YYT(800)
       DIMENSION YP1(40),YP2(40),YTPR(40),YBPR(40)
       DIMENSION ZX(800),YY(800),WW(800),YN(800)
       READ 1,N,NNZ,NCASE
       READ 2,R,TEMP
       READ 3,H,TIME,VOID,A,ERR,YO,DENS
       READ 4,Q,PH,PL
       READ 6,(PURG(I),I=1,NCASE)
       READ 5,AK
       READ 7,DP,VISC,ALPHA,BETA,AMAV
 7     FORMAT(8F10.5)
```

```
5          FORMAT(F20.10)
2          FORMAT(3F10.4)
1          FORMAT(5I10)
3          FORMAT(8F10.4)
2020        FORMAT('1')
11         FORMAT(///)
           PRINT 2020
6          FORMAT(F10.4)
4          FORMAT(3F10.4)
           PRINT 3030
3030       FORMAT(9X,'N',8X,'NNZ',5X,'NCASE'//)
           PRINT 1,N,NNZ,NCASE
           PRINT 11
           PRINT 4040
4040       FORMAT( 5X,'R', 5X,'TEMP'//)
           PRINT 2,R,TEMP
           PRINT 11
           PRINT 5050
5050       FORMAT(5X,'H',7X,'TIME',7X,'VOID',9X,'A',8X,'ERR',8X,'YO',6X,
          1'DENS'//)
           PRINT 3,H,TIME,VOID,A,ERR,YO,DENS
            PRINT 11
           PRINT 6060,AK
6060       FORMAT('-',10X,'AK = ',F20.10)
           PRINT 11
           PRINT 7070
7070        FORMAT(5X,'Q',8X, 'PH',9X,'PL'//)
           PRINT 4,Q,PH,PL
           PRINT 11
            PRINT 8080
8080       FORMAT(2X,'PURGE RATIO'//)
           PRINT6,(PURG(I),I=1,NCASE)
           DH=PH/(R*TEMP)
           DL=PL/(R*TEMP)
           PRINT 6091
6091       FORMAT('-',15X,'DH',15X,'DL')
           PRINT 8085,DH,DL
8085       FORMAT('-',2E20.5)
           PRINT 9002
9002       FORMAT('-',4X,'DP',7X,'VISC',7X,'DIFF',7X,'ALPHA',7X,'BETA',7X,'AM
          1AV'///)
           PRINT 7,DP,VISC,DIFF,ALPHA,BETA,AMAV
           YMH(1)=YO
           DO 600II=1,NCASE
           DT=H/NNZ
           VO1=Q/(A*VOID)
           VO2=Q*PURG(II)/(A*VOID)
           DZ1=H/(NNZ*VO1)
           DZ2=H/(NNZ*VO2)
           NNT1=TIME/DZ1
           PRINT 8086
8086       FORMAT('-',15X,'DZ1',15X,'DZ2',10X,'NNT1',15X,'VO1',15X,'VO2')
           PRINT 6090,DZ1,DZ2,NNT1,VO1,VO2
6090        FORMAT('-',2E20.5,I10,2E20.5)
           GPH=Q*DH
           GPL=Q*DL*PURG(II)
           DIFFH=7.488
           DIFFL=22.476
```

```
      CKGH=CMASC(DP,VISC,DH,GPH,ALPHA,BETA,VOID,AMAV,H,A,DIFFH)
      CKGL=CMASC(DP,VISC,DL,GPL,ALPHA,BETA,VOID,AMAV,H,A,DIFFL)
      PRINT 9001,GPH,GPL,CKGH,CKGL
 9001 FORMAT('-','GPH=',E12.5,10X,'GPL=',E12.5,10X,'CKGH=',E12.5,10X,'CK
     1GL=',E12.5///)
      NT1=NNT1+2
      NNT2=TIME/DZ2
      NT2=NNT2+2
      NZ=NNZ+1
      M=1
      DO 33 J=1,NZ
      AA=J-1
      ZX(J)=DT*AA
      Y1(J)=Y0
      W1(J)=AK*PH*Y1(J)/(R*TEMP)
      YY(J)=Y0
      WW(J)=W1(J)
      Y2(J)=Y0
   33 W2(J)=AK*PH*Y2(J)/(R*TEMP)
      YP1(1)=Y0
      NN=NT1
      DO 70 J=1,NT1
   70 YYT (J)=Y0
      GO TO 71
    8 IND=1
      CALL CNEW(PH,PL,NNZ,H,IND,Y0,Y2,YN,NZ,ZX)
      DO 20 K=1,NZ
      KK=K-1
      YIN(K)=YN(NZ-KK)
   20 WIN(K)=W2(NZ-KK)
      DO 34 J=1,NT1
   34 YTT (J)=Y0
      CALL XYCAL(VOID,TIME,DENS,PH,DH,YIN,WIN,VO1,DZ1,YTT ,M,IND,NTT,YY,
     1WW,YYAV1,YYT ,NZ,R,TEMP,CKGH,AK,H,YEND)
      YMH(M)=YEND
      YP1(M)=YYAV1
      NN=NTT+1
   71 CALL TOPCAL(NN,NT2,DZ1,DZ2,YYT,YTT )
      IND=2
      DO 99J=1,NZ
      JJ=J-1
   99 Y2(J)=Y1(NZ-JJ)
      CALL CNEW(PH,PL,NNZ,H,IND,Y0,Y2,YN,NZ,ZX)
      DO 97 K=1,NZ
      KK=K-1
      YIN(K)=YN(K)
   97 WIN(K)=W1(NZ-KK)
      DO 66L=1,NZ
      Y1(L)=YY(L)
   66 W1(L)=WW(L)
      CALL XYCAL(VOID,TIME,DENS,PL,DL,YIN,WIN,VO2,DZ2,YTT ,M,IND,NTT,Y2,
     1W2,YYAV2,YYT ,NZ,R,TEMP,CKGL,AK,H,YEND)
      YML(M)=YEND
      YP2(M)=YYAV2
      IF (M.EQ.N)GO TO 104
      M=M+1
      GO TO  8
  600 CONTINUE
```

```
 333  FORMAT(I5,10X,2(E20.5,10X),2E20.5)
 104  PRINT 105
 105  FORMAT('-',3X,'N',21X,'<YTP>',24X,'<YBP>',24X,'YPT/YO',14X,'YBP/YO
     1'//)
      DO 101 J=1,N
      YTPR(J)=YP1(J)/YO
      YBPR(J)=YP2(J)/YO
 101  PRINT 333,J,YP1(J),YP2(J),YTPR(J),YBPR(J)
      PRINT 446
 446  FORMAT('1',15X,'MINIMUM AND MAXIMUM CONCENTRATION AT THE END OF
     1HALF CYCLE'///)
      PRINT 447
 447  FORMAT('-',12X,'YMIN',16X,'YMAX'///)
 445  FORMAT(2E20.5)
      DO 444 JJ=1,N
 444  PRINT 445,YMH(JJ),YML(JJ)
      STOP
      END

      FUNCTION CMASC(DP,VISC,DS,Q,ALPHA,BETA,VOID,AMAV,H,A,DIFF)
C *******************************************************************
C     THIS SUBFUNCTION CALCULATES MASS TRANSFER COEFFICIENT
C *******************************************************************
      BF=(VISC/(DS*DIFF*AMAV))**(2./3.)
      AJD=ALPHA*((Q*DP*AMAV/(VISC*(1.-VOID)*A*VOID))**(BETA))
      CMASC=AJD*Q/(BF*H*DS*A*VOID)
      RETURN
      END
C

      FUNCTION RK(WINE,WI,CKG,DZ)
C *******************************************************************
C     RUNGE - KUTTA METHOD FOR THE CALCULATION OF SOLID PHASE CONCENTRATION
C     SOLID PHASE EQUILIBRIUM CONCENTRATION HAS BEEN TAKEN CONSTANT
C *******************************************************************
      AK1=CKG*(WINE-WI)*DZ
      W=WI+AK1/2.
      AK2=CKG*(WINE-W )*DZ
      W=WI+AK2/2.
      AK3=CKG*(WINE-W )*DZ
      W=WI+AK3
      AK4=CKG*(WINE-W )*DZ
      DW=(AK1+2.*AK2+2.*AK3+AK4)/6.
      RK=WI+DW
      RETURN
      END
C

      SUBROUTINE CNEW(PH,PL,NNZ,H,IND,YO,Y,YN,NP,DHX)
C *******************************************************************
C     THIS SUBROUTINE IS FOR DEPRESSURIZATION AND REPRESSURIZATION STEP
C     THIS IS BASED ON IDEAL GAS LAW P1*V1 = P2*V2
C *******************************************************************
      DIMENSION Y(800),YN(800),DIST(800),DHX(800)
      DIST(1)=0.0
```

```
      NZ=NNZ+1
      DO 40 I=2,NP
      IF((-1)**IND.LT.0.0)GO TO 29
      DIST(I)=DHX(I)*PH/PL
      GO TO 40
   29 DIST(I)=DHX(I)*PL/PH
   40 CONTINUE
      A=10.**(-10.)
      YN(1)=Y(1)
      DO 24 J=2,NZ
      DO 25 M=2,NP
      IF (Y(J).LT.A)GO TO 10
      GO TO 18
   10 PRINT15,J,Y(J)
   15 FORMAT('-','Y(',I2,')=',5X,E20.5)
   18 IF(DHX(J)-DIST(M))26,26,22
   22 IF(M.EQ.NZ)GO TO 27
   25 CONTINUE
   26 YN(J)=Y(M-1)+(Y(M)-Y(M-I))*(DHX(J)-DIST(M-1))/(DIST(M)-DIST(M-1))
      GO TO 24
   27 YN(J)=YO
   24 CONTINUE
      RETURN
      END
C

      SUBROUTINE TOPCAL(NN,NT2,DZ1,DZ2,YYT,YYT2)
C ******************************************************************************
C     THIS SUBROUTINE IS FOR LINEAR INTERPOLATION OF TOP PRODUCT OR INLET
C     CONCENTRATION FOR SECOND COLUMN
C ******************************************************************************
      DIMENSION YYT(800),YYT2(800)
      YYT2(1)=YYT(1)
      DO 40 J=2,NT2
      CNK =J-1
      TT2=CNK*DZ2
      M=1
   20 CN=M
      TT1=CN*DZ1
      IF(TT2-TT1)50,55,60
   60 IF ((M+1).EQ.NN)GO TO 55
      M=M+1
      GO TO 20
   55 YYT2(J)=YYT(M+1)
      GO TO 40
   50 YYT2(J)=YYT(M)    +(YYT(M+1)-YYT(M))*DZ2/DZ1
   40 CONTINUE
      RETURN
      END

      FUNCTION RK1(WE,WA,CNST,DZ,CNST1,YI)
C ******************************************************************************
C     RUNGE - KUTTA METHOD FOR THE CALCULATION OF GAS PHASE CONCENTRATION
C     SOLID PHASE CONCENTRATION HAS BEEN TAKEN CONSTANT
      AKK1=CNST*(WE-WA)*DZ
      Y=YI+AKK1/2.
```

```
      WE=Y*CNST1
      AKK2=CNST*(WE-WA)*DZ
      Y=YI+AKK2/2.
      WE=Y*CNST1
      AKK3=CNST*(WE-WA)*DZ
      Y=YI+AKK3
      WE=Y*CNST1
      AKK4=CNST*(WE-WA)*DZ
      DY=(AKK1+2.*AKK2+2.*AKK3+AKK4)/6.
      RK1=YI+DY
      RETURN
      END
C
      SUBROUTINE XYCAL(VOID,TIME,DENS,PS,DF,YY2,WW2,VO,DZ,YTT,M,IND,K,YY
     1,WW,YYAV,YBT,NZ,R,TEMP,CKG,AK,H,YYAV1)
C ***********************************************************************
C     THIS SUBROUTINE CALCULATES CONCENTRATION PROFILE
C ***********************************************************************
      DIMENSION YTT(800),YBT(800)
      DIMENSION YY2(800),WW2(800),YY(800),WW(800)
      CNST1=AK*PS/(R*TEMP)
      CNST=-(1.-VOID)*DENS*CKG/(VOID*DF)
      NNZ=NZ-1
      SUM=YY2(NZ)
      YBT(1)=YY2(NZ)
      K=1
  155  CNK=K
      WI=WW2(1)
      TT=DZ*CNK
      YY(1)=YTT(K+1)
      YIN=YTT(K+1)
      WINE=AK*PS*YIN/(R*TEMP)
      WW(1)=RK(WINE,WI,CKG,DZ)
      WW1E=AK*PS*YY2(1)/(R*TEMP)
      I=2
   85 WW2E=AK*PS*YY2(I)/(R*TEMP)
      YY(I)=RK1(WW1E,WW2(I-1),CNST,DZ,CNST1,YY2(I-1))
      WW(I)=RK(WW2E,WW2(I),CKG,DZ)
      IF(I-NZ)81,90,90
   81 I=I+1
      WW1E=WW2E
      GO TO 85
   90 SUM=SUM+YY(NZ)
      YBT(K+1)=YY(NZ)
      IF(TT-TIME)150,200,200
  150 DO 151 L=1,NZ
      YY2(L)=YY(L)
  151 WW2(L)=WW(L)
      K=K+1
      GO TO 155
  200 TOTK=K+1
      YYAV=SUM/TOTK
      YYAV1=YY(NZ)
      IF(IND.EQ.2)GO TO 1
      PRINT 995,M
  995 FORMAT('-',10X,' END VALUES OF HIGH PRESSURE COLUMN WHEN M=',I2//)
```

```
        GO TO 2
1       PRINT 996,M
996     FORMAT('-',10X,' END VALUES OF LOW PRESSURE COLUMN WHEN M=',I2///)
2        PRINT 998
998     FORMAT('-','END VALUES',7X,'I',8X,'WW(I)',15X,'YY(I)')
999     FORMAT('-',10X,I10,3E20.8)
        DO 153 L=1,NZ,20
153     PRINT 999,L       ,WW(L),YY(L)
        MC=M
        PRINT 800,MC,YYAV,YYAV1
800     FORMAT('-',20X,'M=',I2,10X,'YYAV=',E12.5,5X,'YYAV1=',E12.5)
        RETURN
         END
```

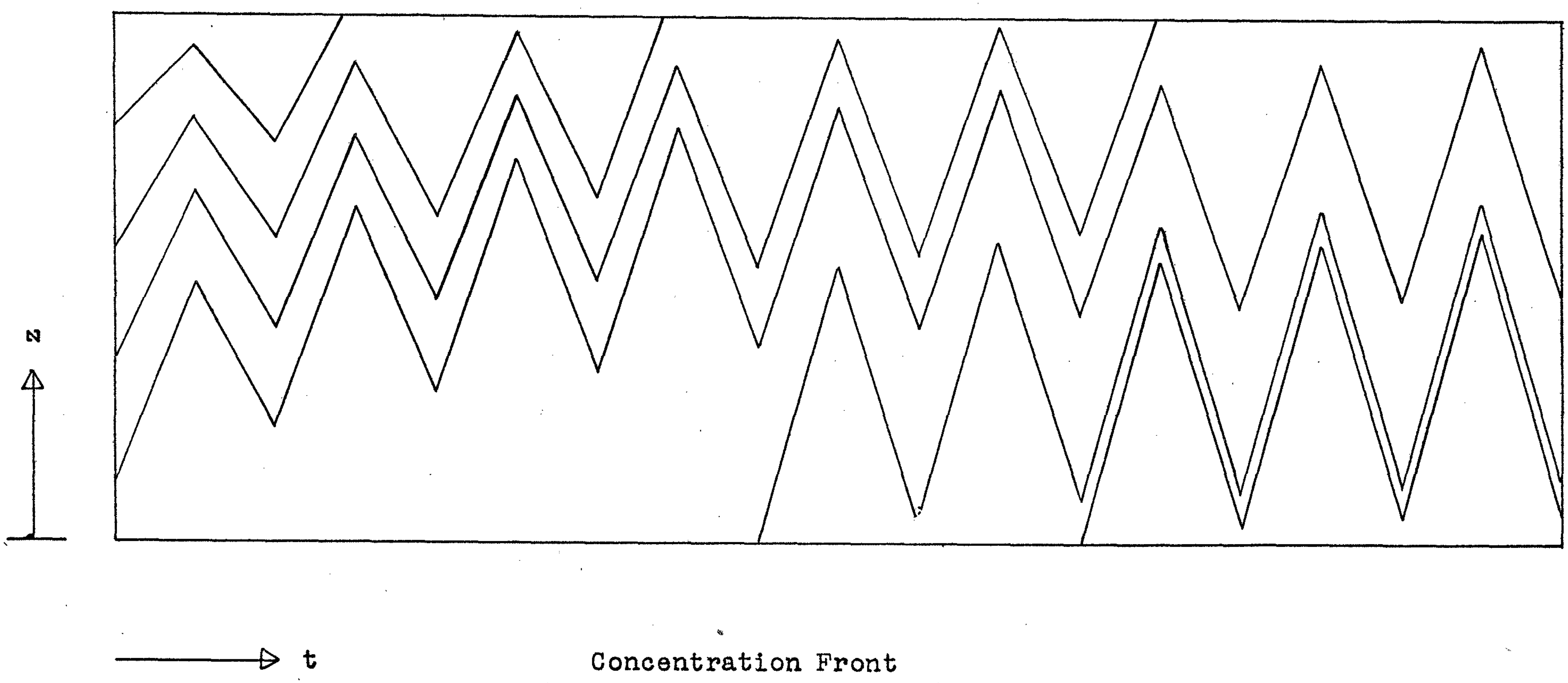
APPENDIX - IV

Figures

Figure :10

$\frac{\pi}{\omega}$ = 60 mins.,Q($\frac{\pi}{\omega}$) = 25 cc

ϕ_B = 0.01 , C_0 = 0.1 M



Concentration Front

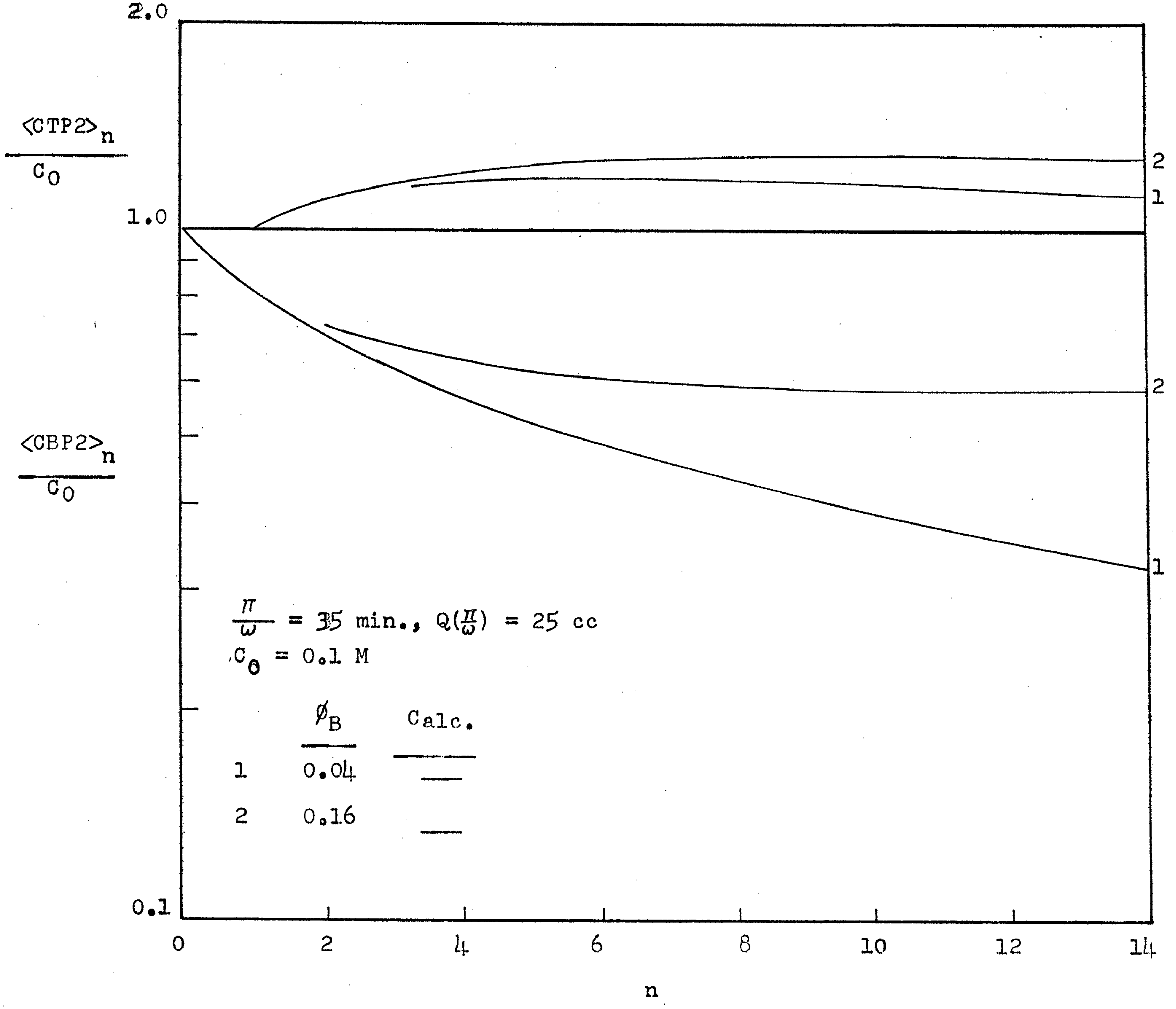

2.0
1.0
0.1
$\frac{\langle CTP2\rangle_n}{C_0}$
$\frac{\langle CBP2\rangle_n}{C_0}$
2
1
2
1
$\frac{\pi}{\omega}$ = 35 min., $Q(\frac{\pi}{\omega})$ = 25 cc
C_0 = 0.1 M
ϕ_B
Calc.
1 0.04
2 0.16
0
2
4
6
8
10
12
14
n

Figure 12

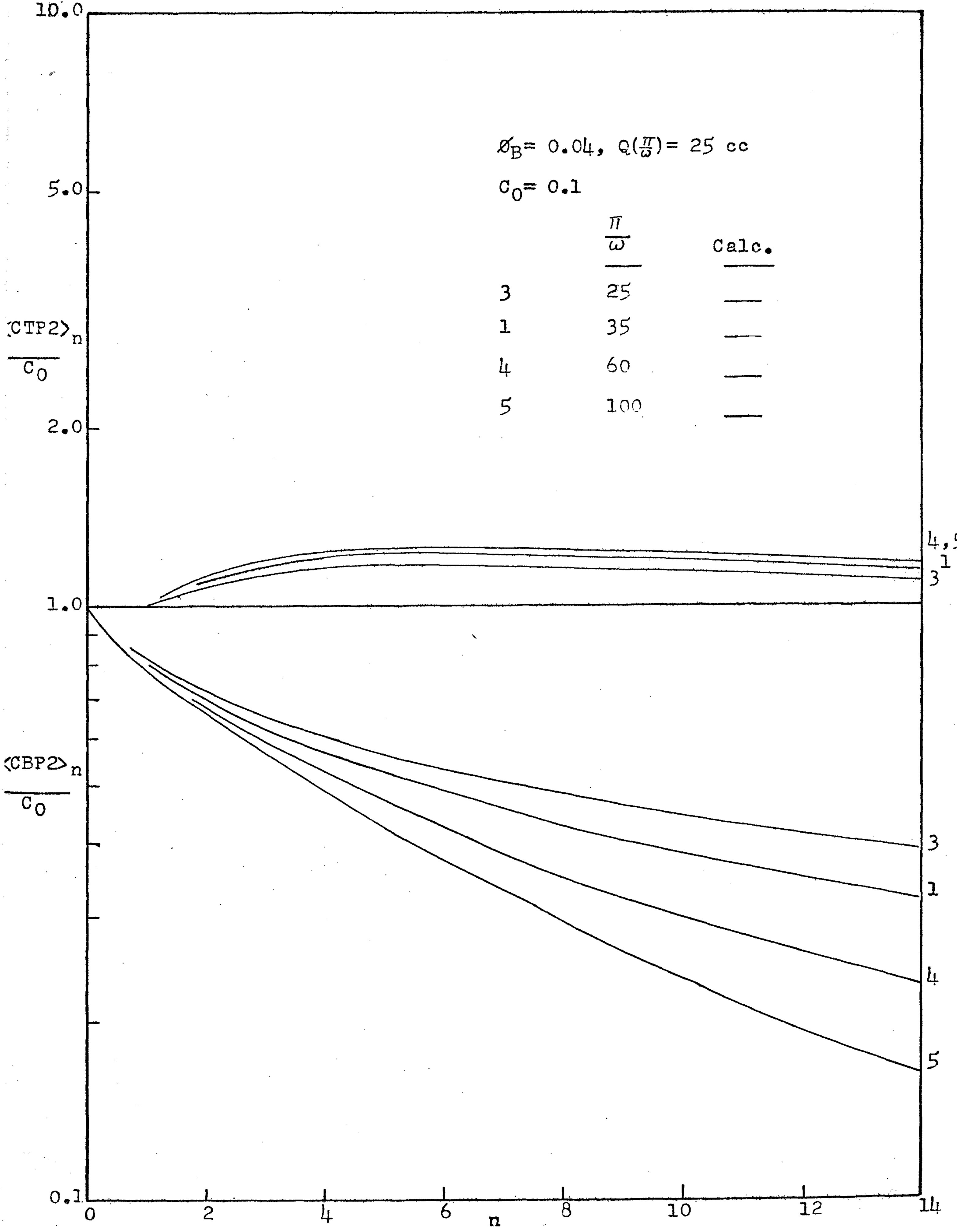

10.0
5.0
2.0
1.0
0.1
⟨CTP2⟩n / C0
⟨CBP2⟩n / C0
ØB = 0.04, Q(π/ω) = 25 cc
C0 = 0.1
π/ω
Calc.
3 25
1 35
4 60
5 100
4,5
1
3
3
1
4
5
0
2
4
6
8
10
12
14
n

Figure 15

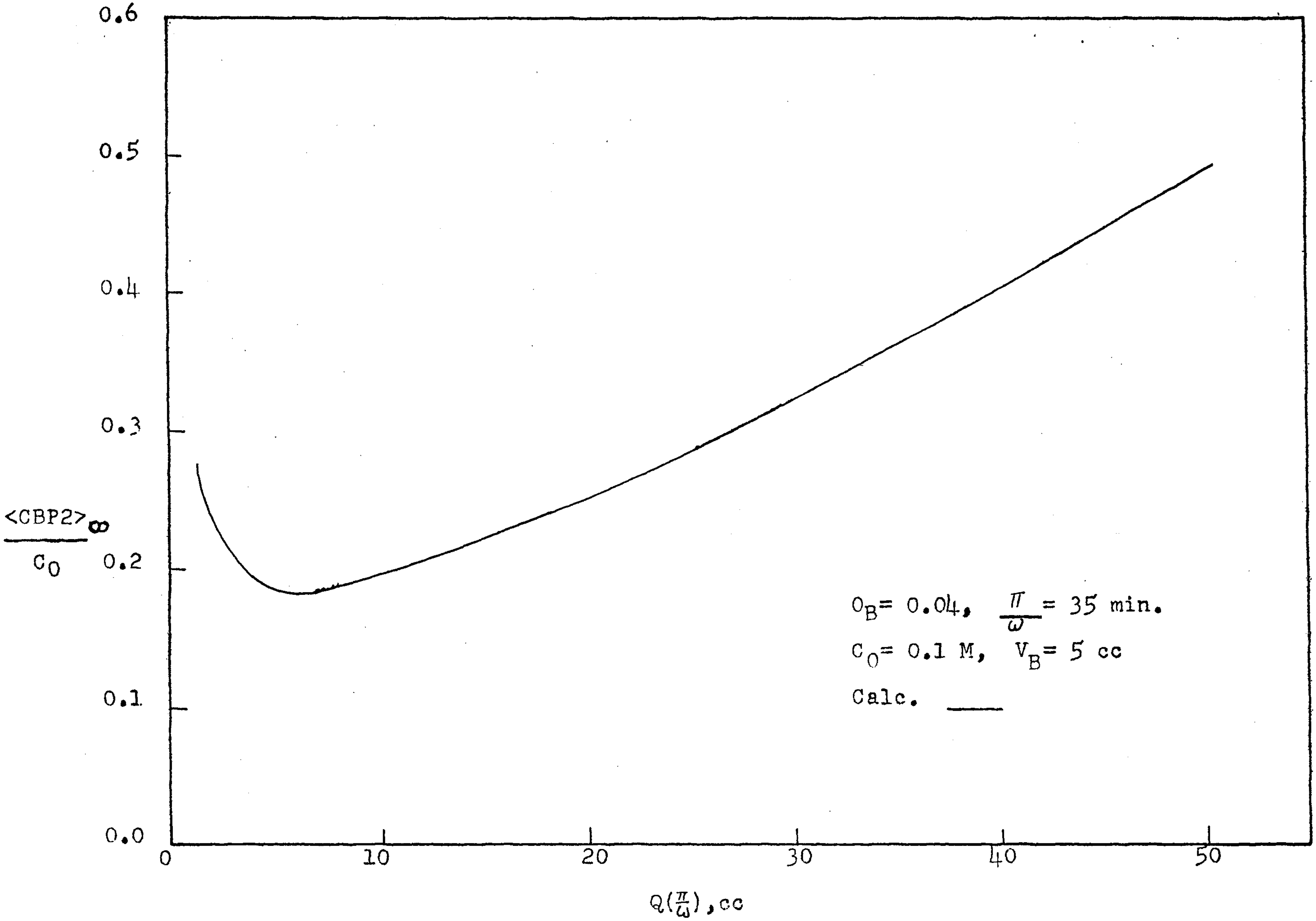

0.6
0.5
0.4
0.3
0.2
0.1
0.0
$\frac{\langle CBP2 \rangle_\infty}{C_0}$
0
10
20
30
40
50
$Q(\frac{\pi}{\omega})$,cc
O_B= 0.04, $\frac{\pi}{\omega}$= 35 min.
C_0= 0.1 M, V_B= 5 cc
Calc. ——

Figure 14

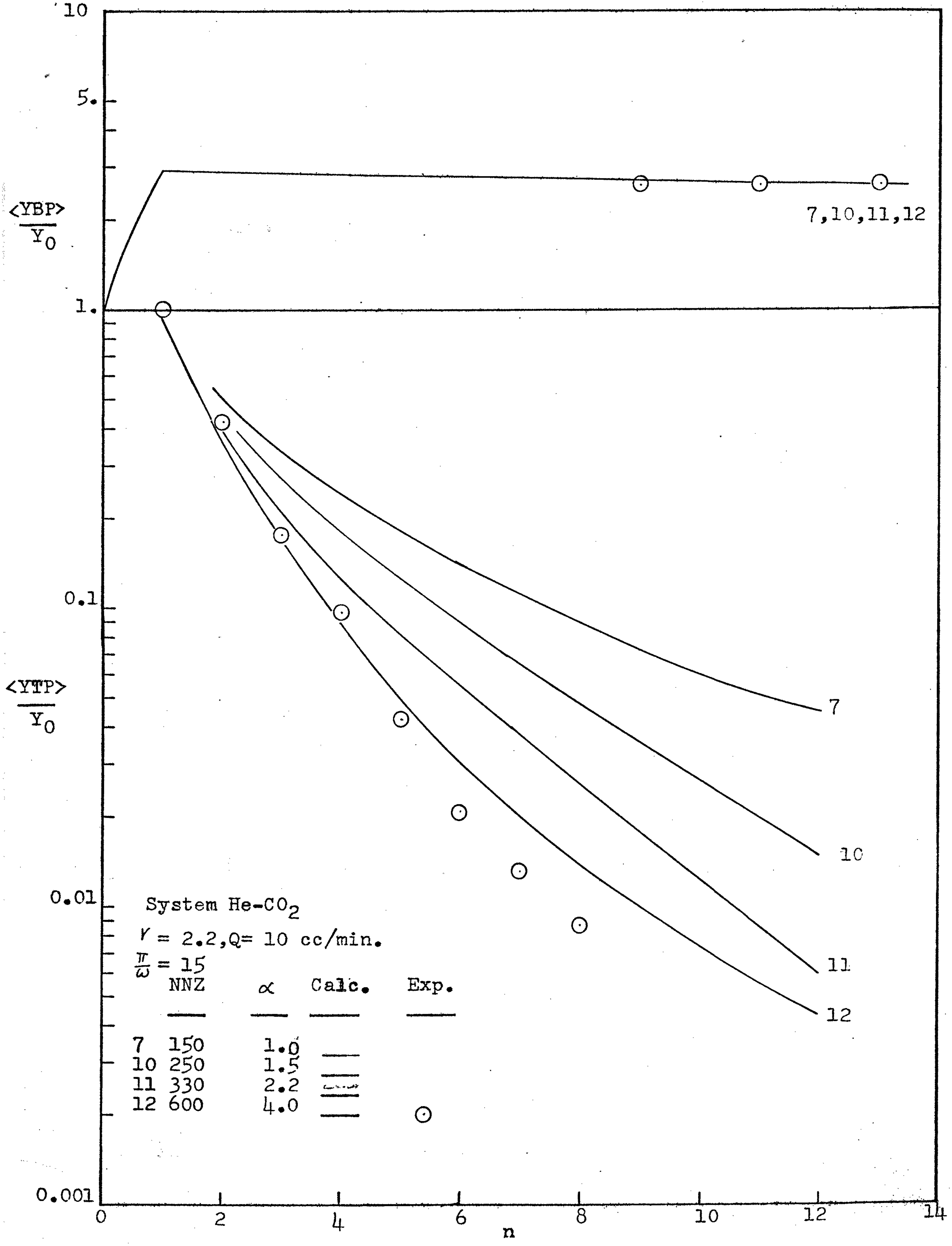

10
5.
1.
0.1
0.01
0.001
$\frac{\langle YBP \rangle}{Y_0}$
$\frac{\langle YTP \rangle}{Y_0}$
7,10,11,12
7
10
11
12
0
2
4
6
8
10
12
14
n
System He-CO_2
γ = 2.2, Q= 10 cc/min.
$\frac{\pi}{\omega}$ = 15
NNZ
α
Calc.
Exp.
7 150 1.0
10 250 1.5
11 330 2.2
12 600 4.0

Figure 15

Calibration for He-CO_2 system

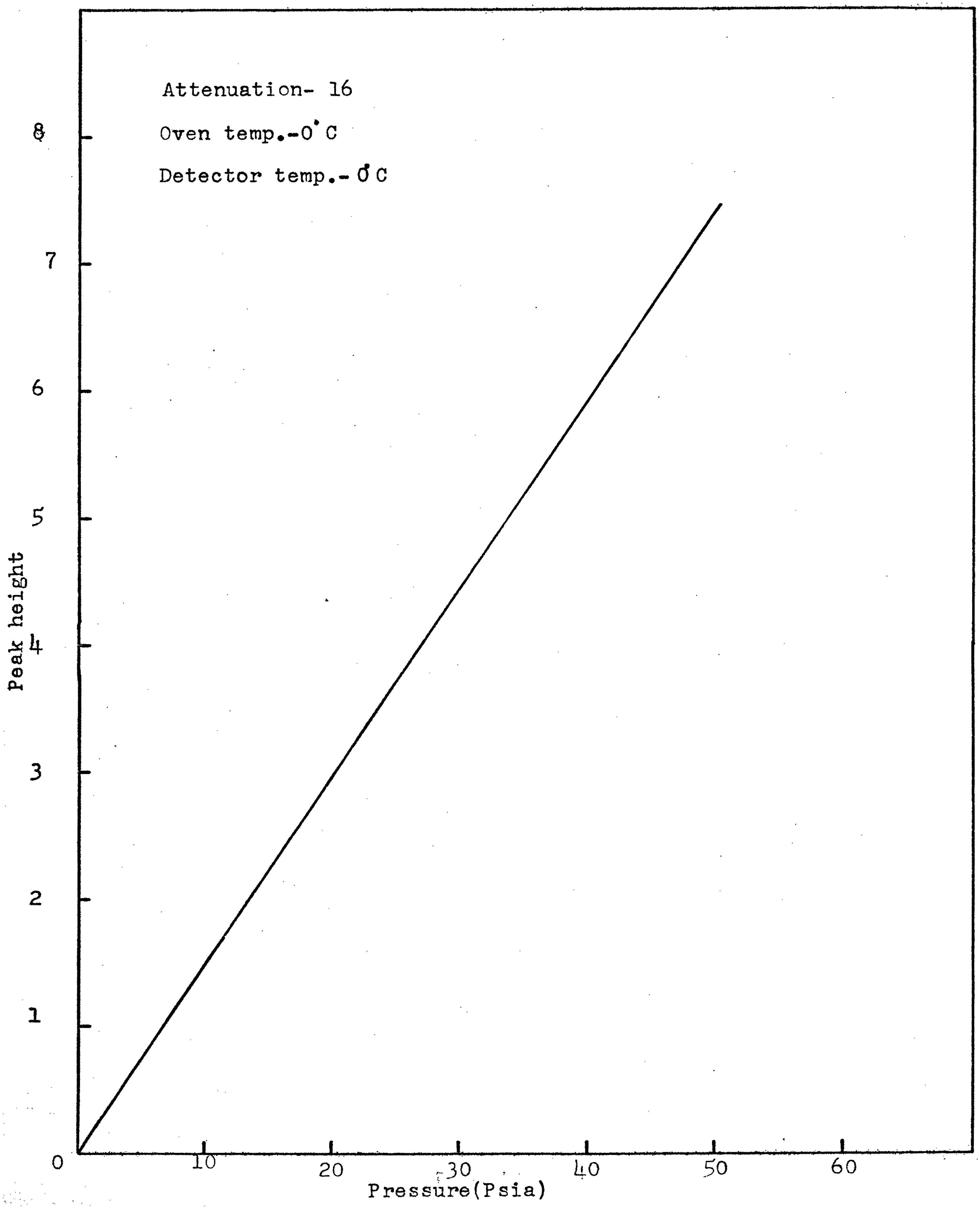


Figure 16

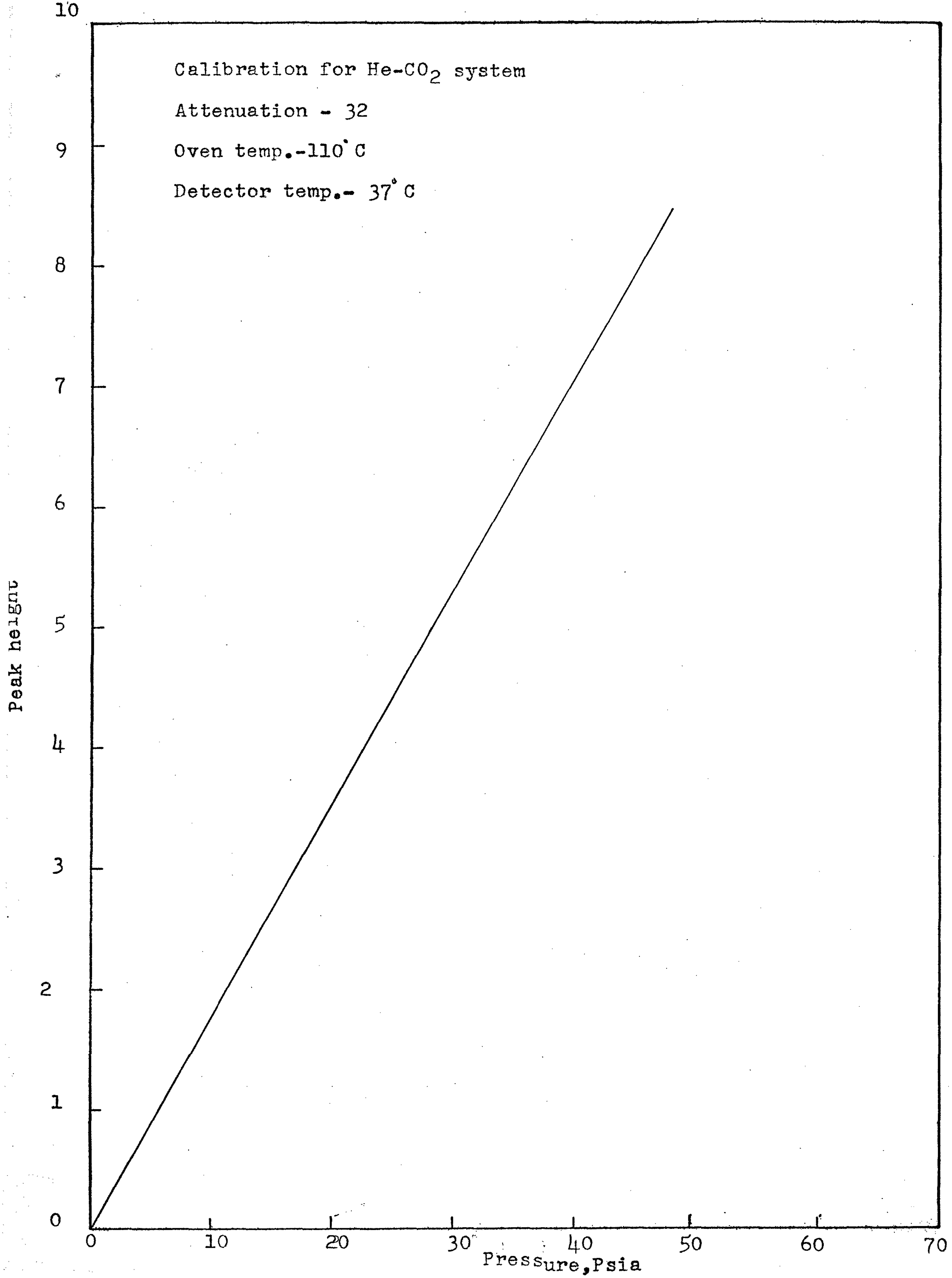

Calibration for He-CO_2 system
Attenuation - 32
Oven temp.-110° C
Detector temp.- 37° C
Peak height
Pressure, Psia
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70

Figure 17

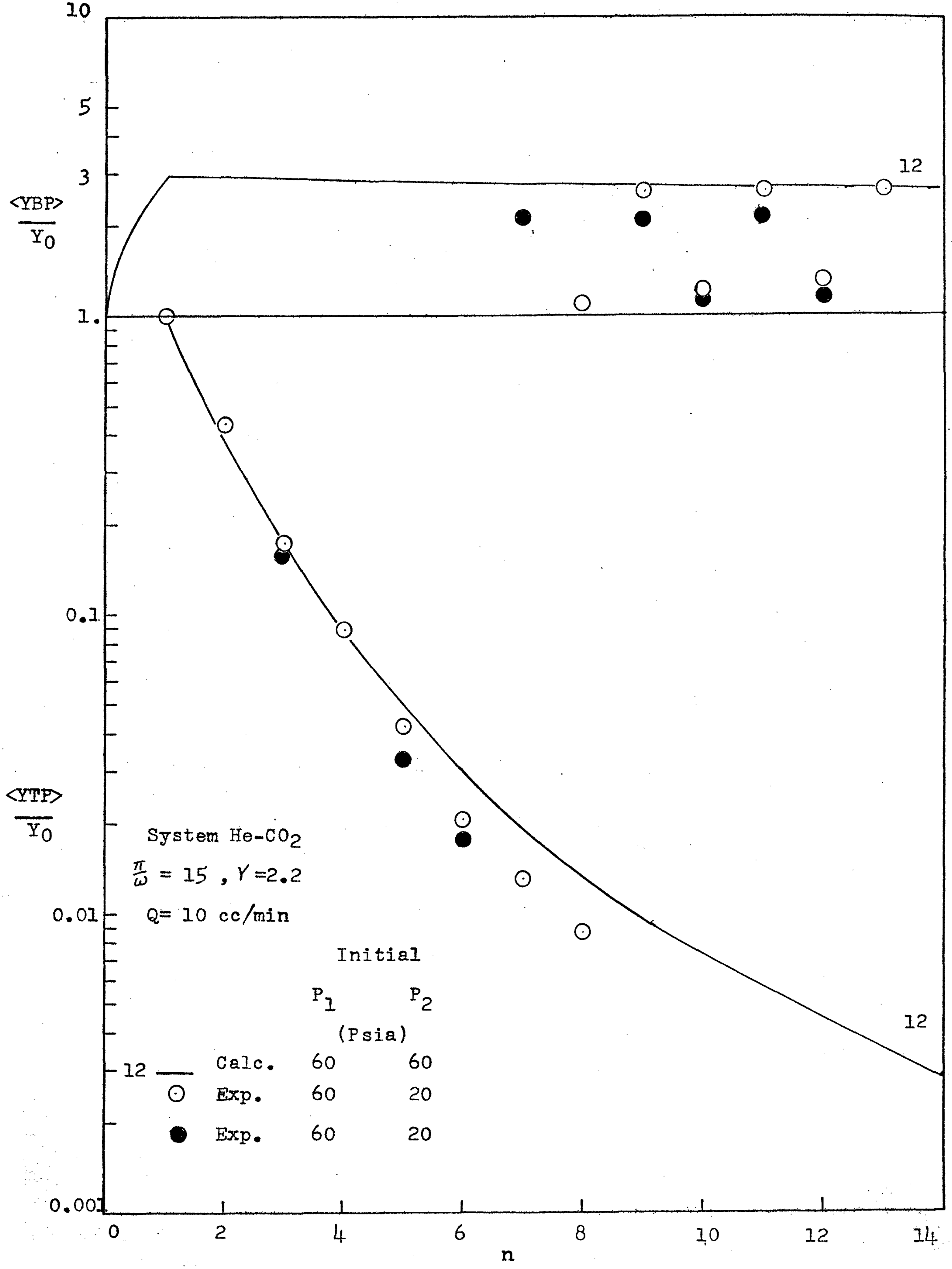

10
5
3
1.
0.1
0.01
0.001
<YBP>/Y0
<YTP>/Y0
12
12
System He-CO2
π/ω = 15 , γ =2.2
Q= 10 cc/min
Initial
P1 P2
(Psia)
12 Calc. 60 60
⊙ Exp. 60 20
● Exp. 60 20
0
2
4
6
8
10
12
14
n

Figure 18

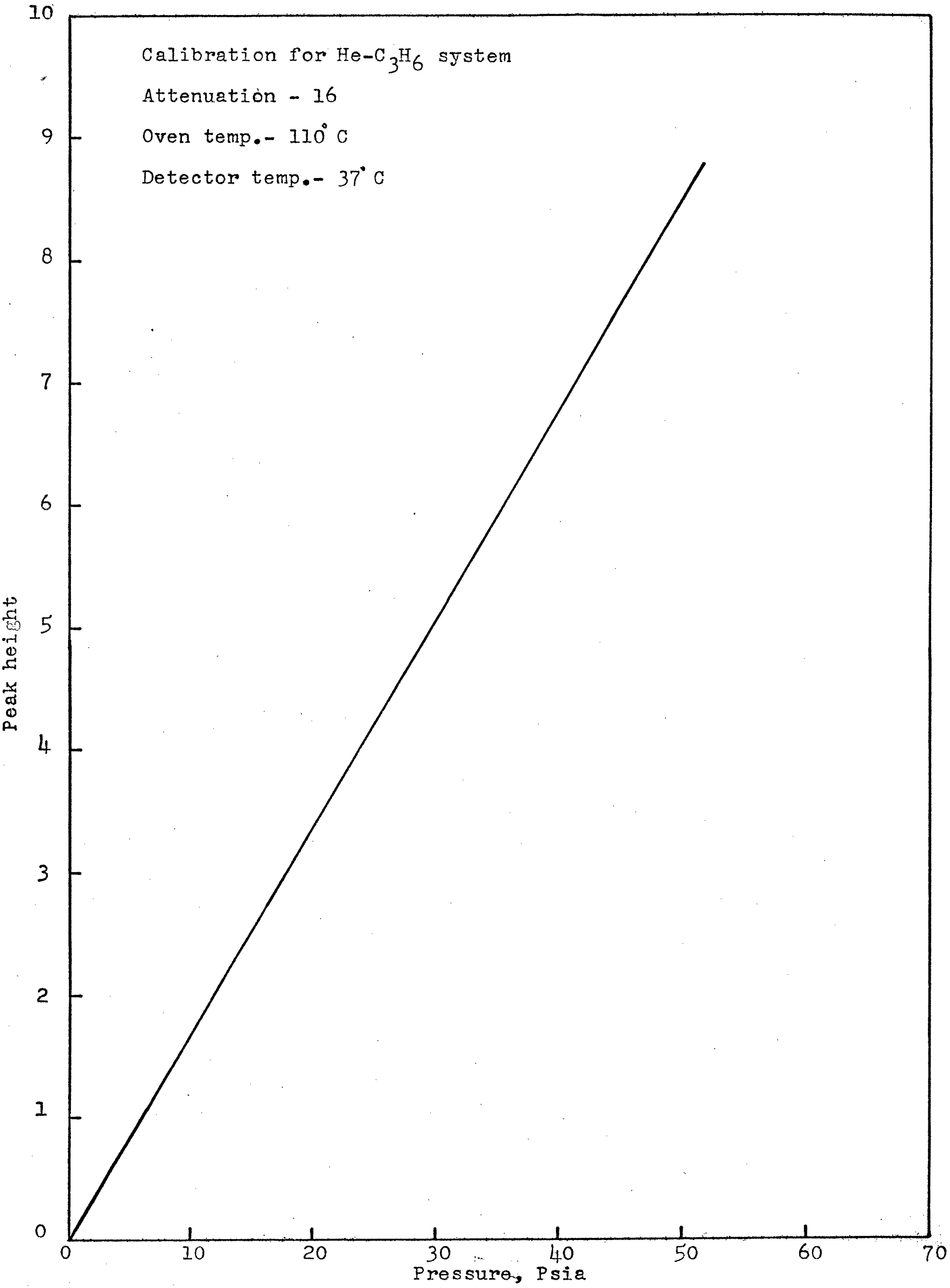

Calibration for He-C_3H_6 system
Attenuation - 16
Oven temp.- 110° C
Detector temp.- 37° C
Peak height
Pressure, Psia
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70

Figure 19

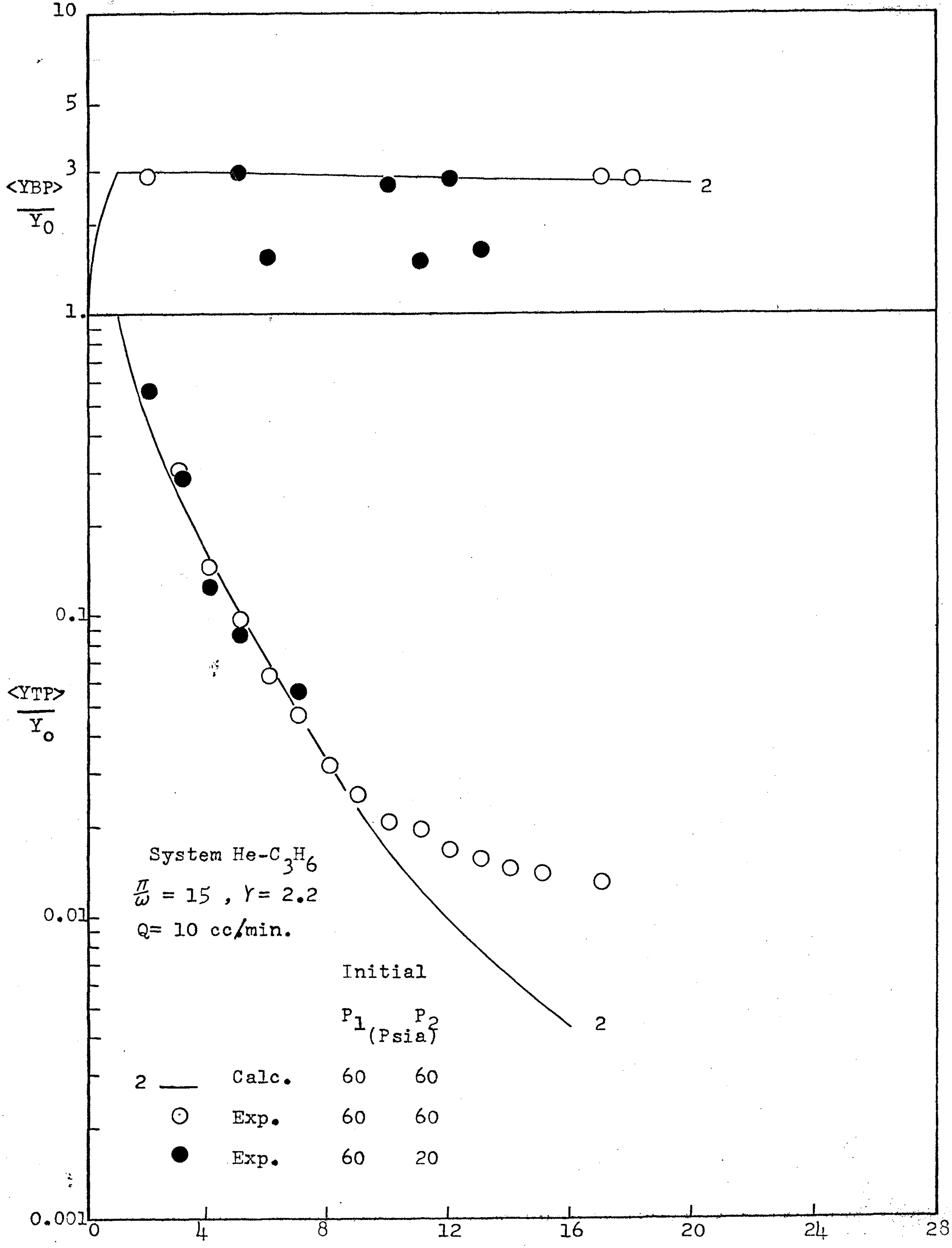

10
5
3
1.
0.1
0.01
0.001
$\frac{\langle YBP \rangle}{Y_0}$
$\frac{\langle YTP \rangle}{Y_o}$
0
4
8
12
16
20
24
28
2
2
System He-C_3H_6
$\frac{\pi}{\omega} = 15$, $\gamma = 2.2$
Q= 10 cc/min.
Initial
P_1 (Psia) P_2
2 — Calc. 60 60
○ Exp. 60 60
● Exp. 60 20

Figure 20

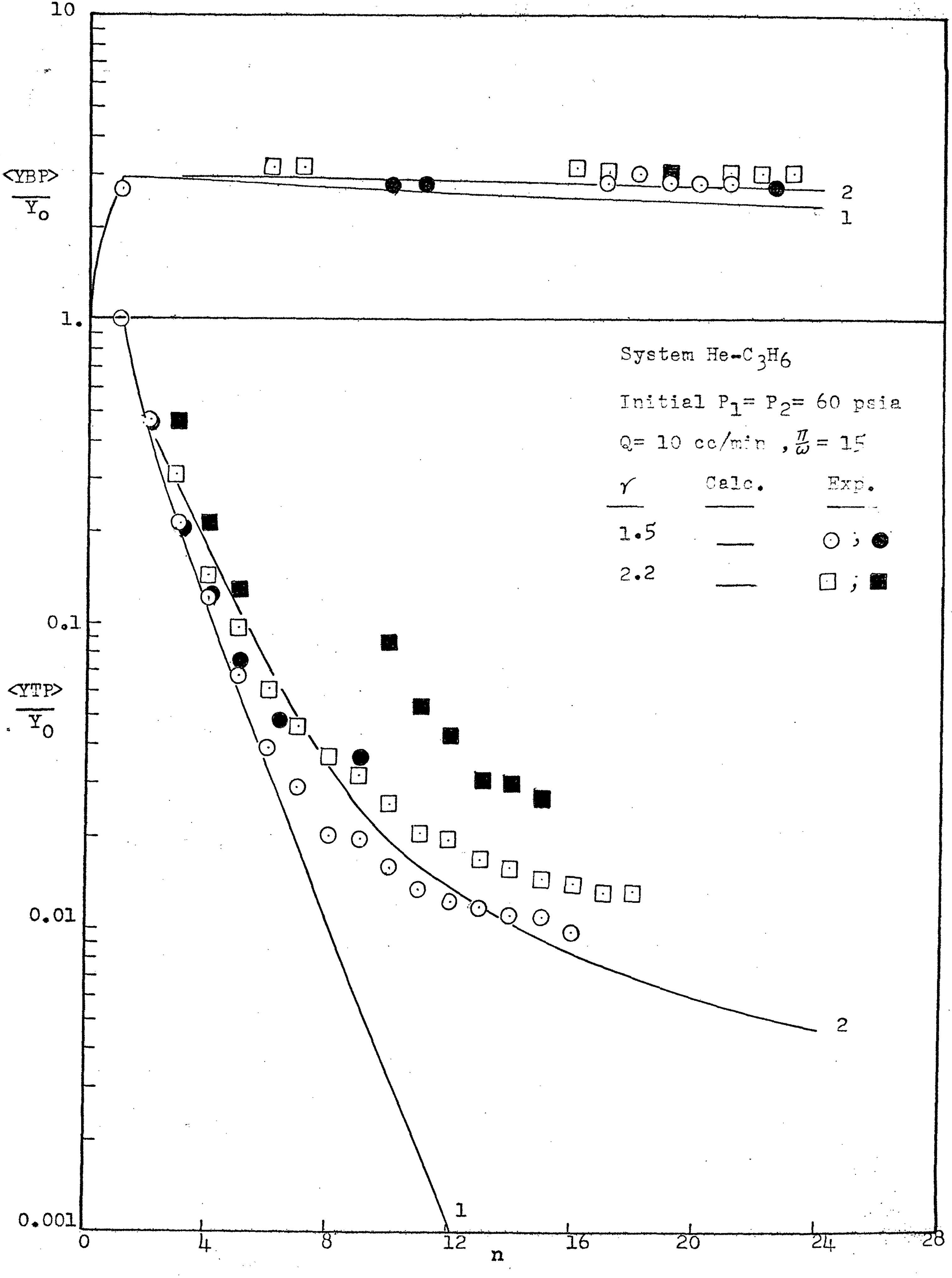
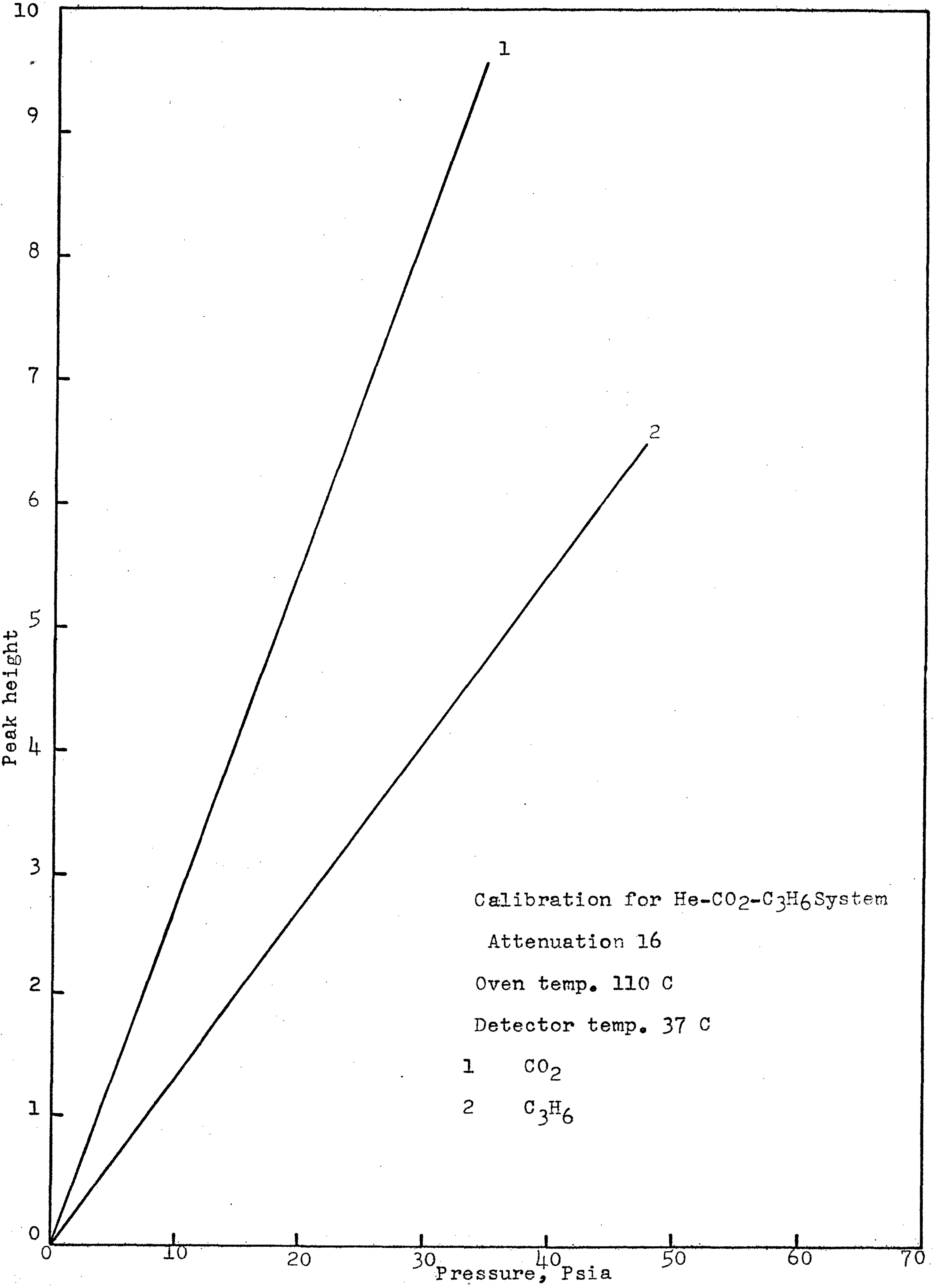
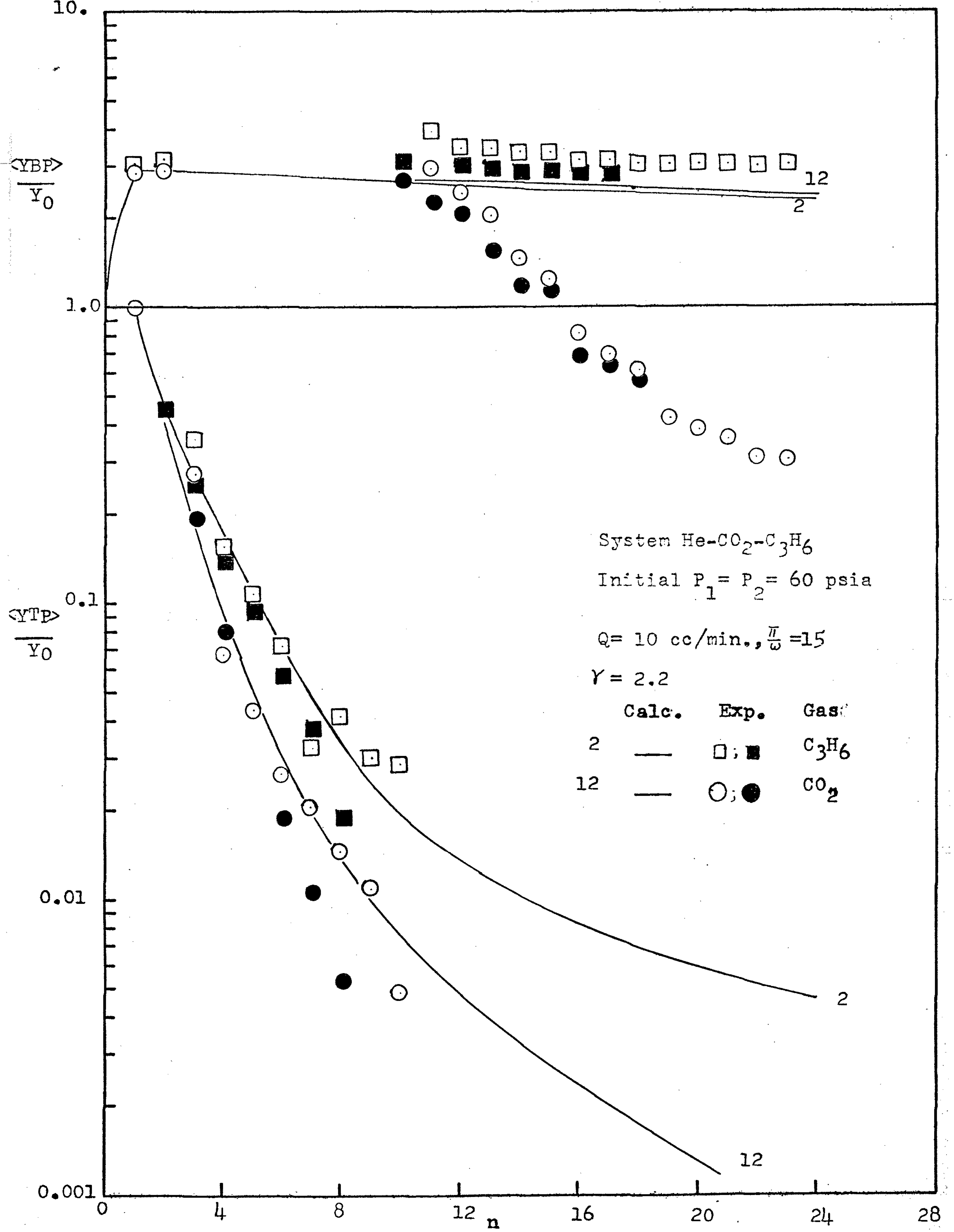

10
1.
0.1
0.01
0.001
$\frac{\langle YBP \rangle}{Y_o}$
$\frac{\langle YTP \rangle}{Y_o}$
0
4
8
12
16
20
24
28
n
2
1
2
1
System He-C_3H_6
Initial $P_1 = P_2 = 60$ psia
Q= 10 cc/min , $\frac{\pi}{\omega} = 15$
γ
Calc.
Exp.
1.5
○ ; ●
2.2
□ ; ■

Figure 21



Calibration for He-CO_2-C_3H_6 System
Attenuation 16
Oven temp. 110 C
Detector temp. 37 C
1 CO_2
2 C_3H_6
1
2
Peak height
0
1
2
3
4
5
6
7
8
9
10
Pressure, Psia
0
10
20
30
40
50
60
70

Figure : 22


10.
1.0
0.1
0.01
0.001
$\frac{\langle YBP \rangle}{Y_0}$
$\frac{\langle YTP \rangle}{Y_0}$
0
4
8
12
n
16
20
24
28
12
2
2
12
System $He-CO_2-C_3H_6$
Initial $P_1 = P_2 = 60$ psia
$Q = 10$ cc/min., $\frac{\pi}{\omega} = 15$
$\gamma = 2.2$
Calc.
Exp.
Gas
2
□ ; ■
C_3H_6
12
○ ; ●
CO_2

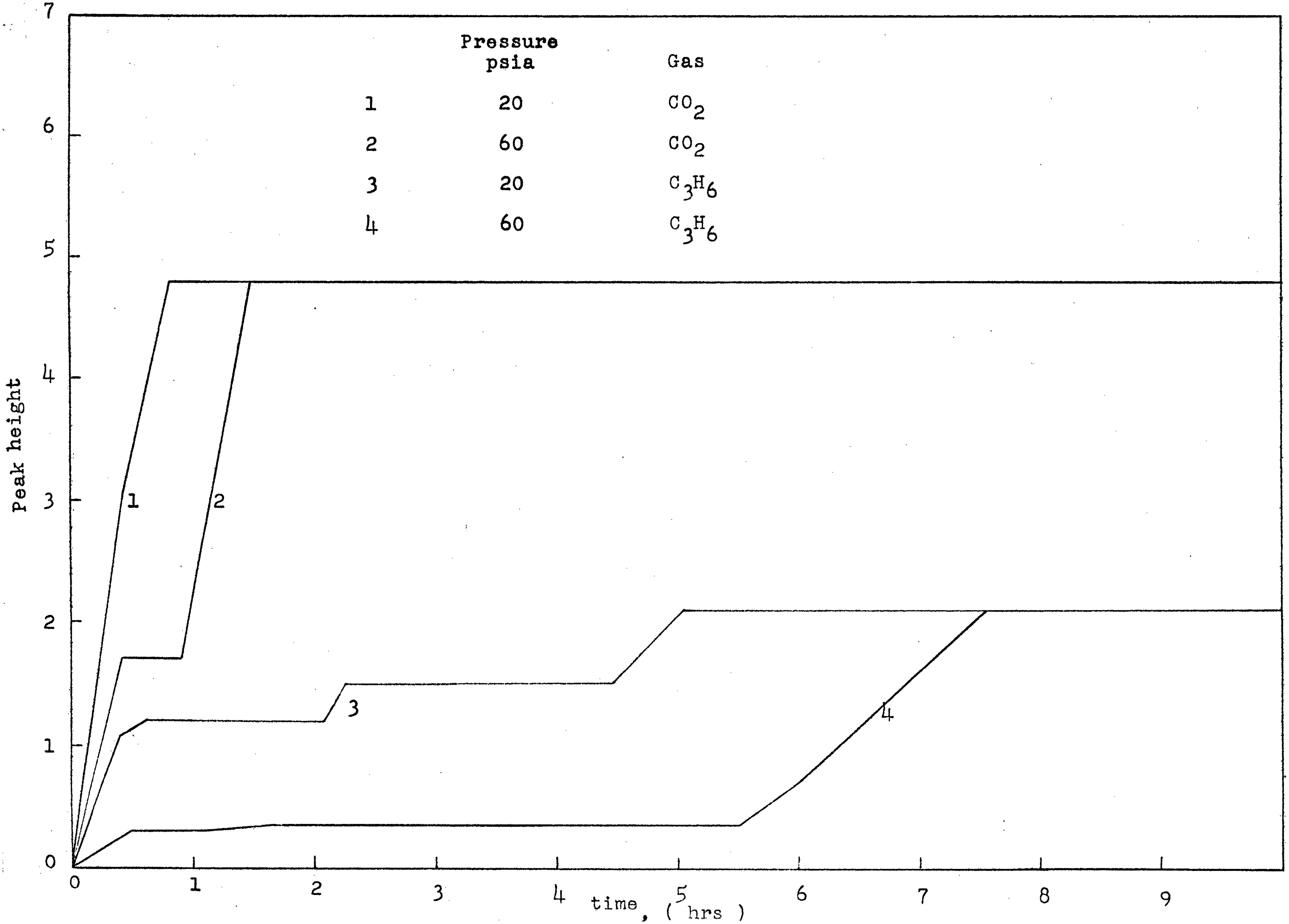
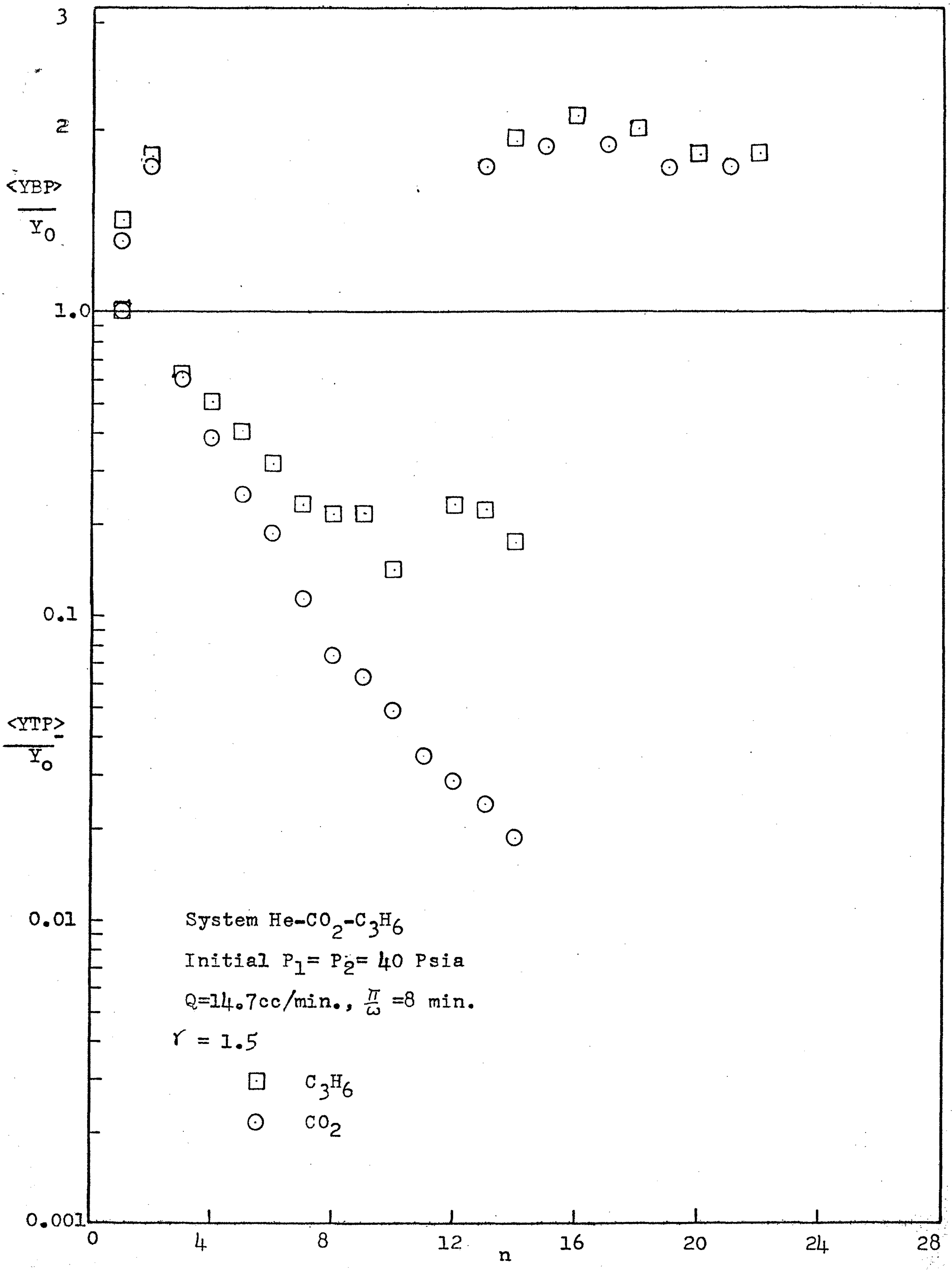


Figure :23

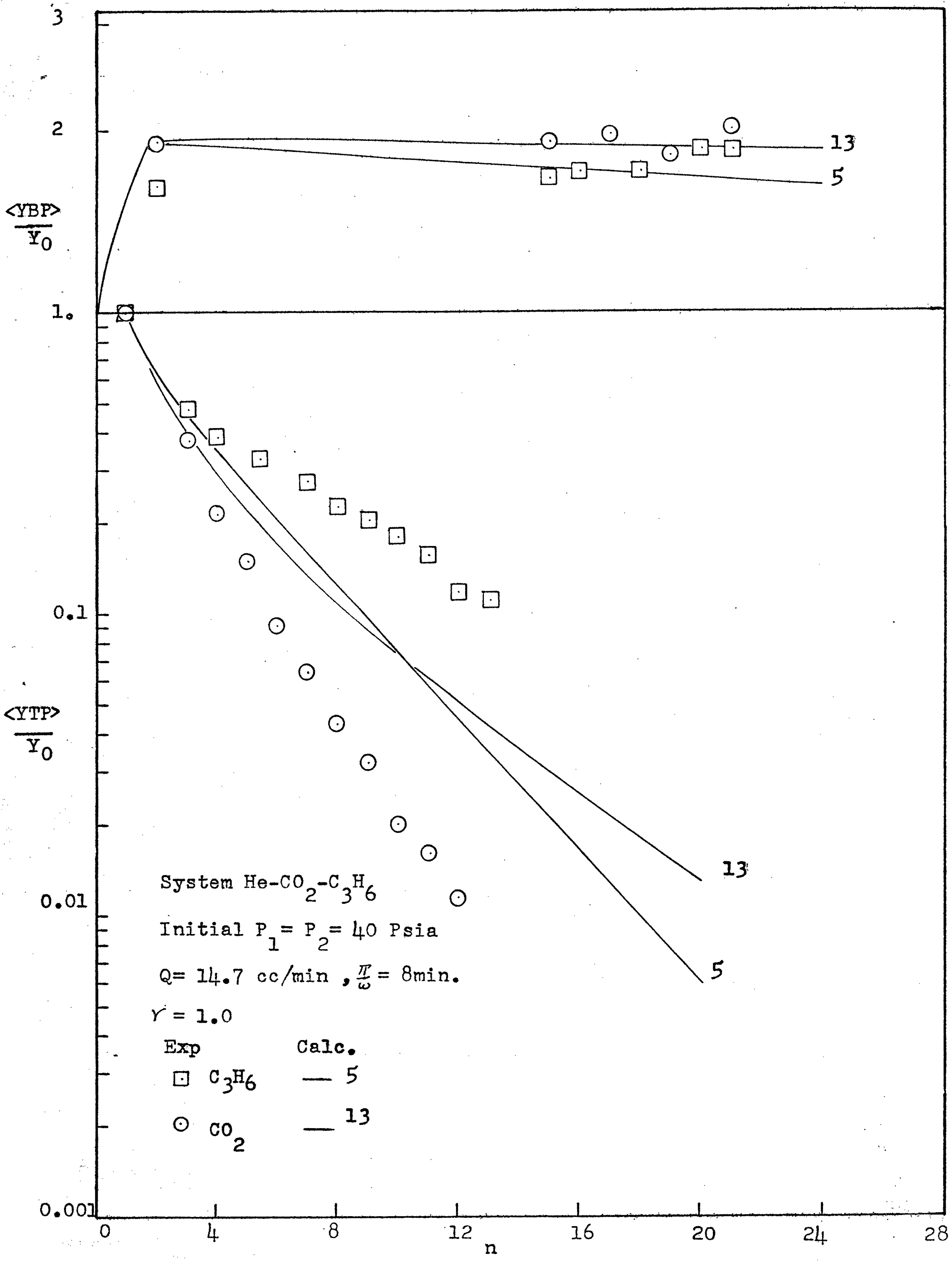
Pressure psia
Gas
1 20 CO_2
2 60 CO_2
3 20 C_3H_6
4 60 C_3H_6
Peak height
0
1
2
3
4
5
6
7
time, (hrs)
0
1
2
3
4
5
6
7
8
9
1
2
3
4

Figure 24



3
2
$\frac{<YBP>}{Y_0}$
1.0
0.1
$\frac{<YTP>}{Y_o}$
0.01
0.001
0
4
8
12
16
20
24
28
n
System He-CO_2-C_3H_6
Initial P_1= P_2= 40 Psia
Q=14.7cc/min., $\frac{\pi}{\omega}$ =8 min.
γ = 1.5
⊡ C_3H_6
⊙ CO_2

Figure 25


3
2
1.
0.1
0.01
0.001
<YBP>/Y0
<YTP>/Y0
0
4
8
12
16
20
24
28
n
13
5
13
5
System He-CO2-C3H6
Initial P1 = P2 = 40 Psia
Q= 14.7 cc/min , π/ω = 8min.
γ = 1.0
Exp
Calc.
☐ C3H6
— 5
⊙ CO2
— 13

APPENDIX - V

Tables

Table no. 1

MATHEMATICAL RESULT - THERMAL PARAMETRIC PUMPING - SYSTEM : $NaCl - H_2O$

Run No.	C_0 (M)	$\frac{\pi}{\omega}$ (min.)	$Q(\frac{\pi}{\omega})$ (cc.)	ϕ_B	$\phi_B + \phi_T$	$C_1 = V_T/Q$	$C_2 = V_B/Q$
1	0.1	35	25	0.04	0.4	5/25	5/25
2	0.1	35	25	0.16	0.4	5/25	5/25
3	0.1	25	25	0.04	0.4	5/25	5/25
4	0.1	60	25	0.04	0.4	5/25	5/25
5	0.1	100	25	0.04	0.4	5/25	5/25
6	0.1	35	35	0.04	0.4	5/35	5/35
7	0.1	100	25	0.16	0.4	5/25	5/25
8	0.1	35	25	0.01	0.4	5/25	5/25
9	0.1	60	25	0.01	0.4	5/25	5/25
10	0.1	60	25	0.16	0.4	5/25	5/25
11	0.1	100	25	0.01	0.4	5/25	5/25
12	0.05	35	25	0.04	0.4	5/25	5/25
13	0.5	35	25	0.04	0.4	5/25	5/25

Table No.2

EXPERIMENTAL RESULTS - HEATLESS PARAMETRIC PUMP

Run No.	Y_0	Initial Pressure (Psia)		Operaring Pressure (Psia)		$\frac{\pi}{\omega}$ (min.)	Q $(\frac{cc}{min.})$	Y	figure No.	System
		P_1	P_2	P_1	P_2					
1	1 % CO_2	-	-	-	-	--	--	--	16	He - CO_2 (calibration
2	1 % CO_2	60	20	60	20	15	10	2.2	19	He - CO_2
3	1 % CO_2	-	-	-	-	--	--	--	1	He - CO_2 (calibration)
4	1 % CO_2	60	20	60	20	15	10	2.2		He - CO_2
5	1 % C_3H_6	-	-	-	-	-	-	-		He - C_3H_6 (calibration)
6	1 % C_3H_6	60	20	60	20	15	10	2.2		He - C_3H_6
7	1 % C_3H_6	60	60	60	20	15	10	2.2		He - C_3H_6
8	1 % C_3H_6	60	60	60	20	15	10	1.5		He - C_3H_6
9	1 % C_3H_6	60	60	60	20	15	10	1.5		He - C_3H_6
10	1 % C_3H_6	60	60	60	20	15	10	2.2		He - C_3H_6
11	1 % C_3H_6 1 % CO_2	-	-	-	-	-	-	-		He - CO_2- C_3H_6 (calibration)
12	1 % C_3H_6 1 % CO_2	60	60	60	20	15	10	2.2		He - CO_2- C_3H_6
13	1 % C_3H_6 1 % CO_2	60	60	60	20	15	10	2.2		He - CO_2- C_3H_6
14	1 % C_3H_6 1 % CO_2	40	40	40	20	8	14.7	1.5		He - CO_2- C_3H_6
15	1 % C_3H_6 1 % CO_2	40	40	40	20	8	14.7	1.0		He - CO_2- C_3H_6

Table no. 3

MATHEMATICAL RESULTS - HEATLESS PARAMETRIC PUMP

Run No.	Y_0	Initial Pressure (Psia)		Operating Pressure (Psia)		$\frac{\pi}{\omega}$ (min.)	Q $(\frac{cc}{min.})$	γ	$\propto$	NNZ	System
		P_1	P_2	P_1	P_2						
1	1 % C_3H_6	60	60	60	20	15	10	1.5	1.25	600	He - C_3H_6
2	1 % C_3H_6	60	60	60	20	15	10	2.2	1.25	600	He - C_3H_6
3	1 % C_3H_6	60	60	60	20	15	10	2.2	0.25	100	He - C_3H_6
4	1 % C_3H_6	60	60	60	20	15	10	2.2	0.25	150	He - C_3H_6
5	1 % C_3H_6	40	40	40	20	8	14.7	1.0	1.25	600	He - C_3H_6
6	1 % CO_2	60	60	60	20	15	10	2.2	1.00	100	He - CO_2
7	1 % CO_2	60	60	60	20	15	10	2.2	1.00	150	He - CO_2
8	1 % CO_2	60	60	60	20	15	10	2.2	1.00	250	He - CO_2
9	1 % CO_2	60	60	60	20	15	10	2.2	1.00	300	He - CO_2
10	1 % CO_2	60	60	60	20	15	10	2.2	1.50	250	He - CO_2
11	1 % CO_2	60	60	60	20	15	10	2.2	2.20	330	He - CO_2
12	1 % CO_2	60	60	60	20	15	10	2.2	4.00	600	He - CO_2
13	1 % CO_2	40	40	40	20	8	14.7	1.0	4.00	600	He - CO_2

Table no.- 4

Run No.- 1 System- He-CO_2

Oven temp.: 0° C Cell current: 185 mA.

Pressure of carrier gas = 30 psig

Detector temp.: 0° C Carrier gas: Helium

Attenuation = 8

Pressure absolute psia	Peak height
19.7	3.08
24.7	3.70
34.7	5.20
39.7	5.95
44.7	6.63

Table no.- 5

Run No.- 3 System- He-CO_2

Oven temp.:110°C Cell current:185 mA.

Pressure of carrier gas = 30 psig

Detector temp.: 37°C Carrier gas: Helium

Attenuation = 32 for CO_2

Pressure absolute psia	Peak height
14.7	2.9
19.7	3.55
24.7	4.15
29.7	4.65

Table no.- 6

Run No.- 2 System- He-CO_2

Oven temp.: 0°C
Cell current: 185 mA.
Detector temp: 0°C
Carrier gas : Helium
Feed concn.: 1 % CO_2
Pressure of Carrier gas: 30 psig
Half cycle time: 15.0 mints.
Purge ratio: 2.2
Initial saturation pressure for:-
Column 1= 60. psia
Column 2= 20.0 psia
Volumetric flow rate of:-
Feed @ 60.0 psia= 10.0cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height, h_0= 5.0 @ 8 Attenuation for CO_2

End of half cycle no.	Attn.	Peak height Top Product	Bottom Product	h/h_0
0	8	5.0	5.0	1.00
1	8	2.05	---	0.41
2	1	6.30	---	0.1575
3	1	3.10	---	0.0775
4	1	1.30	---	0.0325
5	1	0.70	---	0.0175
6	-	-----	---	------
7	16	----	6.5	2.6000
8	16	----	2.8	1.1200
9	16	----	6.4	2.6000
10	16	----	2.8	1.1200

Table no.- 7

Run No.- 4 System- He-CO_2

Oven temp.:110° C Cell current: 185 mA.
Detector temp:37° C Carrier gas : Helium
Feed concn.:1 % CO_2 Pressure of Carrier gas: 30 psig
Half cycle time: 15.0 mints. Purge ratio:2.2
Initial saturation pressure for:-
Column 1= 60.0psia Column 2= 20.0 psia
Volumetric flow rate of:-
Feed @ 60.0 psia= 10.0cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height,h_0= 5.8 @ 16 Attenuation for CO_2

End of half cycle no.	Attn.	Peak height Top Product	Bottom Product	h/h_0
0	16	5.8	5.8	1.00
1	16	2.5	---	0.431
2	4	4.0	---	0.1724
3	2	4.1	---	0.0884
4	1	3.9	---	0.0420
5	1	1.9	---	0.0205
6	1	1.2	---	0.0129
7	1	0.8	---	0.0086
8	16	---	6.3	1.0862
9	32	---	8.4	2.8960
10	16	---	6.9	1.1896
11	32	---	8.1	2.7460
12	16	---	7.5	1.2931

Table no.- 8

Run No.- 5 System-He-C_3H_6

Oven temp.:110°C Cell current:185 mA.

Pressure of carrier gas = 30 psig

Detector temp.: 37°C Carrier gas: Helium

Attenuation = 16 for C_3H_6

Pressure absolute psia	Peak height
14.7	2.7
19.7	3.4
24.7	4.2
29.7	5.0
34.7	5.8
39.7	6.5

Table no.- 9

Run No.- 6 System-He-C_3H_6

Oven temp.:110°C Cell current: 185 mA.
Detector temp:37°C Carrier gas : Helium
Feed concn.: 1 % C_3H_6 Pressure of Carrier gas: 30 psig
Half cycle time: 15.0 mints. Purge ratio: 2.2
Initial saturation pressure for:-
Column 1= 60. psia Column 2= 20.0 psia
Volumetric flow rate of:-
Feed @ 60.0 psia= 10.0 cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height,h_0= 2.5 @ 16 Attenuation for C_3H_6

End of half cycle no.	Attn.	Peak height Top Product	Bottom Product	h/h_0
0	16	2.5	2.5	1.0
1	8	2.95	---	0.5673
2	8	1.50	---	0.2885
3	2	2.60	---	0.1250
4	2	1.80	---	0.0865
5	16	----	7.7	2.9615
6	16	----	4.05	1.5570
7	--	----	---	------
8	2	1.20	---	0.0577
9	16	----	7.5	2.8800
10	16	----	3.9	1.5000
11	16	----	7.6	2.9230
12	16	----	4.2	1.6150

Table no.- 10

Run No.- 7 System- He-C_3H_6

Oven temp.: 110°C Cell current: 185 mA.
Detector temp: 37°C Carrier gas : Helium
Feed concn.: 1 % C_3H_6 Pressure of Carrier gas: 30 psig
Half cycle time: 15.0 mints. Purge ratio: 2.2
Initial saturation pressure for:-
Column 1= 60.0psia Column 2= 60.0 psia
Volumetric flow rate of:-
Feed @ 60.0 psia= 10.0cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height, h_0= 2.6 @ 16 Attenuation for C_3H_6

End of half cycle no.	Attn.	Peak height Top Product	Bottom Product	h/h_0
0	16	2.6	2.6	1.00
1	16	2.6	---	1.00
2	--	---	---	----
3	8	2.4	---	0.4615
4	8	1.1	---	0.2115
5	2	2.7	---	0.1298
6	16	----	8.2	3.1538
7	16	----	8.3	3.1923
8	--	----	---	------
9	--	----	---	------
10	2	1.8	---	0.0865
11	2	1.1	---	0.0529
12	1	1.8	---	0.0433
13	1	1.25	---	0.0301
14	1	1.25	---	0.0301
15	1	1.00	---	0.0264
16	16	----	8.2	3.1538
17	16	----	7.9	3.0380
18	--	----	---	------
19	16	----	7.9	3.0380
20	--	----	---	------
21	16	----	8.0	3.0770

Table no.- 11

Run No.- 8 System- He-C_3H_6

Oven temp.: 110° C Cell current: 185 mA.
Detector temp: 37° C Carrier gas : Helium
Feed concn.: 1 % C_3H_6 Pressure of Carrier gas: 30 psig
Half cycle time: 15.0 mints. Purge ratio: 1.5
Initial saturation pressure for:-
Column 1= 60.0psia Column 2= 60.0 psia
Volumetric flow rate of:-
Feed @ 60.0 psia= 10.0cc/min.
Purge @ 20.0 psia= 15.0 cc/min.
Feed peak height, h_0= 2.6 @ 16 Attenuation for C_3H_6

End of half cycle no.	Attn.	Peak height		h/h_0
		Top Product	Bottom Product	
0	16	2.6	2.6	1.00
1	16	2.6	---	1.00
2	16	1.2	---	0.4615
3	8	1.1	---	0.2115
4	4	1.3	---	0.1250
5	2	1.55	---	0.0745
6	2	1.00	---	0.04801
7	--	----	---	------
8	-	----	---	------
9	2	0.75	---	0.0306
10	16	----	7.3	2.8070
11	16	----	7.5	2.8850
12	--	----	---	------
13	--	----	---	------
14	16	----	7.1	2.7310
15	16	----	7.4	2.8460

Table no.-12

Run No.- 9 System-He-C_3H_6

Oven temp.:110° C Cell current: 185 mA.
Detector temp: 37° C Carrier gas : Helium
Feed concn.: 1 % C_3H_6 Pressure of Carrier gas: 30 psig
Half cycle time:15.0 mints. Purge ratio: 1.5
Initial saturation pressure for:-
Column 1= 60.0 psia Column 2= 60.0 psia
Volumetric flow rate of:-
Feed @ 60 psia= 10.0 cc/min.
Purge @ 20.0 psia= 15.0 cc/min.
Feed peak height, h_0= 2.6 @ 16 Attenuation for C_3H_6

End of half cycle no.	Attn.	Peak height Top Product	Bottom Product	h/h_0
0	16	2.6	2.6	1.00
1	16	---	7.2	2.769
2	16	1.2	---	0.4615
3	8	1.1	---	0.2115
4	4	1.25	---	0.1202
5	2	1.40	---	0.0673
6	2	0.80	---	0.0385
7	1	1.20	---	0.0289
8	1	0.85	---	0.0204
9	1	0.80	---	0.0192
10	1	0.65	---	0.0156
11	1	0.55	---	0.0132
12	1	0.50	---	0.0120
13	1	0.48	---	0.0115
14	1	0.45	---	0.0108
15	1	0.45	---	0.0108
16	1	0.40	---	0.0096
17	16	---	7.5	2.8850
18	16	---	7.8	3.0000

Table no.- 13

Run No.- 10 System- He-C_3H_6

Oven temp.: 110° C Cell current: 185 mA.
Detector temp: 37° C Carrier gas : Helium
Feed concn.: 1 % C_3H_6 Pressure of Carrier gas: 30 psig
Half cycle time: 15.0 mints. Purge ratio: 2.2
Initial saturation pressure for:-
Column 1= 60 psia Column 2= 60 psia
Volumetric flow rate of:-
Feed @ 60.0 psia= 10.0 cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height, h_0= 2.6 @ 16 Attenuation for C_3H_6

End of half cycle no.	Attn.	Peak height Top Product	Bottom Product	h/h_0
0	16	2.6	2.6	1.0
1	16	---	7.4	2.846
2	--	---	---	-----
3	16	0.8	---	0.3077
4	4	1.5	---	0.1442
5	2	2.0	---	0.0962
6	1	2.5	---	0.0601
7	1	1.9	---	0.0457
8	1	1.5	---	0.0361
9	1	1.3	---	0.0313
10	1	1.05	---	0.0252
11	1	0.85	---	0.0204
12	1	0.80	---	0.0192
13	1	0.70	---	0.0168
14	1	0.65	---	0.0156
15	1	0.60	---	0.0144
16	1	0.58	---	0.0139
17	1	0.54	---	0.0130
18	1	0.55	---	0.0132

Table no.- 14

Run No.- 11 System- He-CO_2-C_3H_6

Oven temp.:110°C Cell current:185 mA.

Pressure of carrier gas = 30 psig

Detector temp.:37°C Carrier gas: Helium

Attenuation = 16

Pressure absolute	Peak height	
psia	CO_2	C_3H_6
14.7	4.8	2.1
19.7	5.8	2.7
24.7	7.1	3.4
29.7	8.1	4.0
34.7	8.9	4.7

Table no.- 15

Run No.-12 System-He-CO_2-C_3H_6

Oven temp.:110°C Cell current:185 mA.
Detector temp.:37°C Carrier gas : Helium
Half cycle time: 15.0 mints. Pressure of carrier gas: 30 psig
Feed concn.:1%CO_2,1%C_3H_6 Purge ratio: 2.2
Initial saturation pressure for -
Column 1= 60.0 psia Column 2= 60.0 psia
Volumetric flow rate of:-
Feed @60.0 psia=10.0 cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height,h_0= 4.7 @ 16Attenuation for CO_2

= 2.0 @16 Attenuation for C_3H_6

End of half cycle no.	Attn.	Peak height Top Product CO_2	Peak height Top Product C_3H_6	Peak height Bottom Product CO_2	Peak height Bottom Product C_3H_6	h/h_0 CO_2	h/h_0 C_3H_6
0	16	4.7	2.0	4.7	2.0	1.0	1.0
1	16	4.7	2.0	---	---	1.0	1.0
2	16	2.0	0.9	---	---	0.4255	0.450
3	4	3.6	2.0	---	---	0.1915	0.250
4	4	1.5	1.10	---	---	0.0798	0.1375
5	2	1.6	1.5	---	---	0.0426	0.0938
6	2	0.7	0.9	---	---	0.0186	0.0563
7	1	0.8	1.2	---	---	0.0106	0.0375
8	1	0.4	0.6	---	---	0.0053	0.0186
9	1	0.4	0.6	---	---	0.0053	0.0186
10	32	---	---	6.3	3.1	2.681	3.100
11	32	---	---	5.3	3.0	2.255	3.000
12	32	---	---	4.9	3.0	2.085	3.000
13	32	---	---	3.6	2.9	1.532	2.900
14	32	---	---	2.8	2.8	1.192	2.800
15	32	---	---	2.7	2.9	1.149	2.900
16	32	---	---	1.6	2.8	0.681	2.800
17	32	---	---	1.5	2.8	0.638	2.800
18	32	---	---	1.3	2.8	0.565	2.800

Table no.-16

Run No.- 13 System-He-CO_2-C_3H_6

Oven temp.:110° C Cell current:185 mA.
Detector temp.:37° C Carrier gas : Helium
Half cycle time: 15.0 mints. Pressure of carrier gas: 30 psig
Feed concn.:1%CO_2,1%C_3H_6 Purge ratio: 2.2
Initial saturation pressure for -
Column 1= 60.0 psia Column 2= 60.0 psia
Volumetric flow rate of:-
Feed @ 60.0 psia= 10.0 cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height,h_0= 5.2 @ 16Attenuation for CO_2
= 2.1 @16 Attenuation for C_3H_6

		Peak height					
		Top Product		Bottom Product			
End of half cycle no.	Attn.	CO_2	C_3H_6	CO_2	C_3H_6	h/h_0	
						CO_2	C_3H_6
0	16	5.2	2.1	--	---	1.0	1.0
1	32	---	---	7.3	3.2	2.8076	3.0476
2	32	---	---	7.5	3.3	2.8846	3.1430
3	4	5.7	3.0	---	---	0.2740	0.3570
4	4	1.6	1.3	---	---	0.0769	0.1548
5	4	0.9	0.9	---	---	0.0433	0.1071
6	2	1.1	1.2	---	---	0.0264	0.0714
7	1	1.7	1.1	---	---	0.0204	0.0327
8	1	1.2	1.4	---	---	0.0144	0.0417
9	1	0.9	1.0	---	---	0.0108	0.0298
10	1	0.4	0.7	---	---	0.0048	0.0283
11	32	---	---	7.6	4.1	2.9230	3.9047
12	32	---	---	6.3	3.6	2.4230	3.4286
13	32	---	---	5.3	3.6	2.0384	3.4286
14	32	---	---	3.8	3.5	1.4615	3.3333
15	32	---	---	3.2	3.5	1.2310	3.3333
16	32	---	---	2.1	3.3	0.8077	3.1430
17	32	---	---	1.8	3.3	0.6923	3.1430
18	32	---	---	1.6	3.2	0.6154	3.0476
19	32	---	---	1.1	3.2	0.4231	3.0476
20	32	---	---	1.0	3.2	0.3846	3.0476
21	16	---	---	1.85	6.4	0.3558	3.0476
22	16	---	---	1.6	6.4	0.3077	3.0000
23	16	---	---	1.6	6.3	0.3077	3.0000

Table no.- 17

Run No.-14 System-He-CO_2-C_3H_6

Oven temp.:110°C Cell current:185 mA.
Detector temp.:37°C Carrier gas : Helium
Half cycle time: 8.0 mints. Pressure of carrier gas: 30 psig
Feed concn.:1%CO_2,1%C_3H_6 Purge ratio:1.5
Initial saturation pressure for -
Column 1=40.0 psia Column 2=40.0 psia
Volumetric flow rate of:-
Feed @ 40.0 psia= 14.7 cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height,h_0= 4.4 @ 16 Attenuation for CO_2

= 2.05 @16 Attenuation for C_3H_6

End of half cycle no.	Attn.	Peak height Top Product CO_2	 C_3H_6	 Bottom Product CO_2	 C_3H_6	h/h_0 CO_2	 C_3H_6
0	16	4.4	2.05	---	---	1.0	1.0
1	16	4.4	2.05	---	---	1.0	1.0
2	16	4.4	2.05	---	---	1.0	1.0
3	16	2.7	1.30	---	---	0.6136	0.634
4	16	1.7	1.05	---	---	0.3864	0.5122
5	16	1.1	0.84	---	---	0.2500	0.4097
6	4	3.3	2.60	---	---	0.1875	0.3170
7	4	2.0	1.90	---	---	0.1136	0.2317
8	4	1.3	1.8	---	---	0.0739	0.2195
9	2	2.2	3.60	---	---	0.0625	0.2195
10	2	1.7	2.30	---	---	0.0483	0.1402
11	2	1.2	4.70	---	---	0.0341	0.2866
12	2	1.0	3.80	---	---	0.0284	0.2317
13	1	1.7	7.30	---	---	0.0240	0.2226
14	1	1.3	5.70	---	---	0.0195	0.1738
15	32	---	----	4.2	1.7	1.9100	1.6580
16	32	---	----	4.2	1.75	1.9100	1.7070
17	32	---	----	4.35	1.75	1.9770	1.7070
18	32	---	----	4.30	1.75	1.9540	1.7070
19	32	---	----	4.00	1.30	1.8180	1.2680
20	32	---	----	3.90	1.90	1.7730	1.8540
21	32	---	----	4.40	1.90	2.0000	1.8540

Table no.-18

Run No.- 15 System-He-CO_2-C_3H_6

Oven temp.:110°C Cell current:185 mA.
Detector temp.:37°C Carrier gas : Helium
Half cycle time: 8.0 mints. Pressure of carrier gas: 30 psig
Feed concn.:1%CO_2,1%C_3H_6 Purge ratio: 1.0
Initial saturation pressure for -
Column 1= 40.0 psia Column 2= 40.0 psia
Volumetric flow rate of:-
Feed @ 40.0 psia= 14.7 cc/min.
Purge @ 20.0 psia= 22.0 cc/min.
Feed peak height,h_0=4.7 @ 16Attenuation for CO_2
=2.1 @16 Attenuation for C_3H_6

		Peak height					
		Top Product		Bottom Product		h/h_0	
End of half cycle no.	Attn.	CO_2	C_3H_6	CO_2	C_3H_6	CO_2	C_3H_6
0	16	4.7	2.1	---	---	1.0	1.0
1	32	---	---	3.1	1.5	1.319	1.428
2	32	---	---	4.1	1.9	1.745	1.810
3	16	1.7	1.0	---	---	0.362	0.476
4	16	1.0	0.8	---	---	0.213	0.381
5	4	2.8	2.9	---	---	0.149	0.3214
6	4	1.7	2.3	---	---	0.0904	0.2740
7	4	1.2	1.9	---	---	0.0640	0.2260
8	2	1.6	3.4	---	---	0.0430	0.2024
9	2	1.2	3.0	---	---	0.0319	0.1790
10	1	1.5	5.2	---	---	0.0199	0.1550
11	1	1.2	3.9	---	---	0.0159	0.1160
12	1	0.9	3.7	---	---	0.0120	0.1100
13	32	---	---	3.2	1.5	1.7450	1.7140
14	32	---	---	4.4	1.8	1.8720	1.9040
15	32	---	---	4.4	2.0	1.8720	1.9050
16	32	---	---	4.5	2.2	1.9150	2.0950
17	32	---	---	4.4	2.0	1.8720	1.9040
18	32	---	---	4.4	2.1	1.8720	2.0000
19	32	---	---	4.05	1.85	1.7230	1.7520
20	32	---	---	4.1	1.9	1.7450	1.8100
21	32	---	---	4.2	1.9	1.7450	1.8100
22	32	---	---	4.1	1.9	1.7450	1.8100

Table No: 19

Run no: 16 System: He-CO_2-C_3H_6

Saturation pressure - 20 psia

Detector temp. - 37°C

Oven temp. - 110°C

Cell current - 185 mA

Carrier gas - Helium

Attenuation - 16

Time	Peak height	
hr - min.	CO_2	C_3H_6
0 - 15	1.8	0.65
0 - 25	3.0	1.05
0 - 50	4.8	1.20
1 - 15	4.8	1.20
1 - 30	4.8	1.20
2 - 05	4.8	1.20
2 - 15	4.8	1.50
2 - 30	4.8	1.50
3 - 00	4.8	1.50
3 - 30	4.8	1.50
4 - 00	4.8	1.50
4 - 30	4.8	1.50
5 - 00	4.8	2.10
5 - 30	4.8	2.10
6 - 00	4.8	2.10

Table No: 20

Run no: 17 System: He-CO_2-C_3H_6

Saturation pressure - 60 psia

Detector temp. - 37°C

Oven temp. - 110°C

Cell Current - 185 mA

Carrier gas - Helium

Attenuation - 16

Time hr - min.	Peak height CO_2	 C_3H_6
0 - 15	1.0	0.15
0 - 25	1.7	0.25
0 - 45	1.7	0.30
0 - 55	1.7	0.30
1 - 10	3.05	0.30
1 - 30	4.8	0.35
2 - 00	4.8	0.35
2 - 30	4.8	0.35
3 - 00	4.8	0.35
3 - 30	4.8	0.35
4 - 00	4.8	0.35
4 - 30	4.8	0.35
5 - 00	4.8	0.35
5 - 30	4.8	0.35
6 - 00	4.8	0.75
6 - 30	4.8	1.15
7 - 00	4.8	1.60
7 - 30	4.8	2.10
8 - 00	4.8	2.10

Table No:21

THERMAL PARAMETRIC PUMP

- Physical parameters for use in computations -

Column diameter =1.0 cm

Column height = 90.0 cm.

Column cross-sectional area = 0.785 cm^2

Packing - Bio-Rad AG 11 AS-Resin

Density for silica gel 'ρ_s' = 0.761 gm/cm^3

Bed voidage 'ϵ' = 0.38

bed height = 90.0 cms.

Top reservoir dead volume 'V_T' = 5.0 cc.

bottom reservoir dead volume 'V_B' = 5.0 cc.

Operating temperature -

Hot temperature = 70.0°C

Cold temperature = 5.0°C

Equilibrium constants for system $NaCl-H_2O$-

An expression given by Swwed (1971) has been used:

$$M_T = a_m - b_m . T \text{ , where } a_m = 4.6347$$

$$b_m = 0.00993$$

Mass transfer coefficient for $NaCl-H_2O$ system-

Following expression has been used as given by Sweed (1971) -

$$\lambda = \alpha . v^{1-\beta}$$

where, $\beta = 0.7$

$\alpha = 0.328$ @ 70°C

$\alpha = 0.0736$ @ 5°C

Table No: 22

HEATLESS PARAMETRIC PUMP

- Physical parameters for use in computations -

Column diameter = 3.175 cm.

column diameter = 100.0 cm.

Column cross-sectional area = 7.913 cm^2

Packing - Silica gel type

density of silica gel ' ρ_s ' = 0.73 $gm./cm^3$

Particle diameter for 12-28 tylor mesh size = 0.1 cm

bed voidage ' ϵ ' = 0.42

bed height = 100 cm.

A constant value of equilibrium coefficient 'K_p' calculated at 60 psia has been used for both systems.

System	K_p
He - CO_2	52.7
He - C_3H_6	250.0

Operating temperature = 25.0°C

Mas transfer coefficient calculated from equation (C)- Appendix - I

System	flow rate (cc/min)				(min^{-1}) @ Pressure		
					60	40	20
He-CO_2	10.0	4.0	-0.51	2.2	0.49465	--	1.2746
He-CO_2	14.7	4.0	-0.51	1.0	--	0.72717	1.0461
He-C_3H_6	10.0	1.25	-0.51	2.2	0.13001	--	0.33515
He-C_3H_6	10.0	1.25	-0.51	1.5	0.13001	--	0.27780
He-C_3H_6	14.7	1.25	-0.51	1.0	--	0.19304	0.27507

Table : 23

$\phi_B = 0.01,\ \frac{\pi}{\omega} = 60\text{mins.},\ c_0 = 0.1\ \text{M}$

```
   M                      IND               TT
   1                       2              60,851

   I          YY                    XX                                NTR
   1      0,10000E-03           0,18271E-03                            1
   2      0,99739E-04           0,18150E-03                            2
   3      0,99441E-04           0,18026E-03                            2
   4      0,99108E-04           0,17899E-03                            2
   5      0,98742E-04           0,17770E-03                            2
   6      0,98345E-04           0,17640E-03                            2
   7      0,97919E-04           0,17508E-03                            2
   8      0,97467E-04           0,17375E-03                            2
   9      0,96990E-04           0,17242E-03                            2
  10      0,96491E-04           0,17109E-03                            2
  11      0,95972E-04           0,16976E-03                            2
  12      0,95434E-04           0,16843E-03                            1
  13      0,94880E-04           0,16711E-03                            1
  14      0,94313E-04           0,16580E-03                            1
  15      0,93733E-04           0,16450E-03                            1
  16      0,93143E-04           0,16322E-03                            1
  17      0,92544E-04           0,16195E-03                            1
  18      0,91939E-04           0,16070E-03                            1
  19      0,91328E-04           0,15948E-03                            1
  20      0,90713E-04           0,15827E-03                            1
  21      0,90097E-04           0,15708E-03                            1
  22      0,89479E-04           0,15592E-03                            1
  23      0,88862E-04           0,15478E-03                            1
  24      0,88246E-04           0,15367E-03                            1
  25      0,87633E-04           0,15258E-03                            1
  26      0,87024E-04           0,15152E-03                            1
  27      0,86419E-04           0,15049E-03                            1
  28      0,85820E-04           0,14948E-03                            1
  29      0,85228E-04           0,14850E-03                            1
  30      0,84643E-04           0,14755E-03                            1
  31      0,84065E-04           0,14662E-03                            1
  32      0,83496E-04           0,14572E-03                            1
  33      0,82937E-04           0,14485E-03                            1
  34      0,82387E-04           0,14400E-03                            1
  35      0,81846E-04           0,14318E-03                            1
  36      0,81317E-04           0,14239E-03                            1
  37      0,80798E-04           0,14162E-03                            1
  38      0,80290E-04           0,14088E-03                            1
  39      0,79793E-04           0,14017E-03                            1
  40      0,79308E-04           0,13948E-03                            1
  41      0,78834E-04           0,13881E-03                            1
  42      0,78372E-04           0,13817E-03                            1
  43      0,77922E-04           0,13755E-03                            1
  44      0,77484E-04           0,13695E-03                            1
  45      0,77058E-04           0,13637E-03                            1
  46      0,76643E-04           0,13582E-03                            1
  47      0,76241E-04           0,13529E-03                            1
  48      0,75850E-04           0,13478E-03                            1
  49      0,75471E-04           0,13429E-03                            1
  50      0,75103E-04           0,13382E-03                            1
  51      0,74747E-04           0,13337E-03                            1
  52      0,74402E-04           0,13293E-03                            1
  53      0,74069E-04           0,13252E-03                            1
  54      0,73746E-04           0,13212E-03                            1
  55      0,73434E-04           0,13174E-03                            1
  56      0,73133E-04           0,13137E-03                            1
  57      0,72843E-04           0,13102E-03                            1
  58      0,72562E-04           0,13069E-03                            1
  59      0,72292E-04           0,13037E-03                            1
  60      0,72031E-04           0,13006E-03                            1
  61      0,71790E-04           0,12977E-03                            1
  62      0,71538E-04           0,12949E-03                            1
  63      0,71305E-04           0,12922E-03                            1
  64      0,71081E-04           0,12897E-03                            1
  65      0,70866E-04           0,12872E-03                            1
  66      0,70659E-04           0,12849E-03                            1
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          M                        IND                 TT
          2                         1                60.077

          I            YY                          XX                           NTR
          1        0.73255E-04              0.89893E-04                          1
          2        0.73255E-04              0.89893E-04                          1
          3        0.73255E-04              0.89893E-04                          1
          4        0.73255E-04              0.89894E-04                          1
          5        0.73256E-04              0.89895E-04                          1
          6        0.73256E-04              0.89897E-04                          1
          7        0.73258E-04              0.89902E-04                          1
          8        0.73261E-04              0.89910E-04                          1
          9        0.73266E-04              0.89923E-04                          1
         10        0.73275E-04              0.89945E-04                          1
         11        0.73288E-04              0.89977E-04                          1
         12        0.73309E-04              0.90023E-04                          1
         13        0.73339E-04              0.90087E-04                          1
         14        0.73379E-04              0.90174E-04                          2
         15        0.73434E-04              0.90286E-04                          2
         16        0.73507E-04              0.90430E-04                          2
         17        0.73601E-04              0.90610E-04                          2
         18        0.73721E-04              0.90832E-04                          2
         19        0.73870E-04              0.91099E-04                          2
         20        0.74052E-04              0.91418E-04                          2
         21        0.74270E-04              0.91791E-04                          2
         22        0.74528E-04              0.92222E-04                          2
         23        0.74830E-04              0.92713E-04                          2
         24        0.75177E-04              0.93266E-04                          2
         25        0.75571E-04              0.93882E-04                          2
         26        0.76014E-04              0.94561E-04                          2
         27        0.76507E-04              0.95302E-04                          2
         28        0.77050E-04              0.96102E-04                          2
         29        0.77641E-04              0.96960E-04                          2
         30        0.78280E-04              0.97872E-04                          2
         31        0.78965E-04              0.98833E-04                          2
         32        0.79692E-04              0.99839E-04                          2
         33        0.80460E-04              0.10088E-03                          2
         34        0.81264E-04              0.10196E-03                          2
         35        0.82100E-04              0.10307E-03                          2
         36        0.82964E-04              0.10420E-03                          2
         37        0.83853E-04              0.10535E-03                          2
         38        0.84760E-04              0.10651E-03                          2
         39        0.85684E-04              0.10768E-03                          1
         40        0.86618E-04              0.10885E-03                          1
         41        0.87558E-04              0.11002E-03                          1
         42        0.88500E-04              0.11118E-03                          1
         43        0.89441E-04              0.11232E-03                          1
         44        0.90377E-04              0.11346E-03                          1
         45        0.91306E-04              0.11457E-03                          1
         46        0.92225E-04              0.11567E-03                          1
         47        0.93131E-04              0.11674E-03                          1
         48        0.94024E-04              0.11780E-03                          1
         49        0.94901E-04              0.11883E-03                          1
         50        0.95764E-04              0.11984E-03                          2
         51        0.96608E-04              0.12084E-03                          1
         52        0.97437E-04              0.12180E-03                          2
         53        0.98248E-04              0.12275E-03                          2
         54        0.99040E-04              0.12368E-03                          1
         55        0.99817E-04              0.12459E-03                          1
         56        0.10058E-03              0.12548E-03                          1
         57        0.10132E-03              0.12636E-03                          1
         58        0.10206E-03              0.12722E-03                          1
         59        0.10278E-03              0.12808E-03                          1
         60        0.10349E-03              0.12892E-03                          1
         61        0.10419E-03              0.12976E-03                          1
         62        0.10489E-03              0.13060E-03                          1
         63        0.10557E-03              0.13143E-03                          1
         64        0.10626E-03              0.13226E-03                          1
         65        0.10694E-03              0.13309E-03                          1
         66        0.10762E-03              0.13392E-03                          1

      YYAV
    0.12226E-03
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         M                    IND                  TT
         2                     2                 60,851


         I              YY                    XX                         NTR
         1        0.10798E-03         0.19739E-03                       1
         2        0.10770E-03         0.19604E-03                       2
         3        0.10736E-03         0.19464E-03                       2
         4        0.10702E-03         0.19320E-03                       2
         5        0.10662E-03         0.19172E-03                       2
         6        0.10618E-03         0.19020E-03                       2
         7        0.10570E-03         0.18865E-03                       2
         8        0.10519E-03         0.18708E-03                       2
         9        0.10465E-03         0.18548E-03                       2
        10        0.10408E-03         0.18385E-03                       2
        11        0.10348E-03         0.18222E-03                       2
        12        0.10285E-03         0.18056E-03                       2
        13        0.10220E-03         0.17890E-03                       2
        14        0.10153E-03         0.17722E-03                       2
        15        0.10083E-03         0.17554E-03                       2
        16        0.10012E-03         0.17385E-03                       1
        17        0.99385E-04         0.17215E-03                       1
        18        0.98636E-04         0.17045E-03                       1
        19        0.97872E-04         0.16876E-03                       1
        20        0.97095E-04         0.16706E-03                       1
        21        0.96305E-04         0.16536E-03                       1
        22        0.95504E-04         0.16367E-03                       1
        23        0.94694E-04         0.16197E-03                       1
        24        0.93874E-04         0.16029E-03                       1
        25        0.93048E-04         0.15860E-03                       1
        26        0.92214E-04         0.15693E-03                       1
        27        0.91375E-04         0.15526E-03                       1
        28        0.90531E-04         0.15360E-03                       1
        29        0.89683E-04         0.15194E-03                       1
        30        0.88833E-04         0.15030E-03                       1
        31        0.87979E-04         0.14866E-03                       1
        32        0.87125E-04         0.14704E-03                       1
        33        0.86269E-04         0.14543E-03                       1
        34        0.85414E-04         0.14384E-03                       1
        35        0.84559E-04         0.14226E-03                       1
        36        0.83706E-04         0.14069E-03                       1
        37        0.82855E-04         0.13915E-03                       1
        38        0.82007E-04         0.13762E-03                       1
        39        0.81162E-04         0.13612E-03                       1
        40        0.80322E-04         0.13463E-03                       1
        41        0.79487E-04         0.13317E-03                       1
        42        0.78658E-04         0.13174E-03                       1
        43        0.77836E-04         0.13033E-03                       1
        44        0.77021E-04         0.12895E-03                       1
        45        0.76214E-04         0.12760E-03                       1
        46        0.75416E-04         0.12627E-03                       1
        47        0.74627E-04         0.12498E-03                       1
        48        0.73849E-04         0.12372E-03                       1
        49        0.73081E-04         0.12249E-03                       1
        50        0.72324E-04         0.12129E-03                       1
        51        0.71579E-04         0.12012E-03                       1
        52        0.70847E-04         0.11899E-03                       1
        53        0.70128E-04         0.11789E-03                       1
        54        0.69422E-04         0.11682E-03                       2
        55        0.68729E-04         0.11579E-03                       2
        56        0.68050E-04         0.11479E-03                       2
        57        0.67386E-04         0.11381E-03                       2
        58        0.66736E-04         0.11287E-03                       2
        59        0.66101E-04         0.11196E-03                       2
        60        0.65481E-04         0.11109E-03                       2
        61        0.64876E-04         0.11024E-03                       2
        62        0.64287E-04         0.10942E-03                       2
        63        0.63712E-04         0.10863E-03                       2
        64        0.63152E-04         0.10786E-03                       2
        65        0.62608E-04         0.10713E-03                       2
        66        0.62078E-04         0.10642E-03                       2


           YYAV
     ✓ 0.54911E-04
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  M                    IND                  TT
  5                     1                 60,077

  I          YY                    XX                         NTR
  1     0,41034E-04           0,50354E-04                      1
  2     0,41034E-04           0,50354E-04                      1
  3     0,41034E-04           0,50354E-04                      1
  4     0,41035E-04           0,50355E-04                      1
  5     0,41035E-04           0,50356E-04                      1
  6     0,41035E-04           0,50357E-04                      1
  7     0,41037E-04           0,50361E-04                      1
  8     0,41039E-04           0,50368E-04                      1
  9     0,41043E-04           0,50379E-04                      1
 10     0,41050E-04           0,50397E-04                      1
 11     0,41062E-04           0,50424E-04                      1
 12     0,41079E-04           0,50463E-04                      1
 13     0,41103E-04           0,50517E-04                      2
 14     0,41137E-04           0,50589E-04                      2
 15     0,41183E-04           0,50685E-04                      2
 16     0,41245E-04           0,50808E-04                      2
 17     0,41327E-04           0,50964E-04                      2
 18     0,41430E-04           0,51158E-04                      2
 19     0,41560E-04           0,51394E-04                      2
 20     0,41719E-04           0,51677E-04                      2
 21     0,41912E-04           0,52011E-04                      2
 22     0,42143E-04           0,52401E-04                      2
 23     0,42414E-04           0,52850E-04                      2
 24     0,42729E-04           0,53362E-04                      2
 25     0,43093E-04           0.53938E-04                      3
 26     0,43506E-04           0,54581E-04                      3
 27     0,43970E-04           0,55292E-04                      3
 28     0,44486E-04           0,56071E-04                      3
 29     0,45056E-04           0,56916E-04                      3
 30     0,45679E-04           0,57827E-04                      3
 31     0,46356E-04           0,58804E-04                      3
 32     0,47084E-04           0,59842E-04                      2
 33     0,47864E-04           0,60937E-04                      2
 34     0,48693E-04           0,62089E-04                      2
 35     0,49571E-04           0,63293E-04                      2
 36     0,50494E-04           0,64547E-04                      2
 37     0,51460E-04           0,65848E-04                      2
 38     0,52466E-04           0.67191E-04                      2
 39     0,53513E-04           0,68572E-04                      2
 40     0,54593E-04           0,69990E-04                      2
 41     0,55705E-04           0,71440E-04                      2
 42     0,56848E-04           0,72919E-04                      2
 43     0,58017E-04           0,74424E-04                      2
 44     0,59211E-04           0,75954E-04                      2
 45     0,60428E-04           0,77505E-04                      2
 46     0,61665E-04           0,79077E-04                      2
 47     0,62921E-04           0,80666E-04                      2
 48     0,64194E-04           0,82273E-04                      2
 49     0,65482E-04           0,83895E-04                      2
 50     0,66785E-04           0,85532E-04                      2
 51     0,68102E-04           0,87184E-04                      2
 52     0,69433E-04           0,88849E-04                      1
 53     0,70774E-04           0,90530E-04                      2
 54     0,72129E-04           0,92224E-04                      1
 55     0,73496E-04           0,93932E-04                      1
 56     0,74874E-04           0,95654E-04                      1
 57     0,76263E-04           0,97390E-04                      1
 58     0,77664E-04           0,99142E-04                      1
 59     0,79077E-04           0,10091E-03                      1
 60     0,80502E-04           0,10269E-03                      1
 61     0,81939E-04           0,10449E-03                      1
 62     0,83339E-04           0,10630E-03                      1
 63     0,84851E-04           0,10813E-03                      1
 64     0,86326E-04           0,10997E-03                      1
 65     0,87814E-04           0,11184E-03                      1
 66     0,89316E-04           0,11371E-03                      1

   YYAV
 0,12067E-03
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    M                IND               TT
    5                 2              60,851

    I          YY                  XX                         NTR
    1     0,10920E-03         0,19808E-03                      1
    2     0,10883E-03         0,19616E-03                      2
    3     0,10839E-03         0,19421E-03                      2
    4     0,10790E-03         0,19219E-03                      2
    5     0,10735E-03         0,19010E-03                      2
    6     0,10674E-03         0,18795E-03                      2
    7     0,10608E-03         0,18574E-03                      2
    8     0,10537E-03         0,18349E-03                      2
    9     0,10461E-03         0,18119E-03                      2
   10     0,10381E-03         0,17885E-03                      2
   11     0,10296E-03         0,17648E-03                      2
   12     0,10208E-03         0,17407E-03                      2
   13     0,10115E-03         0,17165E-03                      2
   14     0,10019E-03         0,16920E-03                      2
   15     0,99197E-04         0,16674E-03                      2
   16     0,98173E-04         0,16426E-03                      2
   17     0,97120E-04         0,16178E-03                      2
   18     0,96040E-04         0,15929E-03                      2
   19     0,94937E-04         0,15679E-03                      2
   20     0,93813E-04         0,15430E-03                      2
   21     0,92668E-04         0,15181E-03                      2
   22     0,91506E-04         0,14932E-03                      1
   23     0,90329E-04         0,14684E-03                      1
   24     0,89138E-04         0,14437E-03                      1
   25     0,87935E-04         0,14191E-03                      1
   26     0,86722E-04         0,13947E-03                      1
   27     0,85501E-04         0,13705E-03                      1
   28     0,84273E-04         0,13464E-03                      1
   29     0,83041E-04         0,13225E-03                      1
   30     0,81805E-04         0,12989E-03                      1
   31     0,80567E-04         0,12755E-03                      1
   32     0,79329E-04         0,12523E-03                      1
   33     0,78091E-04         0,12295E-03                      1
   34     0,76857E-04         0,12069E-03                      1
   35     0,75625E-04         0,11847E-03                      1
   36     0,74399E-04         0,11628E-03                      1
   37     0,73179E-04         0,11412E-03                      1
   38     0,71967E-04         0,11200E-03                      1
   39     0,70763E-04         0,10992E-03                      1
   40     0,69569E-04         0,10788E-03                      1
   41     0,68385E-04         0,10588E-03                      1
   42     0,67214E-04         0,10392E-03                      1
   43     0,66056E-04         0.10200E-03                      2
   44     0,64911E-04         0,10013E-03                      2
   45     0,63781E-04         0.98305E-04                      2
   46     0,62667E-04         0,96525E-04                      2
   47     0,61570E-04         0,94791E-04                      2
   48     0,60490E-04         0,93104E-04                      2
   49     0,59426E-04         0,91464E-04                      2
   50     0,58385E-04         0,89871E-04                      2
   51     0,57361E-04         0,88325E-04                      2
   52     0,56358E-04         0,86827E-04                      2
   53     0,55375E-04         0,85374E-04                      2
   54     0,54412E-04         0,83968E-04                      2
   55     0,53471E-04         0,82608E-04                      2
   56     0,52551E-04         0,81292E-04                      2
   57     0,51653E-04         0,80021E-04                      2
   58     0,50777E-04         0,78793E-04                      2
   59     0,49923E-04         0,77607E-04                      2
   60     0,49091E-04         0,76463E-04                      2
   61     0,48281E-04         0,75360E-04                      2
   62     0,47492E-04         0,74297E-04                      2
   63     0,46726E-04         0,73273E-04                      2
   64     0,45981E-04         0,72287E-04                      2
   65     0,45256E-04         0,71338E-04                      2
✓  66     0,44557E-04         0,70425E-04                      2

✓    YYAV
   0,35076E-04
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      N                    IND                    TT
      8                     1                   60.077

      I           YY                    XX                              NTR
      1      0.29738E-04          0.36492E-04                           1
      2      0.29738E-04          0.36492E-04                           1
      3      0.29738E-04          0.36492E-04                           1
      4      0.29738E-04          0.36493E-04                           1
      5      0.29738E-04          0.36493E-04                           1
      6      0.29739E-04          0.36495E-04                           1
      7      0.29740E-04          0.36498E-04                           1
      8      0.29742E-04          0.36503E-04                           1
      9      0.29745E-04          0.36513E-04                           1
     10      0.29751E-04          0.36528E-04                           1
     11      0.29761E-04          0.36550E-04                           1
     12      0.29774E-04          0.36583E-04                           2
     13      0.29795E-04          0.36627E-04                           2
     14      0.29823E-04          0.36688E-04                           2
     15      0.29862E-04          0.36768E-04                           2
     16      0.29914E-04          0.36872E-04                           2
     17      0.29982E-04          0.37003E-04                           2
     18      0.30069E-04          0.37166E-04                           2
     19      0.30178E-04          0.37365E-04                           2
     20      0.30313E-04          0.37604E-04                           2
     21      0.30476E-04          0.37888E-04                           2
     22      0.30672E-04          0.38220E-04                           3
     23      0.30904E-04          0.38604E-04                           3
     24      0.31174E-04          0.39042E-04                           3
     25      0.31484E-04          0.39537E-04                           3
     26      0.31837E-04          0.40090E-04                           3
     27      0.32235E-04          0.40704E-04                           3
     28      0.32675E-04          0.41377E-04                           3
     29      0.33171E-04          0.42111E-04                           3
     30      0.33710E-04          0.42905E-04                           3
     31      0.34298E-04          0.43757E-04                           3
     32      0.34934E-04          0.44668E-04                           3
     33      0.35617E-04          0.45635E-04                           3
     34      0.36347E-04          0.46656E-04                           3
     35      0.37122E-04          0.47728E-04                           3
     36      0.37939E-04          0.48849E-04                           2
     37      0.38798E-04          0.50016E-04                           2
     38      0.39698E-04          0.51226E-04                           2
     39      0.40635E-04          0.52478E-04                           2
     40      0.41609E-04          0.53769E-04                           2
     41      0.42617E-04          0.55096E-04                           2
     42      0.43657E-04          0.56457E-04                           2
     43      0.44727E-04          0.57851E-04                           2
     44      0.45826E-04          0.59275E-04                           2
     45      0.46952E-04          0.60727E-04                           2
     46      0.48103E-04          0.62206E-04                           2
     47      0.49278E-04          0.63712E-04                           2
     48      0.50475E-04          0.65242E-04                           2
     49      0.51695E-04          0.66796E-04                           2
     50      0.52935E-04          0.68374E-04                           2
     51      0.54196E-04          0.69975E-04                           2
     52      0.55476E-04          0.71599E-04                           2
     53      0.56775E-04          0.73246E-04                           2
     54      0.58094E-04          0.74916E-04                           2
     55      0.59431E-04          0.76608E-04                           2
     56      0.60787E-04          0.78324E-04                           2
     57      0.62163E-04          0.80063E-04                           2
     58      0.63557E-04          0.81826E-04                           2
     59      0.64970E-04          0.83612E-04                           2
     60      0.66402E-04          0.85423E-04                           2
     61      0.67854E-04          0.87257E-04                           2
     62      0.69325E-04          0.89116E-04                           2
     63      0.70816E-04          0.90999E-04                           2
     64      0.72327E-04          0.92907E-04                           2
     65      0.73857E-04          0.94839E-04                           2
     66      0.75407E-04          0.96796E-04                           2

        YYAV
     0.10897E-03
```

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      M                    IND              TT
      8                     2             60,851

      I          YY                       XX                           NTR
      1     0,10415E-03            0,18811E-03                          1
      2     0,10375E-03            0,18601E-03                          2
      3     0,10326E-03            0,18391E-03                          2
      4     0,10274E-03            0,18172E-03                          2
      5     0,10215E-03            0,17947E-03                          2
      6     0,10149E-03            0,17715E-03                          2
      7     0,10078E-03            0,17477E-03                          2
      8     0,10001E-03            0,17235E-03                          2
      9     0,99194E-04            0.16988E-03                          2
     10     0,98328E-04            0,16737E-03                          2
     11     0,97415E-04            0,16482E-03                          2
     12     0,96460E-04            0,16225E-03                          2
     13     0,95465E-04            0,15966E-03                          2
     14     0,94433E-04            0,15705E-03                          2
     15     0,93365E-04            0,15442E-03                          2
     16     0,92266E-04            0.15179E-03                          2
     17     0,91138E-04            0,14915E-03                          2
     18     0,89983E-04            0,14650E-03                          2
     19     0,88803E-04            0,14386E-03                          2
     20     0,87602E-04            0,14123E-03                          2
     21     0,86381E-04            0,13860E-03                          2
     22     0,85143E-04            0,13598E-03                          1
     23     0,83890E-04            0,13337E-03                          1
     24     0,82625E-04            0,13078E-03                          1
     25     0,81349E-04            0,12821E-03                          1
     26     0,80064E-04            0,12566E-03                          1
     27     0,78772E-04            0,12313E-03                          1
     28     0,77476E-04            0,12063E-03                          1
     29     0,76176E-04            0,11815E-03                          1
     30     0,74876E-04            0,11571E-03                          1
     31     0,73575E-04            0,11329E-03                          1
     32     0,72276E-04            0,11091E-03                          1
     33     0,70980E-04            0,10856E-03                          1
     34     0,69690E-04            0,10624E-03                          1
     35     0,68405E-04            0,10396E-03                          1
     36     0,67128E-04            0,10173E-03                          1
     37     0,65860E-04            0.99529E-04                          1
     38     0,64602E-04            0,97373E-04                          1
     39     0,63355E-04            0,95260E-04                          1
     40     0,62120E-04            0,93191E-04                          2
     41     0,60898E-04            0,91167E-04                          2
     42     0,59691E-04            0.89190E-04                          2
     43     0,58500E-04            0,87259E-04                          2
     44     0,57325E-04            0,85376E-04                          2
     45     0,56167E-04            0,83542E-04                          2
     46     0,55027E-04            0,81756E-04                          2
     47     0,53906E-04            0,80019E-04                          2
     48     0,52805E-04            0,78332E-04                          2
     49     0,51724E-04            0,76694E-04                          2
     50     0,50664E-04            0,75105E-04                          2
     51     0,49625E-04            0,73565E-04                          2
     52     0,48607E-04            0,72073E-04                          2
     53     0,47612E-04            0,70629E-04                          2
     54     0,46639E-04            0,69233E-04                          2
     55     0,45685E-04            0,67883E-04                          2
     56     0,44762E-04            0,66578E-04                          2
     57     0,43858E-04            0,65319E-04                          2
     58     0,42977E-04            0,64104E-04                          2
     59     0,42119E-04            0,62932E-04                          2
     60     0,41284E-04            0,61803E-04                          2
     61     0,40472E-04            0,60714E-04                          2
     62     0,39683E-04            0,59666E-04                          2
     63     0,38917E-04            0,58657E-04                          2
     64     0,38173E-04            0,57687E-04                          2
     65     0,37451E-04            0,56753E-04                          2
     66     0,36752E-04            0,55856E-04                          2


      YYAV
  0,27314E-04
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   M                       IND                   TT
  11                        1                  60.077

   I            YY                     XX                       NTR
   1       0.25045E-04            0.30733E-04                    1
   2       0.25045E-04            0.30733E-04                    1
   3       0.25045E-04            0.30734E-04                    1
   4       0.25045E-04            0.30734E-04                    1
   5       0.25045E-04            0.30734E-04                    1
   6       0.25046E-04            0.30736E-04                    1
   7       0.25047E-04            0.30739E-04                    1
   8       0.25049E-04            0.30744E-04                    1
   9       0.25052E-04            0.30752E-04                    1
  10       0.25057E-04            0.30765E-04                    1
  11       0.25066E-04            0.30786E-04                    1
  12       0.25078E-04            0.30815E-04                    2
  13       0.25096E-04            0.30856E-04                    2
  14       0.25122E-04            0.30911E-04                    2
  15       0.25157E-04            0.30983E-04                    2
  16       0.25205E-04            0.31078E-04                    2
  17       0.25266E-04            0.31197E-04                    2
  18       0.25345E-04            0.31346E-04                    2
  19       0.25445E-04            0.31527E-04                    2
  20       0.25567E-04            0.31745E-04                    2
  21       0.25717E-04            0.32005E-04                    3
  22       0.25897E-04            0.32309E-04                    3
  23       0.26108E-04            0.32661E-04                    3
  24       0.26355E-04            0.33063E-04                    3
  25       0.26639E-04            0.33518E-04                    3
  26       0.26964E-04            0.34026E-04                    3
  27       0.27329E-04            0.34591E-04                    3
  28       0.27738E-04            0.35212E-04                    3
  29       0.28191E-04            0.35890E-04                    3
  30       0.28689E-04            0.36624E-04                    3
  31       0.29232E-04            0.37414E-04                    3
  32       0.29820E-04            0.38259E-04                    3
  33       0.30453E-04            0.39158E-04                    3
  34       0.31130E-04            0.40108E-04                    3
  35       0.31851E-04            0.41109E-04                    3
  36       0.32613E-04            0.42157E-04                    3
  37       0.33416E-04            0.43252E-04                    3
  38       0.34257E-04            0.44390E-04                    2
  39       0.35136E-04            0.45567E-04                    2
  40       0.36050E-04            0.46785E-04                    2
  41       0.36998E-04            0.48039E-04                    2
  42       0.37979E-04            0.49329E-04                    2
  43       0.38991E-04            0.50652E-04                    2
  44       0.40032E-04            0.52007E-04                    2
  45       0.41100E-04            0.53392E-04                    2
  46       0.42195E-04            0.54807E-04                    2
  47       0.43316E-04            0.56250E-04                    2
  48       0.44461E-04            0.57720E-04                    2
  49       0.45630E-04            0.59218E-04                    2
  50       0.46821E-04            0.60741E-04                    2
  51       0.48035E-04            0.62291E-04                    2
  52       0.49271E-04            0.63866E-04                    2
  53       0.50528E-04            0.65467E-04                    2
  54       0.51806E-04            0.67094E-04                    2
  55       0.53106E-04            0.68747E-04                    2
  56       0.54427E-04            0.70426E-04                    2
  57       0.55769E-04            0.72132E-04                    2
  58       0.57133E-04            0.73864E-04                    2
  59       0.58518E-04            0.75623E-04                    2
  60       0.59925E-04            0.77408E-04                    2
  61       0.61354E-04            0.79222E-04                    2
  62       0.62805E-04            0.81062E-04                    2
  63       0.64277E-04            0.82930E-04                    2
  64       0.65772E-04            0.84825E-04                    2
  65       0.67299E-04            0.86747E-04                    2
  66       0.68829E-04            0.88696E-04                    2

   YYAV
0.10267E-03
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    N                      IND                     TT
   14                       1                    60.077

    I            YY                      XX                          NTR
    1       0,23008E-04            0,28234E-04                        1
    2       0,23008E-04            0,28234E-04                        1
    3       0,23008E-04            0,28234E-04                        1
    4       0,23008E-04            0,28234E-04                        1
    5       0,23008E-04            0,28235E-04                        1
    6       0,23009E-04            0,28236E-04                        1
    7       0,23010E-04            0,28239E-04                        1
    8       0,23011E-04            0,28243E-04                        1
    9       0,23014E-04            0,28252E-04                        1
   10       0,23020E-04            0,28264E-04                        1
   11       0,23028E-04            0,28284E-04                        1
   12       0,23040E-04            0,28312E-04                        2
   13       0,23057E-04            0,28350E-04                        2
   14       0,23081E-04            0,28403E-04                        2
   15       0,23115E-04            0,28472E-04                        2
   16       0,23160E-04            0,28562E-04                        2
   17       0,23219E-04            0,28676E-04                        2
   18       0,23295E-04            0,28818E-04                        2
   19       0,23390E-04            0,28992E-04                        2
   20       0,23507E-04            0,29201E-04                        2
   21       0,23651E-04            0,29450E-04                        3
   22       0,23823E-04            0,29741E-04                        3
   23       0,24025E-04            0,30079E-04                        3
   24       0,24262E-04            0,30464E-04                        3
   25       0,24534E-04            0,30901E-04                        3
   26       0,24845E-04            0,31390E-04                        3
   27       0,25196E-04            0,31932E-04                        3
   28       0,25589E-04            0,32529E-04                        3
   29       0,26024E-04            0,33182E-04                        3
   30       0,26503E-04            0,33889E-04                        3
   31       0,27026E-04            0,34650E-04                        3
   32       0,27593E-04            0,35466E-04                        3
   33       0,28203E-04            0,36333E-04                        3
   34       0,28857E-04            0,37252E-04                        3
   35       0,29552E-04            0,38220E-04                        3
   36       0,30289E-04            0,39235E-04                        3
   37       0,31066E-04            0,40295E-04                        3
   38       0,31880E-04            0,41399E-04                        2
   39       0,32732E-04            0,42543E-04                        2
   40       0,33619E-04            0,43726E-04                        2
   41       0,34535E-04            0,44946E-04                        2
   42       0,35493E-04            0,46202E-04                        2
   43       0,36477E-04            0,47492E-04                        2
   44       0,37190E-04            0,48815E-04                        2
   45       0,38532E-04            0,50168E-04                        2
   46       0,39601E-04            0,51552E-04                        2
   47       0,40396E-04            0,52965E-04                        2
   48       0,41816E-04            0,54407E-04                        2
   49       0,42960E-04            0,55876E-04                        2
   50       0,44128E-04            0,57372E-04                        2
   51       0,45319E-04            0,58896E-04                        2
   52       0,46532E-04            0,60447E-04                        2
   53       0,47768E-04            0,62025E-04                        2
   54       0,49027E-04            0,63630E-04                        2
   55       0,50307E-04            0,65262E-04                        2
   56       0,51610E-04            0,66921E-04                        2
   57       0,52935E-04            0,68608E-04                        2
   58       0,54283E-04            0,70323E-04                        2
   59       0,55653E-04            0,72066E-04                        2
   60       0,57045E-04            0,73837E-04                        2
   61       0,58461E-04            0,75637E-04                        2
   62       0,59899E-04            0,77465E-04                        2
   63       0,61361E-04            0,79322E-04                        2
   64       0,62846E-04            0,81207E-04                        2
   65       0,64354E-04            0,83121E-04                        2
   66       0,65885E-04            0,85063E-04                        2

      YYAV
   0,99774E-04
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         M                      IND                  TT
        14                       2                 60,851

         I              YY                     XX                            NTR
         1        0,99969E-04           0,18000E-03                           1
         2        0,99550E-04           0,17781E-03                           2
         3        0,99039E-04           0,17563E-03                           2
         4        0,98503E-04           0,17337E-03                           2
         5        0,97883E-04           0,17103E-03                           2
         6        0,97203E-04           0,16864E-03                           2
         7        0,96464E-04           0,16618E-03                           2
         8        0,95669E-04           0,16368E-03                           2
         9        0,94822E-04           0,16113E-03                           2
        10        0,93925E-04           0,15854E-03                           2
        11        0,92982E-04           0,15593E-03                           2
        12        0,91995E-04           0,15328E-03                           2
        13        0,90967E-04           0,15062E-03                           2
        14        0,89901E-04           0,14794E-03                           2
        15        0,88801E-04           0,14525E-03                           2
        16        0,87668E-04           0,14255E-03                           2
        17        0,86506E-04           0,13985E-03                           2
        18        0,85318E-04           0,13714E-03                           2
        19        0,84105E-04           0,13445E-03                           2
        20        0,82871E-04           0,13176E-03                           2
        21        0,81619E-04           0,12908E-03                           2
        22        0,80350E-04           0,12642E-03                           1
        23        0,79066E-04           0,12378E-03                           1
        24        0,77771E-04           0,12115E-03                           1
        25        0,76467E-04           0,11855E-03                           1
        26        0,75155E-04           0,11597E-03                           1
        27        0,73837E-04           0,11341E-03                           1
        28        0,72516E-04           0,11089E-03                           1
        29        0,71194E-04           0,10840E-03                           1
        30        0,69871E-04           0,10594E-03                           1
        31        0,68550E-04           0,10351E-03                           1
        32        0,67232E-04           0,10112E-03                           1
        33        0,65919E-04           0,98767E-04                           1
        34        0,64613E-04           0,96454E-04                           1
        35        0,63314E-04           0,94181E-04                           1
        36        0,62025E-04           0,91950E-04                           1
        37        0,60746E-04           0,89762E-04                           1
        38        0,59478E-04           0,87619E-04                           2
        39        0,58223E-04           0,85520E-04                           2
        40        0,56982E-04           0,83468E-04                           2
        41        0,55755E-04           0.81464E-04                           2
        42        0,54545E-04           0,79507E-04                           2
        43        0,53352E-04           0,77599E-04                           2
        44        0,52176E-04           0,75740E-04                           2
        45        0,51019E-04           0,73931E-04                           2
        46        0,49882E-04           0,72172E-04                           2
        47        0,48764E-04           0,70463E-04                           2
        48        0,47667E-04           0,68803E-04                           2
        49        0,46592E-04           0,67194E-04                           2
        50        0,45538E-04           0,65634E-04                           2
        51        0,44506E-04           0,64123E-04                           2
        52        0,43497E-04           0,62660E-04                           2
        53        0,42510E-04           0,61246E-04                           2
        54        0,41547E-04           0,59879E-04                           2
        55        0,40607E-04           0,58559E-04                           2
        56        0,39690E-04           0,57284E-04                           2
        57        0,38797E-04           0,56054E-04                           2
        58        0,37927E-04           0,54867E-04                           2
        59        0,37081E-04           0,53724E-04                           2
        60        0,36258E-04           0,52622E-04                           2
        61        0,35459E-04           0,51561E-04                           2
        62        0,34682E-04           0,50540E-04                           2
        63        0,33929E-04           0,49558E-04                           2
        64        0,33198E-04           0,48614E-04                           2
        65        0,32489E-04           0,47706E-04                           2
        66        0,31803E-04           0,46833E-04                           2


          YYAV
       0.22550E-04
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       M                       IND                      TT
      17                        1                     60,077

       I             YY                        XX                              NTR
       1        0,22114E-04               0,27137E-04                          1
       2        0,22114E-04               0,27137E-04                          1
       3        0,22114E-04               0,27137E-04                          1
       4        0,22114E-04               0,27137E-04                          1
       5        0,22115E-04               0,27138E-04                          1
       6        0,22115E-04               0,27139E-04                          1
       7        0,22116E-04               0,27142E-04                          1
       8        0,22117E-04               0,27146E-04                          1
       9        0,22120E-04               0,27154E-04                          1
      10        0,22126E-04               0,27167E-04                          1
      11        0,22133E-04               0,27186E-04                          1
      12        0,22145E-04               0,27213E-04                          2
      13        0,22162E-04               0,27251E-04                          2
      14        0,22186E-04               0,27302E-04                          2
      15        0,22219E-04               0,27370E-04                          2
      16        0,22263E-04               0,27458E-04                          2
      17        0,22321E-04               0,27570E-04                          2
      18        0,22395E-04               0,27709E-04                          2
      19        0,22488E-04               0.27880E-04                          2
      20        0,22604E-04               0,28084E-04                          3
      21        0,22744E-04               0,28328E-04                          3
      22        0,22912E-04               0,28614E-04                          3
      23        0,23111E-04               0,28945E-04                          3
      24        0,23343E-04               0,29324E-04                          3
      25        0,23611E-04               0,29752E-04                          3
      26        0,23916E-04               0,30232E-04                          3
      27        0,24260E-04               0,30765E-04                          3
      28        0,24646E-04               0,31351E-04                          3
      29        0,25073E-04               0,31992E-04                          3
      30        0,25544E-04               0,32688E-04                          3
      31        0,26058E-04               0,33437E-04                          3
      32        0,26615E-04               0,34239E-04                          3
      33        0,27215E-04               0,35092E-04                          3
      34        0,27358E-04               0,35997E-04                          3
      35        0,28543E-04               0,36950E-04                          3
      36        0,29268E-04               0,37950E-04                          3
      37        0,30033E-04               0,38995E-04                          3
      38        0,30836E-04               0,40084E-04                          3
      39        0,31675E-04               0,41213E-04                          2
      40        0,32550E-04               0,42381E-04                          2
      41        0,33458E-04               0,43586E-04                          2
      42        0,34399E-04               0,44827E-04                          2
      43        0,35371E-04               0,46102E-04                          2
      44        0,36373E-04               0,47410E-04                          2
      45        0,37402E-04               0,48749E-04                          2
      46        0,38460E-04               0,50119E-04                          2
      47        0,39543E-04               0,51519E-04                          2
      48        0,40651E-04               0,52947E-04                          2
      49        0,41785E-04               0,54404E-04                          2
      50        0,42942E-04               0,55888E-04                          2
      51        0,44122E-04               0,57400E-04                          2
      52        0,45326E-04               0,58940E-04                          2
      53        0,46552E-04               0,60507E-04                          2
      54        0,47802E-04               0,62102E-04                          2
      55        0,49073E-04               0,63725E-04                          2
      56        0,50368E-04               0,65375E-04                          2
      57        0,51685E-04               0,67054E-04                          2
      58        0,53025E-04               0,68760E-04                          2
      59        0,54388E-04               0,70496E-04                          2
      60        0,55774E-04               0,72260E-04                          2
      61        0,57184E-04               0,74053E-04                          2
      62        0,58616E-04               0,75876E-04                          2
      63        0,60073E-04               0,77727E-04                          2
      64        0,61553E-04               0,79608E-04                          2
      65        0,63056E-04               0,81517E-04                          2
      66        0,64583E-04               0,83455E-04                          2

       YYAV
   0,98486E-04
```

```
      M                      IND                  TT
     17                       2                 60,851

      I              YY                    XX                        NTR
      1        0,99378E-04           0,17885E-03                      1
      2        0,98957E-04           0,17666E-03                      2
      3        0,98464E-04           0.17447E-03                      2
      4        0,97905E-04           0.17220E-03                      2
      5        0,97282E-04           0.16985E-03                      2
      6        0,96598E-04           0,16744E-03                      2
      7        0,95856E-04           0,16498E-03                      2
      8        0,95058E-04           0.16246E-03                      2
      9        0,94207E-04           0.15991E-03                      2
     10        0,93307E-04           0,15731E-03                      2
     11        0,92360E-04           0,15469E-03                      2
     12        0,91369E-04           0.15203E-03                      2
     13        0,90337E-04           0,14936E-03                      2
     14        0,89267E-04           0,14667E-03                      2
     15        0,88162E-04           0.14397E-03                      2
     16        0,87025E-04           0,14127E-03                      2
     17        0,85859E-04           0,13856E-03                      2
     18        0,84667E-04           0,13585E-03                      2
     19        0,83450E-04           0,13315E-03                      2
     20        0,82213E-04           0,13045E-03                      2
     21        0,80956E-04           0,12777E-03                      2
     22        0,79683E-04           0,12511E-03                      1
     23        0,78396E-04           0.12246E-03                      1
     24        0,77098E-04           0,11933E-03                      1
     25        0,75790E-04           0,11722E-03                      1
     26        0,74475E-04           0,11464E-03                      1
     27        0,73155E-04           0,11208E-03                      1
     28        0,71831E-04           0,10956E-03                      1
     29        0,70505E-04           0,10706E-03                      1
     30        0,69180E-04           0,10460E-03                      1
     31        0,67857E-04           0,10217E-03                      1
     32        0,66537E-04           0,99783E-04                      1
     33        0,65223E-04           0,97431E-04                      1
     34        0,63915E-04           0,95119E-04                      1
     35        0,62615E-04           0,92848E-04                      1
     36        0,61324E-04           0,90619E-04                      1
     37        0,60044E-04           0,88433E-04                      1
     38        0,58775E-04           0,86292E-04                      2
     39        0,57520E-04           0,84197E-04                      2
     40        0,56279E-04           0,82148E-04                      2
     41        0,55052E-04           0,80147E-04                      2
     42        0,53842E-04           0,78194E-04                      2
     43        0,52649E-04           0,76290E-04                      2
     44        0,51474E-04           0,74435E-04                      2
     45        0,50318E-04           0,72631E-04                      2
     46        0,49181E-04           0,70876E-04                      2
     47        0,48064E-04           0,69171E-04                      2
     48        0,46968E-04           0,67516E-04                      2
     49        0,45894E-04           0,65911E-04                      2
     50        0,44841E-04           0,64356E-04                      2
     51        0,43811E-04           0,62850E-04                      2
     52        0,42803E-04           0,61392E-04                      2
     53        0,41818E-04           0.59982E-04                      2
     54        0,40857E-04           0,58620E-04                      2
     55        0,39919E-04           0,57304E-04                      2
     56        0,39004E-04           0,56033E-04                      2
     57        0,38112E-04           0.54808E-04                      2
     58        0,37245E-04           0,53626E-04                      2
     59        0,36400E-04           0,52487E-04                      2
     60        0,35580E-04           0,51390E-04                      2
     61        0,34782E-04           0,50333E-04                      2
     62        0,34008E-04           0,49316E-04                      2
     63        0,33256E-04           0,48338E-04                      2
     64        0,32527E-04           0,47397E-04                      2
     65        0,31821E-04           0,46493E-04                      2
     66        0,31136E-04           0,45625E-04                      2


    YYAV
 0.21913E-04
```

```
  M                 IND            TT
  20                 1           60,077

  I        YY                 XX                   NTR
  1    0,21721E-04       0,26654E-04                1
  2    0,21721E-04       0,26654E-04                1
  3    0,21721E-04       0,26654E-04                1
  4    0,21721E-04       0,26655E-04                1
  5    0,21721E-04       0,26655E-04                1
  6    0,21722E-04       0,26657E-04                1
  7    0,21723E-04       0,26659E-04                1
  8    0,21724E-04       0,26664E-04                1
  9    0,21727E-04       0,26672E-04                1
 10    0,21732E-04       0,26684E-04                1
 11    0,21740E-04       0,26703E-04                1
 12    0,21751E-04       0,26730E-04                2
 13    0,21766E-04       0,26767E-04                2
 14    0,21792E-04       0,26818E-04                2
 15    0,21825E-04       0,26886E-04                2
 16    0,21868E-04       0,26973E-04                2
 17    0,21926E-04       0,27084E-04                2
 18    0,21999E-04       0,27221E-04                2
 19    0,22091E-04       0,27390E-04                2
 20    0,22206E-04       0,27593E-04                3
 21    0,22345E-04       0,27835E-04                3
 22    0,22512E-04       0,28119E-04                3
 23    0,22709E-04       0,28447E-04                3
 24    0,22939E-04       0,28822E-04                3
 25    0,23204E-04       0,29247E-04                3
 26    0,23507E-04       0,29722E-04                3
 27    0,23848E-04       0,30251E-04                3
 28    0,24231E-04       0,30833E-04                3
 29    0,24655E-04       0,31469E-04                3
 30    0,25122E-04       0,32159E-04                3
 31    0,25631E-04       0,32902E-04                3
 32    0,26184E-04       0,33699E-04                3
 33    0,26780E-04       0,34546E-04                3
 34    0,27418E-04       0,35444E-04                3
 35    0,28098E-04       0,36391E-04                3
 36    0,28819E-04       0,37385E-04                3
 37    0,29579E-04       0,38423E-04                3
 38    0,30377E-04       0,39505E-04                3
 39    0,31210E-04       0,40628E-04                2
 40    0,32080E-04       0,41789E-04                2
 41    0,32983E-04       0.42987E-04                2
 42    0,33918E-04       0,44221E-04                2
 43    0,34884E-04       0,45490E-04                2
 44    0,35881E-04       0,46792E-04                2
 45    0,36905E-04       0,48125E-04                2
 46    0,37957E-04       0,49488E-04                2
 47    0,39035E-04       0,50882E-04                2
 48    0,40139E-04       0,52305E-04                2
 49    0,41267E-04       0,53756E-04                2
 50    0,42419E-04       0,55235E-04                2
 51    0,43595E-04       0,56742E-04                2
 52    0,44795E-04       0,58276E-04                2
 53    0,46017E-04       0,59839E-04                2
 54    0,47262E-04       0,61429E-04                2
 55    0,48530E-04       0.63047E-04                2
 56    0,49821E-04       0,64694E-04                2
 57    0,51134E-04       0,66369E-04                2
 58    0,52471E-04       0,68072E-04                2
 59    0,53831E-04       0.69804E-04                2
 60    0,55214E-04       0,71565E-04                2
 61    0,56621E-04       0.73356E-04                2
 62    0,58051E-04       0.75175E-04                2
 63    0,59505E-04       0.77024E-04                2
 64    0,60983E-04       0.78903E-04                2
 65    0,62484E-04       0,80810E-04                2
 66    0,64010E-04       0,82747E-04                2

    YYAV
 0,97917E-04
```

Table No: 24

```
         N          NNZ      NCASE

        10          660        1


      R     TEMP

    82.0600  296.0000


       H         TIME          VOID           A          ERR          YO        DENS

   100.0000   15.0000       0.4200      7.9173     0.0010      0.0100      0.7300


                AK =         250.0000000000


       G          PH            PL

   10.0000     4.0816       1.3605


   PURGE RATIO

     2.2000

                 DH                         DL

          0.16691E-03              0.55635E-04

       DP         VISC          DIFF         ALPHA          BETA          AMAV

   0.10000     0.01190     4.20000     1.25000     -0.51000      4.40000

                 DZ1                       DZ2               NNT1                  VO1                    VO2



          0.55421E-01             0.25191E-01          270 .            0.30073E 01            0.66160E 01

   GPH= 0.16691E-02            GPL= 0.12240E-02            CKGH= 0.13001E 00            CKGL= 0.33515E 00


             END VALUES OF LOW PRESSURE COLUMN WHEN M= 1


   END VALUES          I          WW(I)                 YY(I)

                       1       0.14090272E-03       0.99999979E-02

                      21       0.41145575E-03       0.29420532E-01

                      41       0.41342736E-03       0.29723972E-01

                      61       0.41345530E-03       0.29725976E-01

                      81       0.41348324E-03       0.29727764E-01

                     101       0.41351118E-03       0.29729996E-01
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                    141       0.41352492E-03     0.29731117E-01

                    161       0.41352492E-03     0.29731117E-01

                    181       0.41352492E-03     0.29731117E-01

                    201       0.41352492E-03     0.29731117E-01

                    221       0.41352492E-03     0.29731117E-01

                    241       0.41352492E-03     0.29731117E-01

                    261       0.41352492E-03     0.29731117E-01

                    281       0.41352492E-03     0.29731117E-01


                    301       0.41352492E-03     0.29731117E-01

                    321       0.41352492E-03     0.29731117E-01

                    341       0.41352492E-03     0.29731117E-01

                    361       0.41352492E-03     0.29731117E-01

                    361       0.41352492E-03     0.29731117E-01

                    401       0.41352492E-03     0.29731117E-01

                    421       0.41352492E-03     0.29731117E-01

                    441       0.41352492E-03     0.29731117E-01

                    461       0.41352492E-03     0.29731117E-01

                    481       0.41352492E-03     0.29731117E-01

                    501       0.41352492E-03     0.29731117E-01

                    521       0.41352492E-03     0.29731117E-01

                    541       0.41352492E-03     0.29731117E-01

                    561       0.41352492E-03     0.29731117E-01

                    581       0.41352492E-03     0.29731117E-01

                    601       0.41352492E-03     0.29731117E-01

                    M= 1            YYAV= 0.29677E-01      YYAV1= 0.29731E-01

               END VALUES OF HIGH PRESSURE COLUMN WHEN M= 2


   END VALUES       I         WW(I)               YY(I)

                    1       0.41672844E-03     0.99999979E-02


                    21      0.41356171E-03     0.99110119E-02

                    41      0.41356171E-03     0.99110119E-02

                    61      0.41356171E-03     0.99110119E-02
```

```
            141     0.41356171E-03     0.99110119E-02
            161     0.41356171E-03     0.99110119E-02
            181     0.41356171E-03     0.99110119E-02
            201     0.41356171E-03     0.99110119E-02
            221     0.41356171E-03     0.99110119E-02
            241     0.41356171E-03     0.99110119E-02
            261     0.41356171E-03     0.99110119E-02
            281     0.41356171E-03     0.99110119E-02
            301     0.41356171E-03     0.99110119E-02
            321     0.41356171E-03     0.99110119E-02
            341     0.41356171E-03     0.99110119E-02
            361     0.41356171E-03     0.99110119E-02
            381     0.41356171E-03     0.99110119E-02
            401     0.41356171E-03     0.99110119E-02
            421     0.42173592E-03     0.10106854E-01

            441     0.42176875E-03     0.10107640E-01
            461     0.42177900E-03     0.10107934E-01
            481     0.42177900E-03     0.10107934E-01
            501     0.42176596E-03     0.10107670E-01
            521     0.42173825E-03     0.10106999E-01
            541     0.42171055E-03     0.10106340E-01
            561     0.42168284E-03     0.10105677E-01
            581     0.42082253E-03     0.10093942E-01
            601     0.18430728E-03     0.50751120E-02
              M= 2          YYAV= 0.44062E-02     YYAV1= 0.50751E-02
         END VALUES OF LOW PRESSURE COLUMN WHEN M= 2

  END VALUES      I      WH(I)              YY(I)
              1     0.69009053E-04     0.50721057E-02
             21     0.41084317E-03     0.29327113E-01
             41     0.41342713E-03     0.29723957E-01
             61     0.41345507E-03     0.29725958E-01
             81     0.41348301E-03     0.29727977E-01
            101     0.41[illegible]E-03     0.297[illegible]E-01
```

```
                     161     0.41352492E-03       0.29731125E-01

                     181     0.41352492E-03       0.29731125E-01

                     201     0.41352492E-03       0.29731125E-01

                     221     0.41352492E-03       0.29731125E-01

                     241     0.41352492E-03       0.29731125E-01

                     261     0.41352492E-03       0.29731125E-01

                     281     0.41352492E-03       0.29731125E-01

                     301     0.41352492E-03       0.29731125E-01

                     321     0.41352492E-03       0.29731125E-01

                     341     0.41352492E-03       0.29731125E-01

                     361     0.41352492E-03       0.29731125E-01

                     381     0.41352492E-03       0.29731125E-01

                     401     0.41352492E-03       0.29731125E-01

                     421     0.41352492E-03       0.29731125E-01

                     441     0.41352492E-03       0.29731125E-01

                     461     0.41352492E-03       0.29731125E-01

                     481     0.41352492E-03       0.29731125E-01

                     501     0.41352492E-03       0.29731125E-01

                     521     0.41352492E-03       0.29731125E-01

                     541     0.41352492E-03       0.29731125E-01

                     561     0.41352492E-03       0.29731125E-01



                     581     0.41352492E-03       0.29731117E-01

                     601     0.41352492E-03       0.29731117E-01

                       M= 2           YYAV= 0.29677E-01      YYAV1= 0.29731E-01


           END VALUES OF HIGH PRESSURE COLUMN WHEN M= 6


  END VALUES         I        WW(I)               YY(I)

                       1     0.41579013E-03       0.99999979E-02

                      21     0.40641380E-03       0.97396635E-02

                      41     0.40644174E-03       0.97403340E-02

                      61     0.40645129E-03       0.97400060E-02
```

```
          101       0.40645129E-03      0.97406060E-02

          121       0.40645129E-03      0.97406060E-02

          141       0.40645129E-03      0.97406060E-02

          161       0.40645129E-03      0.97406060E-02

          181       0.40645129E-03      0.97406060E-02

          201       0.40645129E-03      0.97406060E-02

          221       0.40645129E-03      0.97406060E-02

          241       0.40645106E-03      0.97406022E-02

          261       0.40645106E-03      0.97406022E-02

          281       0.40645106E-03      0.97406022E-02


          301       0.40645106E-03      0.97406022E-02

          321       0.40645106E-03      0.97406022E-02

          341       0.40645106E-03      0.97406022E-02

          361       0.40645106E-03      0.97406022E-02

          381       0.40663220E-03      0.97430348E-02

          401       0.41780481E-03      0.99813603E-02

          421       0.43005287E-03      0.10306165E-01

          441       0.43008546E-03      0.10306951E-01

          461       0.43007592E-03      0.10306805E-01

          481       0.43005706E-03      0.10306355E-01

          501       0.43003797E-03      0.10305904E-01

          521       0.43001864E-03      0.10305427E-01

          541       0.43041515E-03      0.10314733E-01

          561       0.42922865E-03      0.10294028E-01

          581       0.34765317E-03      0.87158494E-02

          601       0.29939925E-04      0.95096882E-03

            M= 6          YYAV= 0.69375E-03      YYAV1= 0.95097E-03

       END VALUES OF LOW PRESSURE COLUMN WHEN M= 6


 END VALUES       I        WW(I)               YY(I)

          1       0.11904299E-04      0.94966567E-03


         21       0.28005507E-03      0.17910322E-01
```

```
        61      [illegible]          [illegible]

        81      0.42205094E-03       0.30339776E-01

       101      0.42207609E-03       0.30345809E-01

       121      0.42209541E-03       0.30347190E-01

       141      0.42211437E-03       0.30348562E-01

       161      0.42213313E-03       0.30349914E-01

       181      0.42215199E-03       0.30351266E-01

       201      0.42021926E-03       0.30270241E-01

       221      0.40677423E-03       0.29266614E-01

       241      0.40634256E-03       0.29214732E-01

       261      0.40634256E-03       0.29214729E-01

       281      0.40634256E-03       0.29214729E-01

       301      0.40634256E-03       0.29214729E-01

       321      0.40634256E-03       0.29214736E-01

       341      0.40634256E-03       0.29214736E-01

       361      0.40634256E-03       0.29214729E-01

       381      0.40634279E-03       0.29214755E-01

       401      0.40634279E-03       0.29214747E-01

       421      0.40634279E-03       0.29214751E-01


       441      0.40634279E-03       0.29214747E-01

       461      0.40634279E-03       0.29214751E-01

       481      0.40634279E-03       0.29214751E-01

       501      0.40634279E-03       0.29214751E-01

       521      0.40634279E-03       0.29214751E-01

       541      0.40634279E-03       0.29214755E-01

       561      0.40634256E-03       0.29214736E-01

       581      0.40632370E-03       0.29213689E-01

       601      0.40691276E-03       0.29231593E-01

         H= 6          YYAV= 0.29267E-01     YYAV1= 0.29232E-01


      END VALUES OF HIGH-PRESSURE COLUMN WHEN H=10


   END VALUES       I        WW(I)                YY(I)

                    1      0.41492586E-03       0.99999979E-02
```

```
 [illegible]
         81       0.39973436E-03       0.95799715E-02

        101       0.39974018E-03       0.95797740E-02

        121       0.39974018E-03       0.95797740E-02

        141       0.39973995E-03       0.95797703E-02



        161       0.39973948E-03       0.95797628E-02

        161       0.39973971E-03       0.95797628E-02

        201       0.39973971E-03       0.95797628E-02

        221       0.39973948E-03       0.95797628E-02

        241       0.39973925E-03       0.95797591E-02

        261       0.39973925E-03       0.95797591E-02

        281       0.39973925E-03       0.95797591E-02

        301       0.39973948E-03       0.95797591E-02

        321       0.39973925E-03       0.95797591E-02

        341       0.39973925E-03       0.95797591E-02

        361       0.39974344E-03       0.95798112E-02

        381       0.40394469E-03       0.96634477E-02

        401       0.42454922E-03       0.10146067E-01

        421       0.43754606E-03       0.10485742E-01

        441       0.43755909E-03       0.10486156E-01

        461       0.43752720E-03       0.10485396E-01

        481       0.43748249E-03       0.10484353E-01

        501       0.43739076E-03       0.10482296E-01

        521       0.43725618E-03       0.10478806E-01

        541       0.43762964E-03       0.10491803E-01

        561       0.40963129E-03       0.99498630E-02


        581       0.18697492E-03       0.49883313E-02

        601       0.69931612E-05       0.23496668E-03

          M=10          YYAV= 0.15970E-03      YYAV1= 0.23497E-03

     END VALUES OF LOW PRESSURE COLUMN WHEN M=10


  END VALUES      I       WW(I)                 YY(I)

                  1       0.28441750E-05        [illegible]
```

```
        101     0.42965938E-03     0.30869904E-01

        121     0.42970637E-03     0.30859966E-01

        141     0.42984239E-03     0.30904062E-01

        161     0.42987592E-03     0.30906573E-01

        181     0.42990432E-03     0.30908607E-01

        201     0.42781699E-03     0.30823093E-01

        221     0.40557142E-03     0.29253509E-01

        241     0.39961189E-03     0.28735407E-01

        261     0.39956300E-03     0.28727312E-01

        261     0.39956300E-03     0.28727308E-01


        301     0.39956300E-03     0.28727312E-01

        321     0.39956300E-03     0.28727315E-01

        341     0.39956300E-03     0.28727312E-01

        361     0.39956300E-03     0.28727308E-01

        381     0.39956346E-03     0.28727323E-01

        401     0.39956346E-03     0.28727334E-01

        421     0.39956323E-03     0.28727338E-01

        441     0.39956323E-03     0.28727323E-01

        461     0.39956323E-03     0.28727336E-01

        481     0.39956369E-03     0.28727334E-01

        501     0.39956346E-03     0.28727341E-01

        521     0.39956346E-03     0.28727327E-01

        541     0.39955531E-03     0.28726917E-01

        561     0.39952737E-03     0.28724916E-01

        581     0.39949059E-03     0.28722443E-01

        601     0.40081446E-03     0.28767679E-01

           N=10        YYAV= 0.28893E-01     YYAV1= 0.28768E-01

  N            <YTP>                    <YBP>                    YPT/YO          YBP/YO

  1         0.10000E-01              0.29677E-01              0.10000E 01     0.29677E 01
  2         0.44062E-02              0.29677E-01              0.44062E 00     0.29677E 01
  3         0.27902E-02              0.29465E-01              0.27902E 00     0.29465E 01
  4         0.16432E-02              0.29465E-01              0.16432E 00     0.29465E 01
  5         0.10874E-02              0.29267E-01              0.10874E 00     0.29267E 01
  6         0.69375E-03              0.29267E-01              0.69375E-01     0.29267E 01
  7         0.47653E-03              0.29077E-01              0.47653E-01     0.29077E 01


  8         0.32069E-03              0.29077E-01              0.32069E-01     0.29077E 01
  9         0.22917E-03              0.28893E-01              0.22917E-01     0.28893E 01
            [illegible]              [illegible]              0.16670E-01     0.28893E 01
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