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SUPPORT OF THE EIGHT-FOOT HIGH TEMPERATURE TUNNEL MODIFICATION PROJECT

By

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Kim Chi Ngo[1] and Roland R. Mielke[2]

LIQUID OXYGEN-LIQUID NITROGEN MIXING AND SELF-CLEANING STUDY

INTRODUCTION

In the past several years, there has been a resurgent interest in hypersonics. In order to meet the need for propulsion testing in the high supersonic range from Mach 4 to Mach 7, NASA has undertaken the modification of the Langley Eight-Foot High Temperature Tunnel to add alternate Mach number capability and add oxygen enrichment to allow the testing of operating engines at these Mach numbers and at true temperature tunnel.

The transfer of liquid oxygen (LOX) from a storage vessel to a rocket engine generally requires the use of a pressurizing gas at high pressures. Among the common gases, helium, oxygen, and nitrogen have been considered. However, helium is expensive, and oxygen is hazardous at high pressures. Therefore, nitrogen is preferred. Unfortunately, when gaseous nitrogen (GN_2) is used as the pressurant to transfer liquid oxygen from a storage tank to the tunnel combustor, it contaminates the liquid oxygen and effects a loss of performance in the engine.

The purpose of this study is to describe the contamination of the LOX by the pressurizing GN_2, which may prove to be an important operational constraint. It is desirable to have reliable data concerning the penetration of GN_2 into LOX during pressurization and the subsequent of self-cleaning after "blowdown."

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EXPERIMENTAL PROCEDURE

The experiment was carried out at the 7" Mach Seven Tunnel, the pilot tunnel for the 8 Foot High Temperature Tunnel. The LOX-LN_2 contamination experimental set-up is shown in Appendix A, and the experimental procedure is illustrated in Fig. 1. The test procedure consisted of three steps. First, the 2-gallon cylindrical vessel was filled to a level of 46 inches with LOX, as measured by a nuclear monitor. At this point the LOX was pressurized by GN_2 and held at a specific pressure for a period of time. Secondly, after the pressurization was completed, the nitrogen was blown down to 0 psig. Finally, the evaporating liquid from the tank was vented through a 100% Beckman Oxyen Analyzer. The data were taken by an analog to digital converter in an Apple II^+ computer, which records the reading from the analog instrumentation.

RESULTS AND ANALYSIS

The interpretation of the experimental results is based on the following model:

1) During pressurization N_2 penetrates into the LOX by simple molecular diffusion.

2) The depth of penetration depends upon the GN_2 pressure, which determines the surface concentration, and the holding time.

3) After blowdown the liquid evaporates. At any given time the composition of the evaporating liquid reflects the concentration profile established in the liquid by diffusion.

To analyze this experiment, the first step is to derive the continuity equation for the number of GN_2 moles in the lage volume. This well known concentration profile due to diffusion equation can be written as:

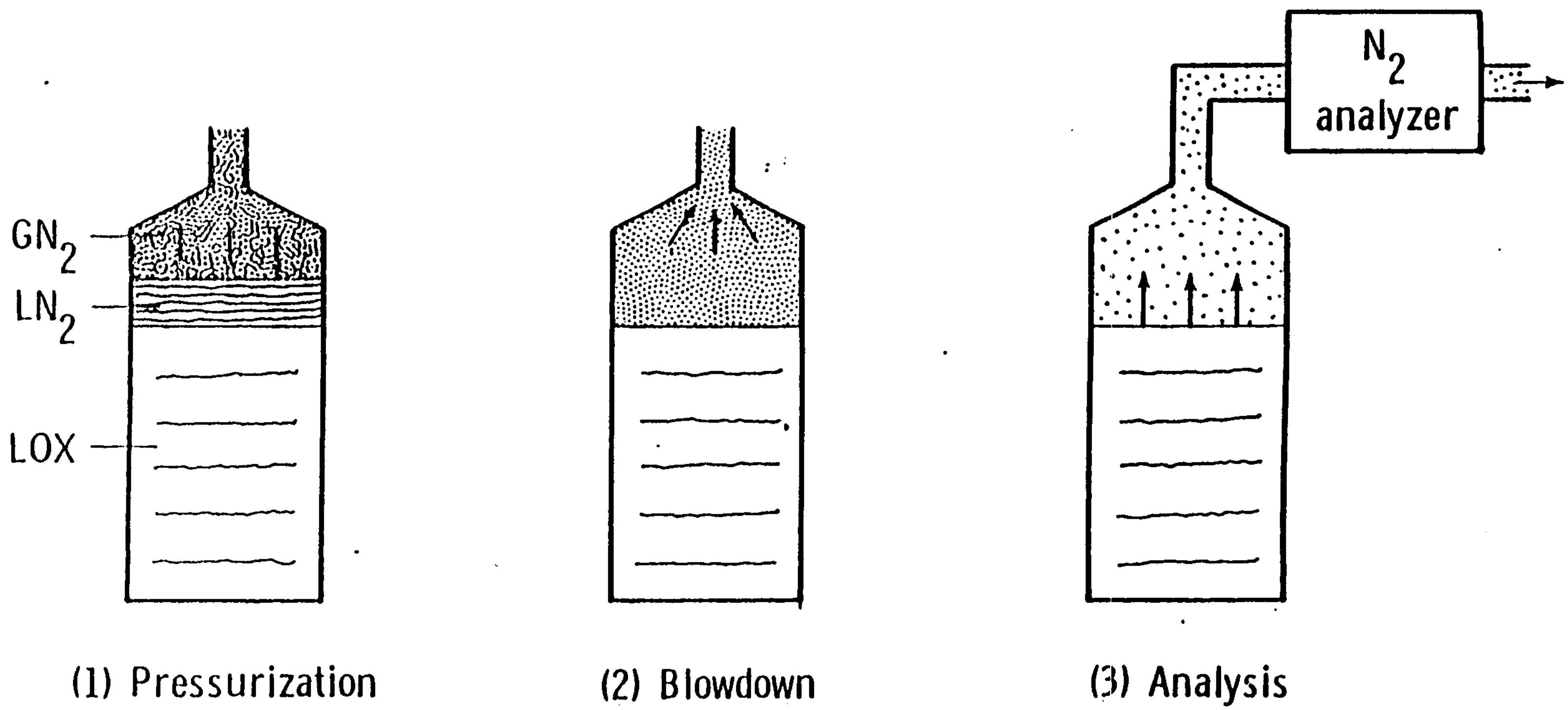


Figure 1. Illustration of the test procedure.

$$n_T \frac{dx_n}{dt} + R\, X_n = \frac{R}{2} \left[1 - \text{erf} \left(\frac{Z_0}{h} + \frac{RV_L t}{Ah} \right) \right] \quad (1)$$

where

n_T:	the number of moles of N_2 at time t
X_n:	the instantaneous mole fraction N_2 in the liquid
R:	the evaporation rate in mole/sec
V_L:	the molar volume of the liquid
A:	the cross sectional area of the dewar
Z_0/h:	starting depth penetration
erf(x):	error function of x

since

$$\tau_1 = \frac{n_T}{R} \quad (2)$$

$$\tau_2 = \frac{Ah}{RV_L} \quad (3)$$

substitute Eqs. (2) and (3), into Eq. (4), it yields in the form as:

$$\frac{dxn}{dt} + \frac{1}{\tau_1} X_n = \frac{1}{2\tau_1} \left[1 - \text{erf} \left(t/\tau_2 + \frac{Z_0}{h} \right) \right]. \quad (4)$$

By using the Laplace transform to solve for the differential Eq. (4), the solution of the continuity equation can be written as:

$$X_n(t) = X_{n_0}\, e^{-t/\tau_1} + \frac{1}{2}\,[1- \mathrm{Erf}\,(Z_0/h)]\,(1-e^{-t/\tau_1})$$

$$- \frac{1}{2}\,[\mathrm{Erf}\,(t/\tau_2 + Z_0/h) - \mathrm{Erf}\,(Z_0/h)]$$

$$+ \frac{1}{2}\, e^{-(t/\tau_1 + \frac{Z_0\tau_2}{h\,\tau_1} - \tau_2^2/4\,\tau_1^2)}\,[\mathrm{Erf}\,(t/\tau_2 + \frac{Z_0}{h} - \frac{\tau_2}{2\tau_1})$$

$$- \mathrm{Erf}\,(\frac{Z_0}{h} - \frac{\tau_2}{2\tau_1})] \qquad (5)$$

where

$$X_{n_0} = \frac{1}{2}\,[1 - \mathrm{Erf}\,(\frac{Z_0}{h} + \frac{t}{\tau_2})].$$

Using a best-fit procedure, one can determine the values for the time constants τ_1 and τ_2 for each test.

Plots of the data and Eq. (5) using preliminary estimates of τ_1 and τ_2 are shown in Figs. 2, 3, 4 and 5. Once the values of τ_1 and τ_2 were established, the evaporation rate R and the penetration depth can be determined from Eqs. (2) and (3).

ENTERDATA, PLOTDATA, BEST-FIT, and SUMT2 are the four computer softwares which were written in the BASIC to analyze the experiment. The flowcharts and the programs are listed in the Appendixes B, C, D, and E.

CONCLUSION

As of this writing the final data analysis is not yet completed, but preliminary analysis indicates that at the low pressure < 1000 psi, the

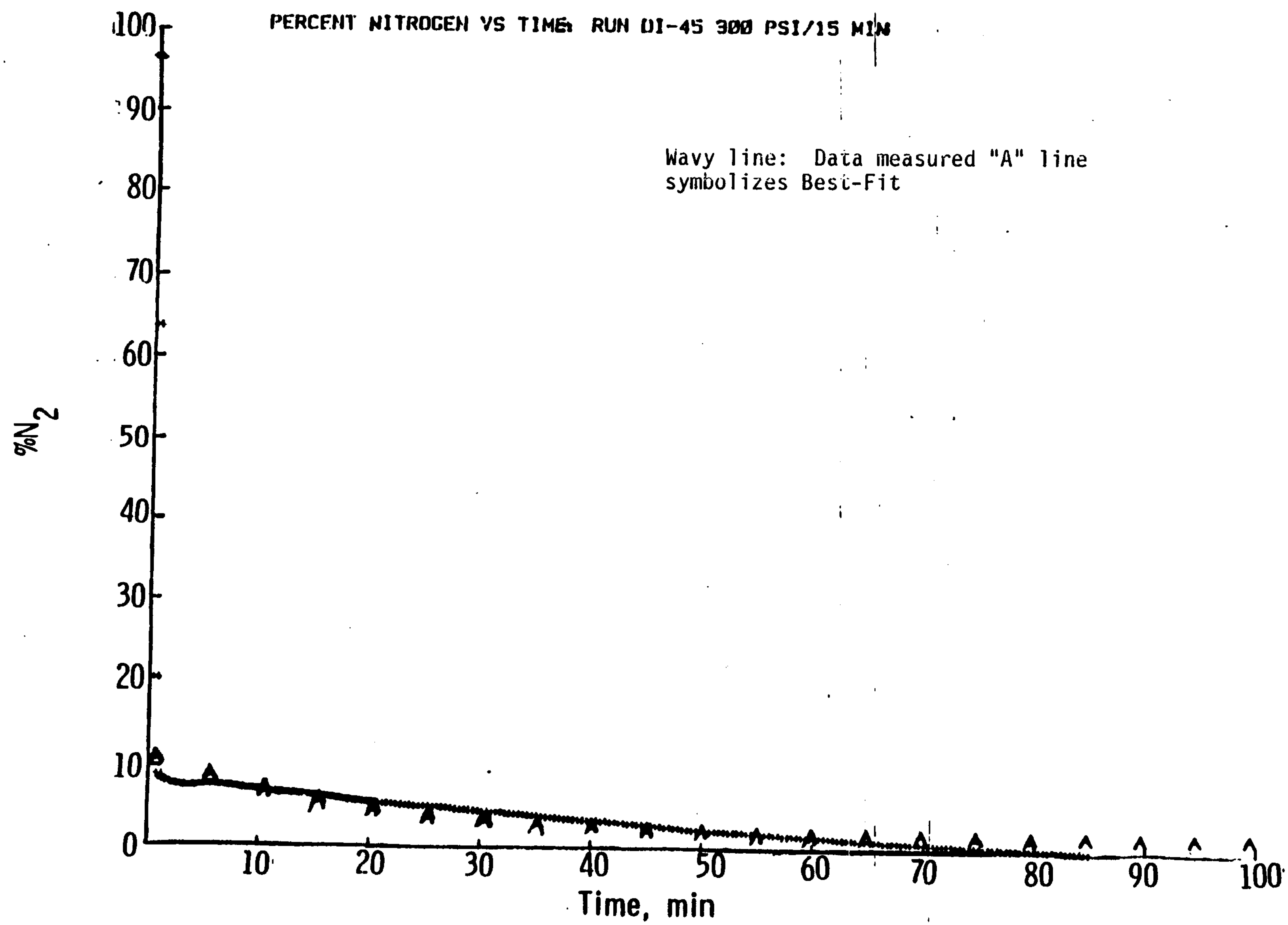


Figure 2. Percent nitrogen vs. time: 300 psi/15 min.

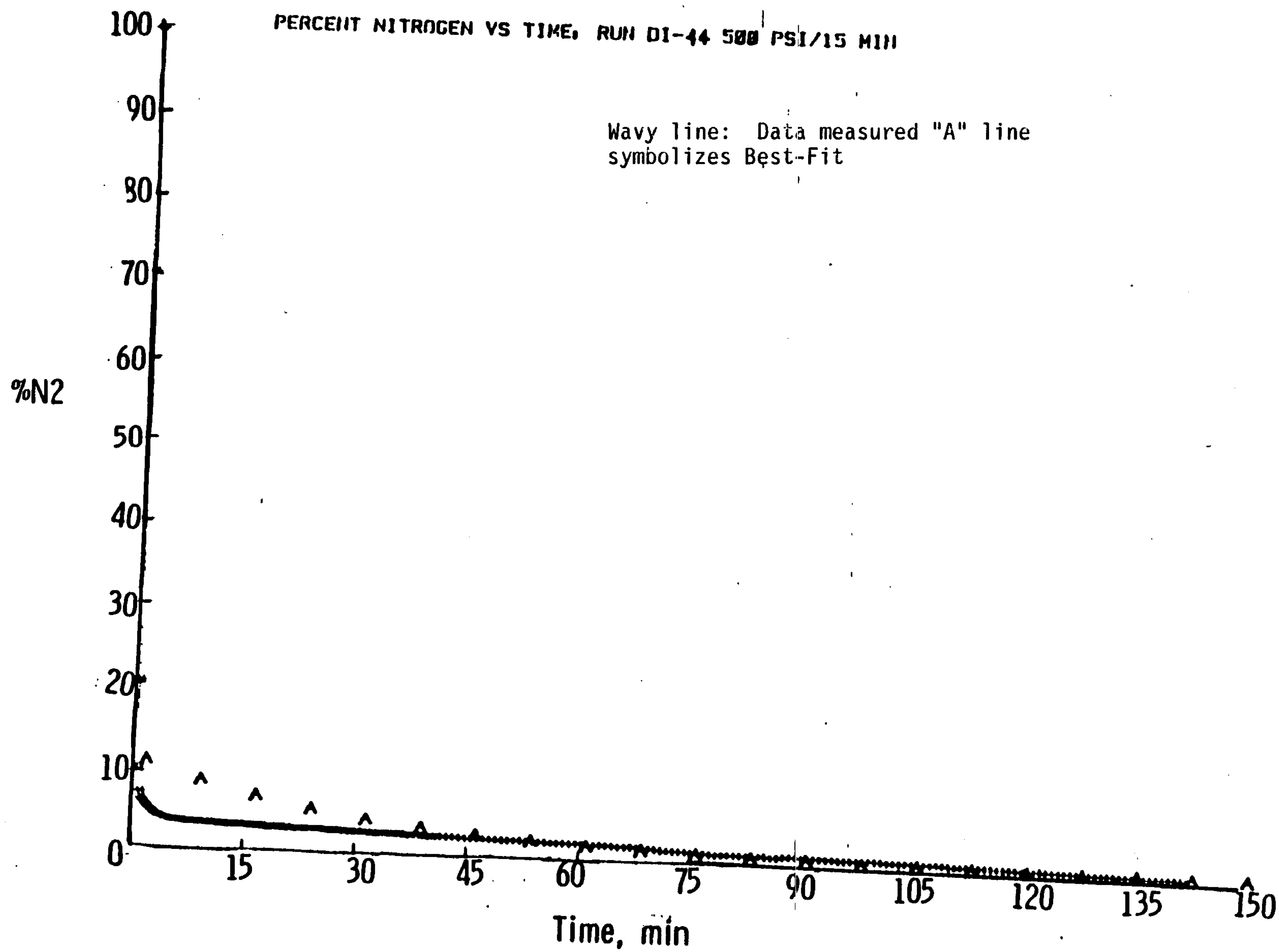


Figure 3. Percent nitrogen vs. Time: 500 psi/15 min.

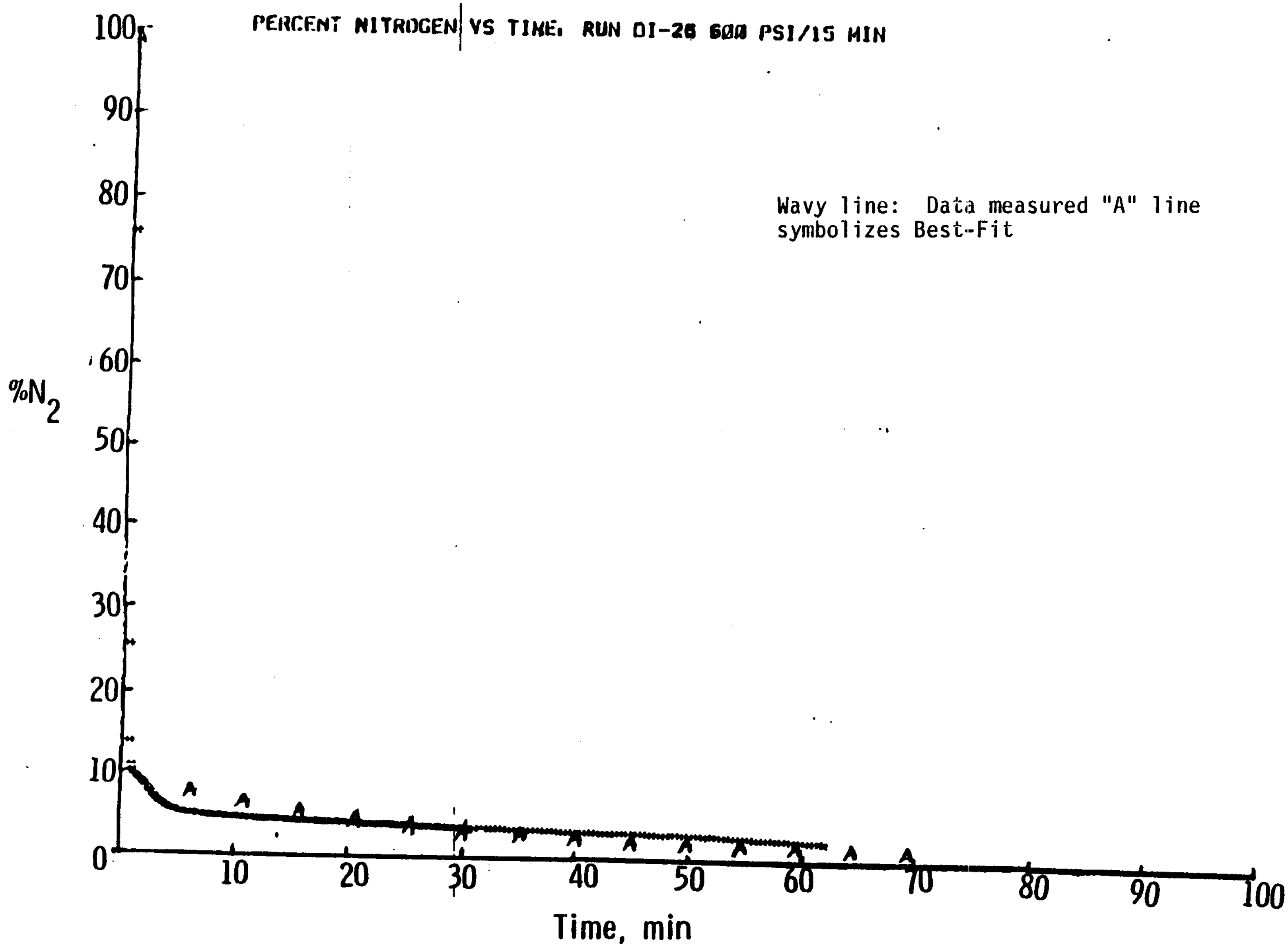


Figure 4. Percent nitrogen vs. time: 600 psi/15 min.

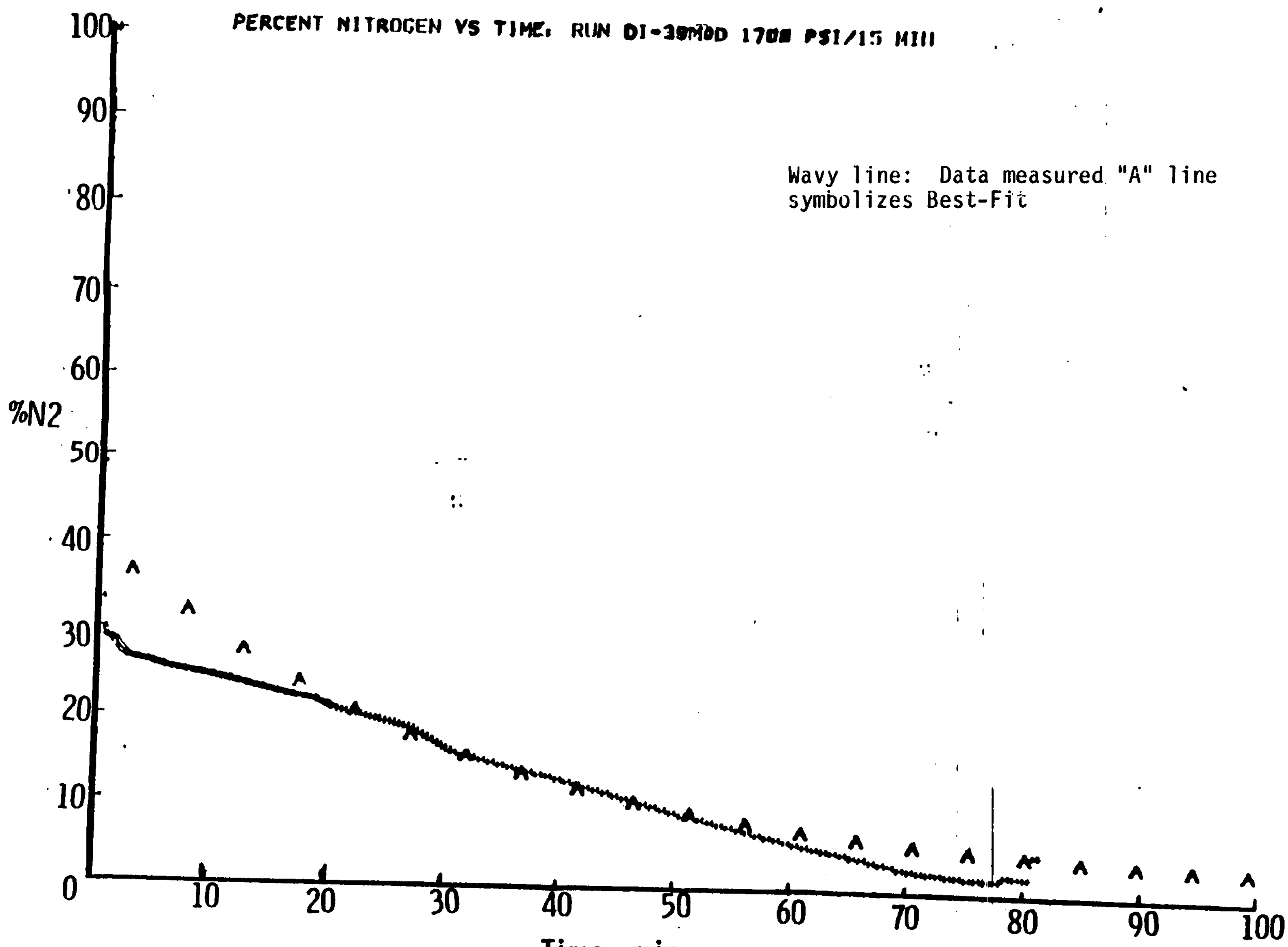


Figure 5. Percent nitrogen vs. time: 1700 psi/15 min.

depth penetration is very small. In some tests, there were evidences that LN_2 was at the bottom of the vessel. It is hoped that the additional testing can be undertaken at 7" Mach Seven Tunnel in the near future to fully define the significances of the evaporation rate and the depth penetration of GN_2 into LOX during pressurization.

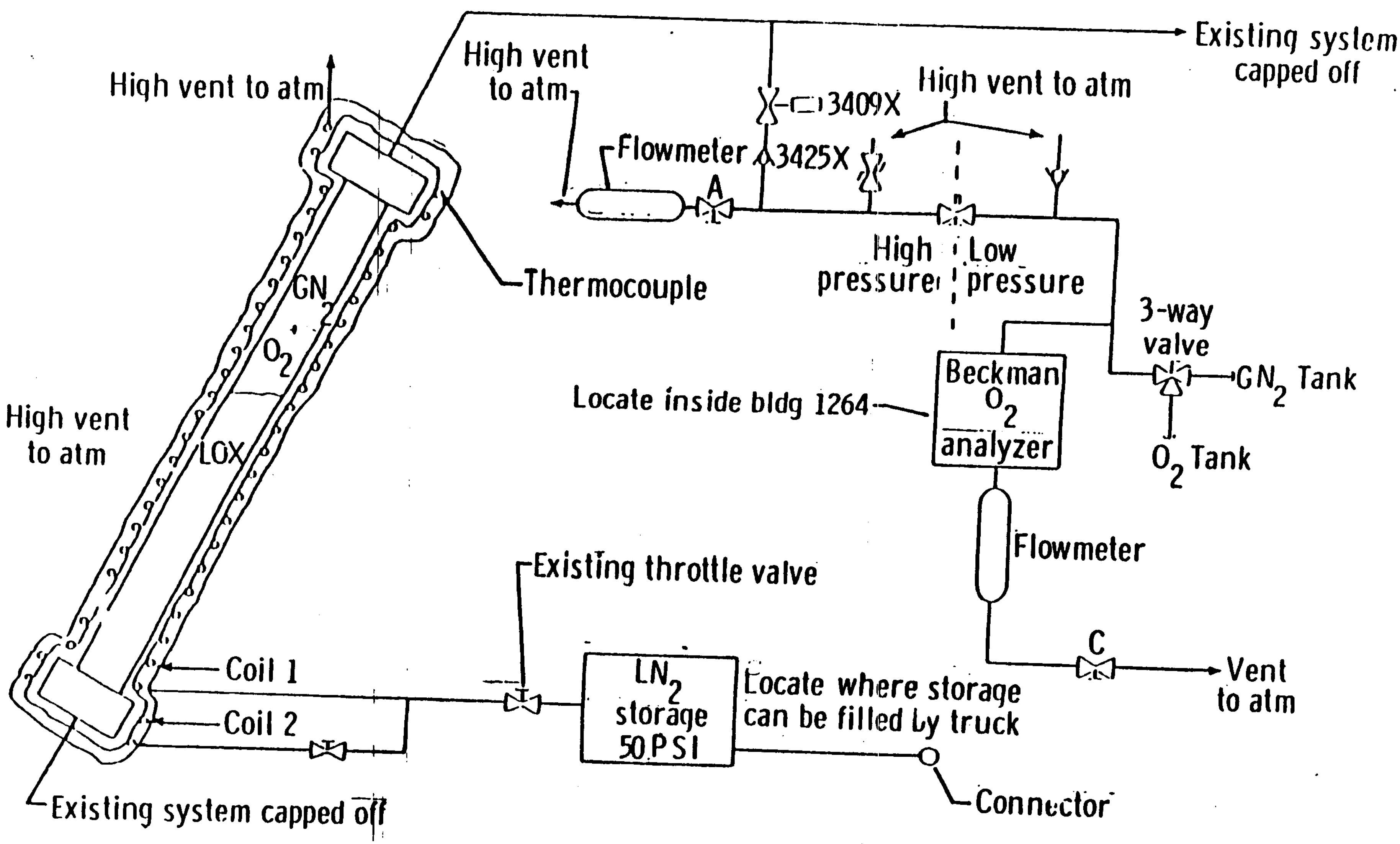
REFERENCES

1. Allan J. Zuckerwar, "Preliminary Study of Gaseous Nitrogen-Liquid Oxygen Mixing and Self-Cleaning," NASA Technical Memorandum 87658, December 1985.

APPENDIX A

LOX-LN_2 CONTAMINATION EXPERIMENTAL SET-UP

LOX-LN_2 CONTAMINATION EXPERIMENT



LOX Contamination Monitoring Test DI-___ Date__________

A. Set Up Procedure

1. Install connector for cooling coil 2.
2. Cap off run tank.
3. Connect valves 3409X and 3425X to monitoring system.
4. Install and check out nuclear monitor. Locate at 46 inches.
5. Calibrate Beckmann O2 Analyzer.
6. Close valves "A", "B", "C", and "D".

B. Precooling Procedure

1. Open valve "A."
2. Follow existing checklist for "Cooldown with LN2."
3. Drain LN2.
4. Run LN2 through cooling coils 1 and 2.
5. Follow existing checklist for "LOX Transfer Operation."
6. Fill to 46 inches, as observed on nuclear monitor.
7. Wait ___ min.

C. Pressurization and Blowdown Procedure

1. Close valve "A."
2. Follow existing checklist for pressurizing with GN2 to ______ psi.
3. Maintain pressure for ___ min.
4. Close 3431N.
5. Open 3411N.
6. Open valve 3412X to vent pressure.

D. GO2 Monitoring Procedure

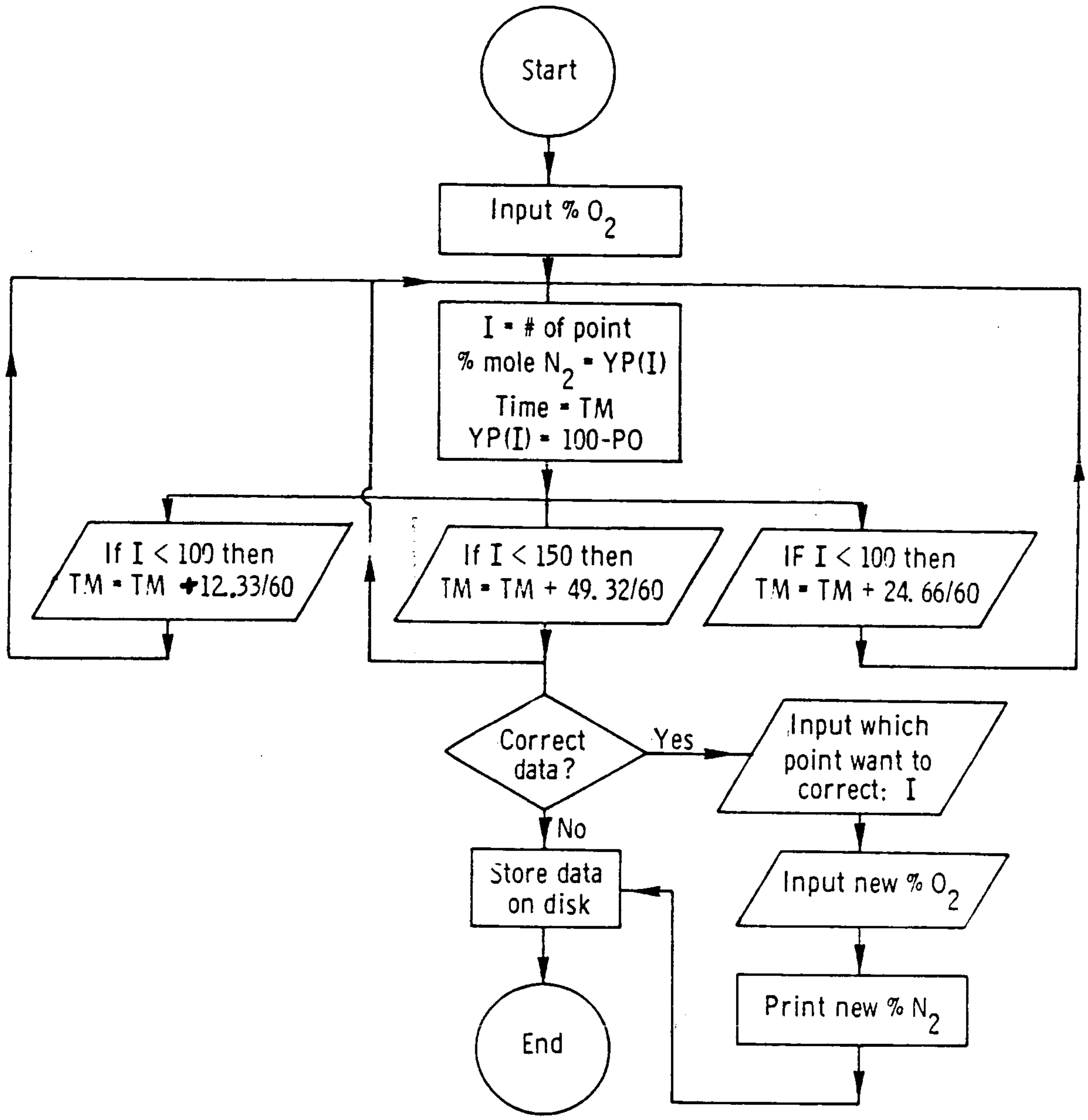
1. Close valve 3412X at 0 psi.
2. Close 3410N. (3411N optional).
3. Open valve 3409X.
4. Open valve "A". NOTE: This insures that pressurized GN2 is completely blown down.
5. Open valve "C".
6. Adjust valve "B" until flow rate reads _________ units.
7. Monitor thermocouple, Beckmann, O2 pressure, and both flowmeter readings continuously.

E. Shutdown Procedure

Follow existing checklist for "Vent and Shutdown Procedure".

APPENDIX B

SOFTWARE ENTERDATA



Start
Input % O_2
I = # of point
% mole N_2 = YP(I)
Time = TM
YP(I) = 100-PO
If I < 100 then
TM = TM + 12.33/60
If I < 150 then
TM = TM + 49. 32/60
IF I < 100 then
TM = TM + 24. 66/60
Correct data?
Yes
Input which point want to correct: I
Input new % O_2
Print new % N_2
No
Store data on disk
End

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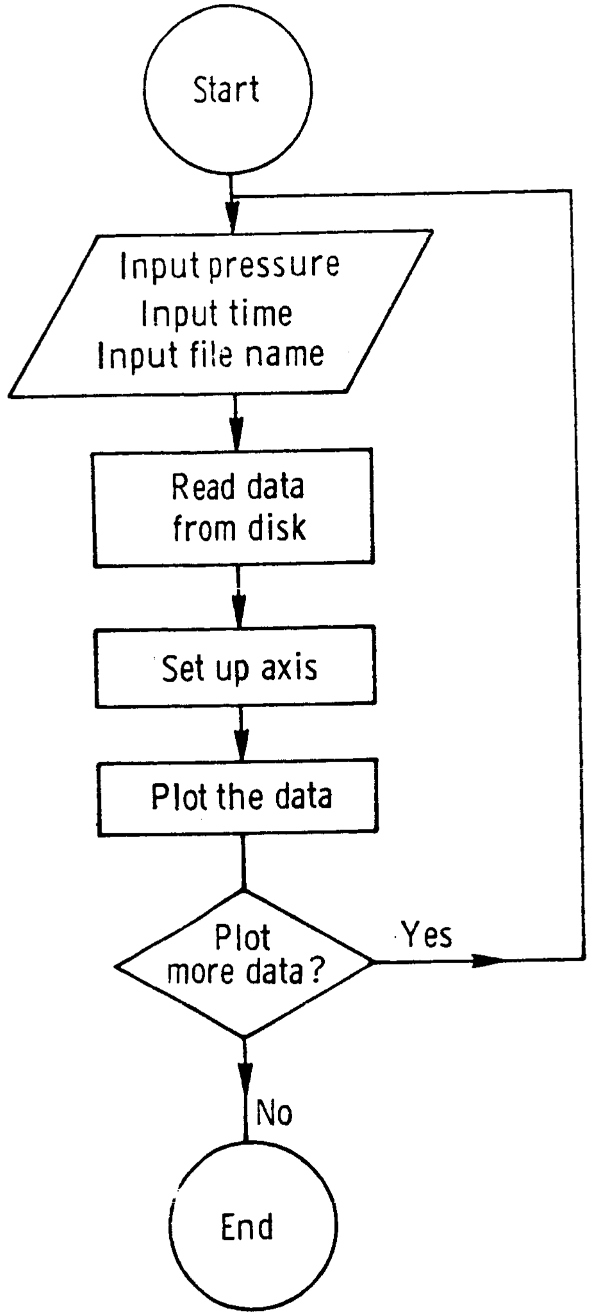
]LIST

10  REM  PROGRAM FOR ENTER DATA
20  DIM XP(400),YP(400)
30 I = 0:TM = 0
40  HOME : PRINT "INPUT %02": PRINT
50  PRINT "IF END OF DATA TYPE 111": PRINT
60  INPUT "PERCENT=";PO
70  IF PO = 111 THEN  GOTO 130
80 XP(I) = TM
90 YP(I) = 100 - PO
100 I = I + 1
101  IF I > 150 THEN  GOTO 111
102  IF I > 100 THEN  GOTO 113
109 TM = I * 12.33 / 60
110  GOTO 40
111 TM = TM + 49.32 / 60
112  GOTO 40
113 TM = TM + 24.66 / 60
120  GOTO 40
130 NP = I
140  REM  CORRECT DATA
150  INPUT "DO YOU WISH TO CORRECT DATA (Y OR N) ";A$
160  IF A$ <  > "Y" THEN  GOTO 300
170  INPUT "DATA POINT? ";I
180  PRINT "PO= ";100 - YP(I): PRINT
190  INPUT "NEW % 02 ";PO
200 YP(I) = 100 - PO: PRINT : PRINT "YP(";I;") =";YP(I): PRINT
210  GOTO 150
300  REM  WRITE DATA TO DISK
310 D$ =  CHR$ (4)
320  INPUT "FILE NAME ";R$
330  PRINT D$;"OPEN";R$
340  PRINT D$;"DELETE";R$
350  PRINT D$;"OPEN";R$
360  PRINT D$;"WRITE";R$
370  PRINT NP
380  FOR I = 0 TO NP - 1
390  PRINT XP(I): PRINT YP(I)
400  NEXT I
410  PRINT D$;"CLOSE";R$
420  PRINT D$;"LOCK";R$
430  END

]
```

APPENDIX C

SOFTWARE PLOTDATA


Start
Input pressure
Input time
Input file name
Read data
from disk
Set up axis
Plot the data
Plot
more data?
Yes
No
End

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LOAD
]LIST

10  REM  PROGRAM TO PLOT DATA :PLOT3
20  REM  DEFINE VARIABLES
30  DIM XP(400),YP(400)
40  REM  INPUT AXIS PARAMETER VALUES
50  DATA     0,0,100,10,1,0,0,5,.5          ,1,100,10
60  READ X0,X1,X2,X3,XL,Y0,Y1,Y2,Y3,YL,SX,SY
65  INPUT "PRESSURE= ";P$
66  INPUT "TIME= ";TM$
70  REM  READ DATA FROM DISK
80  GOSUB 1000
90  REM  LABEL PLOT:
100 X$ = "TIME,MIN.":Y$ = "%N2":TI$ = "PERCENT NITROGEN VS TIME: RUN " +
     R$ + " " + P$ + " PSI" + "/" + TM$ + " MIN"
110  REM  SUBROUTINE TO SETUP AXIS
115  CALL 1002
120  GOSUB 2000
130  REM  SUBROUTINE TO PLOT DATA
140  GOSUB 2500
150 J = 0
160  HOME : INPUT "DO YOU WANT TO PLOT MORE DATA? (YES OR NO)   ";A$
180  IF  LEN (A$) = 2 THEN  GOTO 260
190 J = J + 1
200  GOSUB 1000
205  CALL 1002
210  GOSUB 3000
220  CALL 1002
245  GOSUB 2500
250  GOTO 160
260  END
1000  REM  SUBROUTINE READ DATA FROM DISK
1010 D$ =  CHR$ (4)
1020  INPUT "FILE NAME ";R$
1030  PRINT D$;"OPEN";R$
1040  PRINT D$;"READ";R$
1050  INPUT NP
1060  FOR I = 0 TO NP - 1
1070  INPUT XP(I): INPUT YP(I)
1080  NEXT I
1090  PRINT D$;"CLOSE";R$
1100  RETURN
2000  REM   SUBROUTINE PLOT AXES WO INPUTS (IIE)
2010  REM        VALUES ARE NEEDED FOR X0=X0,XMIN=X1,XMAX=X2,XTIC=X3,XLAB=X
     L,Y0=Y0,YMIN=Y1,YMAX=Y2,YTIC=Y3,YLAB=YL,NO. PTS=NP,SFX=SX,SFY=SY,DAT
     A COORDINATES=XP(I),YP(I),LABEL XAXIS=X$,LABEL YAXIS=Y$,TITLE=TI$
2020 T$ = "WT%":D$ =  CHR$ (4):Z$ =  CHR$ (26)
2030 X1 = X1 * SX:X2 = X2 * SX:X3 = X3 * SX:Y1 = Y1 * SY:Y2 = Y2 * SY:Y3 =
     Y3 * SY:X0 = X0 * SX:Y0 = Y0 * SY
2040  PRINT D$;"PR#3": PRINT T$;Z$;"IN;IP1328,1000,9328,6760;SC"X1","X2",
     "Y1","Y2";PA"X1","Y0";PD;"
2050 X4 = 0
2060  FOR X = X1 TO X2 STEP X3
2070  IF  INT (X4 / XL) = X4 / XL THEN 2090
2080  PRINT T$;Z$;"TL ;PA"X","Y0";XT;": GOTO 2100
2090  PRINT T$;Z$;"TL1;PA"X","Y0";XT;PU;CP-.4,-.9;LB"X / SX";PA"X","Y0";P
     D;"
2100 X4 = X4 + 1
2110  NEXT X
2120  PRINT T$;Z$;"PU;PA" INT (X1 + (X2 - X1) / 2.5)"," INT (Y1 - (Y2 - Y
     1) / 12.5)";LB"X$";PA"X0","Y1";PD;"
2130 Y4 = 0
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2130 Y4 = 0
2140  FOR Y = Y1 TO Y2 STEP Y3
2150  IF  INT (Y4 / YL) = Y4 / YL THEN 2170
2160  PRINT T$;Z$;"TL ;PA"X0","Y";YT;": GOTO 2180
2170  PRINT T$;Z$;"TL1;PA"X0","Y";YT;PU;CP-4.5,-.3;LB"Y / SY";PA"X0","Y";
     PD;"
2180 Y4 = Y4 + 1
2190  NEXT Y
2200  PRINT T$;Z$;"PU;PA" INT (X1 - (X2 - X1) / 10)"," INT (Y1 + (Y2 - Y1
     ) / 4)";DI0,1;LB"Y$";"
2210  PRINT T$;Z$;"PU;PA" INT (X1 + (X2 - X1) / 10)"," INT (Y2)";DI1,0; L
     B"TI$";"
2220  PRINT D$;"PR#0": PRINT D$;"IN#0":X0 = X0 / SX:X1 = X1 / SX:X2 = X2 /
     SX:X3 = X3 / SX:Y0 = Y0 / SY:Y1 = Y1 / SY:Y2 = Y2 / SY:Y3 = Y3 / SY
2230  RETURN
2240  REM  TO PLOT ON GRAPH PAPER CHANGE LINE 2040 TO IP1150,960,9150,696
     0
2500  REM  SUBROUTINE PLOT DATA (IIE)
2510  REM   MUST FOLLOW A  PLOT AXES ROUTINE.  TO PLOT ON GRAPH PAPER CHA
     NGE LINE 2550 TO IP1150,960,9150,6960.
2520  PRINT D$;"PR#0": PRINT D$;"IN#0": INPUT "CHOOSE SYMBOL ";SP$
2530 T$ = "WT%":D$ =  CHR$ (4):Z$ =  CHR$ (26)
2540 X1 = X1 * SX:X2 = X2 * SX:X3 = X3 * SX:Y1 = Y1 * SY:Y2 = Y2 * SY:Y3 =
     Y3 * SY:X0 = X0 * SX:Y0 = Y0 * SY
2550  PRINT D$;"PR#3": PRINT T$;Z$;"IN;IP1328,1000 ,9328,6760;SC"X1","X2"
     ,"Y1","Y2";PU;"
2560  PRINT T$;Z$;"SI.2,.2;DI;"
2570  FOR I = 0 TO NP - 1
2580 X =  INT (SX * XP(I)):Y =  INT (SY * YP(I))
2590  PRINT T$;Z$;"SM"SP$";PA"X","Y";SM;"
2600  NEXT I
2610  PRINT D$;"PR#0": PRINT D$;"IN#0":X0 = X0 / SX:X1 = X1 / SX:X2 = X2 /
     SX:X3 = X3 / SX:Y0 = Y0 / SY:Y1 = Y1 / SY:Y2 = Y2 / SY:Y3 = Y3 / SY
2620  RETURN
3000  REM  SUBROUTINE TO PLOT MORE DATA
3010 SI$ = "                            ," + R$
3020 T$ = "WT%":D$ =  CHR$ (4):Z$ =  CHR$ (26)
3030 X1 = X1 * SX:X2 = X2 * SX:X3 = X3 * SX:Y1 = Y1 * SY:Y2 = Y2 * SY:Y3 =
     Y3 * SY:X0 = X0 * SX:Y0 = Y0 * SY
3040  PRINT D$;"PR#3": PRINT T$;Z$;"IN;IP1328,1000,9328,6760;SC"X1","X2",
     "Y1","Y2";PA"X1","Y0";PD;"
3050  PRINT T$;Z$;"PU;PA" INT (X1 + (X2 - X1) / 10 + (J * 6 * SX))"," INT
     (Y2)";DI1,0;LB"SI$";"
3060  PRINT D$;"PR#0": PRINT D$;"IN#0":X0 = X0 / SX:X1 = X1 / SX:X2 = X2 /
     SX:X3 = X3 / SX:Y0 = Y0 / SY:Y1 = Y1 / SY:Y2 = Y2 / SY:Y3 = Y3 / SY
3070  RETURN

]
```
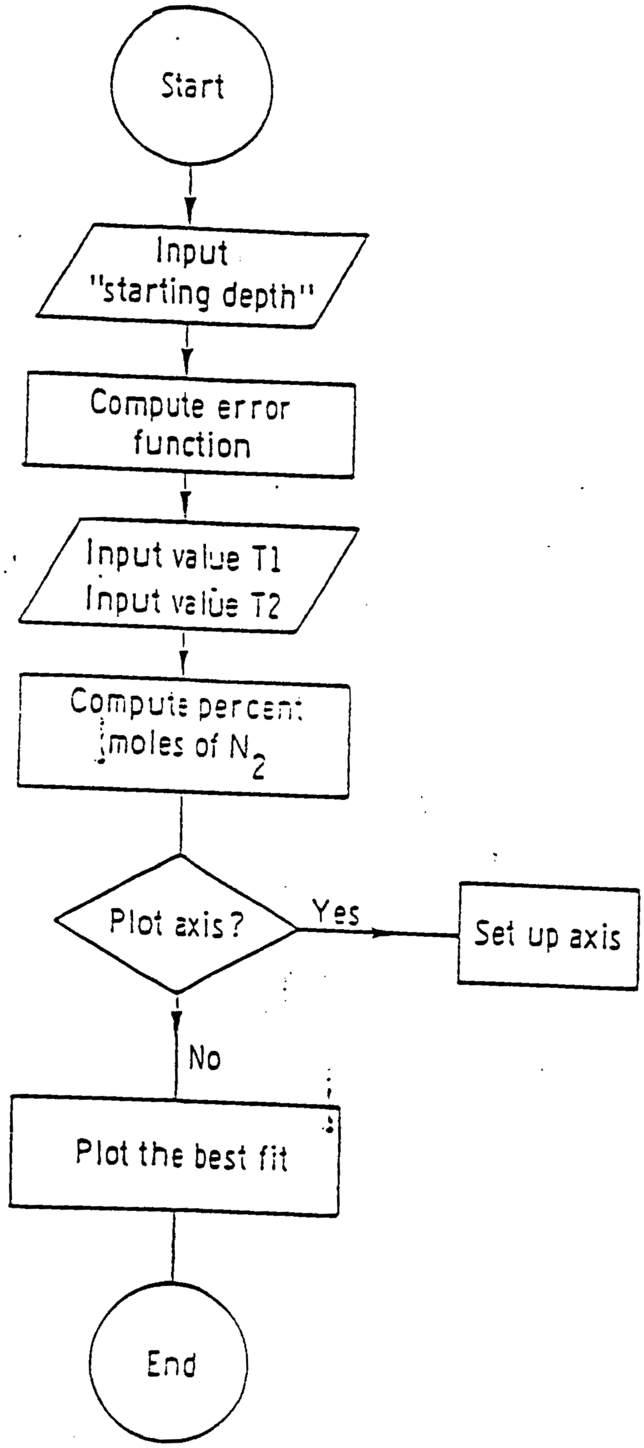

APPENDIX D

SOFTWARE BEST-FIT


Start
Input
"starting depth"
Compute error
function
Input value T1
Input value T2
Compute percent
moles of N2
Plot axis?
Yes
Set up axis
No
Plot the best fit
End

```
LOAD
DEBET

10  REM  PROGRAM TO PLOT MOLES VS TIME : BEST-FIT
20  DIM XP(500),YP(500)
30 X$ = "TIME,MIN.":Y$ = "XN(T),NO. OF MOLES":TI$ = "XN(T) VS TIME"
40 A = 5.94:NT = 1.08:R = .066:VL = 1.9098
50  INPUT "STARTING DEPTH Z0/H= ";Z0
60 ARG =  ABS (Z0)
62  GOSUB 1000: REM  COMPUTE ERF
64 XN = .5 * (1 - RF *  SGN (Z0))
66  PRINT "XN0= ";XN
70  INPUT "VALUE OF TAU1= ";T1
80  INPUT "VALUE OF TAU2= ";T2
90  INPUT "PLOT AXES (Y OR N) ";PL$
100 L = 100
110  REM  COMPUTE XN(T)
120  FOR I = 0 TO L STEP 5
130 XP(I) = I:B1 =  EXP ( - I / T1)
140 Q0 = Z0:G =  SGN (Q0):ARG =  ABS (Q0)
150  GOSUB 1000: REM  COMPUTE ERF
160 E0 = RF:G0 = G
170 Q1 = I / T2 + Z0:G =  SGN (Q1):ARG =  ABS (Q1)
180  GOSUB 1000: REM  COMPUTE ERF
190 E1 = RF:G1 = G
200 Q2 = I / T2 + Z0 - T2 / 2 / T1:G =  SGN (Q2):ARG =  ABS (Q2)
210  GOSUB 1000: REM  COMPUTE ERF
220 E2 = RF:G2 = G
230 Q3 = Z0 - T2 / 2 / T1:G =  SGN (Q3):ARG =  ABS (Q3)
240  GOSUB 1000: REM  COMPUTE ERF
250 E3 = RF:G3 = G
260 AX = I / T1 + Z0 * T2 / T1 - (T2 / 2 / T1) ^ 2
270  IF (G2 * E2 - G3 * E3) = 0 THEN EX = (A1 / P) * ( -  EXP ( - AX - Q2
    ^ 2) / Q2 +  EXP ( - AX - Q3 ^ 2) / Q3): GOTO 310
280  IF AX >  = 0 THEN EX =  EXP ( - AX) * (G2 * E2 - G3 * E3): GOTO 310
290 LX =  - AX +  LOG (G2 * E2 - G3 * E3)
300 EX =  EXP (LX)
310 YP(I) = XN * B1 + (1 - G0 * E0) * (1 - B1) / 2 - (G1 * E1 - G0 * E0) /
    2 + EX / 2:YP(I) = YP(I) * 100
320  PRINT I;"   ";YP(I)
330  NEXT I
340 X0 = 0:X1 = 0:Y0 = 0:Y1 = 0
350 X2 = L
360 X3 = X2 / 10
370 XL = 5
380 SX = 100
390  PRINT "MAX. MOLE VALUE = ";XN0
400 Y2 = 100
410 Y3 = Y2 / 10
420 YL = 5
430 SY = 10
440 NP = L
450  IF PL$ <  > "Y" THEN  GOTO 480
460  REM  PLOT AXIS
470  GOSUB 2000
480  REM  PLOT DATA
490  GOSUB 2500
500  END
1000  REM  SUBROUTINE TO CALCULATE ERF(X)
1010  REM  BASED ON 7.1.26 RATIONAL APPROXIMATION
1020 P = .3275911:A1 = .254829592:A2 =  - .284496736:A3 = 1.421413741:A4 =
     - 1.453152027:A5 = 1.061405430
1030 T = 1 / (1 + P * ARG)
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1030 T = 1 / (1 + P * ARG)
1040 RF = (A1 * T) + (A2 * T ^ 2) + (A3 * T ^ 3) + (A4 * T ^ 4) + (A5 * T
     ^ 5)
1050 RF = RF *  EXP ( - (ARG ^ 2))
1060 RF = 1 -  INT (1E3 * RF + 0.5) / 1E3
1070  RETURN
2000  REM   SUBROUTINE PLOT AXES WO INPUTS (IIE)
2010  REM       VALUES ARE NEEDED FOR X0=X0,XMIN=X1,XMAX=X2,XTIC=X3,XLAB=X
     L,Y0=Y0,YMIN=Y1,YMAX=Y2,YTIC=Y3,YLAB=YL,NO. PTS=NP,SFX=SX,SFY=SY,DAT
     A COORDINATES=XP(I),YP(I),LABEL XAXIS=X$,LABEL YAXIS=Y$,TITLE=TI$
2020 T$ = "WT%":D$ =  CHR$ (4):Z$ =  CHR$ (26)
2030 X1 = X1 * SX:X2 = X2 * SX:X3 = X3 * SX:Y1 = Y1 * SY:Y2 = Y2 * SY:Y3 =
     Y3 * SY:X0 = X0 * SX:Y0 = Y0 * SY
2040  PRINT D$;"PR#3": PRINT T$;Z$;"IN;IP1328,1000,9328,6760;SC"X1","X2",
     "Y1","Y2";PA"X1","Y0";PD;"
2050 X4 = 0
2060  FOR X = X1 TO X2 STEP X3
2070  IF  INT (X4 / XL) = X4 / XL THEN 2090
2080  PRINT T$;Z$;"TL ;PA"X","Y0";XT;": GOTO 2100
2090  PRINT T$;Z$;"TL1;PA"X","Y0";XT;PU;CP-.4,-.9;LB"X / SX";PA"X","Y0";P
     D;"
2100 X4 = X4 + 1
2110  NEXT X
2120  PRINT T$;Z$;"PU;PA" INT (X1 + (X2 - X1) / 2.5)"," INT (Y1 - (Y2 - Y
     1) / 12.5)";LB"X$";PA"X0","Y1";PD;"
2130 Y4 = 0
2140  FOR Y = Y1 TO Y2 STEP Y3
2150  IF  INT (Y4 / YL) = Y4 / YL THEN 2170
2160  PRINT T$;Z$;"TL ;PA"X0","Y";YT;": GOTO 2180
2170  PRINT T$;Z$;"TL1;PA"X0","Y";YT;PU;CP-4.9,-.3;LB"Y / SY";PA"X0","Y";
     PD;"
2180 Y4 = Y4 + 1
2190  NEXT Y
2200  PRINT T$;Z$;"PU;PA" INT (X1 - (X2 - X1) / 10)"," INT (Y1 + (Y2 - Y1
     ) / 4)";DI0,1;LB"Y$";"
2210  PRINT T$;Z$;"PU;PA" INT (X1 + (X2 - X1) / 10)"," INT (Y2)";DI1,0; L
     B"TI$";"
2220  PRINT D$;"PR#0": PRINT D$;"IN#0":X0 = X0 / SX:X1 = X1 / SX:X2 = X2 /
     SX:X3 = X3 / SX:Y0 = Y0 / SY:Y1 = Y1 / SY:Y2 = Y2 / SY:Y3 = Y3 / SY
2230  RETURN
2240  REM  TO PLOT ON GRAPH PAPER CHANGE LINE 2040 TO IP1150,960,9150,696
     0
2500  REM  SUBROUTINE PLOT DATA (IIE)
2510  REM   MUST FOLLOW A  PLOT AXES ROUTINE.  TO PLOT ON GRAPH PAPER CHA
     NGE LINE 2550 TO IP1150,960,9150,6960.
2520  PRINT D$;"PR#0": PRINT D$;"IN#0": INPUT "CHOOSE SYMBOL ";SP$
2530 T$ = "WT%":D$ =  CHR$ (4):Z$ =  CHR$ (26)
2540 X1 = X1 * SX:X2 = X2 * SX:X3 = X3 * SX:Y1 = Y1 * SY:Y2 = Y2 * SY:Y3 =
     Y3 * SY:X0 = X0 * SX:Y0 = Y0 * SY
2550  PRINT D$;"PR#3": PRINT T$;Z$;"IN;IP1328,1000,9328,6760;SC"X1","X2",
     "Y1","Y2";PU;"
2560  PRINT T$;Z$;"SI.2,.2;DI;"
2570  FOR I = 0 TO NP STEP 5
2580 X =  INT (SX * XP(I)):Y =  INT (SY * YP(I))
2590  PRINT T$;Z$;"SM"SP$";PA"X","Y";SM;"
2600  NEXT I
2610  PRINT D$;"PR#0": PRINT D$;"IN#0":X0 = X0 / SX:X1 = X1 / SX:X2 = X2 /
     SX:X3 = X3 / SY:Y0 = Y0 / SY:Y1 = Y1 / SY:Y2 = Y2 / SY:Y3 = Y3 / SY
2620  RETURN

]
```
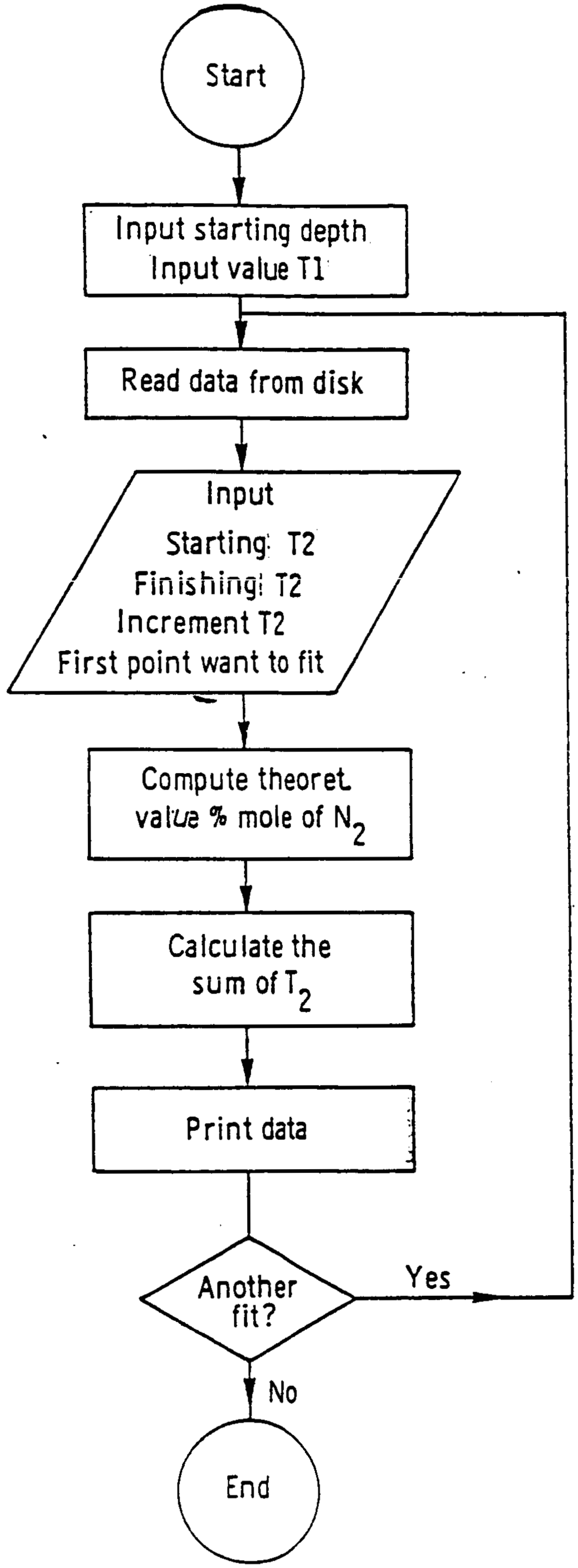

APPENDIX E

SOFTWARE MINIMUM T2


Start
Input starting depth
Input value T1
Read data from disk
Input
Starting T2
Finishing T2
Increment T2
First point want to fit
Compute theoret
value % mole of N_2
Calculate the
sum of T_2
Print data
Another
fit?
Yes
No
End

```
]LIST

10  REM  PROGRAM TO COMPUTE THE MINIMUM VALUE OF T2 :MT2
20  DIM XP(500),YP(500),YT(200)
30  INPUT "STARTING DEPTH Z0/H= ";Z0
40 ARG =  ABS (Z0)
50  GOSUB 1000: REM   COMPUTE ERF
60 XN = .5 * (1 - RF *  SGN (Z0))
70  PRINT "MAX. MOLE VALUE = ";XN
80  INPUT "VALUE OF TAU1= ";T1
90  REM  READ DATA FROM DISK
100 D$ =  CHR$ (4)
110  INPUT "FILE NAME ";R$
120  PRINT D$;"OPEN";R$
122  PRINT D$;"READ";R$
124  INPUT NP
126  FOR I = 0 TO NP - 1
128  INPUT XP(I): INPUT YP(I)
130  NEXT I
150  PRINT D$;"CLOSE";R$
155  REM  FIT DATA
160  INPUT "STARTING T2= ";TS
170  INPUT "FINISHING T2= ";TF
180  INPUT "STEP T2= ";TC
190  INPUT "FIRST POINT WANT TO PLOT= ";I1
195  PR# 1: PRINT "T2","SUM": PR# 0
200  FOR T2 = TS TO TF STEP TC
210 S = 0
220  FOR I = I1 TO NP - 1
230  REM  COMPUTE THEORETICAL VALUE YT(I)
300 B1 =  EXP ( - XP(I) / T1)
310 Q0 = Z0:G =  SGN (Q0):ARG =  ABS (Q0)
350  GOSUB 1000: REM   COMPUTE ERF
360 E0 = RF:G0 = G
370 Q1 = XP(I) / T2 + Z0:G =  SGN (Q1):ARG =  ABS (Q1)
380  GOSUB 1000: REM   COMPUTE ERF
390 E1 = RF:G1 = G
400 Q2 = XP(I) / T2 + Z0 - T2 / 2 / T1:G =  SGN (Q2):ARG =  ABS (Q2)
410  GOSUB 1000: REM   COMPUTE ERF
420 E2 = RF:G2 = G
430 Q3 = Z0 - T2 / 2 / T1:G =  SGN (Q3):ARG =  ABS (Q3)
440  GOSUB 1000: REM   COMPUTE ERF
450 E3 = RF:G3 = G
460 AX = XP(I) / T1 + Z0 * T2 / T1 - (T2 / 2 / T1) ^ 2
470  IF (G2 * E2 - G3 * E3) = 0 THEN EX = (A1 / P) * ( -  EXP ( - AX - Q2
     ^ 2) / Q2 +  EXP ( - AX - Q3 ^ 2) / Q3): GOTO 510
480  IF AX >  = 0 THEN EX =  EXP ( - AX) * (G2 * E2 - G3 * E3): GOTO 510
490 LX =  - AX +  LOG (G2 * E2 - G3 * E3)
500 EX =  EXP (LX)
510 YT(I) = XN * B1 + (1 - G0 * E0) * (1 - B1) / 2 - (G1 * E1 - G0 * E0) /
     2 + EX / 2:YT(I) = YT(I) * 100
520  REM  CALCULATE THE SUM OF T2
530 S = S + (YP(I) - YT(I)) ^ 2
540  NEXT I
550  PR# 1: PRINT T2,S: PR# 0
560  NEXT T2
570  INPUT "ANOTHER FIT ? (Y OR N) ";FT$
580  IF FT$ <  > "Y" THEN  GOTO 600
590  GOTO 155
600  END

]
```